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Inženieru fakultāte

REZEKNE ACADEMY OF TECHNOLOGIES
Faculty of Engineering

VIDE. TEHNOLOĢIJA. RESURSI

XIII starptautiskās zinātniski praktiskās konferences materiāli
2021.gada 17.-18.jūnijs

1.SĒJUMS

ENVIRONMENT. TECHNOLOGY. RESOURCES

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I

ENVIRONMENT AND RESOURCES

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Environment and Resources

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Assessing Mercury Pollution Using Black Stork Eggshells

Anda Abola
Institute of Atomic Physics and Spectroscopy
University of Latvia
Riga, Latvia
anda.abola@lu.lv

Maris Strazds
Institute of Biology
University of Latvia
Riga, Latvia
mstrazds@latnet.lv

Rita Veilande
Institute of Atomic Physics and Spectroscopy
University of Latvia
Riga, Latvia
rita.veilande@lu.lv

Zanda Gavare
Depasrtment of Physics
Latvia University of Life Sciences and Technology
Jelgava, Latvia
zanda.gavare@gmail.com

Female birds whose bodies contain environmental contaminants produce eggs with shells that are likewise contaminated, making bird eggshells appropriate indicators for monitoring environmental toxins. Common contaminants include organic mercury compounds, especially methylmercury, which are known to bioaccumulate and biomagnify in the food chain. Black storks (Ciconia nigra) predominantly consume fish and are thus at risk for high mercury intake. In this study, we used eggshells of black storks as a proxy to reconstruct the concentration levels and distribution of mercury, a well-known toxic element, in various parts of Latvia. Preliminary analyses have shown that deposition levels of mercury vary in different parts of the eggshell. Specifically, the shell and shell membrane differ in their level of mercury contamination by an average factor of nine; therefore, we measured the mercury content in these components separately whenever possible. We analysed 34 eggshell samples from nesting sites in Latvia using an atomic absorption spectrometer with Zeeman correction Lumex RA-915M and its attachment for pyrolytic combustion. We found that mercury concentrations varied from 5 to 22 ng/g in eggshells and from 42 to 293 ng/g in shell membranes. We discuss possible contamination sources and reasons behind this disparity.

Keywords - black stork, eggshells, mercury

I. INTRODUCTION

Mercury is one of the most toxic elements affecting living organisms and the environment. All of its compounds are deemed toxic, and its organic compounds are generally more toxic than its inorganic compounds. Mercury's methylation processes occurs in aquatic environments [1] – [3], resulting in methylmercury, which is highly toxic. Afterwards, methylmercury enters the food chain through small organisms, such as algae and plankton, and it bioaccumulates and biomagnifies, rapidly increasing its concentration [4].

Because of these biogeochemical processes, even moderate mercury concentration levels in the surrounding environment can result in serious toxicity for organisms that are positioned higher on the food chain, such as large fish, fish-eating birds, and humans [3], [5]. Birds' intestines absorb only a small percentage of inorganic mercury but almost all organic mercury, and nearly all mercury in fish is methylmercury [6].

Bird eggs have become a widely used tool for mercury pollution assessment because utilizing them is non-invasive, and they are relatively easy to collect [7]. Numerous studies have analysed mercury content in various egg parts, including the yolk, albumen, membrane, and shell of many bird species (e.g. [7] -[10]), and have found that the egg content has considerably higher mercury concentrations than the egg shells [7], [9]. Several studies have established correlation between mercury concentrations in different egg components [7], [10], as well as in eggs and blood samples [8]. While these findings cannot be extrapolated to other bird species, as correlations vary and there is some concern about differences between methodologies when processing eggshells [10], identifying

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correlations in this area could widen possibilities and options when working with endangered species.

Measuring mercury from eggshells offers a number of benefits in comparison with direct measurements of mercury content in streams, fish ponds and prey items of storks. Eggshells retain contaminants that are deposited within them, and thus can be used to trace the contaminant's origin. Additionally, eggshells are useful because they do not require specific storage conditions, can be easily archived for long periods of time [11], and can be collected using non-invasive methods. Moreover, using shells of hatched or failed eggs ensures that no viable eggs are lost.

The black stork (Ciconia nigra) is predominantly a fish-eating bird and forages primarily in streams, fish ponds, and similar aquatic environments. They usually lay eggs with an interval of two days [12]. The time frame between the arrival of females on the breeding grounds in Latvia and the laying of their first eggs varies from four to fourteen days (mean = 7) [13]. Consequently, the contaminants that are transferred from the mother to her eggs likely represent the contaminants that are present around the nesting site at the time of egg laying.

Black storks often remove any eggshells that remain in the nest after hatching. Less commonly, halved or smashed egg remains can be found under nests that were depredated by predators. In both cases, researchers can obtain eggshells without approaching (i.e. climbing to) the nest itself, thereby limiting disturbance, which is especially critical for endangered species such as the black stork [14]. A study by Černova revealed unexpectedly high mercury concentration levels in the blood and livers of juvenile black storks [15], providing a basis for our study. We aimed to further investigate contaminants in black storks by testing different parts of their eggshells for mercury. We analysed various types of egg remains from black storks in different parts of Latvia for mercury to determine whether these eggs can be used to understand mercury pollution levels and reconstruct contamination history in the area.

II. Material and Methods

A. Eggshells

We used black stork eggshells collected from 2007–2009 and 2018 for this study. We analysed a total of 34 samples from >30 nesting sites in Latvia. The eggshells that we collected varied in size, ranging from almost whole eggs to fragments on the ground under the nest. We placed eggshells in three categories: (1) halves and "caps" remaining after hatching, which adult birds often (but not always) threw out of the nest, (2) remnants of eggs depredated by predators at different stages of incubation, and (3) remnants of complete eggs, resulting from conflicts between storks, that were thrown out of the nest.

When stork conflicts occur, they are typically during the initial period of incubation [13]. Consequently, eggs thrown out of nests as a result of such conflicts are mostly fresh or only partially incubated, and the membrane adheres very tightly to the shell and is difficult to separate. In the case of hatched eggs, remaining membrane fragments usually separate on their own. This likely results from processes during incubation in which the egg shell becomes thinner and more fragile as the growing chick uses calcium from the shell to form its skeleton [16]. Damage from predators can occur at any stage of the incubation period. Camera traps documented predation on days 9 and 27 after the first egg was laid (by pine martens) and on days 10, 14 and 18 (by white-tailed sea eagles). Incubating one egg takes an average of 32 days [13].

B. Eggshell collection and preparation

We collected eggshells in almost all regions of Latvia (Fig. 1). We immediately labelled all eggshell samples with a nest number and described the shell characteristics. We also tried to determine the hatching status for each eggshell (hatched, unhatched or unknown; Table 1). Afterwards, we air-dried eggshells and cleaned larger pieces with a soft brush as thoroughly as possible to remove any debris.

TABLE 1 Number of eggshells by hatching status

Hatched	Possibly hatched	Unhatched	Unknown
3	9	8	14

Prior to taking measurements, we separated the inner membrane from the eggshell when possible. Otherwise, we used samples mixed with both inner membrane and eggshell. To homogenize the samples, we crushed the shells using a mortar and pestle.

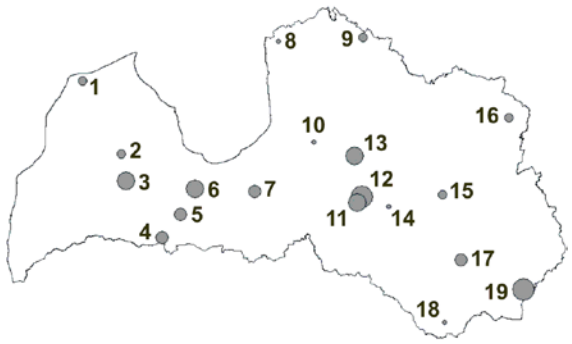

Fig. 1 Distribution of analyzed samples (only mixed samples shown) in the territory of Latvia. Size of the points is depicted in five classes according to natural breaks (jenks) of data: 1) 8–14, 2) 14–20, 3) 20–29, 4) 29–39, 5) 39–60. If a nest had more than one sample (i.e. # 18), we displayed the largest value. See Table 2 for sample numbers.

C. Mercury measurements

We performed total mercury concentration measurements using an atomic absorption spectrometer with Zeeman correction LUMEX RA-915M and its attachment for pyrolytic analysis PYRO-915+. The threshold of detection was approximately 2 ng/g for our chosen setup and sample type [17].

To conduct measurements, we first weighed the sample, followed by thermal decomposition occurring inside atomizer PYRO-915+. Subsequently, we measured the absorption of the mercury 254 nm resonance radiation and calculated its concentration. Pyrolytic combustion allows

direct measurements without specific pretreatment procedures, diminishing possible sample contamination and providing almost instant results.

We calibrated the spectrometer and periodically tested it using a certified reference material of mussel tissue – ERM-278k (by the European Commision Joint Research Centre). We used chicken eggshells, which we previously confirmed to be sufficiently mercury free (rendering mercury concentration below threshold of detection, close to 0 ng/g), as blank samples, as well as to test the equipment's cleanliness. The average measured sample size was 50–100 mg dry weight (d.w.) for eggshells and mixed samples and 20–30mg d.w. for inner membranes. We repeated measurements for each sample 5 times on average and calculated the standard deviation.

III. Results and discussion

A. Results

We separated all measurements into three groups – eggshells, membranes, and mixed samples; the latter group was the largest. Since we only collected hatched or failed eggs, and often crushed eggshell parts, the quality of the available samples differed. All of our samples were at or higher than the mercury detection limit (Table 2, sample name indicates the nest number and year when the collected egg was laid).

As expected, eggshells had the lowest mercury concentrations, ranging from 6 to 22 ng/g. Inner membranes contained more mercury, with the lowest concentration we recorded at 42 ng/g, but results varied among nesting sites. Typically, concentrations were over 100 ng/g, ranging up to 300 ng/g.

In cases where both eggshells and membranes were available for analyses, membranes contained much more mercury than the eggshell itself (Fig 2). Samples had an average ratio of mercury in the membrane to mercury in the eggshell of 9:1, with results ranging from ratios of 5:1 to 13:1.

B. Discussion

All of our samples contained a detectable amount of mercury, but there was a large degree of variation in the amount of mercury in each sample. We were unable to determine the hatching status (i.e. hatched or not hatched) of our samples with certainty (Table 1), making our results more difficult to interpret. We could only determine the origin of eggshells if there was a camera trap at the nest documenting the hatching process. Strazds and Ķuze began using camera traps at black stork nests in 2011 and initially only a tracked a few nests per year [18] Even if juveniles are present in a nest and it appears to be successful, shells on the ground do not necessarily mean that an egg has hatched because a stork conflict may have occurred in spring, resulting in the first clutch being thrown out of the nest and shell pieces remaining on the ground [13]. An additional problem may be that carnivores can destroy the eggs at different stages of incubation. It is unknown whether the membrane separates easily only from hatched eggs, or if this also occurs when an embryo is eaten during the late stage of development (i.e. shortly before hatching), and if so, how long before hatching.

TABLE 2 MERCURY CONCENTRATIONS IN EGGSHELL SAMPLES.

Year	Sample name	Concentration , ng/g			Nº in map
		Eggshells	*Membranes*	*Mixed*	
2007	064502-07		160±10	16±1	9
	173401-07		221	20±3	2
	623303-07			35±4	13
	672503-07	8±1	85±7	12±1	14
	752622-07		138	16±3	15
2008	104501-08			15±2	1
	272401-08		211±8	25±4	5
	532304-08	11±1	101±13		
	553630-08			12±6	10
	622701-08			60±12	12
	781601-08			29±1	17
2009	182901-09		236±4	33±4	3
	183501-09	12±1	58±12		
	292952-09	22±1	293±30	37±8	6
	553630-09	9±1	56±17		
	622606-09			39±2	11
	631702-09	22±4	200±30		
	750601-09			14±4	18
	873802-08			19±4	16
2018	103704-18		143±56		
	173402-17	17±1			
	182902-18		107±39		
	242002-18			28±2	4
	262201-18	9±1	79±11		
	452801-18			27±7	7
	492801-18	12±2	128±36		
	505203-18			11±4	8
	562104-17	7±2			
	644185-18		123±13		
	750601-18.1			10±2	18
	750601-18.2			12±3	18
	804402-18	7±1			
	831703-17		90±24		
	881102-18	6±2		51±11	19

It is also unknown which processes affect the separation of the membrane in non-productive (addled) eggs. Strazds et al. determined the amount of DDT in eggs [19] and found that in some, eggs membranes detached very easily in some but were inseparable in others. Camera trap and webcam data show that adult birds may accidentally squash addled eggs that have remained in the nest and discard them afterwards [13]. As a result, remains of unhatched eggshells may be present under successful nests. Thus, undocumented findings from previous years must be treated with caution, regardless of how they were labelled at the time of collection. Further analysis of the amount of mercury in egg membranes that may have been deposited from the embryo

during egg development should only be performed on eggshells/ membranes whose status is known with certainty.

Mixed samples contain an unspecified amount of eggshell and membrane stuck together, so their respective contributions to the final concentration cannot be determined. Thus, mixed samples give less precise results and are difficult to use. This explains why mercury values in mixed samples are lower than those of membranes and higher than for eggshells. Nevertheless, mixed samples give some indication of pollution levels if no other data are available.

There are several possible explanations for the difference in mercury concentrations between eggshells and membranes. First, the difference could be purely chemical. Membranes are organic in nature, consisting mostly of elastin-like protein surrounded by muccopolysaccaride mantle. Conversely, eggshells are predominantly inorganic, and their organic compound, a polysaccharide complex with calcium binding properties, is distributed across the shell unevenly [19]. Thus, the organic matrix may be more prone to bonding mercury compounds. Alternatively, the difference in concentrations could result from the physiology of egg formation. Bird eggs swell in utero of the female prior to the process of eggshell mineralization [19]. The location of "initial mercury" in the female body may also play some role if contaminants are deposited in the organs where organic egg content is formatted, but not the eggshells.

Among samples analysed thus far, nests in some regions of Latvia are under-represented (Zemgale, Sēlija) or are not represented at all (south-west Kurzeme; Fig. 1), though samples have been collected from nests there. Therefore, we cannot yet adequately draw conclusions about the prevalence of mercury pollution in the country. However, our results indicate some, although not very high, presence of mercury in the surrounding environment.

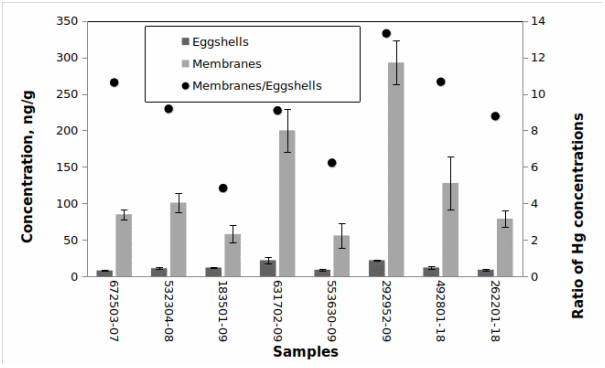

Fig. 2 Comparison of mercury concentration in eggshells (darker bars to the left) and membranes (lighter bars to the right) in 8 samples for which we successfully separated membranes from eggshells. The secondary Y-axis shows the mercury concentration ratio of membranes to eggshells (dark bullets).

Possible local sources of mercury include anthropogenic activity such as peat extraction [21], forestry [22], cement production [23], illegal dumps and waste incineration (van Veizen et al., 2002 [24], Bogans [25], and historical presence of military forces from World War I and II [26]. Possible natural sources of mercury include beaver ponds [26]. There are several peat bogs near the nests with the highest mercury concentrations, and an ex-military base is situated near No. 5 (see Fig.1). These potential mercury sources could influence the varying mercury concentration levels that we exhibited in different nests. Peterson et al. found that eggshells of older embryos had less mercury, which they speculated was influenced by changes in the shell matrix during embryo growth [10]. This is a possible factor explaining our results for addled eggs. Another possible source of contamination is connected with female choice of wintering locations and/or staging grounds on the way back to the breeding grounds. In this case, mercury might be "imported" from another country. While existing data does not allow us estimate of mercury contamination trends over time, we plan to continue our ongoing study to expand our dataset, which is now incomplete for most years.

IV. Conclusions

Our preliminary results reveal that concentrations in various eggshell parts, specifically the eggshell and inner membrane, differ by a ratio of 1:9. Interpreting our results is difficult because of many unknowns, such as whether or not eggs were hatched and what factors affect membrane separability from eggshells. Eggshells are a potential material to use for mercury contamination assessments, but more data are required to study how spatial and temporal components influence mercury accumulation in eggshells.

Acknowledgements

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References

[1] F. M. M. Morel, A. M. L. Kraepiel and M. Amyot, "The chemical cycle and bioaccumulation of mercury," Annual Review of Ecology and Systematics, Vol. 29(1), pp. 543–566, 1998. https://doi.org/10.1146/annurev.ecolsys.29.1.543

[2] S. R. Segade, T. Dias and E. Ramalhosa, "Mercury methylation versus demethylation: main processes involved," in Methylmercury: Formation, Sources and Health Effects, A.P. Clampet, Ed. New York: Nova Science Publishers, 2011, pp. 123–166.

[3] D. Evers, "The Effects of Methylmercury on Wildlife: A Comprehensive Review and Approach for Interpretation" in The Encyclopedia of the Anthropocene, D. A. DellaSala and M. I. Goldstein, Eds. Oxford: Elsevier, 2018, vol. 5, pp. 181–194.

[4] G. Harding, J. Dalziel and P. Vass, "Bioaccumulation of methylmercury within the marine food web of the outer Bay of Fundy, Gulf

of Maine", PLOS ONE, Vol.13(7), 2018. https://doi.org/10.1371/journal.pone.0197220

[5] C. A. Eagles-Smith , J. T. Ackerman, S. E.W. De La Cruz and J. Y. Takekawa, "Mercury bioaccumulation and risk to three waterbird foraging guilds is influenced by foraging ecology and breeding stage," Environmental Pollution, Vol. 157, pp. 1993–2002, 2009. https://doi.org/10.1016/j.envpol.2009.03.030

[6] C. J. Henny and J. E. Elliott, "Toxicology" in Raptor Research and Management Techniques Manual, Second Edition, D.M. Bird, K.L. Bildstein, Eds. British Columbia, Canada: Hancock House Publishing, Ltd. Surrey, 2007 pp. 329–350.

[7] R. L. Brasso, S. Abel and M. J. Polito "Pattern of mercury allocation into egg components is independent of dietary exposure in gentoo penguins", Archives of Environmental Contamination and Toxicology, Vol.62, pp.494–501, 2012. https://doi.org/10.1007/s00244-011-9714-7

[8] D. C. Evers, K.M. Taylor, A. Major, R.J. Taylor, R.H. Poppenga and A.M. Scheuhammer, "Common Loon Eggs as Indicators of Methylmercury Availability in North America," Ecotoxicology Vol. 12, pp. 69–81, 2003. https://doi.org/10.1023/A:1022593030009

[9] A. Aliakbari, M. Savabieasfahani and S.M. Ghasempouri, "Mercury in Egg and Eggshell of Whiskered Tern (Chlidonias hybrida) from Anzali Wetlands of the Caspian Sea, Iran," Bulletin of Environmental Contamination and Toxicology, Vol. 86, pp. 175–179, 2011. https://doi.org/10.1007/s00128-010-0155-1

[10] S. H. Peterson, J. T. Ackerman, C. A. Eagles-Smith, C. A. Hartman and M.P. Herzog, "A critical evaluation of the utility of eggshells for estimating mercury concentration in avian eggs," Environmental Toxicology and Chemistry, Vol.36, Issue 9, pp. 2417-–2427, 2017. https://doi.org/10.1002/etc.3777

[11] L.-Q. Xu, X.-D. Liu, L.-G. Sun, Q.-Q. Chen, H. Yan, Y. Liu, Y. H. Luo, J. Huang, "A 700-year record of mercury in avian eggshells of Guangjin Island, South China Sea," Environmental Pollution, Vol. 159, Issue 4, pp. 889–896, 2011. https://doi.org/10.1016/j.envpol.2010.12.021

[12] G. Janssen, M. Hormann and C. Rohde, Der Schwarzstorch (Ciconia nigra), Die Neue Brehm-Bücherei Bd. 468, Hohenwarsleben, Deutschland : Westarp Wissenschaften, 2004.

[13] M. Strazds, unpublished data

[14] V. Ķerus, A. Dekants, A. Auniņš un I. Mārdega, Latvijas ligzdojošo putnu atlanti 1980–2017, Putnu skaits, izplatība un to pārmaiņas. Rīga: Latvijas Ornitoloģijas biedrība, 2021.

[15] J. Černova, "Ekoloģiskā piesārņojuma kumulācija melnā stārķa (Ciconia nigra) organismā," Internatūras prakses atskaites darbs. Latvijas Lauksaimniecības Universitāte. Jelgava, 2015.

[16] S. E. Solomon, Egg and Eggshell Quality. London: Manson Publishing Ltd, 1997

[17] Lumex Instruments, Product catalog, Versatile Zeeman mercury analyzer RA-915M with pyrolyzer PYRO-915+ [Online.] Available: https://www.lumexinstruments.com/catalog/atomic-absorption-spectrometry/ra-915m-pyro-915.php [Accessed March 21, 2021]

[18] M. Strazds and J. Ķuze, "Use of trail-cameras in studies of Black Stork behavior and ecology: gains, limitations and the first essential results", Actes du Colloque Cicogne noire. Ornithos Hors-serie, n° 1/2016, pp. 12–13, 2016.

[19] M. Strazds, H. G. Bauer, Ü. Väli, A. Kukāre and V. Bartkevičs, "Recent impact of DDT contamination on Black stork eggs," Journal of Ornithology, Vol. 156, pp. 187–198, 2015. https://doi.org/10.1007/s10336-015-1244-z

[20] R. G. Board and R. Fuller (Eds.) Microbiology of the avian egg. London, UK: Chapman & Hall, 1994

[21] S. Osterwalder, K. Bishop, C. Alewell, J. Fritsche, H. Laudon, S. Åkerblom and M. B. Nilsson, "Mercury evasion from a boreal peatland shortens the timeline for recovery from legacy pollution," Scientific Reports, Vol. 7, Article number: 16022, 2017. https://doi.org/10.1038/s41598-017-16141-7

[22] P. Porvari, M. Verta, J. Munthe and M. Haapanen, "Forestry practices increase mercury and methyl mercury output from boreal forest catchments," Environment Science and Technology, Vol. 37(11), pp. 2389–2393, 2003. https://doi.org/10.1021/es0340174

[23] M. L. Jones, D. L. Laudal and J. H. Pavlish, "Mercury Emission Monitoring for the Cement Industry," IEEE Cement Industry Technical Conference Record, Miami, FL, USA, pp. 161–170, 2008. https://doi.org/10.1109/CITCON.2008.20

[24] D. van Veizen, H. Langenkamp, G. Herb, "Review: mercury in waste incineration", Waste Management and Research, Vol. 20, pp. 556–568, 2002. https://doi.org/10.1177/0734242X0202000610

[25] E. Bogans, J. Skudra, A. Svagere and Z. Gavare, "Analysis of Mercury Pollution in Air in Urban Area of Riga Using Atomic Absorption Spectrometry", In: Sustainable Development, Knowledge Society and Smart Future Manufacturing Technologies, World Sustainability Series, pp 219–228, 2015. https://doi.org/10.1007/978-3-319-14883-0_15

[26] K. Gębka, J. Bełdowski and M. Bełdowska, "The impact of military activities on the concentration of mercury in soils of military training grounds and marine sediments," Environment Science and Pollution Research, Vol. 23, pp. 23103–23113, 2016. https://doi.org/10.1007/s11356-016-7436-0

[27] V. Roy, M. Amyot, R. Carignan, "Beaver Ponds Increase Methylmercury Concentrations in Canadian Shield Streams along Vegetation and Pond-Age Gradients", Environmental Science and Technology, Vol. 43 (15), pp. 5605–5611, 2009. https://doi.org/10.1021/es901193x

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Study of the Distribution of Air Temperature in a Greenhouse Heated By Air to Air Heat Pump

Agris Auce
Institute of Chemical Physics
University of Latvia
Riga, Latvia
a@aa.lv

Aivars Jermuss
Institute of Agronomy
University of Life Sciences and Technologies
Jelgava, Latvia
aivars.jermuss@llu.lv

Adolfs Rucins
Ulbroka Research Center
University of Life Sciences and Technologies
Jelgava, Latvia
adolfs.rucins@llu.lv

Semjons Ivanovs
Ulbroka Research Center
University of Life Sciences and Technologies
Jelgava, Latvia
semjons.ivanovs@llu.lv

Ugis Grinbergs
Institute of Mathematics and Computer Science
University of Latvia
Riga, Latvia
ugis@adsl.lv

***Abstract* - The temperature distribution inside the experimental greenhouse heated by air to air heat pumps and its impact on the growth and productivity of tomato plants were studied. Experimental greenhouse located at SIA Rītausma facility in South-East Latvia.**

Two commercially available regular air to air heat-pumps with a combined heat power of 10 kW were used. To measure the temperature distribution, 18 temperature sensors with solar radiation shields at different heights and positions among the plants were installed. Additional 4 temperature sensors were used to measure the air flow temperature at the heating elements. Reference air temperature was measured at an industrial production facility heated by a common gas heating system.

Temperature was found to be homogenous within 1 °C. Observed temperatures were up to 4 °C lower than set on the control unit of the heat pump. This discrepancy was compensated by higher set values for the controlling unit. As research showed the temperature stability was better than at the water-heated industrial facility at time slots when the sun was suddenly cleared from clouds.

The cooling of the experimental greenhouse by air conditioning during summer time was rather challenging for the tomato plants and productivity. 23% of plant stems died until the end of the season and the yield was 50% lower than in the reference greenhouse. The energy efficiency compared to the industrial facility was approx. 8 times better and the estimated CO_2 emissions were 8-16 times smaller compared to gas heating. There were no increases of heating costs determined.

Further studies are needed to optimize the heating parameters and reach the desired greenhouse productivity.

Keywords* - *air temperature, air to air heat pump, greenhouse heating.

I. Introduction

Greenhouse crop production is an important part of agricultural production, especially for northern countries with cold climate [1]. Air conditioning systems in the greenhouse can provide a suitable environmental condition for agricultural production. Greenhouse crop production in cold regions requires a lot of energy that results in the emission of a significant amount of greenhouse gas (CO_2) and other air pollutants such as NOx into the atmosphere [2]. A large amount of fossil fuels is used for greenhouse heating in industrial farming systems. The burning of coal, natural gas, and oil for electricity and heat is the largest single source of global greenhouse gas emissions and accounts for 25% of global emissions by the economic sector [3]. In the past, heat pumps have not been used widely because of their low coefficient of performance (COP) and high cost of installation [4]. With the rise of energy costs and technological advancements, heat pumps are now being reconsidered as an alternative heating system [5]. The efficiency of heat pumps in subarctic areas are stated in [6].

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CO_2 emissions can be significantly reduced by the integration of renewable energy in industrial applications [7]. The coefficient of performance (COP) of heat pump, especially of air-source heat pumps is decreasing at lower temperatures [8]. A reduction in the energy required for greenhouse heating and cooling by regulation of heating and cooling facilities for an optimum growing environment during the plant growth stage was reported by Rubanga et al. 2019 [9]. Air-to-air heat pumps require little investment compared to other types of heat pumps and other heating systems. However, it is not yet clear whether heating by direct air flow from air-to-air results in an acceptable temperature distribution within a densely packed greenhouse used for tomato growing. Therefore, the performance and CO_2 emissions of air-to air heat pumps should be studied in a real location with real production plants. The aim of this research is to investigate the spatial and temporal distribution of air temperature in an industrial tomato greenhouse heated by air to air heat pump in south eastern Latvia.

II. MATERIALS AND METHODS

The air heating systems were studied in an experimental greenhouse 34 m^2 (B=4.15, L= 8.30, H=3.40+0.7 m ceiling) separated from the main industrial facility at its north east corner.

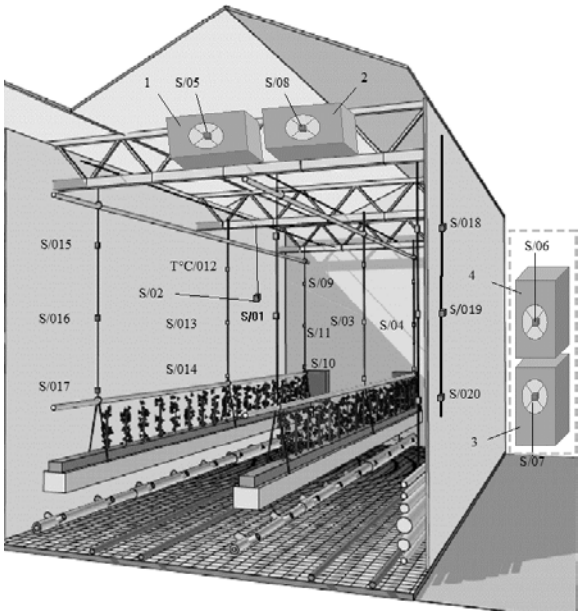

Fig. 1. Location of temperature sensors in the experimental greenhouse.

1., 2. heat pumps; 3., 4. heat pump outdoor unit; S/05, S/08 sensors exhaust air temperature of the heat pump; S/06; S/07 sensors exhaust air temperature of the heat pump outdoor unit; S/01-S/04; S/09-S/17 temperature sensors in the experimental greenhouse, S/18-S/20 sensors in the reference greenhouse.

The geographical location of the experiment was South East part of Latvia at latitude 56.5 °N and longitude 25.8 °E.

Two 5 kW heat Hitachi RAC-50 air to air reversible heat pumps were installed inside the greenhouse at a height of 1.8 m at the end wall and air was blown directly into the plant growing area. Water based pre-existing industrial heating system was disabled using heat insulators. Energy consumption of the heat pumps was measured by measuring the electrical power at the heat pump electricity connection. Reference greenhouse was heated using central heating by natural gas and the total amount of heating gas used was calculated from commercial data from the whole production facility. Assuming that the air temperature variables are irregularly distributed in the greenhouse, 18 temperature sensors with solar shields at different heights and positions were installed at 3 different heights and at 2x3 horizontal grid to measure the air temperature distribution in the experimental greenhouse and 4 sensors were used to measure the exhaust air temperatures of the heat pumps (Fig. 1). The control measurements were made at 3 different heights at the industrial facility heated by a common gas-water heating system.

Temperature spatial distribution measurement system was built to be conformed to the Linked Data nomination (Open, structured machine-readable, non-proprietary format, linked to other data, etc.). Data refer to known events at the time, spatial metadata (refer to OGC services), it is INSPIRE ready. For particular exploitation goals, data can be perceived as Real Time data. Layer for data storage was combined of database storage and file system. The main data storage was the relational database system PostgreSQL (further-DB). The spatial extension of the DB storage PostGIS was prepared for the storage of spatial data. There was a single data model planned and implemented, providing the following roles:

- storage of data produced by deployed temperature sensors;
- storage of data provided by possible other data sources/data producers (future development);
- management of data produced by stuff, activities, and other events (for future use);
- geodata - contextual spatial data related to greenhouses, its location, greenhouse and field species (future development).

Data management layer was based on components providing API for data exchange, analytical, processing and publishing functions. Specific open source application (feeder service) running on the server was created. This component was responsible for receiving sensor data from the defined sensor unit provider, processing the received data, and sending these data to the configured data storage(s) using HTTP API interface. MapServer was a component responsible for the publishing of contextual spatial data for visualization purposes. SensWEB as a web application based on Python framework was planned to provide the main functionality of the system. Initial deployment of the system provided a feeder service instance was prepared for gathering of sensor data from sensor node(s) and sending via defined API to SensWEB WEB server. SensWEB server instance consists of SensWEB web application and the provided data model implemented in the PostgreSQL DB with PostGIS spatial extension. Setup for online data gathering from sensor node(s) was installed. It allowed gathering data from the

sensor units connected to a node named GreeNo over GSM connection in compressed format (Fig.2.).

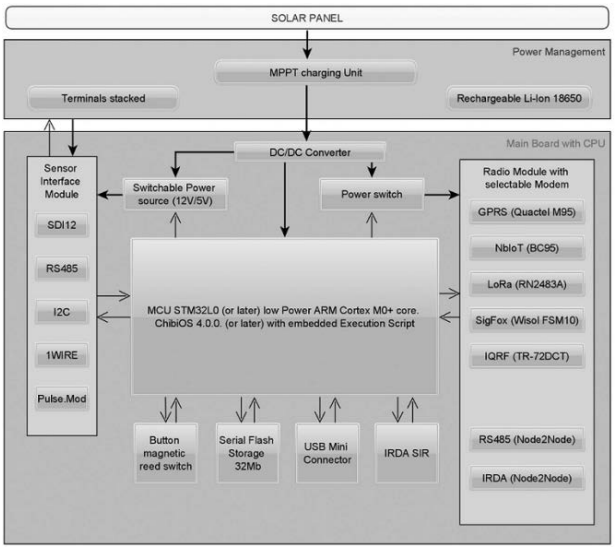

Fig. 2. Block schematics of GreeNo

The temperature sensing devices used a semiconductor thermometer based on chip DS18B20. Sensor units used for the research were specially constructed with explicitly exposed chips to the surrounding air (Fig. 3) providing faster measurement due to the lower connected mass resulting in lower thermal inertia. For data transport from GreeNo nodes to DB public GSM network GPRS and NB-IoT services were used utilizing in GreeNo built-in GSM modem. For research and analysis needs interface for data export and download from the DB in format XLS, XLSX was used.

Fig. 3. Semiconductor thermometer based on DS18B20 chip.

Tomatoes were grown from the first decade of February until the end of October. Winter period of the growing season was warmer than usual. Outside average air temperatures over the whole season varied between -3.8 ℃ and 24.1 ℃ (Fig. 4.) In the experimental as well as reference greenhouse, the temperature had to be kept at 20-25 ℃ during the day and 12-15-18 ℃ during the night depending on the plant development stage and the time of the day.

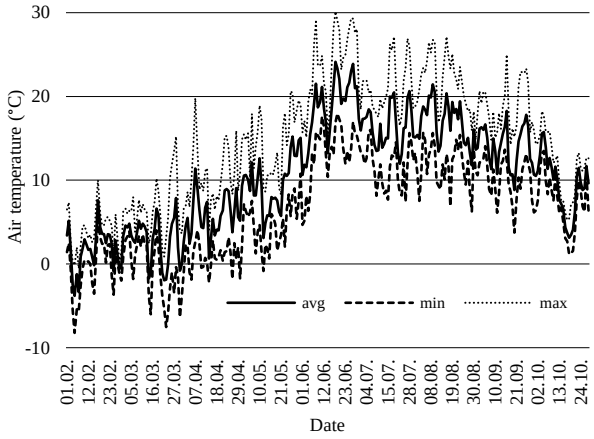

Fig. 4. Average, minimal and maximal day air temperature during vegetation 2020.

Beef type tomato variety Admiro was grown in two rows with 1.2 m distance between the rows. At five to six leaf stage, the transplants were planted into bags filled with coconut fiber. A very shallow stream of water containing all dissolved nutrients required for tomato growth was recirculated past the roots of the plants in each row. The nutrient solution level was controlled by determining EC and pH. Drop irrigation was incorporated into an industrial – reference greenhouse feeding system. Shading and ventilation were disconnected from the common system to test the cooling capacity of the heat pumps.

III. Results and Discussion

Spatial uniformity of the temperature.

The spatial distribution of the temperature, measured as the temperature difference between temperature sensors at different positions in relation to the warm air exhaust of the heat pump was compared to the temperature in the reference greenhouse. For the control, the temperature difference between sensors at the highest and lowest positions was used as reference. In Fig. 5, both the temperature difference in the control and the temperature difference between the two pairs of sensors in the experimental greenhouse, where the highest difference was expected, are plotted against the temperature of the warm air at the heat pump exhaust. Temperature distribution plotted in Fig. 5 was measured in the period with the lowest outside temperatures during the 2020 season. Night between 23-rd and 24-th of March 2020 was the coldest night during the whole tomato growth season with outside temperatures between -3 ℃ and -7 ℃. The vertical temperature difference between the highest sensor at 1.8 m and the lowest at the height of 0.6 m in the experimental greenhouse was within 1.2 ℃ measured at 7.3 meters from the heat pump exhaust. The horizontal temperature distribution in the experimental greenhouse was even more uniform - the temperature difference between the closest and the most remote temperature sensor with the distance of 6.8 m between them was for all measurements within 0.7 ℃ and 90% of the measurements were within 0.5 ℃. This should be compared with the control greenhouse with hot water central heating system where the vertical air

temperature difference was within 1.2 ℃. Even during the coldest time when the heat pump was working with the highest capacity and with the highest hot air temperature, the spatial uniformity of the temperature in the experimental greenhouse heated by the heat pump was similar to the control greenhouse heated by a hot water central heating system.

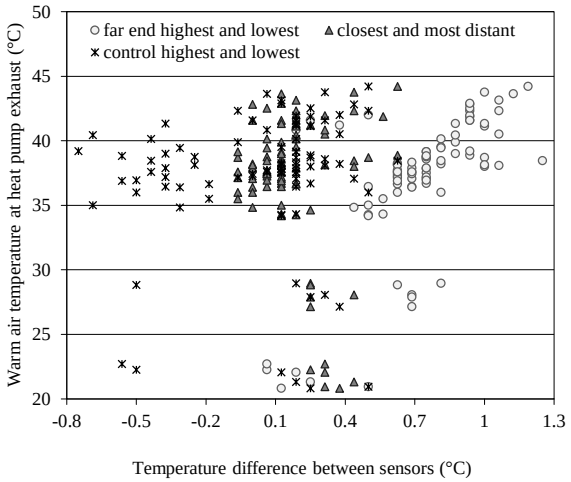

Fig. 5. Uniformity of the temperature inside the greenhouse during the period with the lowest outside temperature, ℃.

Temporal uniformity of the temperature.

Temporal uniformity of the temperature field during heating is one of the most important parameters for the air to air heat pump heating system. The installed air to air heat pumps do not operate in continuous heating mode. Hot air was blown into the greenhouse until the necessary temperature is achieved and then the heating is paused for some time and renewed again when the temperature is below a set limit. The built-in algorithm of the heat pump tries to smooth out these periods and achieve more continuous heating, but in practice there are periods with high and low warm air temperature at the heat pump heated air outlet. Typical heating air temperatures are from 35 ℃ to 45 ℃. One of the concerns with direct heating of the greenhouse by air to air heat pumps is how the temperature of these on-off cycles is affecting the plants. In Fig. 6. the temperature measurements during one of the coldest nights are plotted against the time. Outside air temperature was between -3 ℃ and -7 ℃ and the heat pump was operating at its highest capacity during the whole experiment. Temperature variations inside the greenhouse caused by the on-off cycles were small – within 3 ℃. On-off cycles of the heat pump are well visible in the plot. It can be speculated that the heat inertia of the sunshields around the temperature sensors moderated the temperature fluctuations caused by the heat pump switching on and off. Typical length of the heating cycle in Fig. 6. is approximately 40 minutes, which is sufficient for the temperature sensor to reach the thermal equilibrium with the air flow from the heat pump. By analyzing the temperature data, it was deemed that the temporal uniformity of the temperature is within 3 ℃ even during the coldest periods with the most intense heating was needed and that the fluctuations in the temperature are within the range acceptable for the plants.

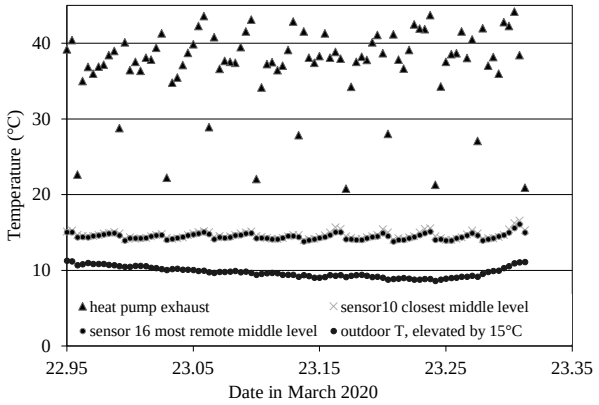

Fig. 6. The changes of air temperature in time ℃, the coolest night in March 2020.

The temporal uniformity of the temperature in the control greenhouse heated by the hot water central heating system showed slower temperature variation during the same period, but the overall temperature variation was also within 3 ℃ within one night.

Spatial temporal uniformity of the temperature field.

Changes in the temperature difference between sensors were studied for the time periods when the most intensive heating was required. In Fig. 7. the temperature differences between the high and low level sensors and the closest and the most remote sensors with respect to the hot air exhaust are plotted for one of the coldest nights in the year 2020 when the outdoor temperature dropped to -7 ℃ during the night. In the control greenhouse, the vertical temperature difference between the highest and the lowest temperature sensors slowly drifted from -0.5 ℃ to 0.5 ℃ during the night. This most probably was caused by the heat flow from the heating pipes at the bottom of the greenhouse and cooling via thermal radiation from the top of the greenhouse into the open sky.

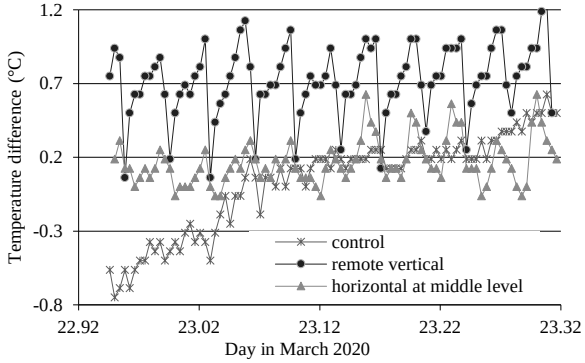

Fig. 7. Temperature difference between sensors plotted against the time during one of the coldest nights.

The vertical temperature difference between the highest and the lowest temperature sensors in the experimental greenhouse had periodic fluctuations from around 0 ℃ to 1 ℃ with the period of close to 1 hour that

corresponds to the cycle of the heat pump activity that can be seen in Fig. 6. The time dependence of the temperature differences along the horizontal axis between the sensor closest to the hot air exhaust and the most remote one was measured to be smaller – temperature difference periodically fluctuated between 0 ℃ and 0.5 ℃ in coherence with the heat pumps activity and increased slightly at the coldest time of the night till 0.6 ℃ as can be seen comparing Fig. 6 and Fig. 7. The measurements showed that the spatial temporal variations of the temperature field in the experimental greenhouse were comparable to the control greenhouse with hot water central heating although the temperature differences fluctuated more frequently following the activity of the heat pump. The time-averaged temperature was more uniform in the experimental greenhouse compared to the reference. The air movement induced by the heat pump was sufficient to ensure equal heating even in most remote positions from the hot air exhaust. The periodic fluctuations of the temperature due to the changes in the heat pump activity were measured to be several times smaller than the temperature differences caused by changed intensity in insolation during the days when the sun was periodically shaded by clouds. In Fig. 8. the temperature difference between sensors is plotted over time at warm outdoor temperatures. Vertical temperature difference in the control greenhouse is represented by crosses, while the vertical temperature difference in the experimental greenhouse measured at the far end from the heat pump air exhaust and the horizontal temperature difference at the middle height are represented by open circles and triangles respectively.

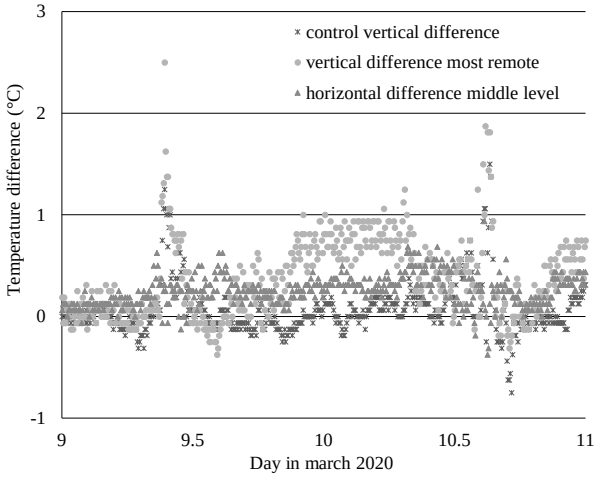

Fig. 8. Temperature difference between sensors at temperatures 1-8 ℃

Time dependent temperature differences between temperature sensors are shown in Fig. 6. Vertical temperature differences in the experimental greenhouse are higher in warm weather than in the coldest weather and reach 1 ℃ while in control there is a decrease in the vertical temperature differences. This can be explained by analyzing the heat pump hot air exhaust temperature shown in Fig. 9.

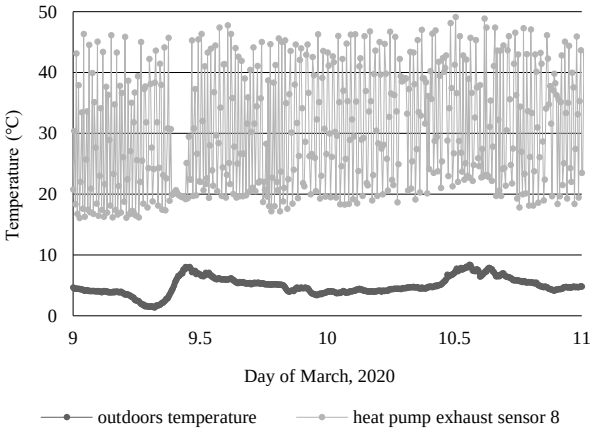

Fig. 9. Heating and outside air temperature fluctuation

The heat pump used in the experiment had the same maximum exhaust hot air temperature of 45 ℃ working at warm outdoors temperatures as during the coldest time periods but increased the pause periods with low exhaust air temperature. The temperature fluctuations in the experimental greenhouse thus increased with increasing the outdoors temperature and decreasing the heating power. A different pattern is observed when solar radiation briefly eliminates the need for heating. A sharp rise of temperature differences up to 2.5 ℃ is observed in the vertical temperature distribution in the experimental greenhouse. In the reference greenhouse, the rise is smaller but is then followed by a dip of similar size in the reverse vertical temperature distribution, which is caused by heat inertia in the hot water heating system. It was established that the temperature uniformity during warm outdoor temperatures is still well within acceptable temperature variations.

Cooling with the heat pump.

During the summer, cooling with the heat pump was tested. The effect on plants was rather disastrous for the plants and productivity in the test facility. 23% of plant stems died until the end of the season and the yield was 50% lower than in the control that was cooled with sunshields and by opening ventilation windows in the roof. One of the explanations can be the very low air temperatures coming out from the heat pump during the cooling cycle. As an example, the temperature data for one of the warmest days in July 2020. are shown in Fig. 10. Heat pump performed the most active cooling during evening time, because the set temperature regime is with lower temperature at night. Very low cold air exhaust temperatures, as low as 8 ℃ were observed during the evening hours that followed warm days. We estimate that these low cooling air temperatures injured plants and lowered their productivity.

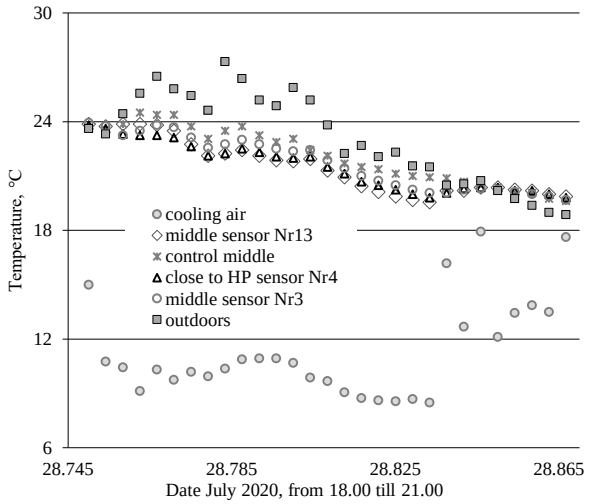

Fig. 10. Greenhouse air temperature in July, °C

Energy efficiency and CO_2 emissions.

It was estimated that the experimental facility had somewhat less solar irradiation because of its location, but these differences were not taken into account. For the overall heating season in 2020 the energy efficiency of the heat pump was approximately 8 times better compared to the reference heating in terms of energy use. In calculating the reduction of CO_2 emissions, some assumptions have to be made for the CO_2 emissions from the production of the electricity used for the heat pumps. Typical energy mix for Latvia electricity grid consists of gas powered cogeneration plants in big cities, coal thermal stations from Russia, nuclear energy from neighboring countries, hydropower from Latvia and Scandinavia, and a small part of other renewables. The proportion varies depending on the availability of different sources, but it can be assumed that approximately half of the electricity usually is from sources with low to zero CO_2 emissions. Depending on the electricity production mode in the energy mix, the CO_2 emissions in the experimental greenhouse were estimated to be 8-16 times smaller compared to the reference greenhouse heated by natural gas. Using market prices for electricity and natural gas, it was estimated that in 2020 heating season heating costs were somewhat smaller for the experimental greenhouse compared to reference heating expenses.

IV. Conclusions

Spatial and temporal temperature differences in the experimental greenhouse heated by air-to-air heat pump were similar to the reference greenhouse with hot water central heating. Colling with direct air flow from air-to-air heat pump was injuring for tomato plants and decreased the productivity significantly. Use of air-to air heat pumps demonstrated 8 to 16 fold reduction in CO_2 emissions when compared to heating by natural gas while there was no increase in heating costs.

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REFERENCES

[1] M. Canakci, N. Yasemin Emekli, S. Bilgin, N. Caglayan, “Heating requirement and its costs in greenhouse structures: A case study for Mediterranean region of Turkey”, Renewable and Sustainable Energy Reviews, vol. 24., , pp. 483–490, 2013.

[2] L. Zhang, X. Hao, Y. Li, G. Jiang, “Response of greenhouse tomato to varied low pre-night temperatures at the same daily integrated temperature,” Hortiscience, vol. 45 (11), pp. 1654 – 1661, 2010.

[3] IPCC. Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014.

[4] Y. Tong a, T. Kozai, N. Nishioka, K. Ohyama, “Greenhouse heating using heat pumps with a high coefficient of performance (COP),” Biosystem Engineering, vol. 106., pp. 405 - 411, 2010.

[5] T. Kozai, K. Ohyama, Y. Tong, P. Tongbai, N. Nishioka, “Integrative environmental control using heat pumps for reductions in energy consumption and CO_2 gas emission, humidity control and air circulation,” Scientia Horticulturae, vol. 893, pp. 445-449, 2011.

[6] R. S Atlason, G. V. Oddsson, R. Unnthorsson, “Heat pumps in subarctic areas: current status and benefits of use in Iceland,” Int J Energy Environ Eng., vol. 8, pp. 283–291, 2017. Available: SprigerLink, https://link.springer.com/article/10.1007/s40095-017-0244-6 [Accessed February 26, 2021], https://doi.org/10.1007/s40095-017-0244-6

[7] A. Grubbauer, J. Flucha, C. Brunnera, T. Ramschaka, V. Wilkb, T. Flecklb, “Renewable and highly efficient energy systems through innovative combination of solar thermal and heat pump systems,” Chemical engineering transactions, vol. 70, pp. 745-750, 2018.

[8] M. K. Mattinen, A. Nissinen, S. Hyysalo, J. K. Juntunen, “Energy use and greenhouse gas emissions of air-source heat pump and innovative ground-source air heat pump in a cold climate,” Journal of Industrial Ecology, vol. 19(1), pp. 61-70. 2014. Aviable: Wiley Online Library, https://onlinelibrary.wiley.com/doi/abs/10.1111/jiec.12166 [Accessed March 8, 2021],

https://doi.org/10.1111/jiec.12166

[9] D. P. Rubanga, K. Hatanaka, S. Shimada, “Development of a simplified smart agriculture system for small-scale greenhouse farming, “ Sensors and Materials, vol. 31, No. 3, pp. 831-843, 2019.

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Expression of Communication Skills and Benefits for Creating an Effective Mentoring Environment. Comparative Analysis of the Case of Lithuania and Latvia

Vitalija Bartuševičienė
Utena University of Applied Sciences
Utena, Lithuania
vitalija@utenos-kolegija.lt

Vaida Bartkutė-Norkūnienė
Utena University of Applied Sciences
Utena, Lithuania
vaidaba@ukolegija.lt

Rasa Jodienė
Utena University of Applied Sciences
Utena, Lithuania
jodiene.rasa@gmail.com

Anda Zvaigzne
Rezekne Academy of Technologies
Rezekne, Latvia
anda.zvaigzne@rta.lv

Inta Kotāne
Rezekne Academy of Technologies
Rezekne, Latvia
inta.kotane@rta.lv

Iveta Mietule
Rezekne Academy of Technologies
Rezekne, Latvia
Iveta.Mietule@rta.lv

Sandra Murinska
Rezekne Academy of Technologies
Rezekne, Latvia
sandra.murinska@rta.lv

***Abstract* - This paper presents a comparative analysis of the survey results on communication competencies in mentoring in Lithuania and Latvia. In mentoring, it is imperative to examine barriers to communication competencies between business consultants (from now on referred to as "mentors") and start-up entrepreneurs or those intending to start a business (from now on referred to as "mentees") and propose solutions on how to enhance and maintain the business mentor network by utilizing communication technologies.**

Keywords - communication skills, mentoring.

I. INTRODUCTION

Fostering sustainability ideas in business development is undoubtedly one of the more prominent recent trends. However, to develop a stronger and more sustainable business with certainty, it is not enough to have a good original business idea. It is the mentorship that helps evaluate your idea and a business plan critically and take the first steps more firmly. Many authors emphasize the importance of mentoring at the beginning of starting a business. In today's practice, a mentor becomes a relevant source of specific knowledge and professionalism and a precious source of experience and assistance. Communication skills are important not only for individuals in the communication industry but also for educators, young people, and entrepreneurs who need to present themselves and their ideas. According to D.Perkumienė and A.Perkumas (2010), quality consulting must be distinguished not only in terms of content but also critical are the factors of communication between clients and consultants. The consultant must be able to understand the client, delve into his/her feelings and character. The client and the consultant's good communication skills and pleasant communication between them have a positive impact on the deepening of clients' knowledge and decision-making (Ester van Laar, et al., 2020). In general, communication, according to J.Fiske (1990), V.Misevičius, R. Urbonienė (2006), and others, is not only

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an exchange of experience, verbal and non-verbal signals, information, and mutual understanding. One of the most common problems encountered in day-to-day communication and business consulting arises when the communicating parties do not understand each other. Therefore, in both general communication and business communication, the skills of communicators are crucial.

This paper presents the comparative analysis of the survey results on communication competencies in mentoring in Lithuania and Latvia. **The object of the research.** The approach of mentors and mentees to their communication skills, barriers and problems encountered in communication. **The article** aims to determine whether business consultants and mentees' opinions about their communication skills and the most common barriers and problems in communication differ significantly between the two countries.

II. RESEARCH METHODOLOGY

The method of the research. The quantitative method of raw data collection – a question-based survey - was chosen for the research. A standard questionnaire was compiled to perform the survey. The research data was collected using two questionnaires in Lithuania (one questionnaire was meant for mentors, the other - for mentees), and a combined survey questionnaire was used for the survey in Latvia. Both questionnaires were standardized, closed-ended, with pre-designed questions. The questions were the same for all the respondents replying to the same questionnaire.

All questions in the questionnaires cover 5 thematic blocks, and nominal, interval, rank and Likert scale formats were used to answer the questions of the questionnaires:

1. the demographics of the respondents (age, position, sector in which the company/institution operates, education) - the nominal scale format was provided for the position, sector in which the company/institution operates, education and the interval scale format was used for the questions about respondents' age and work experience;
2. the importance of the communication elements of mentors and mentees (oral, non-verbal communication, written communication and information content development)- the ranked 5-point scale was used, where 1 meant not important at all, 2 - not important, 3 - neither important nor not important, 4 - important, 5 - very important.
3. the effectiveness of communication in business networks - the ranked 5-point scale was used (the same as in block 2);
4. mentors' and mentees' communication skills and factors influencing their communication – a 5-point Likert scale was used, where 1 means not important at all/no influence, 2 - not important/little influence, 3 - neither important nor not important/influence neither important nor insignificant, 4 - important/important influence, 5 - very important/strong influence;
5. the impact of communication barriers on communication - a 5-point Likert scale was used (the same as in block 4).

The survey sample. Fifty-six mentors having business consulting experience and 50 mentees participated in this survey in Lithuania. In Latvia, a total of 102 questionnaires valid for analysis were filled in and received (54 mentors, 32 mentees, 16 others, indicating that they lacked experience in mentoring or were interested in it etc.). This article provides only a comparative analysis of the opinions of those who have clearly identified themselves as mentors and mentees. The study was conducted according to the Project Development and Introduction of a Communication Competencies Model for Enhancing and Maintaining a Business Mentor Network (DICCMEM, 2019-1-LV01-KA203-060414).

Analysis of the research data. The descriptive statistical analysis method was applied to analyze the obtained questionnaire survey data, calculating the Average, Mode, Median, Standard Deviation indicators. Data analysis was performed using SPSS 22.0 statistical package. To determine statistically significant relationships between Latvian and Lithuanian respondents' replies, a correlation analysis of the data was performed, and the Pearson's chi-squared test criterion p_t with a $p<0.05$ credibility level was calculated. **Hypotheses of the equality of the averages between two independent samples were tested using the *t* criterion**. Differences in indicators were considered statistically significant when $p<0.05$.

III. THE COMPARISON OF MENTOR-MENTEE RESEARCH RESULTS IN LATVIA AND LITHUANIA

Demographics of the Respondents. Figure 1 shows the demographic data of the participants by age. In Lithuania (LT), the most active in the survey were mentees under 30 (38% of 50 mentees, which is 19 mentees) and mentors aged 30-40 (30.4% of the 56 mentors in the survey, which is 17 mentors). In Latvia (LV), the most active were mentees and mentors aged 30-40 (50% of 32 mentees, 16 mentees, and 39,7% of 54 mentors, 21 mentors). In LT, the least involved in the survey were older respondents, i.e. participants over 61: only 2% (1 mentee) of all mentees in the survey and 10.7% of mentors – 6 mentors out of 56. However, in LV, the least involved in the survey were younger respondents, i.e. under 30: 8,9% (3 mentees) of all mentees in the survey and 5,2% of mentors – 3 mentors out of 54.

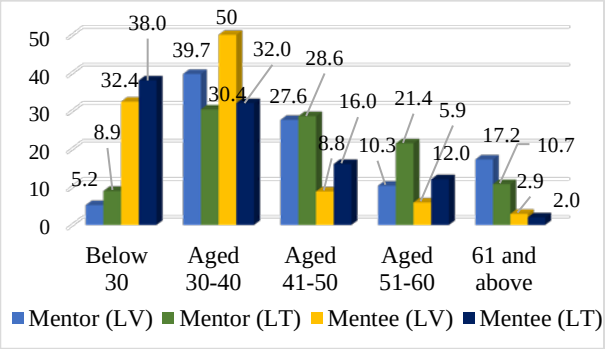

Fig. 1. Distribution of the respondents by age, % (own study)

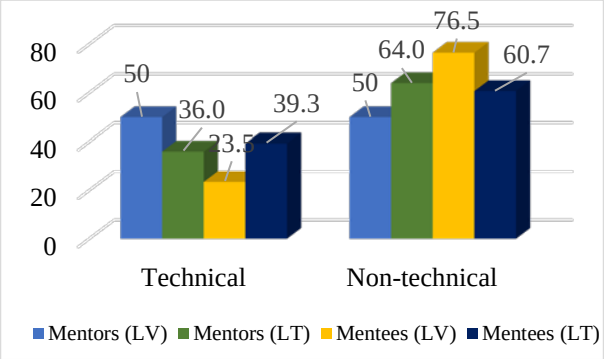

Fig. 2. Distribution of the respondents by education, % (own study)

Depending on which sectors of economic activity in which the respondents are involved or in which the prospective respondents (mentees) intend to start their own business (Figure 3), we observe that the survey involved commerce, transport, agriculture, construction, industry representatives or individuals intending to start their own business in the respective sectors. More than half of the mentors surveyed in LT (51.8%) represented other sectors of economic activity, such as recruitment, selection and management of staff, services, training, non-formal education, public sector, IT, start-up consulting, event organization, rental of premises, finance and business consulting etc. Of the mentees surveyed in LT, the majority, i.e. as many as 38%, would intend to start their own business in the commerce sector. In LV, most of all respondents (more than 38% of the mentors and more than 47% of mentees) represented the agriculture sector, but in LT, the number of respondents represented this sector was the lowest: just 1,8% of mentors and 10% of mentees. The smallest part of mentors and mentees surveyed in Latvia represented the transport sector.

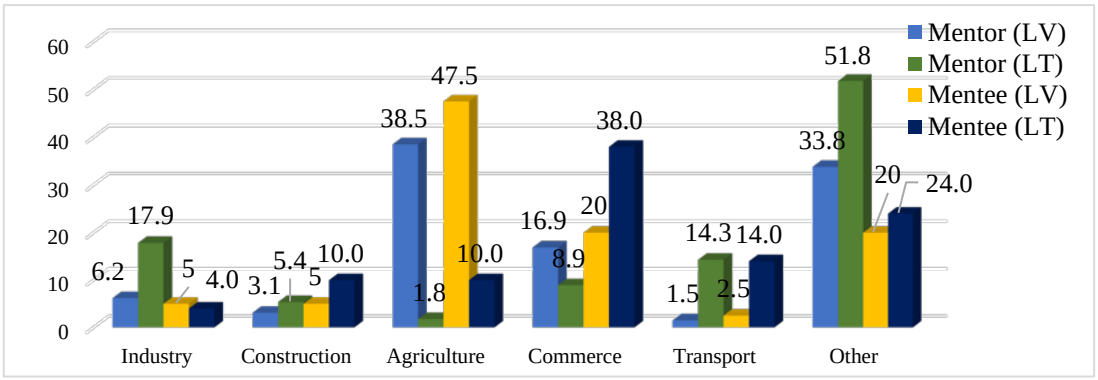

Fig. 3. Distribution of the respondents by field of activity, % (own study)

In terms of positions held (Figure 4) and work experience (Figure 5), the mentors' survey in both countries was dominated by company managers with more than six years of managerial experience.

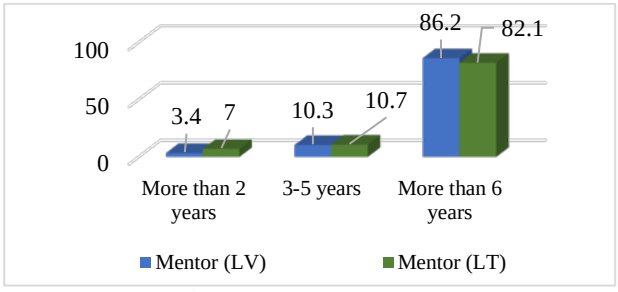

Fig. 4. Distribution of the mentors by work experience, % (own study)

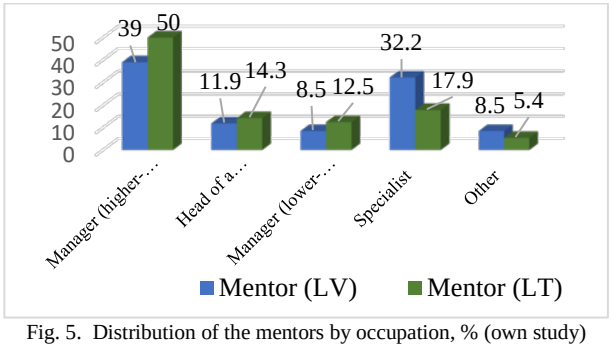

Fig. 5. Distribution of the mentors by occupation, % (own study)

The Importance of Communication Channels of Mentors and Mentees. Effective communication is essential to build a trusting and strong mentoring relationship. Therefore, it is essential to identify appropriate channels of communication. The conducted

survey allowed us to determine which communication channels are important for Lithuanian and Latvian mentors and mentees. The results showed (Table 1) that in nonverbal communication, the essential aspect for Lithuanian mentors is the look and eye contact ($\mu^{LT} = 4.52$), while mentees highlight voice intonation ($\mu^{LT} = 4.48$). In LV both, mentors ($\mu^{LV} = 4.41$) and mentees ($\mu^{LV} = 4.00$) highlighted voice intonation. According to mentors in LT and LV, physical distance is the least important ($\mu^{LT} = 3.96$ and $\mu^{LV} = 3.81$), while mentees find gestures to be the least important ($\mu^{LT} = 4.02$ and $\mu^{LV} = 3.56$). In verbal communication, both mentors and mentees in both countries highlighted face-to-face communication. The least important to mentors and mentees in LT is a face-to-face group meeting: the average value of mentors is 3.71, and mentees are 3.92. In LV, the least important both for mentors and mentees is video or audio conference: the average value of mentors is 3.59 and mentees – 3.63. In written communication, the least important for LT mentors are written letters sent by ordinary mail ($\mu^{LT} = 3.16$), for mentees - notices and announcements ($\mu^{LT} = 3.62$). Websites and blogs are the least important communication channel in written communication both for mentors and for mentees in LV. Mentors in LT ($\mu^{LT} = 4.36$) and mentors ($\mu^{LV} = 3.69$) and mentees ($\mu^{LV} = 4.00$) in LV acknowledged e-mails as the most critical element in written communication. At the same time, Lithuanian mentees distinguish websites and blogs as the most important in written communication ($\mu^{LT} = 4.14$).

Examining the hypothesis that mentors and mentees in both Lithuania and Latvia evaluate communication channel equally on average, we see that out of 20 evaluated communication channels, mentors evaluate the importance of 7 channels and mentees of 9 channels significantly different (mentors: written letters, presentations, e-mail, internal communication platforms, document sharing systems, social media, websites and blogs; mentees: facial expressions, look and eye contact, gestures, posture and body orientation, voice intonation, manuals, social media, websites and blogs, face to face conversation). Mentors in Lithuania assess communication channels' importance on average 5% more favourably than in Latvia, mentees -8% (Table 1).

Table 1 also presents data on the significance of the difference in the average ratings of mentors and mentees in each country separately. As shown in Table 1, the most significant difference between a mentor and a mentee in Lithuania was represented by *written letters* ($p_t^{LT} = 0.038 < 0.05$), i.e. it was important enough to the mentees, but not for mentors. In Latvia, the assessments of most non-verbal communication channels (except for physical distance) differ significantly: mentors evaluate the importance of communication channels more favourably than mentees. For mentors in both countries, non-verbal communication channels are more important than verbal or written communication channels (average rating in LT is 4.24 and in LV is 4.18). However, the mentees' assessments are different; in Lithuania, mentees distinguish non-verbal communication channels as more important (average rating is 4.26 in LT, in LV – 3.83), and in Latvia, verbal communication channels (average rating is 4.16 in LT, in LV – 3.98).

TABLE 1 THE IMPORTANCE OF COMMUNICATION MODEL ELEMENTS BETWEEN MENTORS AND MENTEES IN LATVIA AND LITHUANIA (OWN STUDY)

	Mentors		**Mentees**		**Pearson's chi-squared criterion**			
Means	μ^{LT}	μ^{LV}	μ^{LT}	μ^{LV}	p_t^{LT}	p_t^{LV}	$p_t^{Mentors}$	$p_t^{Mentees}$
Non-verbal communication								
Facial expressions	4.29	4.24	4.30	3.91	0.917	**0.043**	0.747	**0.015**
Look and eye contact	4.52	4.30	4.46	3.91	0.626	**0.035**	0.082	**0.002**
Gestures	4.13	4.11	4.02	3.56	0.483	**0.002**	0.923	**0.012**
Posture and body orientation	4.18	4.20	4.20	3.75	0.877	**0.011**	0.854	**0.012**
Voice intonation	4.34	4.41	4.48	4.00	0.228	**0.011**	0.566	**0.002**
Physical distance	3.96	3.81	4.10	3.84	0.346	0.872	0.313	0.142
Average	*4.24*	*4.18*	*4.26*	*3.83*				
Written communication								
Written letter	3.16	3.59	3.66	3.56	**0.038**	0.895	**0.035**	0.711
Reports	3.61	3.37	3.66	3.38	0.781	0.980	0.157	0.202
Presentations	3.98	3.50	3.98	3.69	0.989	0.324	**0.003**	0.119
Manuals	3.73	3.43	3.94	3.44	0.258	0.955	0.078	**0.024**
Notices and announcements	3.48	3.39	3.62	3.56	0.480	0.378	0.610	0.786
E-mail	4.36	3.69	4.02	4.00	**0.045**	0.070	**0.001**	0.917
Internal communication platforms	3.86	3.46	3.94	3.81	0.593	0.117	**0.023**	0.523
Document sharing systems	3.86	3.50	4.02	3.75	0.302	0.264	**0.045**	0.187
Social media	3.96	3.19	4.04	3.41	0.641	0.324	**0.001**	**0.003**
Websites, blogs	4.13	2.96	4.14	3.09	0.923	0.546	**0.001**	**0.001**
Average	*3.81*	*3.41*	*3.90*	*3.57*				
Oral communication								

	Mentors		Mentees		Pearson's chi-squared criterion			
Means	μ^{LT}	μ^{LV}	μ^{LT}	μ^{LV}	p_t^{LT}	p_t^{LV}	$p_t^{Mentors}$	$p_t^{Mentees}$
Face to face conversation	4.82	4.63	4.70	4.38	0.332	0.063	0.070	**0.035**
Face to face group meeting	3.71	3.93	3.92	3.94	0.266	0.953	0.225	0.933
Phone call	3.89	3.96	4.04	3.97	0.406	0.966	0.637	0.694
Video or audio conference	3.68	3.59	3.98	3.63	0.085	0.867	0.625	0.085
Average	*4.03*	*4.03*	*4.16*	*3.98*				

Pearson's chi-squared criteria: p_t^{LT} - for mentors' and mentees' sets in LT; p_t^{LV} - for mentors' and mentees' sets in LV; $p_t^{Mentors}$ - for mentors' sets in LT and LV; $p_t^{Mentees}$ - for mentees' sets in LT and LV.

The Importance of Content Creation of Mentors and Mentees. In mentor and mentee communication, it is important to single out the ability to create communication content. Communication must focus on completeness, relevance, clarity, accuracy, quality, value, timeliness, etc., of the information to increase the productivity of the communication, reduce the number of errors and increase efficiency and reliability in general. Table 2 contains the evaluation of the importance of content creation for the respondents. From the mentors' point of view in both countries, the most crucial thing in content creation in communication is to present content clearly (average value $\mu^{LT} = 4.89$, $\mu^{LV} = 4.57$), in Latvia, reliability of information is also most important for mentors ($\mu^{LV} = 4.57$). The second important issue in LT is the correctness of the content ($\mu^{LT} = 4.80$), but in LV information completeness ($\mu^{LV} = 4.46$). The third important issue in both countries is the speed of response ($\mu^{LT} = 4.50$, $\mu^{LV} = 4.37$). According to mentees, information reliability in both countries is the most important ($\mu^{LT} = 4.74$, $\mu^{LV} = 4.56$), then – information clarity ($\mu^{LT} = 4.72$) in LT and information completeness in LV ($\mu^{LV} = 4.50$). The third most important issue for mentees in LT is information completeness ($\mu^{LT} = 4{,}58$) and information clarity in LV ($\mu^{LV} = 4.47$). The least important issue for both mentors and mentees in both countries is the provision of solicited information only (mentors – $\mu^{LT} = 4.23$, $\mu^{LV} = 3.91$, mentees – $\mu^{LT} = 4.30$, $\mu^{LV} = 3.78$). Examining the hypothesis that the means of evaluation of various aspects of information content creation in mentors' and mentees' sets differ significantly, we see that in LT, the importance of content clarity in information content creation is evaluated significantly differently by mentors and mentees (p_t=0.032<0.05), i.e. mentees rated this aspect significantly lower than mentors. In LV, assessment of information content creation aspects does not differ significantly in mentors' and mentees' sets. However, statistically significant differences were found between the respondents' assessments in LT and LV. We can record that the importance of information reliability ($p_t^{Mentors}$ =0.017<0.05) and clarity ($p_t^{Mentors}$ =0.001<0.05), and provision of solicited information only ($p_t^{Mentors}$ =0.037<0.05) differ statistically significantly in mentors' sets in Lithuania and Latvia. The importance of the provision of solicited information only ($p_t^{Mentees}$ =0.006<0.05) differs statistically significantly in mentees' sets in Lithuania and Latvia as well.

TABLE 2 THE EVALUATION OF THE IMPORTANCE OF CONTENT CREATION (OWN STUDY)

	Mentors		Mentees		Pearson's chi-squared criterion			
Means	μ^{LT}	μ^{LV}	μ^{LT}	μ^{LV}	p_t^{LT}	p_t^{LV}	$p_t^{Mentors}$	$p_t^{Mentees}$
Information reliability	4.80	4.57	4.74	4.56	0.440	0.930	**0.017**	0.165
Information clarity	4.89	4.57	4.72	4.47	**0.032**	0.455	**0.001**	0.089
Provision of solicited information only	4.23	3.91	4.30	3.78	0.611	0.548	**0.037**	**0.006**
Information completeness	4.46	4.46	4.58	4.50	0.287	0.780	0.991	0.522
Information regular updating	4.38	4.26	4.50	4.44	0.382	0.274	0.457	0.644
Speed of response	4.50	4.37	4.44	4.31	0.665	0.691	0.323	0.411
Average	*4.54*	*4.36*	*4.55*	*4.34*				

Communication skills of mentors and mentees and factors influencing communication. Influence is the basis of communication skills. Therefore, the study was interesting to analyze how mentors and mentees evaluate communication skills that affect communication. When assessing the importance of communication skills (Table 3), we see that, according to mentors' and mentees' point of view, the least important in LT is the ability to put oneself in another's shoes, understand each other's

emotions and experiences (mentors μ^{LT} =3.93, mentees – μ^{LT} =4.06) and in LV - ability to interpret a person by appearance and behaviour (mentors μ^{LV} =3.98, mentees μ^{LV} =3.69).

According to mentors in LV and mentees in both countries, the most critical skill is the skill to create a wish to communicate and cooperate (mentors μ^{LV} = 4.50, mentees – μ^{LT} =4.58, μ^{LV} =4.44). For LT mentors, the most critical skill is the skill to actively listen (reflect, ask questions, conclude, discuss) - μ^{LT} =4.66.

Examining the hypothesis that the means of evaluating communication skills and communication influencing factors in mentor and mentee sets differ significantly (Table 3), we see that the ability to listen actively (p_t =0.039<0.05) among mentors and mentees in LT is treated significantly differently, i.e. mentees value the importance of active listening significantly lower than mentors. The assessment of other skills in Lithuanian mentor and mentee sets does not differ significantly. The importance of all communication skill in the Latvian mentor and mentee sets does not differ significantly as well. However, statistically significant differences were found between assessments comparing the respondents' in LT and LV. Only the importance of interpreting a person by appearance and behaviour ($p_t^{Mentors}$=0.001<0.05) differs statistically significantly in mentees' sets in Lithuania and Latvia. Lithuanian mentees the importance of this skill to evaluate more positively than Latvian. Significant differences in evaluation between mentors in both countries in assessing communication skills are more common. The importance of such skills like the ability to correctly choose the strategy and tactics of dialogue, skill to actively listen (reflect, ask questions, conclude, discuss), ability to put oneself in another's shoes, understand each other's emotions and experiences, and ability to argue differ statistically significantly in mentors' sets in LT and LV. Lithuanian mentors more positively see the importance of these skills than Latvian, except for the ability to put oneself in another's shoes, understand each other's emotions and experiences (μ^{LT} =3.93, μ^{LV} =4.06, $p_t^{Mentors}$=0.018<0.05).

TABLE 3 THE IMPORTANCE OF RATIONAL AND EMOTIONAL ASPECTS AND THE SPECIFICITY OF COMMUNICATION WITH A MENTOR AND THE MENTOR'S COMMUNICATION SKILLS (OWN STUDY)

	Mentors		**Mentees**		**Pearson's chi-squared criterion**			
Means	μ^{LT}	μ^{LV}	μ^{LT}	μ^{LV}	p_t^{LT}	p_t^{LV}	$p_t^{Mentors}$	$p_t^{Mentees}$
Ability to create a wish to communicate and cooperate	4.57	4.50	4.58	4.44	0.932	0.637	0.473	0.330
Ability to correctly choose the strategy and tactics of dialogue	4.45	4.20	4.38	4.38	0.524	0.282	**0.045**	0.971
Ability to arouse the partner's interest in a topic of conversation	4.34	4.31	4.32	4.28	0.865	0.814	0.834	0.778
Ability to ensure correct dialogue	4.39	4.37	4.28	4.19	0.319	0.155	0.843	0.467
Skill to actively listen (reflect, ask questions, conclude, discuss)	4.66	4.33	4.42	4.31	**0.039**	0.894	**0.003**	0.509
Ability to put oneself in another's shoes, understand each other's emotions and experiences	3.93	4.26	4.06	4.28	0.400	0.893	**0.018**	0.243
Ability to interpret a person by appearance and behaviour	4.05	3.98	4.28	3.69	0.119	0.078	0.624	**0.001**
Ability to argue	4.13	4.48	4.08	4.38	0.761	0.516	**0.010**	0.100
Ability to use modern communication technologies	4.30	4.06	4.36	4.16	0.686	0.592	0.121	0.194
Average	*4.31*	*4.28*	*4.31*	*4.23*				

Evaluation of the Impact of Communication Barriers between Mentors and Mentees. For communication to be effective, it is necessary to identify the barriers that should be eliminated; therefore, the respondents were asked to rate the barriers that hindered successful mentoring (see Table 4). From Lithuanian and Latvian mentors' point of view, of all possible barriers, the reliability of the information source and its significance have the greatest impact on communication between a mentor and a mentee, i.e. whether the recipient is confident that s/he can rely on the communicator and the information s/he provides (μ^{LT} =4.41, μ^{LV} =4.30). In terms of Lithuanian mentees, in addition to this barrier, a lack of time is also indicated (μ^{LT}=4.20 for both barriers). In terms of

Latvian mentees, technical barriers and obstacles have the greatest impact on communication between a mentor and a mentee (μ^{LV} =4.25 for both barriers). According to Lithuanian mentors' and mentees' sets, communication is least affected, in terms of mentors and mentees, by cultural and national barriers, i.e. they represent the influence of various national social norms, values and traditions during communication (mentors' μ^{LT} = 3.29, mentees' μ^{LT} =3.22). In Latvia, communication is least affected, in

terms of mentors, by technical barriers and obstacles (μ^{LV}=3.57), in terms of mentees, by differences among personalities, experiences, knowledge, skills, and status (μ^{LV}=3.25).

TABLE 4 THE INFLUENCE OF BARRIERS ON COMMUNICATION BETWEEN A MENTOR AND A MENTEE (OWN STUDY)

	Mentors		**Mentees**		**Pearson's chi-squared criterion**			
Means	μ^{LT}	μ^{LV}	μ^{LT}	μ^{LV}	p_t^{LT}	p_t^{LV}	$p_t^{Mentors}$	$p_t^{Mentees}$
1. Technical barriers and obstacles	3.84	3.57	4.00	4.25	0.308	**0.001**	0.106	0.166
2. Psychological barriers and obstacles: Differences among personalities, experiences, knowledge, skills, and status	3.57	3.80	3.70	3.25	0.442	**0.001**	0.130	**0.016**
2.2. Selective listening	4.02	3.81	4.00	3.38	0.901	**0.010**	0.117	**0.001**
2.3. Attitude to the communicator	3.82	3.96	3.42	3.84	**0.029**	0.499	0.385	**0.040**
2.4. Source reliability	4.41	4.30	4.20	3.81	0.074	**0.010**	0.354	**0.031**
2.5. Filtration - the manipulation of information by the communicator	4.13	3.80	4.12	4.38	0.973	**0.001**	**0.019**	0.153
2.6. Lack of time	4.02	4.11	4.20	3.75	0.184	0.074	0.484	**0.018**
2.7. Dislike to the form (dislike to arguments, the communication style)	3.73	3.76	4.00	3.94	0.080	0.312	0.853	0.733
3. Psychophysiological barriers	4.05	3.91	4.04	3.63	0.914	0.070	0.218	**0.013**
4. Social barriers and obstacles	3.45	3.70	3.58	3.81	0.498	0.552	0.136	0.292
5. Cultural and national barriers and obstacles	3.29	3.72	3.22	3.41	0.750	0.066	**0.010**	0.420
6. Logical barriers and obstacles	3.86	3.94	3.94	3.41	0.581	**0.003**	0.483	**0.007**
7. Stylistic barriers and obstacles	3.68	3.80	3.84	3.66	0.361	0.399	0.421	0.381
8. Semantic barriers and obstacles	3.70	3.81	3.78	3.47	0.586	**0.039**	0.391	0.100
9. Phonematic barriers and obstacles	3.59	3.61	3.64	3.53	0.776	0.664	0.895	0.591
Average	*3,81*	*3,84*	*3,85*	*3,70*				

Examining the hypothesis that the means of the assessment of the influence of communication barriers in Lithuanian mentor and mentee sets differ significantly (Table 4), we see that only the mean assessment of the influence of a single communication barrier, the attitude towards the speaker, differ significantly (p_t=0.029 <0.05) among mentors and mentees, the assessment of the impact of all other barriers does not differ significantly among mentors and mentees. However, the statistically significant difference is more common in Latvian mentor and mentee sets, for example, technical barriers and obstacles, differences among personalities, experiences, knowledge, skills, and status, selective listening, source reliability, filtration, logical barriers and obstacles, semantic barriers and obstacles. The significant difference between Lithuanian and Latvian mentees' mean evaluation of the influence of various communication barriers is more common than mentors'.

CONCLUSIONS

The conducted study showed that the assessment of communication elements (communication channels, content creation through communication, various communication skills and communication barriers) usually differed significantly between Lithuanian and Latvian mentors and mentees. In most cases, mentors and mentees in Lithuania consider various communication elements more important than in Latvia. It can be concluded that this may have been influenced by the different number of respondents by age - in Lithuania, more respondents than younger than 30 years and less old than 60 years participated in the survey. The Latvian respondents to the survey were more concentrated in one field of activity - agriculture, while the Lithuanian respondents represented more different fields. In general, the average assessments of communication skills differ very little in various aspects.

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REFERENCES

[1]. Ester van Laar, Alexander J. A. M. van Deursen, Jan A. G. M. van Dijk and Jos de Haan. (2020). Determinants of 21st-Century Skills and 21st-Century Digital Skills for Workers: A Systematic Literature Review. *SAGE Open*, January-March pp. 1 –14.

[2]. Fiske, J. (1990). *Introduction to Communication studies.* 2nd Edition. London, New York: Routledge.

[3]. Misevičius V. & Urbonienė R. (2006). *Fundamentals of Business Communication*. Šiauliai: Šiauliai University Publishing House. (In Lithuanian).

[4]. Perkumienė, D., & Perkumas, A. (2010). Elements of Communication of Consultants and Clients in Agricultural Consulting Companies. *Management theory and studies for rural business and infrastructure development*, No. 23 (4). Research papers. Retrieved from: http://vadyba.asu.lt/23/85.pdf Access: 05.05.2020.

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Water Springs as a Resource for Nature Tourism in Latvia: a Tourist Perspective

Janis Bikse, Ph D Scholar
Vidzeme University of Applied Sciences
Cesu Street 4, Valmiera LV-4200 LATVIA
janis.bikse@va.lv ; http://va.lv

Mahender Reddy Gavinolla, Assistant Professor,
National Institute of Tourism & Hospitality Management
Gachibowli, Hyderabad, INDIA -500032; www.nithm.ac.in
Guest Lecturer, Vidzeme University of Applied Sciences, LATVIA mhender.reddy@va.

Abstract **- Water springs are considered as one of the important natural resource for tourism due to its socio-economic, cultural, health and religious benefits. Tourists are motivated to visit the water springs due to various reasons like sacredness, health benefits, education and cultural enrichment. Latvia is blessed with several water springs, which are potential attractions for the sacred water or holy water tourism. There are several studies conducted on various aspects of water springs in general. However, the research in the context of tourism, particularly motivations and interest of tourist is very scant. In this regard, aim of the paper is to know the motivations and potential benefits of the water spring tourism to tourist in Latvia. Initially authors reviewed existing literature to know the state of the spring tourism. Semi structured interviews and online-survey method to obtain visitors responses. Interviews were held with the visitor, covering various aspects like motivations and benefits of water spring tourism. To the best of the author's knowledge, very few studies conducted on spring tourism in Latvia, to provide a detailed overview on tourist motivations and potential benefits of visiting water spring tourism. Overall, the study results provide the basis for understanding the most frequently visited water spring resources by the tourists in Latvia. Nature appreciation, natural setting followed by mineral and health benefits are the major reasons to visit the water springs. Further, it allows decision makers to incorporate tourist opinion and their suggestions in the sustainable planning, promotion and management of water springs as tourist destinations in Latvia.**

Keywords - Water Spring Tourism, Sacred Water, Tourist Motivation, Latvia

INTRODUCTION

Visiting the natural spring water for bathing and medical purpose to feel good and spiritual and physical health is in practice for the ages [1]. For example, archaeological evidence shows that several Asians used water springs for about 3000 years before Christ and Japanese used 11000 years ago [2]. Several studies mentioned the sacredness and spiritual importance of the spring water [3]. In India, it is quite common that people take bathing in hot water springs with the belief and faith that it would lead to longevity and curing several diseases like arthritis and skin diseases [4]. Owing to the potential benefits of the springs, several rulers gave immense importance to build tanks, gardens and creation of beautiful landscape for the visitors in the vicinity of the water springs [1]. The creation of pilgrimage centres and building temples around the springs shows evidence of strong belief [5]. Irrespective of the religion or religious beliefs people often visit holy springs with a belief that their wishes will come true on certain occasions and will also supernatural powers [6], fertility power [7], [8]. For example, several people visit the Orthodox Greeks Church in Büyükada, İstanbul annually on the 23rd and 24th day of April month. Further, they believe that the spring water is curative so that drinking and sprinkling on the face or hand will cure some diseases [9].

As per the UNESCO and IUCN, due to the sacred nature and spiritual significance, springs can be considered under the sacred natural sites [10]. This has further led to the recognition of springs as sacred natural sites as protected areas in various places [11]. Water springs are considered as one of the important natural resources for tourism due to their socio-economic, cultural, health and religious benefits [12], [13]. Sacred water springs are significant tourist attractions in several countries that provide several recreational and socio-cultural and economic benefits [14], [15]. Due to its nature, location and multiple characteristics, the water springs are considered as a resource for nature tourism, cultural tourism, religious

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and spiritual tourism and wellness tourism. It is widely understood that the tourist motivation is multi-faceted consist of several reasons and interest to visit the destination [16]. Similarly in the context of sacred water springs, there are several motivations to visit the sacred springs. For example, mystical power [17], to perform the rituals [18], touching and drinking the water for the transformation of life and rebirth [19], [5], [20], spiritual motives [1], curing diseases and healing power [4], [21], appreciation of the culture and nature [22]. Latvia is one of the popular destinations for the several water springs used as a resource for the spiritual, health and wellness, therapeutic and recreational purpose considering the geothermal, mineral and sacred benefits. Nonetheless, the scientific production of literature to understand the usage of spring as a tourism resource is scarce.

There are few studies conducted on various aspects of water springs as a resource for the tourism and motivational factor of the tourists in general? However, the research in the context of tourism, particularly motivations and interest of tourist is very scant. In this regard, the aim of the paper is to know the usage of springs as a resource for tourism, and the motivations and potential benefits of water spring tourism to the tourist in Latvia. In doing so, the authors tried to understand the concept of sacred spring tourism and the usage of sacred springs as a resource of tourism in general. More precisely, to know how the sacred water springs used a resource for tourism in Latvia, and further, the study tried to investigate motivations and benefits of visiting sacred water spring in Latvia. The structure of the chapter includes the theoretical background on water spring tourism and tourist motivations. Then the study elucidates on the methodological framework followed by the contextual framework. The latter part deals with the findings, discussions and conclusion, limitation and future scope of the study.

Review of the literature

Over the centuries, spring water is considered an important element on Earth that has several benefits [23]. Most importantly spring water is considered sacred in nature due to the spiritual, therapeutic and mineral benefits. It is also believed that it gives magical power and cures several diseases. [24]. It is important to know the tourist motivations for the market segmentation of spring tourism products and also to the sustainable management of the destinations. [16]. People may visit them because of the sacred power that they obtain by touching the water, with the hope that it would lead to a life transformation or an important and better pathway [20].

Water springs are also associated with legends and religious activities. Due to this, there are several religious buildings established in the vicinity of the sacred water spring sites. This is further giving an opportunity for recreation tourism for several tourists [25]. For example, springs in Western Kazakhstan surrounded by beautiful landscape, nature and also associated with spiritual and healing power. These are promoted as tourist products [26]. Springs are also considered life-giving sacred powers. For instance, springs dedicated to Virgin Mary at Acropolis in Greece shows a similar belief [27].

It is also observed in the previous studies that men and women exhibit different interests and interact differently with sacred water resources [28]. With increased interest to visit springs by the Europeans in the 18th and 19th century, several of them were converted to a commercial resource of recreational, medical and health tourism attractions [29]. Despite several benefits, overexploitation, irresponsibly managed destinations with mass tourism are sources for several negative impacts, leading to pollution and change in the water quality in several sacred water spring destinations [4], [27].

Water springs are generally divided into two basic types. Gravity springs (descending springs, hillslope springs) - emerge under unconfined conditions where the water table intersects the land surface. The water moves through the ground until it reaches a layer it can't penetrate and starts flowing horizontally until it reaches an opening and water comes out as a spring. Gravity springs are usually found along hillsides or on sandy or gravel slopes. Gravity springs commonly form a spring run without a pool. Artesian springs (rising springs, ascending springs) - discharge under pressure due to confined conditions in the underlying aquifer. The pressure inside the confined aquifer (due to being confined between impermeable formations) is higher than the pressure outside the aquifer, so the water moves in that direction, preferably to converging to joints or faults perforating the upper confined layer. Artesian springs often discharge into a pool, in the bottom of which spring boils occur. By conducting structured interviews, including nature tourism guides, authors obtained answers about the interests of tourists. If we look at the springs from this point of view, then the artesian springs where the water "boils" attract more interest.

MATERIALS AND METHODS

The study is conducted by using a mixed methodology. In the first phase, the authors reviewed published literature to understand the state of spring tourism and the usage of water spring as a resource for the various forms of tourism. In the second phase, the authors further used a survey method such as an online survey. It was a random study sampling. Total respondents were 126 (n=126) in which 51 respondents are male and 75 are female visitors with an average age of 40 years. In the third phase, 10 semi-structured interviews were conducted with the visitors at the site, to obtain the primary data on various aspects like motivations and benefits of water spring tourism. To better understand the sacred spring water as a resource of tourism in Latvia, authors tried to explore the various motivational factors, frequency of the visit, the season

most frequently visited springs. For which, semi-structured interviews were conducted. Detailed findings are provided in the result section followed by discussion.

History and Profile of water springs in Latvia

Water springs are popularly known for the use of springs for health and medical use, due to this spring water-based health tourism is well-known in the Baltic States. Several traditional thermal baths and rehabilitation resorts located across the Baltic seaside, these include Jurmala and Liepaja in Latvia. There are several thermal spas and seaside resorts established over a century ago. Considering the potential spring resources, Baltic Health Tourism Cluster was created in the year 2013 for better collaboration among the states and to improve the quality of the services and marketing of the destinations [30]. However, the literature shows that there are several other reasons to visit water springs in various parts of the world. Considering this, and with the evidence of the lack of literature in the Baltic context, this study is mainly focused on Latvian water springs as a source for tourism.

Latvia is known for the diverse springs with great history. The documented history of water springs in Latvia is related to the springs flowing from the caves shows that the oldest the cave year 1521 mentioned in literature is from Gutmanis Cave [31], [32]. There is a spring in Gutmanis Cave can give away youth. Gutmanis Cave is not only the oldest but also the most visited tourist attraction (see Fig.1). XX century in the second half, it was visited by about 1.5 million tourists every year [33]. The cave is mentioned as the most visited by tourists in the Soviet Union [34], [35]. The number of visitors to the cave and spring as 1.5 million is also mentioned in 1989 [36].

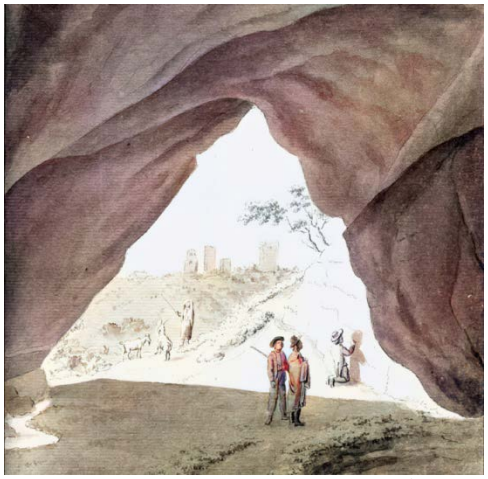

Figure.1 Gutmanis cave. Spring on the left.
(Source: Brotze 1794)

In the Republic of Latvia, number of visitors to Gutmanis cave grows from 100 thousand in 1993 to almost 300 thousand in 2019 [37].

Liepa Lielā Ellīte (Devil's Oven) is an equally old, popular tourist attraction from water-rich springs (see Fig.2). The descriptions tell of even older annual figures [38]. Lielā Ellīte, like Gutmanis cave, is located near the ancient road, so it must be thought that they were already known in the 12th century [39].

Figure.2 Liepas Lielā Ellīte (Devil's Oven).

Liepas Lielā Ellīte is the third most popular spring in Latvia. Also one of the earliest known. With cave and three natural arches.

Figure.3 Baldone sulphur spring "lizard".

Baldone was a famous sulphur water resort in the past (see Fig.3).

Figure.4 Gaujiena Spring of the right bank of the river Gauja.

Gaujiena Spring is a popular water intake (see Fig.4).

Currently, Lielbāta spring water is also sold in PET bottles (see Fig.5).

Figure.5 Lielbāta water spring.

Figure.6 The sacred spring of the Boleni.

Boleni Spring helps against eye diseases (see Fig.6). One of the artesian (fountain) springs, which is very popular with tourists.

Figure.7 Satezele spring.

The Satezele spring is located next to an ancient Liv castle. Currently, it is visited both as a beautiful natural object, where the spring flows from a sandstone cliff (see Fig.7). It is also visited by people who want to get qualitative drinking water.

RESULTS AND DISCUSSION

To understand the frequency of the visit to the spring in a year, we asked the respondents how many times they visited springs in Latvia last year. Results show that only 15% of the respondents visited for the first time and the majority of the respondents (56%) visited a minimum of 1 time to a maximum of 5 times (see Fig. 8). Interestingly about 29% of them visited minimum of 5 times and more.

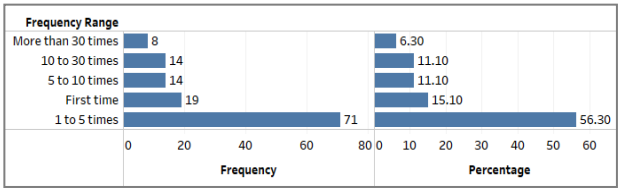

Figure 8. Frequency of the visit

Literature shows that there are several other motivations other than spiritual benefits. In this regard, the authors asked the questions on motivations to visit the springs to understand the motivational factors. Result revealed that there are multiple motivations to visit the springs. Most of the respondents (about 50%) visited due to the natural beauty of the object followed by extraction of water (25%) (see Fig. 9). There are about 10% of the people visit mainly because of a historical object is surrounded by legend. About 8% includes special benefits like health, youthfulness and life expectancy followed by others such as education, research, geo coaching, refreshing, thirst-quenching water, landscape and geology, etc.

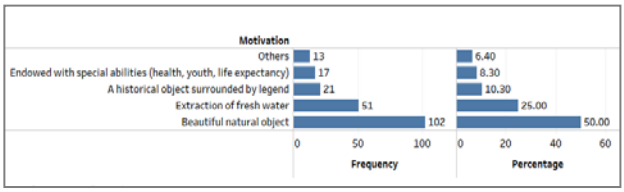

Figure 9. Motivations for the visit

Seasonality as one of the major factors that influences the visitors to visit the destination. Accordingly, the authors tried to understand the best season that the tourist visits the most (see Fig. 10). There are multiple answers by the tourist to visit the destination. However, majority (40%) of them are visiting in the summer, 25% of them are visiting in spring followed by the fall and winter with 20 % & 15% respectively.

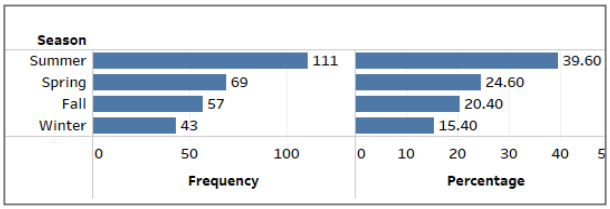

Figure 10. Season of the visit

Further authors tried to understand the most frequently visited spring destination in Latvia. However, we have important to know the most frequently visited springs (see Fig. 11). Results show that "Gutmaņalas avots" and "Raunas Staburags' are the most popular springs visited by almost 15 % each followed by "Lielās Ellītes avots" with 10%. Next popular springs include "Mazās Ellītes avots", "Aglonas svētavots", "Velna Skābumaķērne Skaņkalnē" and "Ķemeru ķirzaciņa".

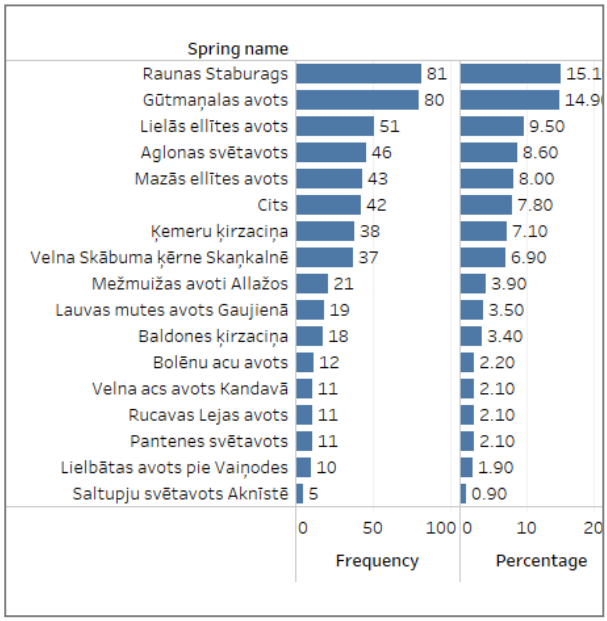

Figure 11. Most frequently visited spring

A very important section of the survey is about the motivations for a tourist visit. It shows that in 50% of cases, tourists visit water sources as beautiful and interesting natural objects. Springs are often associated with objects created by the influence of springs as caves, grottoes, travertine cliffs. Such tourist objects are related to the most frequently visited Latvian springs – Raunas Staburags (travertine cliff), Gutmaņala (grotto, cave), Liepas Lielā Ellīte (cave and three natural arches). The second most common reason for visiting springs is to get drinking water. The third reason is history - there are legends about many springs. As in other countries, many of the water sources have been known for many centuries and have a sacred significance. Some springs have special abilities - to regain youth, improve eye light, and improve health. People have also mentioned that they have visited the springs as a geocaching point, how to learn geology and nature, how to perform sacred rituals, how to refresh, how to walk with or without children. The answers also show seasonality in the visit to the springs. In summer it is higher, then spring, autumn and winter. The good news is that people visit the springs in all seasons.

The authors also conducted semi-structured interviews with people at springs. The authors interviewed the people who took water from Rūcamavots spring near Cēsis, Oliņu spring near Seda, Zāģezers spring near Valka, Vecsautiņi spring near Smiltene. The main reason for taking water is qualitative water with good mineral composition. It replaces the water supplied by the city's water supply. In the water supply, the water tends to be tasteless, with colour and bad smell in some places. Water is filtered, coagulated, sorbents are used, disinfected (chlorinated, ozonated, irradiated with ultraviolet light). Sometimes the water is further treated - Water softening, Fluorination, Iron removal, demanganization). All this reduces the belief in the water supply as a natural product. Most of the interviewed people were from the nearest urban areas as Cesis, Smiltene, Seda, Valka in the North-East part of Latvia called the Vidzeme region. They plan trips to the spring water in their free time. Sometimes they also supply water to neighbours. People whose work involves trips outside the city include one of the famous springs on the route to supply the family with valuable water.

Respondents consider such water from a spring to be more valuable as a spring of water from PET bottles. Some water traders also use a well-known spring of bottled water (Lielbāta spring, Cēsis Svētavots). Also in these cases, people prefer to choose "living" water from the spring. A detailed map of the springs is shown in the map (see Fig. 12).

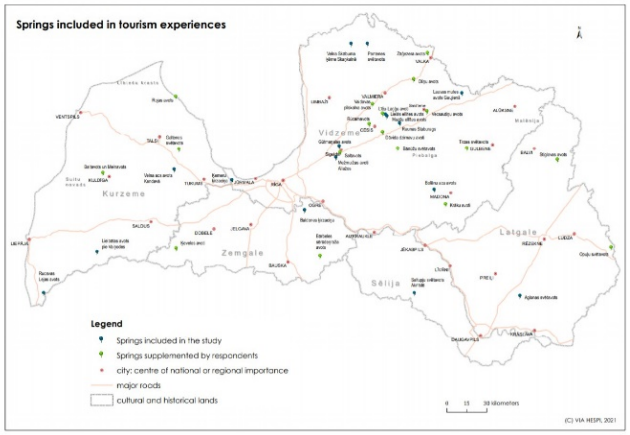

Figure 12. Springs included in the tourism experiences

Nature tourism is one of the important forms of tourism that provides several benefits to the visitors and local community [40], [41]. Spring can be considered an important tourism resource for Latvian tourism. It can be considered as an important nature-based tourism resource due to its natural characteristics and tourist interest to visit these places as a natural object. It is interesting that even in places where good natural water sources have not been preserved, they are created artificially, using the very rich selection of Latvia's underground mineral waters. Thus, in the development plan of Liepāja resort, one of the main accents is the use of groundwater. However, it is well argued in several studies that if tourism is overexploited

and not managed properly, it will lead to several negative impacts such as overtourism, mass tourism, pollution and change in the natural settings [42], [43]. Keeping in view of this it is important to ensure that the spring resources managed and promoted in a sustainable manner to minimize the negative impacts and maximize the positive ones.

CONCLUSION

The study was aimed at understanding the sacred water as a source of tourism object in Latvia. In this regard, the authors reviewed the relevant literature on how the spring is used as a resource for tourism in general. Literature shows that there are different types of water spring based on the location and geographical features. Water springs are having a very long history and mostly used in the past for the purpose of spiritual, religious purpose followed by medical and health purpose. Due to its location and associated benefits, several countries promoting springs as a spiritual or sacred place, religious destination, health and wellness tourism activities. However, in the recent past, people started visiting for non-religious purpose and to enjoy nature, mineral benefits, and natural settings and water flow. Latvia is blessed with several springs and having several potential opportunities for the promotion of tourism. Considering the diverse and intensive springs it is important to promote them as a tourism attraction. In doing so, it is important to know the tourist interest and motivations to visit the springs. The authors conducted a survey on motivations, frequency, interesting and most frequently visited springs and seasonality. Result show that the Latvians are the frequent visitors to water springs. Results revealed that there are multiple motivations to visit the springs. But most of the visitors interested in seeing the natural beauty of the object followed by the extraction of water. Visitors are motivated by history and education. Based on these results, Latvian tourism authority may promote the spring water resources not only for the sacredness or spiritual purpose but also as a nature-based attraction due to the natural settings and geographical features. Seasonality is not a hindrance for the tourist as a visitor visiting all the seasons, however, the majority is visiting in the summer. “Gūtmaņalas avots” and “Raunas Staburags’ are the majority of the most popular spring followed by “Lielās Ellītes avots” followed by “Mazās Ellītes avots”, “Aglonas svētavots”, “Velna Skābumaķērne Skaņkalnē” and “Ķemeru ķirzaciņa” that the tourist showed the most interest to visit. Further, there are several visitors interested in education and history; accordingly, there is a scope to promote educational tourism for the children to understand the spring ecosystem, services. Further, results explained the most frequently visited water springs, most frequently visited spring water resources may be promoted in a sustainable manner. As mentioned in the discussion, if tourism is not properly managed it may lead to several negative impacts and leading to pollution and change of the spring ecosystem. Considering this sustainable management of the spring waters is an important aspect.

There are several limitations to the study. The study is conducted in the COVID-19 pandemic times, due to this there was an only domestic tourist visiting the water spring in Latvia. The study focused only on motivations, frequency and important places. Future studies should focus on the various aspects of spring tourism including implications of spring tourism on the local community, the status of the spring tourism attractions for sustainable management. There should be a study on the motivational factors of the international tourists to promote these places for the international market. There is a scope to study amenities, facilities and promotion of water spring tourism in Latvia. As the majority of the visitors are motivated with religious aspects in general, it is necessary to carry out additional research in Latgale research (orthodox, Catholics etc.). In this research, the semi-structured interviews were done in the Vidzeme region and future research can cover all the areas. Future research may use the quantitative survey to measure motivations in detail for both domestic and international tourists.

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REFERENCES

[1] B. Kiełczawa, “Short history of thermal healing bathing,” in Geothermal Water Management, 2018, pp. 303-318.

[2] I. B. Fridleifsson, “Geothermal energy for the benefit of the people,” Renewable and Sustainable Energy Reviews, vol. 5, no. 3, pp. 299-312, 2001.

[3] L. Coltelli, “Leslie Marmon Silko's Sacred Water,” in Studies in American Indian Literatures, 1996, pp. 21-29.

[4] R. Bhutiani, D. R. Khanna, D. B. Kulkarni, M. Ruhela, “Assessment of Ganga River ecosystem at Haridwar, Uttarakhand, India with reference to water quality indices,” Applied Water Science, vol. 6, pp. 107–113, 2016.

[5] D. Chandrasekharam, “A prehistoric view of the thermal springs of India,” presented at World, Geothermal Congress, 1999, pp. 385-388.

[6] V. E Hart, “The Waters and Water Spirits,” in Votian Folk Beliefs, vol. 4, no. 12, pp. 6-37, 1999.

[7] F. Türkmen, “Batı Anadolu’ da Doğumdan Ölüme Bazı İnanmalar Üzerine,” in Türk Dili ve Edebiyatı Araştırmaları Dergisi, 1991, pp. 2-7.

[8] E. Akman, “Türkve Dünya Kültüründeki Su Kültü Üzerine Düşünceler,” in KastamonuEğitimDergisi, vol. 10, no. 1, pp. 1-10, 2002.

[9] M. N. Önal, "DağKültü, Eren Kültüve Şenliklerinin Muğla'dakiYansımaları," Bilig. 25, 2003.

[10] R. Wild, C. McLeod, "Sacred Natural Sites: Guidelines for Protected Area Managers," in International Union for Conservation of Nature, Gland, Switzerland, 2008.

[11] N. Dudley, Z. L. Higgins, S. Mansourian, "The links between protected areas, faiths, and sacred natural sites," Conservation Biology, vol. 23, no. 3, pp. 568-577, 2009.

[12] C. F. Lee, B. E. King, "Using the Delphi method to assess the potential of Taiwan's hot springs tourism sector," International Journal of Tourism Research, vol. 10, no. 4, pp. 341-352, 2008.

[13] C. F. Lee, B. E. King, "Assessing destination competitiveness: An application to the hot springs tourism sector," Tourism and Hospitality Planning & Development, vol. 3, no. 3, pp. 179-197, 2006.

[14] P. Erfurt-Cooper, "The importance of natural geothermal resources in tourism," In proceedings World Geothermal Congress, 2010, pp. 1-10.

[15] Y. Mansfeld, O. Winckler, "Can this be spring? Assessing the impact of the "Arab Spring" on the Arab tourism industry," Tourism: An International Interdisciplinary Journal, vol. 63, no. 2, pp. 205-223, 2015.

[16] C. Ryan, "Motives, behaviours, body and mind," In The tourist experience, 2002, pp. 27-57.

[17] J. Digance, "Pilgrimage at contested sites," Annals of Tourism Research, vol. 30, no. 1, pp. 143-159, 2003.

[18] M. Eliade, Myth and reality. London: Allen & Unwin, 1964.

[19] J. Hannaford, J. Newton, "Sacrifice, grief and the sacred at the contemporary 'secular' pilgrimage to Gallipoli," Borderlands e-journal, vol. 7, no. 1, 2008.

[20] P. J. Margry, "Secular pilgrimage: a contradiction in terms?" In Shrines and pilgrimage in the modern world: New itineraries into the sacred, 2008, pp. 13-46.

[21] J. Dubisch, In a different place: Pilgrimage, gender, and politics at a greek island shrine, Princeton: Princeton University Press, 1995.

[22] N. Collins-Kreiner, "Research pilgrimage: Continuity and transformation," Annals of Tourism Research, vol. 37, no. 2, pp. 440–456, 2010.

[23] N. Altman, The Spiritual Source of Life Sacred Water, 2002.

[24] M. Eliade, "Sularvesusimgeleri," in DinlerTarihineGiriş. Çev. Lale Arslan, İstanbul, 2003.

[25] Y.A Absalyamova, "The Cult of Sacred Springs among the Bashkir," Shaman, Budapest, vol. 27, pp. 45-53, 2019.

[26] K.M Akhmedenov, "Assessment of the Prospects of Springs in Western Kazakhstan for Use in Religious Tourism," Geojournal of Tourism and Geosites, vol. 31, no. 3, pp. 958-965, 2020.

[27] J. H Håland, "Water sources and the sacred in modern and ancient Greece and beyond," Water History, vol. 1, pp. 83-108, 2009.

[28] T. J. Baker, B. Cullen, L. Debevec, Y. Abebe, "A socio-hydrological approach for incorporating gender into biophysical models and implications for water resources research," Applied Geography, vol. 62, pp. 325-338, 2015.

[29] J. W. Lund, "Historical impact of geothermal resources on the people of North America," in Stories from a heated Earth, our geothermal heritage, Geothermal Resources Council, Davis, CA, pp. 451–478, 1999.

[30] S. Melanie, "Baltic Health Tourism: Uniqueness and Commonalities," Scandinavian Journal of Hospitality and Tourism, vol. 15, no. 4, pp. 357-379, 2015. DOI: 10.1080/15022250.2015.1024819.

[31] E. Guntis, Alas Latvijā, Rīga: Zvaigzne ABC 76.lpp, 2004.

[32] G.Urtāns, Gūtmaņa ala senākais tūrisma objekts Latvijā. Eiropas kultūras mantojuma dienas 2008. Neparastais mantojums. Rīga: Valsts kultūras pieminekļu aizsardzības inspekcija. 54.-55. Lpp.

[33] O.Āboltiņš, G.Eniņš, Gaujas senieleja. 1979. Rīga: Liesma.136.lpp.

[34] Siguldas alas Vaduguns 1973.09.20 (Balvi)

[35] Siguldas alas Za PobeduKommuņizma 1973.09.27 (Ludza)

[36] Kuršs, V., Eniņš, G., Stinkule, A., Straume, J., &Venska, V. Ģeoloģiskie objekti Gaujas nacionālajā parkā. 1989. Rīga: Zinātne, 5.lpp.

[37] Klepers, A. 2021. Apmeklētāju plūsmas uzskaites un visaptveroša monitoringa sistēmas izveide īpaši aizsargājamās dabas teritorijās - *Natura 2000* vietās Latvijā (Latvian). Vidzemes Augstskola.

[38] Heervagen_Ludvig Vella ceplis. Mājas viesis. 1864. 13.janv. (Nr.2) 15.-16.lpp.

[39] Laime Sandis, Svētā pazeme, Rīga: Zinātne, 474.lpp, 2009.

[40] A. Livina, M. Reddy, "Nature Park as a Resource for Nature Based Tourism," in Environment Technologies Resources, Proceedings of the International Scientific and Practical Conference, vol. 1, pp. 179-183, 2017.

[41] I. Berzina, A. Livina, "The Model on Estimating Economic Benefit of Nature-based Tourism Services of Territories of National Parks, Latvia," in 4th International Conference on Educational Technologies, Corfu: Greece University, Corfu, pp. 100-105, 2009.

[42] V. Kaushal, S. Sharma, G. M. Reddy, "A structural analysis of destination brand equity in mountainous tourism destination in northern India," Tourism and Hospitality Research, vol. 19, no. 4, pp. 452-464, 2019.

[43] M. R. Gavinolla, V. Kaushal, A. Livina, S.K Swain, H. Kumar, "Sustainable consumption and production of wildlife tourism in Indian tiger reserves: a critical analysis," Worldwide Hospitality and Tourism Themes, 2021,. https://doi.org/10.1108/WHATT-08-2020-0091

[44] Z. Dumpe "Latvijas avotu sabiedriskā monitoringa vadlīnijas" 2017. Latvijas Universitāte. Maģistra darbs

[45] Liepājas pilsētas dome. "Liepājas kūrorta attīstības koncepcija 2015.-2020.gadam".

[46] http://laiki.lv/latvijas-avotu-karte/

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Financial Management of Micro-Enterprises in Latvian Fisheries Sector

Inese Biukšāne
Institute of Agricultural Resources and Economics
Rezekne Academy of Technologies
Riga, Latvia
inese.biuksane@inbox.lv

***Abstract* - competitiveness of the Latvian fisheries sector in the long term depends on thought-out financial management of enterprises and objective and timely identification of various risks. Sound and innovation- and knowledge-based entrepreneurship can contribute to substantial success and growth. The aim of the research is to assess the financial management of micro-enterprises in the Latvian fisheries sector, at the same time providing recommendations for the need in structural reforms and ensuring sustainable financial stability. Based on the chosen assessment methodology, the skills and opportunities of micro-enterprises in creation of capital structure, distribution of financial resources and return were analysed. The information reflected in the framework of the research can assist the institutions, entrepreneurs and researchers involved in establishment and implementation of fisheries policy to better understand the need in successful financial management to ensure a sustainable operation of the sector.**

Keywords* - *fisheries sector, financial analysis, Latvia, micro enterprises, sustainable development.

I. INTRODUCTION

In Latvia fisheries sector includes fishery, aquaculture and fish processing. The sectors differ in terms of the specific features of their activities and have different development potential [8]. There are 201 enterprises in the fishery sector that catch fish in the inland waters, the Baltic Sea and the Gulf of Riga, as well as on the high seas. There are 94 enterprises operating in the aquaculture sector that breed fish and crustaceans in ponds, basins and recirculation systems. The fish caught in the territorial waters of the state and on the high seas, as well as freshwater fish bred in aquaculture, are used as raw materials in fish processing. There are 108 enterprises operating in the fish processing sector specialising in the production of canned, smoked and salted fish, production of refrigerated and frozen fish, as well as production of mixed fish products. In Latvia, the fisheries sector is closely related to rational and sustainable use of natural resources and conservation of biological diversity, determined by the EU Common Fisheries Policy [2].

In total, 403 enterprises operate in the fisheries sector, most of which (84%) are micro enterprises. The total number of employees in the sector was 4.46 thousand employees with an average net salary of 569 EUR [5]. Although the GDP of the fisheries sector in the common Latvian economy is not significant (in 2018 it was less than 1%), Latvia, unlike most EU Member States, traditionally has a positive foreign trade balance of fisheries products. In 2017, fish products and canned fish were exported to more than 60 countries of the world. The EU countries have maintained their leading positions in the field of exports for several years. The largest export partners are Lithuania, Sweden, Germany, Denmark, the Czech Republic, Poland and Estonia. Using the support of the European Maritime and Fisheries Fund and annually visiting a number of international exhibitions, the enterprises operating in the sector also managed to explore new markets [13], thereby mitigating the consequences caused by the Russian embargo. Competitiveness of the Latvian fisheries sector in the long term depends on sound financial management of enterprises and objective and timely identification of various risks. Sound and innovation- and knowledge-based entrepreneurship can facilitate important success.

Research aim – to assess financial management of the micro-enterprises in the Latvian fisheries sector, at the same time providing recommendations for ensuring sustainable financial stability. To reach the aim, the following work tasks were put forward: 1) to select the most important indicators for the assessment of financial

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management of enterprises; 2) to assess the capital structure established by enterprises, their distribution of financial resources and return.

The research is considered to be innovative, as there are no assessments of the financial management of micro-enterprises in the Latvian fisheries sector carried out to date. The research provides a broad insight describing the skills and opportunities of enterprises in the sector in relation to formation of capital structure, distribution of financial resources and return. The analysis deals with comparison of micro-enterprises in fishery, aquaculture and fish processing in Latvia. The results of the research can help the institutions, entrepreneurs and researchers involved in establishment and implementation of fisheries policy to understand the need for successful financial management better to ensure a sustainable operation of the sector.

The general scientific research methods, statistical research methods and mathematical methods were used in the research. The author mostly applied analysis and synthesis methods in development of conclusions and proposals. Microsoft Excel programme was used to process and analyse the research results.

II. Materials and Methods

The research will deal with the analysis of the available information and data on micro-enterprises in the Latvian fisheries sector. According to the international regulation of the EU, an enterprise with maximum 10 employees and an annual turnover or balance not exceeding 2 million EUR corresponds to the status of a micro-enterprise [7].

The financial management of micro-enterprises in the Latvian fisheries sector was viewed from the aspect of capital structure established by the enterprises, distribution of financial resources and return. The assessment was based on financial analysis, in the framework of which the liquidity, solvency, efficiency and profitability of micro-enterprises was viewed. In general, there were 8 indicators selected: Fixed Assets Turnover Ratio [9], Productivity of Labour [4], Total Liquidity Ratio [1], Total Assets Turnover Ratio [11], Debt to Equity Ratio [6], Return on Sales Ratio (ROS) [3], Return Assets Ratio (ROA) [12], Return on Equity Ratio (ROE) [10]. Availability of data and their quality determined the period of analysis from 2005 to 2018.

III. Results and Discussion

The number of micro-enterprises in the fisheries sector has increased by 62% since 2005, reaching 339 enterprises in 2018. The amount of micro-enterprises in the aquaculture sector increased the most (3 times; in 2018 there were 90 enterprises), which can be largely explained by the availability of EU funds for aquaculture development. In fishery and fish processing, the number of micro-enterprises grew at a slower rate (by 30% and 63%, accordingly) reaching 184 fishery and 65 fish processing enterprises in 2018.

Micro-enterprises in the Latvian fisheries sector are generally not considered as capital-intensive enterprises (Fig. 1). Fishery enterprises are considered to be less capital intensive, and only then followed by fish processing enterprises. On the other hand, enterprises operating in the aquaculture sector can be assessed as capital-intensive enterprises, which means that the enterprises need significant capital investments to produce aquaculture products. The capital intensity of fixed assets decreased in all the sectors, indicating that enterprises make maximum use of the production means available to them in the production process and start to use more contemporary and powerful technologies for their renewal.

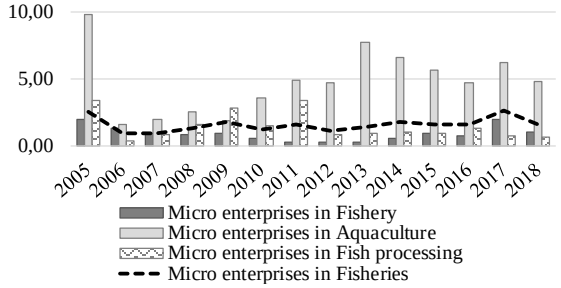

Fig. 1. Fixed Asset Capacity Ratio of the micro-enterprises in the Latvian fisheries sector in 2005-2018 (coefficient) [calculated and created by the author according to 5]

Since 2005, the number of employees in the micro-enterprises of the Latvian fisheries sector has decreased by -36%: from 1.99 thousand employees in 2005 to 1.27 thousand employees in 2018. Productivity of Labour in the micro-enterprises of the sector cannot be assessed as high (Fig. 2). Currently, the highest productivity is observed in fish processing – on average 20.64 thousand EUR per employee, followed by fishery with 20.37 thousand EUR per employee and aquaculture with 14.75 thousand EUR per employee. Since 2005, Productivity of Labour has improved in all the sectors, especially in fish processing. Productivity of Labour in the enterprises operating in the sector can be improved by promoting increase in knowledge and skills of employees, as well as by providing favourable working conditions and implementing binding motivation measures.

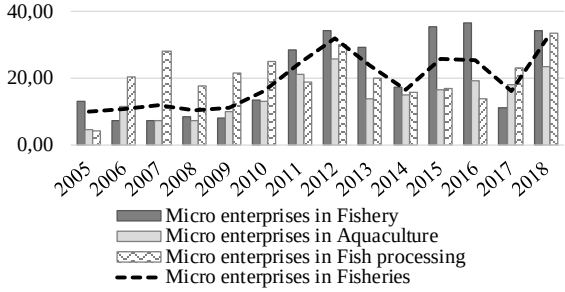

Fig. 2. Productivity of Labour of the micro-enterprises in the Latvian fisheries sector in 2005-2018 (thousand EUR) [calculated and created by the author according to 5]

The liquidity of micro-enterprises in the Latvian fisheries sector can be assessed as optimal, except for certain reporting years (Fig. 3). Total Liquidity Ratio shows that enterprises in the sector as a whole have no problem to cover their short-term liabilities with their available current assets. Higher liquidity was observed in

fishery and aquaculture enterprises. Fish processing enterprises, on the other hand, stood out with low liquidity (Total Liquidity Ratio on <1), which indicates short-term financial problems. Currently the micro-enterprises of the sector show a tendency to improve their liquidity. To ensure liquidity, it is desirable to finance short-term liabilities with current assets.

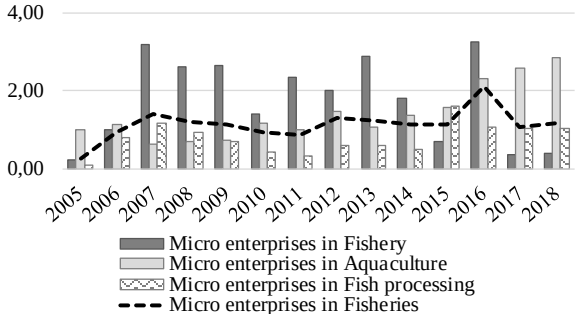

Fig. 3. Total Liquidity Ratio of the micro-enterprises in the Latvian fisheries sector in 2005-2018 (coefficient) [calculated and created by the author according to 5]

Micro-enterprises in the Latvian fisheries sector did not use the assets at their disposal effectively enough to generate net turnover (Fig. 4). This was particularly observed in aquaculture enterprises, suggesting that these enterprises have made considerable investments in their assets while failing to contribute to sufficient turnover. The best asset turnover took place in fishery enterprises. Asset turnover has improved in all enterprises of the sector since 2005. In order to be able to contribute to the asset turnover, the enterprises of the sector have to find a possibility to increase their turnover or to dispose a part of their assets which are unfit for production.

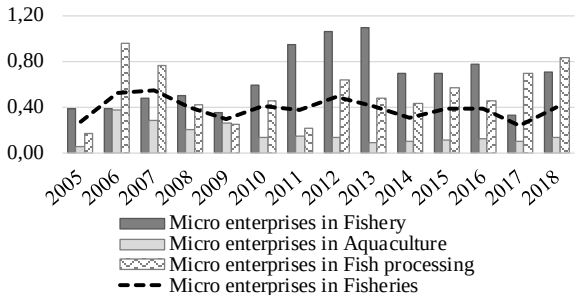

Fig. 4. Total Assets Turnover Ratio of the micro-enterprises in the Latvian fisheries sector in 2005-2018 (coefficient) [calculated and created by the author according to 5]

Micro-enterprises in the Latvian fisheries sector as a whole created an unbalanced capital structure (Fig. 5). Enterprises used a lot of debenture capital, failing to correlate it with equity. A particularly unbalanced capital structure was observed for micro-enterprises in the aquaculture sector, where the total liabilities were several times higher than equity, thus exposing them to high financial risks. On the other hand, micro-enterprises operating in the fish processing sector showed negative equity in some reporting years due to accumulated and newly created losses. This, in turn, suggests potential financial difficulties. The micro-enterprises of the sector can improve their financial balance by establishing a well-considered and balanced structure of equity and debenture capital. This can also be achieved at the national level by setting maximum admissible ceilings of financial equilibrium at which enterprises in the sector can receive funding from EU financial instruments, government and credit institutions.

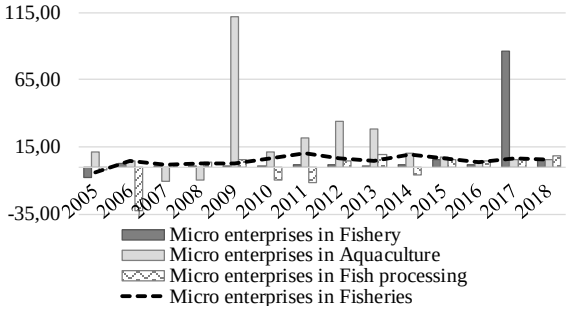

Fig. 5. Debt to Equity Ratio of the micro-enterprises in the Latvian fisheries sector in 2005-2018 (coefficient) [calculated and created by the author according to 5]

The economic activity of micro-enterprises in the Latvian fisheries sector is generally assessed as financially profitable, but not in all reporting years and for all enterprises (Fig. 6). Fishery enterprises are considered to be the most profitable micro-enterprises. Economic activity was not sufficiently profitable in fish processing and aquaculture enterprises.

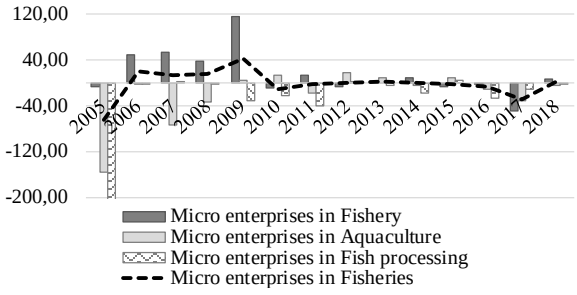

Fig. 6. Return on Sales Ratio of the micro-enterprises in the Latvian fisheries sector in 2005-2018 (%) [calculated and created by the author according to 5]

The economic profitability of micro-enterprises in the Latvian fisheries sector cannot be assessed unequivocally either (Fig. 7). The largest return on invested assets was generated by micro-enterprises in the fishery sector, but not in all the reporting years. Micro-enterprises in the fish processing sector were less profitable. Enterprises in the sector have made both profits and losses, which indicates various problems in the internal and external environment of enterprises.

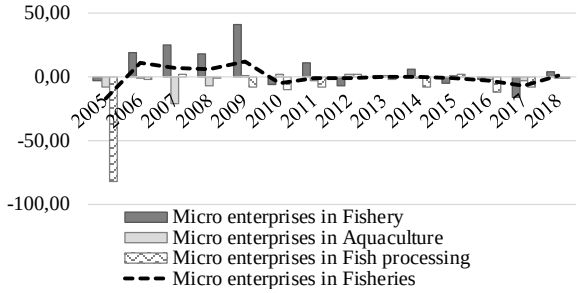

Fig. 7. Return on Assets Ratio of the micro-enterprises in the Latvian fisheries sector in 2005-2018 (%) [calculated and created by the author according to 5]

A similar situation is observed in relation to financial profitability (Fig. 8). The efficiency of use of the invested capital for micro-enterprises in the Latvian fisheries sector generally can be assessed as good, but not in all the reporting years. Micro-enterprises operating in the aquaculture sector obtained the highest return on their equity, while micro-enterprises operating in the fishery sector obtained the lowest return.

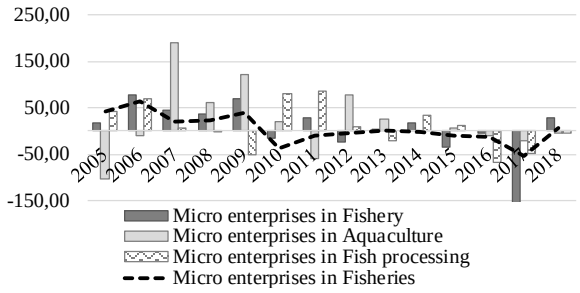

Fig. 8. Return on Equity Ratio of the micro-enterprises in the Latvian fisheries sector in 2005-2018 (%) [calculated and created by the author according to 5]

The financial management of micro-enterprises operating in the Latvian fisheries sector can be improved by complying with several financing rules, using production resources available to the enterprises efficiently and rationally, at the same time providing for proportionate investments in their renewal and education of workforce. It is not mandatory to follow the financing conditions, but it is desirable from the aspect of sustainable financial stability and ensuring competitiveness.

IV. Conclusions

The financial management of micro-enterprises in the Latvian fisheries sector was viewed from the aspect of capital structure created by the enterprises, distribution of financial resources and return, based on application of financial analysis. The evaluation process included 8 indicators, which enabled analysing the liquidity, solvency, efficiency and profitability of micro-enterprises in the fisheries sector. The applied methodology provides the opportunity to understand the need in structural reforms to ensure sustainable financial stability and competitiveness.

Micro-enterprises operating in the Latvian fisheries sector are generally not considered as capital-intensive enterprises (except for enterprises in the aquaculture sector). Although enterprises try to make the most of production means available to them in the production process and use more contemporary and powerful technologies to renew them, the enterprises in the sector do not stand out with high productivity and load of production technologies. Low Productivity of Labour in aquaculture can be explained by lack of knowledge and experience, but in fish processing – with insufficient level of mechanization and automation. In turn, the low production technology load in aquaculture can be related to small production volumes in the fragmented market and the existing competition. Although micro-enterprises in the sector have optimal liquidity (except for enterprises in the fish processing sector), they may face financial difficulties due to an unbalanced capital structure. Enterprises use a lot of debenture capital, which is not commensurate with their equity. The economic activity of enterprises in the sector is not profitable enough, suggesting various problems in the internal and external environment of the enterprises.

The financial management of micro-enterprises operating in the Latvian fisheries sector can be improved by creating a sound and balanced capital structure and distribution of financial resources, while paying attention to rational and efficient use and renewal of resources.

References

[1] A. Gasior, "Financial liquidity analysis of CSR based Capital Group Zywiec SA", Amfiteatru Economic, vol. 15(7), pp. 784-801, 2013.

[2] Agriculture Ministry, "Rīcības programma Zivsaimniecības attīstībai 2014.-2020. gadam (Operational Programme for Development of Fisheries 2014-2020)", 130, 2014 (In Latvian).

[3] B. Bayaraa, "Financial Performance Determinants of Organizations: The Case of Mongolian Companies", Journal of Competitiveness, vol. 9(3), pp. 22-33., doi: 10.7441/joc.2017.03.02., 2017.

[4] B. Walheer, "Labor productivity and technology heterogeneity", Journal of Macroeconomics, vol. 68, 103290, 2021.

[5] Central Statistical Bureau, Database. [Online]. Available: http://data.csb.gov.lv/pxweb/en/?rxid=cdcb978c-22b0-416a-aacc-aa650d3e2ce0. [Accessed: April 4, 2021] (restricted access data).

[6] D. Hertina, A.F. Pranata, R.E. Aulia, "The influence of current ratio, debt to equity ratio and company size on return on assets". Turkish Journal of Computer and Mathematics Education, vol. 12(8), pp. 1702-1709, 2021.

[7] European Commission, "Commission Regulation (EU) No 651/2014 declaring certain categories of aid compatible with the internal market in application of Articles 107 and 108 of the Treaty", Official Journal of the European Union, L 187/1, 78, 2014.

[8] I. Biukšāne, "Latvian fisheries sector cluster", International Multidisciplinary Scientific GeoConference Proceedings, vol. 18 (5.4.), pp. 465-472, doi: 10.5593/sgem2018/5.4/S23.059, 2018.

[9] L.G.V. Springate, Predicting the Possibility of Failure in a Canadian Firm: A Discriminant Analysis. Canada: Simon Fraser University, 164, 1978.

[10] M. Branten, J. Alver, "Profitability Measurement and Analysis in Estonian Business Practice", Proceedings of the 5th International Conference on Accounting, Auditing, and Taxation (ICAAT 2016), vol. 27, pp. 8-22, 2016.

[11] M. Dimitric, I.T. Zikovic, A.A. Blecich, "Profitability determinants of hotel companies in selected Mediterranean countries", Economic Research-Ekonomska Istrazivanja, vol. 32(1), pp. 1977-1993, doi: 10.1080/1331677X.2019.1642785, 2019.

[12] R.S. Njotoprajitno, "Effect of Return on Asset, Return on Equity, Net Profit Margin, Debt to Asset Ratio and Debt to Equity Ratio to

Dividend Payout Ratio of Public Companies Listed in Sharia Securities List in Indonesia Stock Exchange 2009-2012", 2nd World Conference on Islamic Thought & Civilization Proceedings, pp. 1070-1086, 2014.

[13] Rural Support Service, Database. [Online]. Available: http://lad.gov.lv/lv/. [Accessed: April 4, 2021] (restricted access data)

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Development of Smart Villages as a Factor for Rural Digital Transformation

Renāte Cāne
Faculty of Society and Science
Vidzeme University of Applied Sciences
Valmiera, Latvia
renate.cane@va.lv

Abstract **- The concept of digital transformation, which refers to the use of strategically managed digital technologies to achieve various economic and social goals, is increasingly visible in various development programs of the European Union and Latvia. The aim of the digital transformation is to create a society, economy and public administration that purposefully uses the existing and creates new opportunities of digital technologies, improving the quality of life for every individual and society as well, raising the competitiveness of the country and economy.**

The National Development Plan of Latvia for 2021-2027 also identifies the further development of digitalization as a pervasive element for all sectors, especially in such areas as innovation and science, education, health care, inclusive society and labor market, infrastructure, regional development, security, as well as also environment and energy. In order to do this, the "Digital Transformation Guidelines for 2021-2027" have been developed, which set out the goals, directions and tasks of the digital transformation policy.

One of the basic conditions for digital transformation is a digitally skilled society. To develop the rural environment, including through digital solutions, an initiative supported by the European Commission – 'Smart Villages', has been in place since 2016. It is a relatively new concept in EU policy-making and includes a vision for the future of rural areas. 'Smart', in the sense of this concept, means the development of new forms of cooperation – between farmers and other entrepreneurs in rural areas, between municipalities, the private and public sectors, and cooperation takes place from the bottom up and from the top down. Smart village strategies can ensure that the digital needs, priorities and capabilities of the rural population are addressed at local level and can help to link these core activities to national and regional digital strategies.

The aim of the research is to study the development opportunities of smart villages and their potential in the process of digital transformation of the rural environment. The study carried out an analysis of the rural and regional policies, as well as digital transformation strategic documents. The article also examines examples of the use of digital solutions in smart villages in European countries.

The study concludes that the introduction of the concept of smart villages is an effective tool for digital transformation in rural areas, both processes have a common goal and tasks, the most important of which is to take actions to prevent working-age persons from leaving local areas, moving to the capital city Riga or leaving Latvia.

Keywords - digitally skilled society, digital transformation, rural development, smart villages

I. INTRODUCTION

Looking at the development of the world economy and other social processes from a historical point of view, there is a clear significant trend – they are closely related to the development of various technologies and interact with each other. One classic example is the industrial revolution of the second half of the 19th century, in which manufacturers switched from manual to automated processes, resulting in increased revenue and production capacity. Today, we face a similar phenomenon, only in this case it occurs primarily in the digital environment, and it is a digital transformation [1].

The term 'digital transformation' has largely originated in the business environment and, in general, refers to the processes, cultures and customer experiences of using digital technologies to meet changing business and market requirements. Digital transformation has been defined differently in different sources, initially only emphasizing the need to integrate digital technologies into the company's business processes, until the current recognition that digital transformation requires not only technical solutions, but also review the company's strategy and culture, gradually including other aspects. Morakanyane, Grace & O'Reilly (2017) defines digital transformation as "an evolutionary process in which a company integrates digital capabilities and technologies into its business

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models, processes, customer experience to create value" [2]. Rogers (2016) also acknowledges that "digital transformation is not based on technology, it is more related to the company's strategy and new ways of thinking, adapting to new market requirements and changing the company's strategy or even strategic direction accordingly" [3].

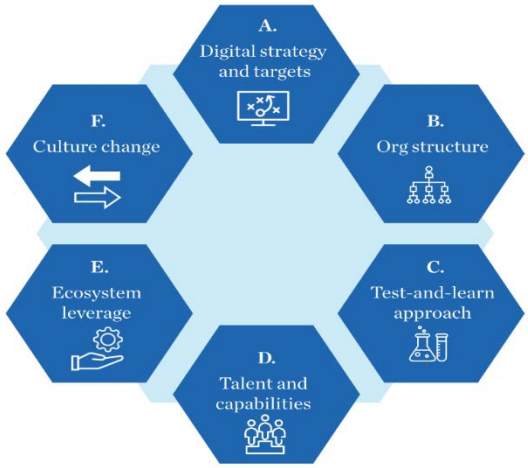

Fig. 1. McKinsey & Company six key elements of digital transformation (source: McKinsey & Company, 2018)

The main benefits of digital transformation are the opportunities to improve services, optimize processes and costs and increase efficiency, improve employee performance and promote internal cooperation, the creation of new business models, all of which increase the company's competitiveness.

In recent decades, business terminology has become increasingly used in the public and public sectors, and the notion of 'digital transformation', which refers to the use of strategically driven digital technologies to achieve a variety of economic and social goals, is no exception. Today, countries and public administrations around the world are changing their way of thinking, innovating and optimizing their IT infrastructure to respond more effectively to citizens' needs. One example is the UK Government, which has set up the Government Digital Service (GDS) to promote the digital transformation. The GDS service manages standards and best practices for other parts of the government as well as leading some successful digital transformation initiatives such as the development of Gov.uk, which hosts over half a million web pages whilst making the information accessible and consistent [4].

Latvia is also working towards digital transformation. The Ministry of Environmental Protection and Regional Development has prepared an important digital transformation strategy for Latvia – "Digital Transformation Guidelines 2021–2027." which is currently in the public consultation before further adoption by the Cabinet of Ministers. The document defines the further development of digitalization in Latvia as a pervasive element of the whole sector, but especially touches on such areas as innovation and science, education, health care, inclusive society and labor market, infrastructure, regional development, environment and energy. The goal of digital transformation policy is to create a society, economy and public administration that purposefully uses the existing and creates new opportunities of digital technologies, improving the quality of life for every individual and society as a whole, raising the competitiveness of the state and economy [5]. It is planned to attract financing from the European Union Structural Funds, the state budget and other financial instruments for the implementation of the actions envisaged in the Guidelines.

The Organization for Economic Co-operation and Development's (OECD, 2018) report "Going Digital in the Multilateral World" sets out visions of how societal and economic development in different countries is expected in the context of such a global digital transformation and the main benefits. One of the directions evaluated is the non-governmental (public) sector, in which the organized communities of the population are defined as a new central pillar that addresses national and local issues in a direct way, adapted to their needs. The report emphasizes the importance of identifying and developing the potential of digital infrastructure, as well as creating local and cross-border groups of like-minded people, addressing a range of issues relevant to these communities [6].

However, the positive outcome of this process may be hampered by a sharp digital divide between generations and rural-urban areas, and a polarization of society may develop, which may leave some communities at a lower level of development. Citizens living in less organized or active local or online communities are less able to defend their interests, lobby for state and municipal services, or promote economic activity in a territory or industry. The development, modernization and structural issues of digital technologies are a major challenge for rural communities across Europe, which are experiencing negative trends such as rural-urban migration and the aging of the local population. However, in order to provide the rural population with basic infrastructure and a comparable quality of life, not only modern technologies but also social innovations are needed. Smart villages, which are becoming an increasingly popular concept among EU Member States, are ready to resist these negative trends.

The aim of the research is to study the development opportunities of smart villages and their potential in the process of digital transformation of the rural environment. The main question of the research – how, using such a tool as smart villages, can the digital transformation of the rural environment in Latvia be promoted?

II. METHODOLOGY OF THE RESEARCH

This study is based on a descriptive and informative analysis of rural and regional policy as well as digital transformation strategic documents. The documents have been viewed at both the European Union and Latvian levels. In order to find out the migration tendencies of the Latvian rural population, a secondary analysis of statistical data was performed.

The possibilities of digital transformation of the rural environment were studied using a case analysis approach. The paper presents examples of the use of digital solutions in smart villages in European countries. As the author of the study has been working for two years in the LEADER local action group "Sea Land" (Carnikava and Saulkrasti County Private and Public Partnership Association), she had the opportunity to study examples of smart village digital solutions in Scotland, as well as participate in exchange discussions with Finnish, Greek, Polish, Belgian, Welsh and Hungarian smart village practitioners. Based on this empirical experience and analysis, combined with document analysis and secondary data analysis, conclusions have been made and recommendations developed on how the development of smart villages in Latvia can contribute to the digital transformation process in rural areas.

III. Results and discussion

In many parts of the European Union, so-called rural areas are being adversely affected by a steady decline in population due to several mutually reinforcing reasons: insufficient labour supply, underdeveloped entrepreneurship, social and cultural opportunities, lack of everyday services and disorganized infrastructure. In Latvia, too, the population in rural and urban areas is changing every year, and in 2020, with a significant predominance, 80.24% of the population lived in cities and suburbs (densely populated areas), while in rural areas – 19.76% [7]. In addition, it must be emphasized that the population of rural areas is declining every year, and this is a stable trend.

TABLE 1 POPULATION OF RURAL AREAS (SPARSELY POPULATED) IN LATVIA (2016-2020)

Year	Population of rural areas (sparsely populated)
2016	408 560
2017	403 549
2018	398 138
2019	382 111
2020	376 459

In order to halt the depopulation of rural areas and develop the rural environment, including through digital solutions, an initiative has been running since 2016, supported by the European Commission, based on the Smart Villages label.

In early September 2016, more than 340 rural stakeholders gathered in Cork, Ireland and developed a vision for the future of EU rural areas. Under the heading "A Better Life in Rural Areas", the Cork Declaration 2.0 sets out the expectations and aspirations of rural areas. Among the priorities to be addressed, it calls for policies to pay particular attention to overcoming the digital divide between rural and urban areas and to develop the potential offered by connectivity and digitisation of rural areas. Emphasis was given to the need for integrated approaches and the interaction between different policy fields in view of increasing complementarity and coherence [8].

Smart villages is a relatively new concept in EU policy-making and also includes a vision for the future of rural areas. 'Smart' in the sense of this concept means the development of new forms of cooperation - between farmers and other rural entrepreneurs, between municipalities, the private and public sectors, this bottom-up and top-down cooperation, and includes the use of digital technologies when is practically applicable, but not because it is modern or contemporary. The challenge of digital technologies and innovation is to promote quality of life, a higher standard of living, public services for citizens, better use of resources, less impact on the environment and new opportunities for rural value chains in terms of products and improved processes.

It should be emphasized that smart villages are not based on technology, but on people – rural communities who take the initiative both in finding practical solutions and in tackling existing problems – the concept focuses on local people and their ability to use local resources and knowledge initiative.

Summarizing these guidelines, a definition of smart villages has been developed: "Smart villages are rural communities that can also include multiple localities, using their local strengths and values to develop new opportunities. It aims to create better public services, make more efficient use of local resources, promote lower environmental impact and innovate in order to improve the quality of life. There is no single solution for the implementation of a smart village, it is territorially sensitive and based on the wishes, needs and potential of the inhabitants of specific rural areas, and it is supported by new or existing territorial strategies" [8].

Placing the concept of smart villages in a broader context and comparing it with the main drivers of economic development in the 21st century (emergence of existing and new technologies, low carbon economy, circular economy, bio economy, new value and supply chains, new mobility models, closer rural-urban links) [9], it is possible to see a number of reasons for large-scale change that can give communities the necessary impetus for the digital transformation of the rural environment:

- Technological changes – for example, access to the Internet and new technologies can increase the use of precision agricultural machinery, which improves crop yields and the use of water and soil. Applied biotechnology promotes the production of new, more efficient crops, pest control and the restoration of ecosystems through bioremediation techniques;

- Demographic change – rising costs of living in big cities and new opportunities to work remotely, on the one hand, slow down rural depopulation and, on the other, encourage young people to return from cities to villages where they can work or set up businesses with a better quality of life;

- Economic change – for example, global consumer trends show a steady increase in organic farming and sustainable products, which are selling five times more

than sustainable products. It provides greater added value for production in rural areas;

- Political change: the development of rural communities also depends on the initiative of local, national and supranational governments to provide infrastructure and support for start-ups through tax exemptions and funding. One example is the European Network for Rural Development's Smart Rural 21 program [10].

Smart village communities are based on the principle of participation in order to build their strategy for strengthening the economy, improving social and environmental conditions, with a special focus on digital solutions. As emphasized above, there is no one-size-fits-all solution to this goal, and each community can do so in a way that suits them and is resource-efficient. The following are a number of practical examples of how specific communities in Europe have implemented the smart village approach using today's digital opportunities.

Callander Hydro community. Callander is a small town (population 3 600) in the council area of Stirling, Scotland, situated on the River Teith. In 2012, LEADER supported a community group in Callander to drive their idea of building a mountain hydroelectric power station, converting rich mountain waters into green energy to generate income that could support other local community projects. The development and implementation of the project, which mostly involved the seniors of the town, took five years, its costs were about 2 million pounds, borrowing from two banks. Within six months, a hydroelectric power plant was built to produce electricity that is sold on the common electricity grid. The proceeds are used to repay the loan and raise around £ 60,000 a year to fund local activities and projects. Local volunteers are involved in the involvement and maintenance of the project. The loan will be repaid over a period of 10 years, after which all proceeds will be used for the community's own decisions. One of the future plans of the community is to create a fund in which to accumulate and increase money.

Aberfoyle Rural Business Center. Aberfoyle is a village in Loch Lomond and Trossachs National Park, Scotland, which has been a tourist favourite for over 100 years. However, over the last 20 years, the volume of tourism has been declining, and so has the demand for various local services and shops. In response, the community set up a Rural Entrepreneurship Center and received LEADER support for the recruitment of a staff member to coordinate economic recovery. These premises currently house the Aberfoyle Business Center, which offers shared and individual workplaces. It has helped to retain and attract the self-employed and other skilled professionals, especially those who need high-speed internet. Another example of local activity is a community service station. A private gas station in the village was forced to suspend its operations, but the local community bought the closed property to restore and continue its operation, thus retaining such an important service, as the nearest gas station is 15 km away.

Neighbouring local food project in the Stirling area. Neighbouring food is an online platform where buyers can order / buy specific local products, while sellers can choose the nearest market to meet their customers, as well as complete orders in a timely manner. Such online local food center models have already been set up in four communities in Scotland.

A similar solution for **the agricultural sales network** was developed in Germany, in the community of Bettzdorf/Siegen (Altenkirchen district) and in the community of Eisenberg and Gelheim (Donnersbergkreis). This project received a state grant of 180,000 euros and started in the research project Digital Villages. It examines how innovative digital technologies can help support and make life easier for people in rural areas. In both test regions, modular logistics systems were developed using digital technologies, based on a strong neighbourhood and ensuring a functioning delivery system at the local level [11].

There are many such examples in European countries and they have made a significant contribution to the digital transformation of rural areas. To support such initiatives, specific programs have been developed at EU level to provide communities with both knowledge and financial assistance. One of these programs is a project “Preparatory Action on Smart Rural Areas in the 21 st Century” (Smart Rural 21) – a two and a half-year project supported by the European Commission with the overall aim to promote and inspire villages to develop and implement smart village approaches and strategies across Europe, and to draw conclusions and support future policy interventions on smart villages. The project started in December 2019 and will conclude in June 2022 [12].

Within the framework of this project, Alsunga, which is one of the two villages in the second smallest municipality in Latvia with 1,390 inhabitants, became the first smart village in Latvia. In the fight for this status, 734 applications were submitted to Smart Rural 21, and 21 villages from different EU countries received support. Alsunga's society is mainly made up of people with a long cultural tradition, called suits. Alsunga is a good place to live, but ongoing depopulation is reducing available resources, thereby changing the living environment and the need for services. The main priorities are to develop sustainable local food and a craft market to increase marketing volumes for home-based producers. Another initiative is to develop the local school. Due to administrative reforms, the Alsunga municipality will be incorporated into a much larger municipality and will become an outskirts parish. This will require the development of a strong village strategy and team to keep the development of Alsunga.

The development of Alsunga as a smart village was formed step by step. By bringing together people from different population groups with different views, the strengths and values of the local area were assessed, and practical solutions to the challenges facing the local area and its inhabitants were sought. In the first years, local activists learned to talk to each other, learned to work

together. Regular meetings of local community activists set goals for which those responsible and their assistants were appointed. All together make sure that the goal is achieved step by step. The smart village movement in Alsunga began with the joint organization of clean-ups and the clean-up of the local area. The smart village initiative has been able to unite different generations. Children and young people are also involved with interest, territories are being improved, playgrounds and recreation places for young people are being created, larger and smaller events are being organized. The co-creation space has also been created, and the environment of Alsunga Secondary School has become more interesting and cognitive for young people. By implementing new forms of cooperation and evaluating the opportunities provided by digital technologies, the residents of Alsunga are currently working on a mobile phone application to promote cooperation between tourism entrepreneurs [13].

Today, the smart village of Alsunga boasts a strong and creative team of more than 40 active locals. However, one of the most significant benefits is that several families with children have returned to life in Alsunga in recent years. This shows that the smart village strategy has had the effect of stopping the external migration of the population.

As already mentioned, Alsunga was the first successful smart village project in Latvia with followers. This approach was also used in Skujene, Amata region, combining existing values with digital communication technologies. In the pilot project on smart villages in coastal areas, one of the participants is the village of Pape in Rucava region.

In February 2021, an international co-operation project "On the way to smart landfall" was launched in Latvia, the aim of which is to acquaint coastal residents with the concept of smart village development and start its gradual pilot implementation in each of the six coastal areas selected by co-operation partners. The project will mobilize local coastal communities by educating their leaders, strengthening the identity of villages and neighbourhoods, and promoting sustainable development based on modern knowledge and innovation and the emergence of new social and economic cooperation. The six pilot sites of this project are both villages (e.g. Kaltene, Bernati, Ainazi), neighbourhoods (e.g. Libiesu krasts and Lapmezciems neighborhood), as well as rural town – Carnikava [14].

Another new initiative has also been launched in March 2021 – the Latvian communities will have the opportunity to receive the "Smart Village" label. The competition has received an unexpected response: 38 applications have been submitted to the evaluation and the large number of applications points to the civic maturity of the community and its members. The results will be announced during the fifth Latvian Parliament of Rural Communities [15].

The criteria to be met in order to be able to give the "Smart Town" awareness mark clearly show the factors needed to allow the village or neighbourhood to start on the path towards the status of a smart village: 1) there must be an open and co-operative population that is actively involved in improving the quality of life of their community, is aware of the community's identity, common values and motivation, and sees a goal and vision for achieving it; 2) the village must be open to the implementation of innovative solutions in one of the three areas: business, social or technological environment; 3) the community must be aware of the technical, territorial, financial and human resources available to the village, as well as develop the knowledge and competencies of the population; 4) population management must be integrated and open, with a clear governance structure, and the decision-making process must be bottom-up [16].

There is no standardized approach to the implementation and digitization of smart villages, they determine the specifics of each specific rural area, and therefore each community must define its own goals, identify its own resources, and develop its own plan for its implementation. The directions in which solutions can be sought for the digital transformation of the rural environment are very diverse:

- E-government and community participation in social platforms;
- E-commerce, new digital markets and / or new niche products;
- 'Smart' agriculture;
- Smart tourism solutions;
- Energy saving solutions, renewable energy;
- Food supply systems;
- Logistics, e-mobility, car sharing;
- Co-working, also in e-environment;
- Distance learning;
- E-medicine, telemedicine;
- New digital environment approaches to housing and construction [17].

Equally diverse are innovations and new digital technologies that can contribute to the development of rural communities today:

- IoT: the Internet of Things is linked to the concept of smart cities, but is also applicable in rural areas. For example, using sensors that allow crops to be more competitive or applied to education and health in isolated areas;

- Artificial intelligence: the adoption of artificial intelligence systems is directly applicable to improving crops and environmental management, as well as in optimising health services and infrastructure use;

- Big Data: the huge amount of data generated today (Big Data), allows changes in climate to be analysed accurately along with water consumption, livestock movements, the growth of pastures and forests, and other essential information;

- Drones: thanks to the use of drones, hectares of land can be monitored automatically thereby collecting

data on temperature, crop status, animal movements or controlling the spread of pests, thus improving the use of pesticides;

- Blockchain: according to the United Nations Food and Agriculture Organization (FAO), blockchain technology can be used to increase efficiency, transparency and traceability in agricultural supply chains and make them more productive and sustainable;

- Nanomaterials: the use of smart materials has the potential to enhance sensors, apply fertilisers, pesticides and protective layers that improve food safety, eliminate waste and even mitigate the effects of climate change on plants;

- Robots: from autonomous tractors that do not need a driver to robots capable of picking delicate fruits one by one without damaging them, the introduction of robots in rural areas is driving a revolution in efficiency and sustainability [18].

One of the basic conditions for digital transformation is a digitally skilled society. Although the opportunities provided by the digital environment in rural development are wide, the question remains: are the people of Latvia ready for a rapid transition to digital transformation, which includes the acquisition of fundamentally new knowledge and skills for almost every profession. A research conducted by *Norstat* in December 2020 found that only 31% of Latvians surveyed said that their skills and knowledge were sufficient to work with new digital tools and compete in the digital transformation era. There are also differences between age groups: while 53% of 20-29 year olds recognized their skills as meeting the requirements of the digital transformation age, 22% of 40-59 year olds and 60-74 year olds for seniors – only 13%. Only 12% of seniors aged 60-74 have attended professional development courses in the last six months. Among those in their thirties, this proportion was 27%. The research also highlighted the gap between Riga, Pieriga and the regions. If in the last six months (during Covid-19) 38% of the respondents had acquired new digital skills in Pieriga, then in Kurzeme and Vidzeme – only 28%. If in this period 27% of digital skills learners in Latgale had attended appropriate professional development courses, then in Vidzeme – only 8%. In the last six months, 48% of respondents had worked remotely in Pieriga and 46% in Riga, but in Kurzeme and Vidzeme they were only 26% and 29%, respectively [19]. This is very unpleasant data, which unfortunately does not bode well for the public's readiness to take advantage of the great potential of digitization.

Therefore, as an important step in the Digital Transformation Guidelines 2021-2027: "To ensure that every citizen in need, regardless of age, social status and level of security, including children, young people, SMEs, needs, seniors, digital agents, etc. groups, coordinated cooperation between different institutions, NGOs and the social partners is needed [17]." There is also a clear need for a well-targeted, sustained and consistent contribution from EU funds and public budgets to break the vicious circle, which is also acknowledged in the document's recognition that none of the public authorities, municipalities or organizations [20]. Therefore, it is important to concentrate the efforts of the whole society to solve this problem, which hinders digital transformation not only in rural areas, but throughout Latvia.

IV. Conclusions

One of the basic conditions for digital transformation is a digitally skilled society. Smart village strategies can ensure that the digital needs, priorities and capabilities of the rural population are addressed at local level and can help to link these key actions to wider national and regional digitization strategies. Smart villages strategies can also help bridge the digital divide between areas with different levels of digital development by identifying the different levels of digital maturity in rural areas and villages and jointly developing solutions for digital skills.

A smart village is one that responds not only to challenges but also to new technological opportunities. However, Alsunga's and other smart villages in Latvia experience shows that without strong support, the "lifting" of smart villages is not possible, as well as the support of the municipality. It is therefore important to identify and implement the factors and conditions needed to ensure that smart villages support systems help rural communities to engage in the digital transformation process, regardless of their starting point, and to become digital innovators and creators of economic, social and environmental value.

The study concludes that the introduction of the concept of smart villages is an effective tool in the digital transformation of rural areas, both processes have a common goal and tasks, the most important of which is to prevent people of working age from leaving local areas when moving to the capital or leaving Latvia.

REFERENCES

[1] T. Saldanha, Why Digital Transformations Fails: The Surprising Disciplines of How to Take Off and Stay Ahead. Berrett-Koehler Publishers, 2019.

[2] R. Morakanyane, A. Grace, P. O'Reilly, Conceptualizing Digital Transformation in Business Organizations: A Systematic Review of Literature. University of Maribor Press, 2017.

[3] D. Rogers, The Design Thinking Playbook. ASV: Springer (2016).

[4] About the Government Digital Service, 2021. [Online]. Available: https://gds.blog.gov.uk/about/ [Accessed: March 21, 2021.]

[5] Digitālās transformācijas pamatnostādnes 2021.-2027.gadam, Projekts, 2021. [Online]. Available: https://www.varam.gov.lv/sites/varam/files/content/files/digitalas-transformacijas-pamatnostadnes-_2021-27.pdf [Accessed: March 12, 2021]

[6] OECD, Going Digital in a Multilateral World, 2018. [Online]. Available: https://www.oecd.org/going-digital/C-MIN-2018-6-EN.pdf [Accessed: March 20, 2021]

[7] Centrālās Statistikas pārvaldes datubāzes, Iedzīvotāji, Teritoriālā statistika, RIG060 Pilsētu un lauku iedzīvotaju skaits reģionos, pilsētās, novados un pagastos (eksperimentālā statistika). [Online]. Available: https://data.csb.gov.lv/pxweb/lv/iedz/iedz__riga/RIG060.px [Accessed: March 3, 2021]

[8] European Commission, EU Action for Smart Villages. [Online]. Available: https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/key_policies/documents/rur-dev-small-villages_en.pdf [Accessed: March 6, 2021]

[9] European Network of Rural Development, How to support Smart Villages strategies which effectively empower rural communities? Orientations for policy-makers and implementers. [Online]. Available: https://enrd.ec.europa.eu/sites/enrd/files/enrd_publications/smart-villages_orientations_sv-strategies.pdf [Accessed: March 6, 2021]

[10] Smart Villages, when technology arrives at a village to stay. [Online]. Available: https://www.iberdrola.com/innovation/smart-village-smart-towns [Accessed: March 15, 2021]

[11] Projekt „Digitale Dörfer“ – Land fördert Testregionen Betzdorf und Eisenberg/Göllheim. [Online]. Available: https://www.digitale-doerfer.de/projekt-digitale-doerfer-land-foerdert-testregionen-betzdorf-und-eisenberggoellheim/ [Accessed: March 6, 2021]

[12] The ‘Preparatory Action on Smart Rural Areas in the 21st Century’, The Smart Rural 21 Project. [Online]. Available: https://www.smartrural21.eu/smart-rural-21-project/about/ [Accessed: March 16, 2021]

[13] Lauku tīkls, Kāds ir īstens viedais ciems. [Online]. Available: http://www.laukutikls.lv/nozares/lauku-telpa/raksti/kads-ir-istens-viedais-ciems [Accessed: March 2, 2021]

[14] Projekts “Ceļā uz viedumu piekrastēs”. [Online]. Available: https://juraszeme.lv/sadarbibas-projekti/projekts-cela-uz-viedumu-piekrastes/ [Accessed: May 8, 2021]

[15] Sākusies pieteikumu vērtēšana atpazīstamības zīmes “Viedais Ciems” piešķiršanai. [Online]. Available: https://laukuforums.lv/lv/archives/12220 [Accessed: May 8, 2021]

[16] Atpazīstamības zīmes „Viedais Ciems” piešķiršanas kritēriji. [Online]. Available: https://laukuforums.lv/wp-content/uploads/2021/02/11012021_Kriteriji_ViedsCiems.pdf [Accessed: May 8, 2021]

[17] Ā. Ādlers, Kas ir viedais ciems. Projekts “Viedo Ciemu attīstības piekrastes teritorijā”, 2019. [Online]. Available: https://lrpartneriba.lv/wp-content/uploads/Viedie_Ciemi.pptx.pdf [Accessed: March 8, 2021]

[18] Smart Villages, when technology arrives at a village to stay. [Online]. Available: https://www.iberdrola.com/innovation/smart-village-smart-towns [Accessed: March 20, 2021]

[19] R. Strazdiņa, Digitālās transformācijas stratēģijas īstenošana nav atliekama, portāls Ir.lv, 9.02.2021. [Online]. Availaible: https://ir.lv/2021/02/09/digitalas-transformacijas-strategijas-istenosana-nav-atliekama/ [Accessed: March 20, 2021]

[20] Digitālās transformācijas pamatnostādnes 2021.-2027.gadam, Projekts, 2021. [Online]. Available: https://www.varam.gov.lv/sites/varam/files/content/files/digitalas-transformacijas-pamatnostadnes-_2021-27.pdf [Accessed: March 20, 2021]

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Seasonal Dynamics of Phytoplankton and Some Hydrochemical Indicators of the Peipsi-Pskov Lake

Tatiana Drozdenko
Pskov State University
Pskov, Russia
email: tboichuk@mail.ru

Sergei Fedorov
Pskov Center for Hydrometeorology and Environmental Monitoring
Pskov, Russia
email: nexx.89@mail.ru

Irina Kek
Pskov State University
Pskov, Russia
email: fedorovairina1996@yandex.ru

***Abstract* - The Peipsi-Pskov Lake is the largest freshwater body in Europe, ranking fourth in area and fifth in volume. It is characterized by shallow water and a high level of trophy. The water in the lake is poorly mineralized and has little transparency due to suspended sediments and the development of plankton. Phytoplankton acts as a primary link in trophic chains, quickly reacts to changes in the aquatic environment and serves as a convenient object in monitoring studies.**

The average concentrations of total nitrogen in the lake during the observation period were in the range of 525-818 µg/dm^3. The content of ammonium, nitrate, and nitrite nitrogen in the samples was mostly below the detection limits. The values of total phosphorus varied from 20 µg/dm^3 to 54 µg/dm^3, and its concentrations were lower than the sensitivity of the method during the flood recession.

The maximum values of total nitrogen and phosphorus were recorded in August: in Lake Peipsi - 1.12 mg/dm^3 and 0.09 mg/dm^3, in Lake Pskov - 1.59 mg/dm^3 and 0.14 mg/dm^3, respectively. BOD_5 values ranged from 1.96 mg/dm^3 in autumn to 4.26 mg/dm^3 in summer.

During the growing season of 2020, 244 species taxa of phytoplankton from 8 phylums were identified in the Peipsi-Pskov Lake: Chlorophyta, Bacillariophyta, Cyanobacteria, Chrysophyta, Euglenophyta, Cryptophyta, Dinophyta and Xanthophyta. Floristic complex was characterized as chlorophyta-diatom-cyanobacterial.

The number of phytoplankton varied between 2.1 and 16.2 million cells/l depending on the season. The average number was 7.6 million cells/l. The biomass values ranged from 0.9 g/m^3 to 3.6 g/m^3. The average biomass was 2.3 g/m^3.

According to the ecological and geographical characteristics of the lake, widespread freshwater forms of microalgae predominated, preferring stagnant-flowing, slightly alkaline waters.

Saprobiological analysis showed that the waters of the Peipsi-Pskov Lake were classified as moderately polluted, class III of water purity quality.

Keywords* - *environmental monitoring, hydrochemical indicators, Peipsi-Pskov Lake, phytoplankton.

I. Introduction

Peipsi-Pskov Lake is located on the border between Estonia and the Pskov and Leningrad regions of Russia, and is the fourth largest lake in Europe. The area of the water mirror of the lake at an average water level is 3555 km^2, the volume is 25 km^3, the average depth is 7.1 m, the largest is 15.3 m. The height above sea level is 30 m. Lake Peipsi is an unstratified eutrophic lake. The water, especially in the southern part of the lake, is rich in nutrients. The lake is characterized by high productivity. Macrophytes occupy 5-8 % of the entire water area. The lake is home to more than 30 species of fish [1].

Currently, Peipsi-Pskov Lake is experiencing a significant anthropogenic load associated with the discharge of wastewater in the catchment area, as well as at the expense of agricultural facilities [2]. Along with biogenic pollution, the lake experiences significant pollution with heavy metals and detergents associated with the development of industry in the catchment area [3].

Phytoplankton is the most important component of aquatic ecosystems, actively participating in the formation of water quality. Planktonic algae are the primary link in the trophic chains and react quickly to any changes in the aquatic environment, changing their structural parameters. The indicator properties of phytoplankton are determined not only by the fact of the presence or absence of certain

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species, but also by the degree of their quantitative development. Therefore, the study of such structural indicators as the species composition, abundance and biomass of algae in the reservoir is of great practical importance [4], [5], [6], [7].

Seasonal dynamics of phytoplankton is associated with changes in abiotic conditions in the annual cycle, as well as fluctuations in hydrochemical parameters [8]. By studying the qualitative and quantitative composition of the phytoplankton of the reservoir, it is possible to determine the main changes that occur in it during the biological seasons of the year.

In this regard, the purpose of this work was to study the seasonal dynamics of phytoplankton and some hydrochemical parameters of the Peipsi-Pskov Lake.

II. Matherials and methods

Studies in the Peipsi-Pskov Lake were conducted in 2020 in spring (May), summer (August) and autumn (October).

Hydrobiological and hydrochemical samples were taken in parallel at permanent monitoring stations (Fig. 1) by conventional methods [9], [10].

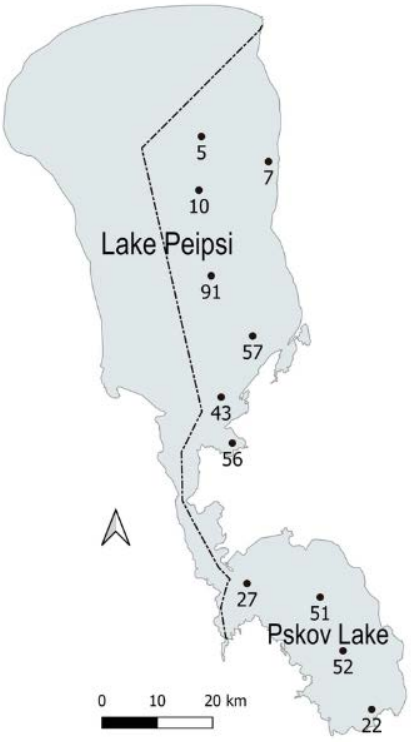

Fig. 1. Permanent sampling stations in the Peipsi-Pskov Lake

In the spring-summer period of observations, the water temperature, depending on the horizon, was 0.5-0.7 °C higher in Lake Pskov than in Lake Peipsi (Table 1). In October, the water of Lake Peipsi was slightly warmer. The acidity of the medium in all seasons was slightly alkaline, with the highest values in the summer. The oxygen content in the Pskov and Peipsi lakes did not differ much, except for the spring period, where the oxygen content was higher in Lake Peipsi. This is probably due to the fact that the processes of destruction were more active in Lake Pskov, so the oxygen consumption was higher.

Table 1 Main abiotic factors of the Peipsi-Pskov Lake, 2020

Indicator	Lake Pskov		Lake Peipsi	
	0.5 m	***bottom***	***0.5 m***	***bottom***
May				
t. C°	10.4±0.3	10.1±0.2	9.9±0.5	9.5±0.3
pH	8.2±0.1	8.2±0.1	8.3±0.1	8.3±0.0
O_2, mg/l	10.8±0.6	10.4±0.5	12.9±0.7	12.5±0.6
August				
t. C°	20.0±0.3	19.8±0.4	19.4±0.5	19.1±0.2
pH	8.8±0.0	8.8±0.0	8.6±0.2	8.6±0.1
O_2, mg/l	9.2±0.4	9.3±0.2	9.0±0.5	8.8±0.1
October				
t. C°	12.5±0.1	12.3±0.2	13.0±0.1	12.7±0.0
pH	8.1±0.1	8.0±0.0	8.2±0.1	8.1±0.0
O_2, mg/l	9.5±0.4	9.5±0.4	9.7±0.7	9,8±0.0

Hydrochemical studies included quantitative determination of the content of nitrite, nitrate and ammonium ions, biochemical oxygen consumption for 5 days (BOD_5), total and gross phosphorus concentrations, total and gross nitrogen, and total iron. The samples were analyzed using titrimetric and spectrophotometric methods in accordance with the methods of the HDPE F series [11], [12], [13], [14], [15], [16].

Phytoplankton samples were processed according to standard methods [17]. The similarity of the taxonomic composition of phytoplankton communities was analyzed using the Sierensen-Chekanovsky index [18]. The dominant species were those with a population of 10% or more of the total. For saprobiological analysis, the method of Pantle and Buck was used in the modification of Sladechek [19].

Statistical data processing and the construction of graphical images were carried out using the program "MO Excel".

III. Results and discussion

Hydrochemistry. Hydrochemical analysis has shown that the content of biogenic elements of the nitrogen and phosphorus groups is largely subject to seasonal fluctuations, which is a consequence of autochthonous biotic processes.

The average seasonal total nitrogen content was 525-818 μg/dm^3 in Lake Peipsi and 604-839 μg/dm^3 in Lake Pskov. In the summer-autumn period, the concentration of total nitrogen was higher in Lake Pskov (Table 2).

The maximum content of total phosphorus in August was observed in Lake Pskov at station 27-20 μg/dm^3, in Lake Peipsi - at station 7 - 38 μg/dm^3. In October, the waters of Lake Pskov were characterized by a higher content of total phosphorus compared to Lake Peipsi. In the central part of the water area, its content reached 54 μg/dm^3 (station 52), in the north-western part - 50 μg/dm^3 (st. 27). The average amount of total phosphorus in the water area of Lake Pskov was 39 μg/dm^3 (Table 2).

TABLE 2 HYDROCHEMICAL PARAMETERS OF LAKE PEIPSI-PSKOV

	Lake Peipsi			Lake Pskov		
	May	***August***	***October***	***May***	***August***	***October***
NH_4^+, µg/1						
min	<20	20	<20	20	20	20
mid	20	20	<20	43	24	28
max	20	20	<20	70	30	30
NO_3^-, µg/1						
min	92	<50	<50	37	<50	<50
mid	172	<50	<50	54	<50	<50
max	314	<50	<50	61	<50	<50
N total, µg/1						
min	525	548	570	604	758	629
mid	652	639	583	652	798	680
max	818	748	595	740	839	738
N gross, µg/1						
min	667	658	646	783	1162	789
mid	796	860	670	848	1378	925
max	957	1137	702	895	1589	1000
P total, µg/1						
min	<20	20	<20	<20	<20	22
mid	<20	30	<20	<20	<20	39
max	<20	38	<20	<20	<20	54
P gross, µg/1						
min	20	24	26	32	1162	54
mid	37	60	37	39	93	60
max	68	92	56	47	1589	70
BOD_5, mg/1						
min	2.10	2.07	1.45	2.27	2.57	1.96
mid	2.47	2.65	1.66	2.49	3.27	2.72
max	2.91	3.84	1.79	2.75	4.26	3.36
Fe total, µg/1						
min	<20	20	21	31	31	41
mid	20	24	24	88	38	47
max	184	31	25	214	51	53

The average concentrations of gross forms of nitrogen and phosphorus in the spring period in Lake Peipsi were 796 µg/dm^3 and 37 µg/dm^3, respectively, in Lake Pskov - 848 µg/dm^3 and 39 µg/dm^3, respectively. During the period of maximum water warming (August), the concentrations of total nitrogen and phosphorus were in Lake Peipsi - 860 µg/dm^3 and 60 µg/dm^3, respectively, in Pskov - 1,4 mg/dm^3 and 93 µg/dm^3, respectively (Table 2). By October, as the waters cooled and biological activity faded, the content of these biogens decreased and was comparable to the values of those at the beginning of the growing season.

Throughout the entire study period, no analytically significant amounts of nitrite nitrogen were detected in any of the selected samples.

In May, in the water area of Lake Peipsi, the average content of nitrate nitrogen was 3 times higher than in Pskov (Table 2).

The results of the studies showed a low level of ammonium nitrogen in Lake Peipsi (on average, 20 µg/dm^3). In the Pskov lake, concentrations were significantly higher, but nevertheless the norms of maximum permissible concentrations for fishery water bodies. The content of mineral forms of phosphorus in all samples was below the sensitivity threshold of the method (Table 2).

The average content of easily oxidized organic matter (according to BOD_5) in Lake Pskov in the spring-summer period varied from 2.07 mg/dm^3 to 3.84 mg/dm^3 (at MAC=2 mg/dm^3). In autumn, the average BOD_5 was 1.66 mg/dm^3. In Lake Peipsi, the concentrations of easily oxidized organic matter, depending on the season of the year, were in the range of 1.96-4.26 mg/dm^3 with the maximum values at stations located in the estuaries of large rivers (the Velikaya River and the Zhelcha River).

The total iron content in Lake Peipsi varied in the range of 24-46 mg/dm^3, in Pskov - 38-88 mg/dm^3, which corresponds to the long-term average values.

According to the conducted studies, the water quality of the Peipsi-Pskov Lake can be described as satisfactory in most hydrochemical indicators. The content of nutrients is comparable to the results of many years of research. The resulting excess of organic matter standards is caused by climatic and hydrometeorological features of the seasons.

Phytoplankton. In the water area of Lake Peipsi-Pskov in 2020, 244 species and intraspecific phytoplankton taxa were identified from 8 phylums: Chlorophyta, Bacillariophyta, Cyanobacteria, Chrysophyta, Euglenophyta, Cryptophyta, Dinophyta and Xanthophyta (Table 3). 201 species of phytoplankton taxa were identified in Lake Pskov, and 205 in Lake Peipsi. According to the Sorensen-Chekanovsky index, the degree of commonality of the species composition of the planktonic algoflora of both lakes was high and amounted to 79.8% (162 common species).

TABLE 3 TAXONOMIC COMPOSITION OF PHYTOPLANKTON OF LAKE PEIPSI-PSKOV IN 2020

Phylums	**Number of phytoplankton species, abs.**			**For all the time**	
	May	***August***	***October***	***abs.***	***%***
Chlorophyta	62	68	53	89	36.5
Bacillariophyta	65	59	43	83	34.0
Cyanobacteria	25	31	23	36	14.8
Chrysophyta	13	9	6	14	5.7
Euglenophyta	8	3	1	9	3.7
Cryptophyta	6	5	5	6	2.5
Dinophyta	3	5	2	5	2.0
Xanthophyta	2	2	1	2	0.8
Total:	184	177	134	244	

The genera *Scenedesmus* (8 species), *Closterium* (8) and *Monoraphidium* (7) from green algae; *Surirella* (11), *Aulacoseira* (8), *Navicula* (7) from diatoms; *Aphanocapsa* and *Chroococcus* (5 each) from cyanobacteria were the most saturated with species.

The greatest species richness of microalgae was recorded in May, the least - in October (Table 3). The floral complex of planktonic algoflora in all seasons of observations was made up of representatives of three phylums: Chlorophyta, Bacillariophyta and Cyanobacteria.

According to the quantitative analysis in May, the number of phytoplankton varied from 645.3 thousand cells/l at st. 7 to 3.8 mln. cells/l at st. 56. The average number of planktonic algae was 2.1 mln. cells/l (in Lake Pskov - 2.6 mln. cells/l, in Lake Peipsi - 1.8 mln. cells/l) (Table 4). The biomass of phytoplankton varied from 424.3 mg/m^3 at st. 7 to 1.3 g/m^3 at st. 22 (average biomass - 0.9 g/m^3).

TABLE 4 PHYTOPLANKTON INDICATORS OF THE PEIPSI-PSKOV LAKE IN 2020

Lake	N, mln. cells/l	B, g/m^3	Cyanobacteria in the total N, %	Bacillariophyta in the total B, %
May				
Pskov	2.6	1.0	63.2	82.2
Peipsi	1.8	0.8		
August				
Pskov	24.4	5.9	90.0	84.1
Peipsi	11.5	2.2		
October				
Pskov	12.0	3.2	78.5	82.6
Peipsi	5.1	1.9		

*N - abundance, B - biomass

In August, the number of phytoplankton ranged from 2.9 mln. cells/l at st. 5 to 49.4 mln. cells/l at st. 27. The average number of microalgae at all stations of the study was 16.2 mln. cells/l (in Lake Pskov - 24.4 mln. cells/l, in Lake Peipsi - 11.5 mln. cells/l) (Table 4). The biomass of phytoplankton varied from 564.8 mg/m^3 at st. 7 to 10.9 g/m^3 at st. 22. The amount of algae was 3.6 g/m^3, which is 4 times higher than in May.

In October 2020, the number of phytoplankton varied from 2.6 mln. cells/l at st. 43 to 22.2 mln. cells/l at st. 52. The average number of planktonic algae was 9.7 mln. cells/l (in Lake Pskov - 12.0 mln. cells/l, in Lake Peipsi - 5.1 mln. cells/l). Phytoplankton biomass varied from 1.1 g/m^3 at st. 43 to 5.8 g/m^3 at st. 52 (average biomass - 2.8 g/m^3; in Lake Pskov - 3.2 g/m^3, in Lake Peipsi - 1.9 g/m^3) (Table 4).

During the studied growing season, cyanobacteria prevailed in the number of cells at all stations of Lake Peipsi: from 44.1% to 95.4%, and their share in the total population in August reached about 90% (Table 4). In all seasons, representatives of the genera *Aphanocapsa* and *Gomphosphaeria* were dominant. *Cyanobacteria* of the genera *Coelosphaerium, Merismopedia, Snowella* in the spring, *Aphanothece* and *Microcystis* in the summer were also among the dominant species. Representatives of the department of Chlorophyta in the total number averaged 4.4-17.1% with the highest rates in May. The proportion of diatoms was 5.1-14.8%, with the maximum content also in spring.

The main contribution to the biomass of the planktonic algoflora of Lake Peipsi was made by representatives of Bacillariophyta (58.1-93.9%). The most significant role in all seasons belonged to the genera *Aulacoseira* and *Cyclotella*, a significant contribution to the total biomass was made by large-cell forms of the genera *Cymatopleura, Gyrosigma, Navicula,* and *Surirella*. Representatives of the department of Chlorophyta in the total biomass accounted for 10.1-12.5%, Cyanobacteria - 2.0-4.3%.

The average seasonal indicator of phytoplankton biomass in the water area of Lake Peipsi-Pskov for the entire period of the study was 2.5 g/m^3, which is significantly lower than the long-term average and allows us to classify the lake waters as "moderately polluted". The average biomass in the water area of Lake Pskov was 3.4 g/m^3, and in Peipsi - 1.6 g/m^3.

According to the ecological characteristics in relation to the habitat in Lake Peipsi in 2020, the group of planktonic algae accounted for 54.5% of the total number of microalgae. The group of planktonic-benthic and benthic organisms, represented mainly by diatoms, accounted for 27.9% and 13.9%, respectively. The inhabitants of growth were 3.3%, intertidal species of 0.4%.

In relation to halobicity in the planktonic algoflora of the lake, more than half of the organisms were indifferent (54.1% of the total number). Halophiles was 9.4%, galophobs - 4.5%, oligogalobs was 2.0%. One-third of the discovered data of microalgae in relation to salinity were not available.

In relation to pH, most of the algae had no information (60.7%). The group of alkaliphiles accounted for 23.0%, indifferent - 11.9 %, acidophiles - 3.3 %, alkalibionts - 1.2 %.

Standing-flowing waters were preferred by 25.8% of microalgae, standing - 7.0%, flowing - 1.2%. Information on rheophilicity was not available in 66.0% of the detected species.

Geographical analysis of the phytoplankton of the Peipsi-Pskov Lake showed that the majority of algae were cosmopolitan (61.1% of the total number). Boreal species accounted for 8.6%, Arctic and holarctic forms accounted for 4.9%, and Arctoalpine forms - 2.0%. A single circumboreal species, *Euglena korshikovii* Gojdics, was found in Lake Peipsi. The distribution data did not include 25.0% of microalgae.

To determine the level of organic pollution and the degree of anthropogenic load on the biogeocenoses of the Peipsi-Pskov Lake, a saprobiological analysis was performed (Table 5).

TABLE 5 VALUES OF THE SAPROBITY INDEX AT DIFFERENT STATIONS OF THE PEIPSI-PSKOV LAKE IN 2020

Stations	Month		
	May	***August***	***October***
Lake Pskov			
22	1.83	1.81	2.00
52	1.82	1.90	2.03
51	1.78	1.74	2.12
27	1.88	1.69	2.02
Average	1.83±0.04	1.79±0.09	2.04±0.05
Lake Peipsi			
56	1.72	1.66	-
43	1.87	1.69	1.93
57	1.78	1.63	1.84
91	1.71	1.80	-
10	1.95	1.84	-
5	2.03	1.72	-
7	1.96	1.58	-
Average	1.86±0.13	1.70±0.09	1.89±0.06

Most of the microalgae was a beta-mesosaprobic. The values of the Pantle-Bukk saprobity indices ranged from 1.58 in August at st. 7 (Lake Peipsi) to 2.12 in October at st. 51 (Lake Pskov). The average saprobity index for the entire study period was 1.82, which corresponds to the

beta-mesosaprobic zone of self-purification, the III quality class – "satisfactory purity".

IV. Conclusions

According to the results of hydrochemical analysis, the values of the recorded indicators in the Peipsi-Pskov Lake in 2020 are comparable with the data of long-term studies and generally did not exceed the MAC. The concentrations of biogenic substances were higher in Lake Pskov, which indicates more active eutrophication processes in the southern part of the Peipsi-Pskov reservoir.

In the phytoplankton of the Peipsi-Pskov Lake during the growing season of 2020, 244 species taxa of phytoplankton with a rank below the genus from 8 phylums were identified. The floral complex of the planktonic algoflora consisted of the phylums Chlorophyta, Bacillariophyta, and Cyanobacteria. The greatest species richness of microalgae in the lake is observed in the spring season (184 species), the least-in the autumn (134 species).

The average number of phytoplankton in the Peipsi-Pskov Lake over the entire study period was 9.5 mln. cells/l with absolute dominance of cyanobacteria. The average biomass was 2.5 g/m^3 with the largest contribution of diatoms.

Ecological and geographical analysis of phytoplankton has shown that freshwater widespread planktonic species predominate in the Peipsi-Pskov Lake, preferring slightly alkaline waters.

The data of saprobiological analysis indicate moderate pollution of the Peipsi-Pskov Lake, which makes it possible to attribute its waters to the III class of quality.

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References

[1] Pskov-Peipsi Lake. T. Timm, A. Raukas, Yu. Khaberman, A. Yaani, Ed. Tartu: Eesti Loodusfoto, 2012.

[2] G. T. Frumin, N. A. Malysheva, "Water quality changes in Lake Pskovskoe (2000–2018)," Transactions of Karelian Research Centre of Russian Academy of Science, Limnology, no. 4, pp. 32-39, 2020.

[3] V. A. Rumyantsev, V. G. Drabkova, A. V. Izmailova, Lakes of the European part of Russia. St. Petersburg: LEMA, 2015.

[4] T. V. Drozdenko, S. G. Mihalap, "Structural and taxonomic diversity and ecological features of phytoplankton in the Velikaya River (Pskov region)," Vestnik Tomskogo gosudarstvennogo universiteta. Biologiya, no. 41, pp. 118-134, 2018, https://doi.org/10.17223/19988591/41/7

[5] A. Basset, G. C. Carrada, M. Fedele, L. Sabetta, "The equilibrium concept in phytoplankton communities.," Encyclopedia of Ecology, Vol. 2, pp. 1394-1402, August 2008. [Abstract]. Available: ProQuest, http://www.umi.com/proquest/, [Accessed January 15, 2021], https://doi.org/10.1016/B978-008045405-4.00711-4

[6] C. Liu, C. Liu, H. Shen, "Seasonal variations of phytoplankton community structure in relation to physico-chemical factors in Lake Baiyangdian, China," Procedia Environmental Sciences, vol. 2, pp. 1622-1631, December 2010. Available: ProQuest, http://www.umi.com/proquest/, [Accessed January 15, 2021], https://doi.org/10.1016/j.proenv.2010.10.173

[7] N. Zivana, M. Buzancic, G. Kuspilic, B. Grbec, S. Matijevic, S. Skejic, I. Marasovic, M. Morovic, "The response of phytoplankton community to anthropogenic pressure gradient in the coastal waters of the eastern Adriatic Sea," Ecological Indicators. vol. 56, pp. 106-115, September 2015. Available: ResearchGate, https://www.researchgate.net/ [Accessed January 15, 2021], https://doi.org/10.1016/j.ecolind.2015.03.018

[8] I. S. Trifonova, Ecology and succession of lake phytoplankton. Leningrad: Nauka, 1990.

[9] A. P. Sadchikov, Methods of studying freshwater phytoplankton: methodological guidelines. Moskow: Universitet i shkola, 2003.

[10] GOST 31861-2012. Water. General requirements for sampling. Moscow, 2014.

[11] Environmental normative document (Federal)14.1:2:4.3-95 Methods of measurement of mass concentration of nitrite ions in drinking water, surface water and sewage of photometric method with Griess reagent. Moscow, 1995 (edition 2011).

[12] Environmental normative document (Federal)14.1:2:4.4-95 Methods of measurement of mass concentration of nitrate ions in drinking water, surface water and sewage of photometric method with salicylic acid. Moscow, 1995 (edition 2011).

[13] Environmental normative document (Federal) 14.1:2:4.50-96 Methods of measuring the total mass concentration of total iron in drinking water, surface water and sewage of photometric method with sulfosalicylic acid. Moscow, 1996 (edition 2011).

[14] Environmental normative document (Federal) 14.1:2:4.112-97 Methods of measurement of mass concentration of phosphate ions in drinking water, surface water and sewage by the photometric method with ammonium molybdate. Moscow, 1997 (edition 2011).

[15] Environmental normative document (Federal)14.1:2:3:4.123-97 Methods of measurement of the biochemical oxygen demand after the n-days of incubation (BOD full) in surface freshwater, groundwater, drinking water, sewage and effluent sewage. Moscow, 1997 (edition 2004).

[16] Environmental normative document (Federal) 14.1:2:4.276-2013 Methods of measurement of the mass concentration of ammonia and ammonium ions in drinking water, natural water and sewage by photometric method with Nessler reagent. Moscow, 2013.

[17] Methods of studying biogeocenosis of inland water bodies. F. D. Mordukhay-Boltovskiy, Ed. Moscow: Nauka, 1975.

[18] V. M. Shmidt, Statistical methods in comparative floristics. Leningrad: Leningradskiy universitet, 1980.

[19] F. Pantle and H. Buck, "The biological monitoring of the waters and the presentation of the results" in Gas and water compartment, Bd 96, № 18, 1955, pp. 604-618.

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Evaluation of Vibration-based Global Structural Health Monitoring Method for Medium-rise Buildings

Liga Gaile
Faculty of Civil Engineering, Institute of Civil Engineering and Reconstruction
Riga Technical University
Riga, Latvia
Liga.gaile_1@rtu.lv

Ivars Radins
Faculty of Civil Engineering, Institute of Civil Engineering and Reconstruction
Riga Technical University
Riga, Latvia
ivars.radins@rtu.lv

***Abstract* - The automated monitoring of a building's structural health during its exploitation is a way to extend its design life without compromising structural safety. In turn, it helps increase the rate of building renovation works compared to demolition works, which reduces future construction and demolition waste levels.**

This research explores the vibration-based global monitoring method application to structurally stiff medium-rise reinforced concrete buildings by analysing predicted building vibration amplitudes and spectrum under regular city traffic excitation. These predictions are based on the results obtained from finite element calculations of building models with variated structural stiffness and inertial mass of the building.

Regular traffic-generated ground frequency spectrum differs from the first natural frequencies of medium-rise reinforced concrete buildings, and the vibration energy is low. Nevertheless, it is found that the structural identification of such building dynamic parameters is still possible, particularly natural frequencies. It was found that the ratio between fundamental frequency for the fixed base model of the building and elastic spring foundation model is the decisive parameter for selecting the building part to be monitored. Structural health monitoring vibration-based methods are also a promising technology for medium-rise mass house buildings when tailored according to some damage sensitive feature.

Keywords* - *Medium-rise building, Structural Health Monitoring, Vibration-based method.

I. INTRODUCTION

The significant adverse effect of the construction industry on the environment is a generation of construction waste (CW). One of the strategies to reduce CW is an extension of building service life [1]. Nowadays, the design life of a building generally does not exceed 50 to 60 years, but it also does not mean that it becomes structurally unsound after this period. According to EC0 [2], it is just an "assumed period for which a structure or part of it is to be used for its intended purpose with anticipated maintenance but without major repair being necessary".

The rapidly developing field of Structural health monitoring (SHM) could help implement justified decisions when the repair of the structure is necessary due to safety issues. SHM is regarded as a process of implementing a damage detection strategy that involves the observation of a structure over time using real-time or periodically spaced and preferably automated dynamic response measurements, the extraction of damage-sensitive features from these measurements and the statistical analysis of these features to determine the current state of structural system health [3].

According to researchers D. M. Frangopol and T.B. Messervey, SHM it is also a powerful and necessary mechanism to reduce uncertainty, to calibrate, and to improve structural assessment and performance of prediction models [4]. Without monitoring information, inaccurate prediction of future performance might cause tremendous consequences due to failure occurrences if later reaching of prescribed performance threshold is

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predicted [5]. As indicated in Fig. 1, service life can be prolonged if SHM is performed.

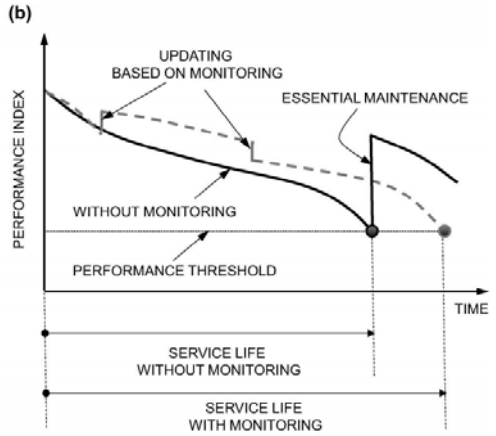

Fig. 1. Performance index profile with and without monitoring (service life with monitoring larger than service life without monitoring) [5]

SHM strategies are divided into two main groups that provide different type of information - local and global strategies. Global SHM methods attempt to simultaneously assess the condition of the whole structure and mainly use vibration-based methods. Successful implementations of such methods have been implemented in major civil infrastructure projects like bridges, stadiums, high-rise structures or underground facilities [6].

SHM system generally consists of five key aspects [7]:

- Sensors and sensing technology,
- Diagnostic signal generation,
- Signal transmission and processing,
- Event identification and interpretation,
- Integration into an operative system for systems life management.

In the case of a medium-rise building, vibration-based monitoring as a diagnostic signal ambient vibrations of the ground are used. As opposed to large and flexible structures, the vibration of such buildings characterises with very low amplitudes of vibrations and main excitors under ambient conditions, is microtremors originating from human activities. Those microtremors are dominated by the components with a frequency higher than 1 Hz [8] as opposed to natural phenomenon like the wind. Experimentally obtained and published case study data from references [9]–[11] shows that most experimentally obtained fundamental frequencies of low and mid-rise buildings with less than 16 floors lies in the range of 1Hz to 4Hz. Fig. 2 presents a graphical display in which the area of boxes of the plot is proportional to the contingency table's cell frequencies. If the building's average storey height is taken as 4m, it follows that the majority of buildings with four floors and less have a fundamental frequency of more than 3,6Hz. Buildings with a storey height of more than ten floors have a fundamental frequency of less than 1,7Hz.

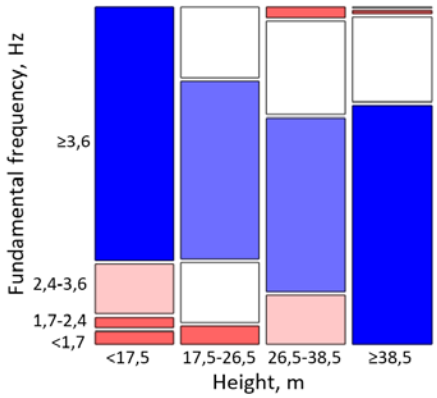

Fig. 2. A mosaic plot of fundamental frequency distributions of buildings (based on data from publications [9]–[11]).

The variance of the fundamental frequencies in Fig. 2 is mainly due to two reasons. Firstly, there is considerable variability of possible plan dimensions and configurations of low and mid-rise buildings. Secondly, the soil-structure interaction (SSI) effect plays a significant role.

A convenient way to determine the SSI effect on building frequencies is the use of a relative measure h/(VsT) [12]. Here height, h, is the effective height to the centre of mass for the first mode shape, taken as approximately two-thirds of the modelled building height. Vs is shear wave velocity that should be taken as the average effective profile velocity calculated based on overburden-corrected shear wave velocities below the foundation. T is a building's period taken as the best estimate value of the fixed-based building period in the direction under consideration. Therefore, for low and mid-rise buildings where the building's height is low, this relative measure is more than 0.1, which is the criteria for the importance of SSI effect. In this case, SSI effect significantly lengthens the building period, modifies damping in the system and distribution of the force and deformation within the structure compared to the fixed base analysis.

On the other hand, the building's vibration amplitudes are heavily dependent on the building vibration source's spectral characteristics relative to the building's dynamic parameters. Authors' previous research [13] experimentally studied the spectral characteristics and ground vibration amplitudes for ambient vibration source - regular traffic. It was found that site power spectrum contains more considerable energy input in frequencies from 10-15 Hz and vertical component of ground vibration amplitude 30m from vibration source is in order of 10^{-4} to 10^{-5}. Nevertheless, it seems like for low and mid-rise buildings in response to a typical traffic spectrum, low vibration modes are still excited [14].

For structural damage event identification and interpretation, a vast amount of methods is proposed. However, these methods are only applicable when a prior quality modal identification is performed. From experimental measurements structural mode shapes are

obtained as well as corresponding natural frequencies and preferably damping ratios.

This research investigates the prospects of applying vibration-based methods for structural health monitoring of stiff medium-rise buildings like cellular or shear wall buildings. The possible effect of soil-structure interaction on building natural frequencies and mode shapes was numerically analysed and the possibilities to perform structural identification of modal parameters for five-story reinforced concrete (RC) buildings with a cellular structure were explored. The building was excited by low-level ambient vibration with an experimentally obtained spectrum characteristic to regular traffic. Structural identification was made using several structural identification methods for two cases: dynamic response of building without introducing sensor noise and introducing sensor noise when the signal-to-noise ratio is 10.

It was found that the ratio between fundamental frequency for the fixed base model of the building and elastic spring foundation model is the decisive parameter for selecting building the part to be monitored.

Additionally, this paper summarises some of the published full-scale experimental research results about building mode shape spectrum, which is essential prior information when mode shape identification is made from noisy sensor records in real-world applications.

II. Characteristic mode shapes of medium-rise buildings

It is advantageous to know information about characteristic mode shapes depending on the building's geometry before analysing noisy sensor records in real-world applications. As shown in the example in the next section of the paper, depending on the precision of the FEM model, mode shapes can take places in a different order that makes identification of higher mode shapes in the experimental data challenging, especially from records of ambient vibrations.

In Table 1, frequency ratios of mode shapes have been calculated (relevant mode shape frequency to fundamental mode shape frequency) obtained from experimental results published in the literature.

When a building behaves like a pure cantilever (pure bending) with a fixed base for transversal mode, this ratio is theoretically 1, 6.27 and 17.55. But for buildings that behave as a pure shear beam, this ratio theoretically is 1, 3 and 5.

It is found that very seldom second (lateral, longitudinal and torsional) global mode shape frequencies for low and medium-rise buildings from full-scale experiments are reported in published literature. Nevertheless, it is clear from the data that mid-rise RC frame buildings behave almost like a pure shear beam. Table 1 also reveals the existence of closely spaced modes. Closely spaced modes arise in structures from geometrical effects such as symmetry or torsional unbalance [15].

Table 1 The ratio of natural frequency and fundamental frequency depending on the number of stories and mode

Nr. of stories (struct. material)	**Approx. plan dimension ratio**	**Fundamental freq., Hz**	**Mode**	**Normalised frequency to fundamental frequency of building (natural frequency *i* /fundamental freq.)**			**Ref.**
				Lateral mode shape	***Longitudinal mode shape***	***Torsional mode shape***	
15 (RC)	1:1.85 (upper part)	0.76	1st 2nd 3rd	1 2.93 5.06	1.11 3.23 5.59	1.46 3.86 5.9	[16]
7 (RC)	1:2	2.37	1st	1	1.16	1.41	[17]
48 (RC)	1:2.1 (“eye” shape)	0.28	1st 2nd	1 4.39	1.72 6.85	2.45 7.28	[18]
4 (M)	1:1.05	2.56	1st 2nd	1 3.46	1.08 3.59	2.79 5.94	[19]
15(RC)	1:3.4 (upper part)	1.16	1st	1	1.05	1.25	[20]
4 (RC)	1:3.7	3.51	1st	1	1.12	1.1	[21]
8 (RC)	1:3.1	2.1	1st	1	1.07	1.1	[22]
9 (RC)	1:2.5 (upper part)	1.95	1st	1	1.24	1.69	[23]
5 (RC)	1:1.5 (upper part)	1.15	1st 2nd	1 3.4	1.33 -	1.43 3.69	[24]
32 (RC)	1:1.1 (upper part)	0.55	1st 2nd	1 4.23	1.18 5.3	2.34 6.65	[25]
Note: "RC" – reinforced concrete building; "M" – masonry building							

These case studies show - buildings with a plan dimensions close to a square have closely spaced first lateral and longitudinal mode shapes as expected. Still, buildings with rectangular plan dimensions could have closely spaced first longitudinal and first torsional mode shape. Torsional mode shapes other are usually well separated from each.

Operational Modal Analysis (OMA) on collected data was used to obtain these mode shapes experimentally. The reviewed papers of full-scale in-situ case studies mostly used high precision force balanced accelerometers and servo-type accelerometers for data collection. The most often chosen sampling rate was 100 Hz for frequencies of interest between 0,1 and 20Hz. Accelerometers have an input range of ±0,5g; ±1g or ±2g and sensitivities 2 V/g or 10 V/g. Most often, the duration of one record is 10 – 15 min. The frequency and volume of collected data depended on the relevant investigation aims.

Different time domain and frequency domain identification techniques for estimation of modal parameters was successfully applied to case study buildings. Among the most popular and usually used in pairs to be able to verify the correctness of the obtained results are Frequency Domain Decomposition (FDD); Enhanced Frequency Domain Decomposition (EFDD); Stochastic Subspace Identification (SSI); Stochastic Subspace Identification - Unweighted principal component (SSI-UPC); Peak-Piking (PP).

III. Materials and Methods

Overall, buildings behave like a Timoshenko beam with properties between a pure shear beam and a pure bending beam. The soil-structure interaction should not be neglected in determining the dynamic behaviour of buildings [26].

For the SSI effect investigation a FEM model of an existing apartment building with strip foundations (see Fig. 3 and Fig.4) was prepared. In the first model, foundation stiffness is considered by modelling vertical springs according to the soil description given in Table 2. The second model does not take foundation stiffness into account, and supports are modelled as pinned. The total mass of the building for dynamic analysis is 3704.4 t.

Analysis of traffic-induced ground vibration is a very complicated problem because it involves a vast number of unknown factors. Therefore, further in the assessment of building dynamic response, several assumptions and simplifications were made.

An experimentally obtained ground acceleration time series is used to assess this building's dynamic response to typical normal traffic-induced ambient vibrations. The time series were obtained in previous research of the authors [13]. Most of the energy generated at the ground surface from traffic is transmitted as Rayleigh surface waves [27]. Rayleigh wave velocity is independent of the exiting frequency and can be derived as a fraction of the shear wave velocity for rocks and soils. Generally, it is a factor of 0.9 - 0.95 of shear wave velocities [28] but soil shear wave velocities can vary from 100 m/s to 1500 m/s - depending on clay content, porosity, water content and overburden depending. The Rayleigh wave particle velocity is perpendicular to the direction of the wave propagation. Therefore, two components appear-in the plane and perpendicular to it to the foundation on an elastic support should be applied.

Fig. 3. Apartment building (464 series)

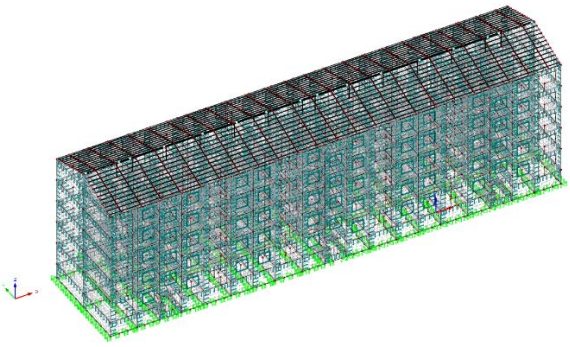

Fig. 4. FEM model of apartment building (464 series)

TABLE 2 DESCRIPTION OF SOIL

Layer #	Δt [m]	Specific weight		E_{def} [MN/m²]	ν
		γ [kN/m³]	γ_{sat} [kN/m³]		
1.	0,8	17,20	19,60	30,00	0,30
2.	2,5	18,80	19,60	34,00	0,30
3.	2,0	17,20	19,60	20,00	0,30
4.	8,7	18,50	20,30	18,00	0,30

Δt - layer thickness; E_{def} – mod. of elasticity; ν - Poisson's r.;
Layer #1. Medium coarse, medium dense sand
Layer #2. Loamy fine, medium dense sand
Layer #3. Silty, fine-medium dense sand
Layer #4. Silty dense sand

The constructed FEM model of the building has 66068 node points. Therefore, the application of ground acceleration time series to the flexible supports would result in the same number of time series that takes considerable computer resources even for a few minutes of computer simulations. Therefore, the equivalent frame model is used in the calculations further and is presented in Fig. 5. In this model, fundamental frequency when

pinned supports is used is 11 Hz, but when spring supports are used – 3,7 Hz. Damping of the fundamental mode is taken as 5%. The reference model for simulations is taken as a frame model with proportionally reduced total mass and stiffness compared to the full 3D FEM model. An example of an applied ground accelerogram to the foundation is demonstrated in Fig. 6.

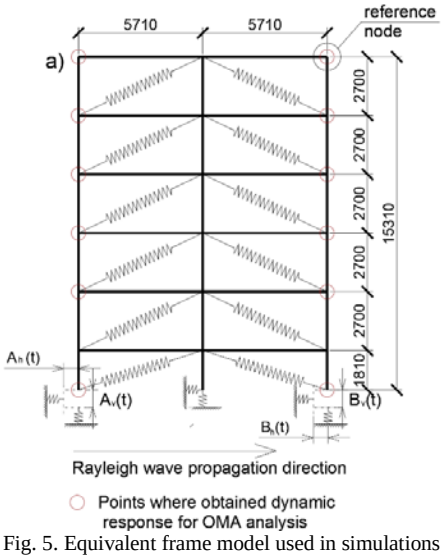

Fig. 5. Equivalent frame model used in simulations

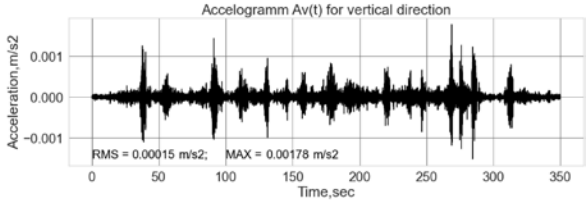

Fig. 6. Example of applied ground accelerogram to the foundation

Accelerograms $A_v(t)$, $A_h(t)$, $B_v(t)$ and $B_h(t)$ were recorded simultaneously with a sample rate of 400 Hz and bandwidth after data filtration of 0.8 - 35Hz. Time series A(t) were recorded 15m from the traffic lane, and B(t) were recorded 30m from the traffic lane. Information about these accelerograms is available in the reference [13]. Then time series were down-sampled to 50 Hz (Nyquist freq = 25Hz) to reduce required storage space and run time for simulation results.

IV. Medium-rise building dynamic response to trafic and identification of modal data

A. Effect of soil-structure interaction

Results from full 3D FEM model numerical calculations of apartment building modal parameters are summarised in Table 3. - 4.

Firstly, the ratio between the first and second model's fundamental frequencies is almost three times; secondly, there is a big difference in the effective modal mass factor for the stiffest translational direction that highlights the differences in mode shapes. The effective modal mass factor describes how much mass is activated by each eigenvalue of the system in each direction.

TABLE 3 FREQUENCIES AND EFFECTIVE MODAL MASS FACTORS

FEM model 1 –elastic spring foundation		
Structural mode (#)	***Frequency, Hz***	***The effective modal mass factor for relevant direction***
1st transverse mode (1)	3,75	0,604
1st torsional mode (2)	7,00	NA
1st longitudinal mode (3)	7,43	0,303
Soil and building vertical (4)	9,07	0,918
Follows 38 local modes with frequencies from 9.9Hz to 13,3 (with an average modal mass of local mode is approx. 4t)		
2nd torsional mode (43)	13,3	NA
Follows 39 local modes with frequencies from 13,4 to 17,6 (average modal mass of local mode is 2.1t)		
2nd vertical mode (83)	19,6	NA

Note: NA – not applicable or not obtained, # - consecutive number of mode.

TABLE 4 FREQUENCIES AND EFFECTIVE MODAL MASS FACTORS

FEM model 2 - the fixed foundation		
Structural mode (#)	***Frequency, Hz***	***The effective modal mass factor for relevant direction***
Starts with 20 local modes		
1st transverse mode (21)	11,05	0,605
1st longitudinal mode (34)	12,64	0,611
1st torsional mode (37)	12,81	NA

Note: NA – not applicable or not obtained, # - consecutive number of mode.

B. Dynamic response of building

When a ground acceleration time series is applied in the manner described in the previous section, reference node maximum and RMS accelerations and Power spectral density (PSD) spectrum values are reflected in Table 5.

Table 5 shows the maximum dynamic response in lateral direction, but comparable amplitudes are also obtained for the vertical direction, which indicates the building's rocking motion. Reference model stiffness or mass changes resulted in different fundamental frequency values that are still in line with typical fundamental frequencies of buildings showed in Fig 2.

The simulations revealed that when there is a big difference between fundamental frequency for a fixed foundation model of building and elastic spring foundation model, the modal frequency is not a sensitive parameter for SHM purposes of the structure itself. Therefore, this ratio is a decisive parameter for selecting building part to be monitored. This feature might be useful for a very stiff

structure to detect sudden changes in the geological situation under the building base. For example, early detection of hazard in the zones where there is a risk of karst formation. However, for buildings where this ratio is close to one, monitoring of structural changes would be possible.

TABLE 5 DYNAMIC RESPONSE OF THE EQUIVALENT MODEL

Equivalent model dynamic response to accelerograms			
Model #	***Fund. frequency of the model, Hz***	***Change in inertia mass model,%***	***Change in stiffness model,%***
1.	3,74	Reference model	
2.	3,57	-	-50%
3.	3,83	-	+50%
4.	2,65	+50%	-
5.	5,29	-50%	-
Model #	***Max response peak amplitude of reference point, m/s2***	***Max response RMS ampl. of reference point, m/s2***	***PSD spectrum magnitude for the fundamental mode***
1.	0,0080	0,00081	$2{,}95 \cdot 10^{-9}$
2.	0,0222	0,00170	$5{,}54 \cdot 10^{-9}$
3.	0,0060	0,00071	$3{,}32 \cdot 10^{-9}$
4.	0,0099	0,00095	$2{,}11 \cdot 10^{-10}$
5.	0,0122	0,00091	$5{,}62 \cdot 10^{-8}$

Note: Foundation stiffness has not changed over simulations.

For all the cases except one acceleration RMS amplitudes of the reference point is in in order of 10^{-4}. From results in Table 5 it follows that maximum response peak amplitude or RMS would not be a good damage sensitive feature for SHM of medium-rise buildings due to its non-sensitivity to minor or moderate changes in global stiffness.

In all cases, higher energy input in PSD spectrum from lateral modes is in the second lateral mode because it corresponds better to the applied bandwidth of mainly from 6.8Hz to 16.6Hz (vertical direction) and from 6.3Hz to 20.7Hz (horizontal direction). Nevertheless, in all cases, a fundamental mode of structure could be identified and well separated from the vibration source's bandwidth. PSD spectrum of equivalent frame reference model response for the reference point is presented in Fig. 7. and Singular Value Decomposition of all data is shown in Fig. 8.

The precision of obtained natural frequencies is better when one of the OMA identification techniques is used compared to peak picking from the PSD spectrum. Nonphysical modes can be identified by looking at mode shapes and mode complexity factor. One of the damage sensitive features is the damping ratio, but generally, it failed to be identified correctly by all the methods.

When the response signal-to-noise ratio is set to S/N=10, the structural identification accuracy for all modes on average changed from 0,74% to 1,31% (expressed as an error between theoretical and calculated results).

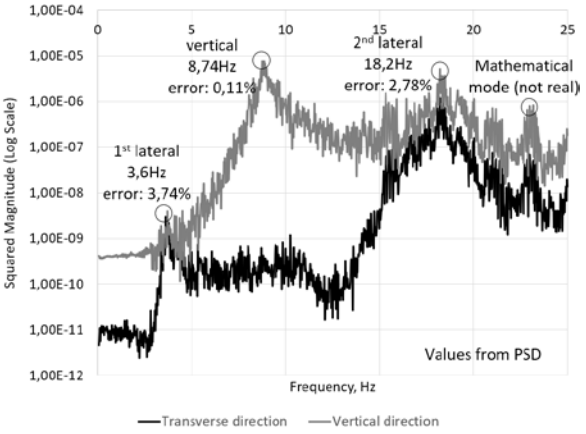

Fig. 7. Power Spectral Density of equivalent frame reference model response

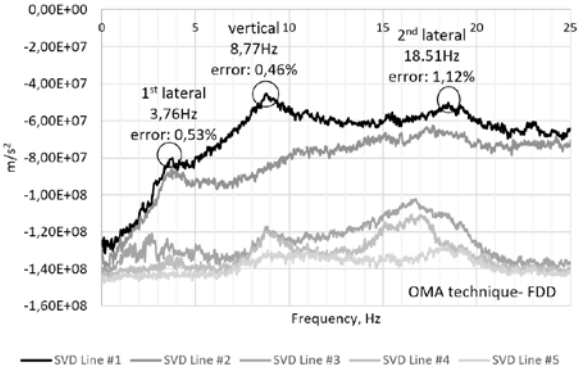

Fig. 8. Singular Value Decomposition of equivalent frame reference model response (FDD technique, no sensor noise)

TABLE 6 IDENTIFIED FREQUENCIES WITH OMA TECHNIQUE

Modes shape	**Exact from FEM, Hz**	**The identified frequency with OMA technique, Hz**			
		FDD	***EFDD***	***CFDD***	***SSI-UPC***
		No additional sensor noise			
1st lateral	3,74	3,76	3,74	3,74	-
vertical	8,73	8,77	8,91*	8,92	8,77*
2nd lateral	18,72	18,51	18,50	18,55	18,72
Signal to noise ratio S/N = $(RMS_{signal}/RMS_{noise})^2$=10					
1st lateral	3,74	3,71	3,69	3,70	-
vertical	8,73	8,81	8,91*	8,92	8,85*
2nd lateral	18,72	18,51	18,37	18,52	18,37
FDD – Frequency Domain Decomposition method EFDD - Enhanced Frequency Domain Decomposition CFDD – Curve-fit Frequency Domain Decomposition SSI-UPC - Stochastic subspace identification - Unweighted principal components * - correctly identified damping of 5%					

V. CONCLUSIONS

This research investigated the prospects of applying vibration-based methods for structural health monitoring of

stiff medium-rise buildings like cellular architecture precast reinforced concrete buildings.

It was found that the ratio between fundamental frequency for the fixed base model of the building and elastic spring foundation model is the decisive parameter for selecting the building part to be monitored. In the case of a stiff medium-rise building, this ratio could be even three. Then changes in natural frequencies might be useful for detecting sudden changes in the geological situation under the building base. An application example could be early detection of hazard in the zones where there is a risk of karst formation.

The damage sensitive feature - the damping ratio - was not correctly identified with any common OMA structural identification techniques for this type of structure. Nevertheless, natural frequencies were identified correctly with a mean error across frequencies of 1,3%, even with a signal-to-noise ratio as high as 10.

VI. Acknowledgement

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References

[1] D. F. Laefer and J. P. Manke, "Building Reuse Assessment for Sustainable Urban Reconstruction," *J. Constr. Eng. Manag.*, 2008.

[2] "EN 1990. Eurocode-Basis of structural design." .

[3] C. R. Farrar and K. Worden, *Structural Health Monitoring: A Machine Learning Perspective*. 2012.

[4] D. M. Frangopol and T. B. Messervey, "Maintenance Principles for Civil Structures," in *Encyclopedia of Structural Health Monitoring*, John Wiley & Sons, Ltd, 2009.

[5] D. M. Frangopol, "Life-Cycle performance, management, and optimisation of structural systems under uncertainty: Accomplishments and challenges," *Struct. Infrastruct. Eng.*, 2011.

[6] H. N. Li, L. Ren, Z. G. Jia, T. H. Yi, and D. S. Li, "State-of-the-art in structural health monitoring of large and complex civil infrastructures," *J. Civ. Struct. Heal. Monit.*, 2016.

[7] V. M. Karbhari and F. Ansari, *Structural health monitoring of civil infrastructure systems*. 2009.

[8] O. Kulhanek, "Anatomy of seismograms," *Anat. Seism.*, 1990.

[9] M. R. Gallipoli *et al.*, "Empirical estimates of dynamic parameters on a large set of European buildings," *Bull. Earthq. Eng.*, 2010.

[10] R. K. Goel and A. K. Chopra, "Period formulas for moment-resisting frame buildings," *J. Struct. Eng.*, 1997.

[11] C. S. Oliveira and M. Navarro, "Fundamental periods of vibration of RC buildings in Portugal from in-situ experimental and numerical techniques," *Bull. Earthq. Eng.*, 2010.

[12] NEHRP Consultants Joint Venture, *Soil-Structure Interaction for Building Structures*. 2012.

[13] Gaile L; Sliseris J; Ratnika L, "Towards SHM of medium-rise buildings in non-seismic areas." Proceedings of 10th International Conference on Structural Health Monitoring of Intelligent Infrastructure - SHMII 10 (submitted), 2021.

[14] H. Hao, T. C. Ang, and J. Shen, "Building vibration to traffic-induced ground motion," *Build. Environ.*, 2001.

[15] C. Manu, "Dynamic analysis of structures with closely spaced modes using the response spectrum method," *Comput. Struct.*, 1986.

[16] Y. Tamura, L. Zhang, A. Yoshida, S. Nakata, and T. Itoh, "Ambient Vibration Tests and Modal Identification of Structures by FDD and 2DOF-RD Technique," *SEWC, Yokohama, Japan*, 2002.

[17] S. Kechidi and N. Bourahla, "Effective use of ambient vibration measurement for modal updating," in *Les Premières Rencontres Nationales sur le Génie Civil RNGC'2014*, 2014.

[18] C. E. Ventura, J.-F. Lord, and R. D. Simpson, "Effective Use of Ambient Vibration Measurements for Modal Updating of a 48 Storey Building in Vancouver, Canada," *Int. Conf. "Structural Dyn. Model. Anal. Correl. Valid.*, 2002.

[19] L. F. Ramos, "Damage identification on masonry structures based on vibration signatures," 2007.

[20] C. Michel, P. Guéguen, S. El Arem, J. Mazars, and P. Kotronis, "Full-scale dynamic response of an RC building under weak seismic motions using earthquake recordings, ambient vibrations and modelling," *Earthq. Eng. Struct. Dyn.*, 2010.

[21] F. Butt and P. Omenzetter, "Long term seismic response monitoring and finite element modeling of a concrete building considering soil flexibility and non-structural components," in *Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2011*, 2011.

[22] D. Gargaro, C. Rainieri, and G. Fabbrocino, "Structural and seismic monitoring of the 'cardarelli' Hospital in Campobasso," in *Procedia Engineering*, 2017.

[23] A. F. Kamarudin *et al.*, "Structural health monitoring on medium rise reinforced concrete building using ambient vibration method," in *IOP Conference Series: Earth and Environmental Science*, 2018.

[24] A. Nguyen, K. A. T. L. Kodikara, T. H. T. Chan, and D. P. Thambiratnam, "Toward effective structural identification of medium-rise building structures," *J. Civ. Struct. Heal. Monit.*, 2018.

[25] N. J. Savnik, E. I. Katsanos, S. D. R. Amador, C. E. Ventura, and R. Brincker, "Influence of diaphragm modelling on the dynamic performance of a reinforced concrete high-rise building," in *Proceedings of ISMA 2018 - International Conference on Noise and Vibration Engineering and USD 2018 - International Conference on Uncertainty in Structural Dynamics*, 2018.

[26] M. H. Cheng and T. H. Heaton, "Simulating building motions using ratios of the building's natural frequencies and a timoshenko beam model," *Earthq. Spectra*, 2015.

[27] V. V. Krylov, "Control of traffic-induced ground vibrations by placing heavy masses on the ground surface," *J. Low Freq. Noise Vib. Act. Control*, 2007.

[28] D. Gunn, G. Williams, H. Kessler, and S. Thorpe, "Rayleigh wave propagation assessment for transport corridors," *Proc. Inst. Civ. Eng. Transp.*, 2015.

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On one Scientifically Based Sowing Management for Getting Pareto-optimal Crops Harvest

Sharif E. Guseynov
Faculty of Science and Engineering;
Institute of Science and Innovative Technologies
Liepaja University
Liepaja, Latvia
sh.e.guseinov@inbox.lv

Ruslans Aleksejevs
Faculty of Mechanics and Mathematics
Lomonosov Moscow State University
Moscow, Russia
aleksejevs.ruslans@gmail.com

Sergey I. Matyukhin
Department of Technical Physics and Mathematics
Orel State University
Orel, Russia
sim1@mail.ru

Jekaterina V. Aleksejeva
Institute of Science and Innovative Technologies
Liepaja University
Liepaja, Latvia
Riga Secondary School 34
Riga, Latvia
jekaterina.v.aleksejeva@gmail.com

Galina A. Semenova
Department of Technical Physics and Mathematics
Orel State University
Orel, Russia
greece-g2011@yandex.ru

***Abstract* - In the present work, we construct and study a mathematical model for one important agrarian problem of grain production, in which it is necessary to obtain such a guaranteed harvest of crops, the yield of which depends on soil-climatic conditions, so that the gross income from the sale of the grown crop is maximum. The constructed mathematical model is a multi-criteria optimization problem (with five criteria), and it can be attributed to optimal control, in which the controlled parameters are the kind and proportion of crops to be sown. Based on the results obtained, a concrete example is implemented using the application package Mathcad, version 14.0.0.163.**

Keywords - Optimization problem, Pareto-optimal decision-making, guaranteed harvest, cereal crops

I. INTRODUCTION

For almost all countries in the world, agriculture is one of the most important branches of material production – growing cultivated plants and raising animals to provide population with food, and obtaining raw materials for needs of many industries. There are about 50 varieties of agriculture that can be divided into two groups: high-commodity agriculture and low-commodity agriculture. High-commodity agriculture includes: intensive farming and animal husbandry, gardening and horticulture, extensive steam and fallow farming, livestock farming; low-commodity agriculture includes more backward plough and hoe-mattock farming, pastoralism, nomadic cattle breeding, as well as gathering, hunting and fishing. The countries of the European Union are characterized by high-commodity agriculture, which is achieved by a high level of mechanization and chemicalization, as well as by direct and indirect application of the combined achievements of a number of scientific fields, such as mathematics, physics, chemistry, biology, geology, botany, and economics. Currently, the agro-industrial complex in the highly developed countries of the European Union (Austria, Belgium, France, Germany, Italy, the Netherlands, Sweden) has acquired the form of agribusiness using agricultural SMART-machines, nano-technologies and nano-materials, genetic engineering and biotechnology, robotics and electronics etc., which gives the agriculture of these countries a post-industrial character, whose unchanging sign is an extremely high level of intensification. In all other countries of the European Union, the agro-industrial complex has an industrial character with varying degrees of intensification. Developed agriculture is one of security factors of the European Union's countries – due to it food dependence is decreasing. For this reason, agriculture in the European Union is supported and subsidized in concordance with the Common Agricultural Policy. One of the main branches of

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agriculture is farming – the use of land for the purpose of growing crops, in particular, crops which will be discussed in this paper. Depending on soil and climatic conditions, farming is divided into the following categories: land reclamation (melioration farming); irrigated cropping; dry farming. Most countries of the European Union, including Latvia, have irrigation cropping/farming [1]. In turn, the section of agriculture devoted to the cultivation of cereal crops is called grain farming. Cereals – the most important group of crops – are the main human product, nutritious feed for farm animals, and raw materials for many industries [2]-[5].

The main indicators of soil fertility necessary for the formation of high yields of cereal crops are agrophysical indicators (basic: density, porosity, fine-grained structure, water-strength structure), biological indicators (basic: the presence of organic matter, including humus, phytosanitary state, biological activity, enzymatic activity) and agrochemical indicators (absorption capacity, soil reaction (pH), the presence of nutrients). Crop yields are very sensitive not only to soil fertility indicators, but also to climatic indicators, the main of which are temperature-humidity and temperature-wind (taking into account radiation) indicators. Together these indicators are called soil-climatic indicators (conditions), and it is these conditions that determine the success or failure of all stages of the process of growing cereal crops – the stage of selecting a variety of grain culture, its vernalization, the stages of processing and preparing the soil, the stages of determining the optimal sowing time and optimal seeding rates, stage of seed treatment, stages of seasonal treatment of crops, etc. [2], [3], [6], [7]. The yield of cereal crops by country, depending on soil and climatic conditions, crop farming, as well as macroeconomic conditions, is quite different. Even in the countries of the European Union, there are noticeable differences both in the yield of cereal crops and in the costs of growing them, and, consequently, in their costs to the final consumer [2], [8]-[11]. In addition, different crops respond differently to the same soil and climatic conditions that occur during a particular growing season. For example, wheat, rye, barley, and oats are grains of a temperate climate, however, with the same indicators of soil fertility, they differ greatly in terms of required climatic conditions; there are differences even between their winter and spring forms; these differences are significant also between kinds of crops when they adapt to certain soil and climatic conditions; winter rye tolerates the lowest temperatures, winter barley is the most sensitive cereal crop; winter wheat on this basis occupies a middle position. Winter crops tolerate lower temperatures when they gradually harden. Changing temperatures close to the freezing point cause enzymatic activity inside the cells, which reduces their cold resistance. Highly developed or early-growing crops are especially sensitive to this. The danger of death is high in crops that are affected by diseases, pests, birds or sudden onset of cold during intense metabolic processes. This is usually observed at the beginning of winter or during spring frosts. In addition, the death of winter crops from freezing is caused not only by mechanical destruction of the cells by ice, but also by bulging/drying of the sprouts of crops. It is caused by a change of negative night temperatures and positive daytime temperatures, and as a result of soil movement, root hairs or even skeletal roots break off, and the sprouts themselves appear to be squeezed out of the soil.

In this work, we consider the problem of obtaining guaranteed harvest of cereal crops that does not depend on soil and climatic conditions. The importance of studying such a problem, among other things, is due to global climate changes that have been observed in recent years. The verbal statement of the considered problem is given in the next section. The authors of this work, having analysed more than 200 publications on crops growing published in international journals of various levels over the past 25 years, did not find a similar statement of the problem: there are many publications on obtaining guaranteed harvest (chiefly, single-criterion optimality), and in the majority of these publications, statistical approaches are used, which causes results to have probabilistic nature.

II. Verbal formulation of the considering agrarian problem

Let us suppose that some agricultural enterprise is going to sow N sown fields with M kinds of crops, yield of which depends on K types of soil-climatic conditions [1]-[7] (we will call these conditions climatic scenarios). According to the procurement contract (see Remark 1) between an agricultural enterprise and a procurer (for example, a state) that purchases produced crops for further processing and/or sale, the agricultural company is obliged to sell to the procurer cereals of m-th $\left(m=\overline{1,M}\right)$ kind in amount of not less than $\underline{Q}_m^{\text{p.c.}} \geq 0$ quintals for the purchase price $p_m^{p.p.}$ (see Remark 3 as well as [8]-[10]). Provided that the demand for each of the produced crops is unlimited, it is necessary to determine what kinds of crops and in what proportions should be sown in order, firstly, to obtain a guaranteed crop (the maximum of the minimum possible) that does not depend on climatic scenarios, and secondly, the gross income (see Remark 2) from the sale of the crop would be the largest?

Remark 1. A procurement contract is a type of contract of sale, and is an agreement governing relations associated with the procurement from agricultural organizations and peasant farms of agricultural products grown or produced by them. In accordance with the contract agreement, the agricultural producer agrees to transfer the agricultural products grown or produced by him to the buyer-procurer (for example, the state), who purchases such products for further processing and/or sale. In the considered problem absence of a procurement contract between an agricultural enterprise and a procurer regarding any crop of the kind m $\left(m=\overline{1,M}\right)$ means that one needs to put $Q_m^{\text{p.c.}}=0$; if such an agreement does not take place at all, then, obviously, $Q_m^{\text{p.c.}}=0$ for $\forall m=\overline{1,M}$. End of Remark (EOR)

Remark 2. Gross income is the income that the company receives from its core business, as well as from interest, dividends or royalties that other companies pay

them. The sum of gross income, as a rule, refers to all gross income or gross income for a certain period of time in a certain currency. EOR

Remark 3. The purchase price is the type of wholesale price used in the procurement of agricultural products by procurers (for example, the state) in the domestic market. Purchase prices are differentiated depending on the quality of products, taking into account the geographical segmentation of the market, and are defined as the price of agricultural products purchased by procurers from producers under contract agreements. EOR

Let us introduce the following notation for the original data of the above formulated verbal problem: S_n is area (ha) of n-th $\left(n=\overline{1,N}\right)$ sown field; $q_{n,m,k}$ is yield (quintal/ha) of cereal crop of m-th $\left(m=\overline{1,M}\right)$ kind, grown under k-th $\left(k=\overline{1,K}\right)$ climatic scenario in n-th $\left(n=\overline{1,N}\right)$ sown field; $p_{m,k}^{\text{p.p.}}$ is purchase price (euro) of 1 quintal of cereal crop of m-th $\left(n=\overline{1,M}\right)$ kind, grown under k-th $\left(k=\overline{1,K}\right)$ climatic scenario; $p_{m,k}^{\text{m.p.}}$ is purchase price (euro) of 1 quintal of cereal crop of m-th $\left(n=\overline{1,M}\right)$ kind, grown under k-th $\left(k=\overline{1,K}\right)$ climatic scenario. In this work we will assume that the purchase price $P^{\text{purchasing price}}=\left\{p_{m,k}^{\text{p.p.}}\right\}_{m=\overline{1,M}}^{k=\overline{1,K}}$ of the grown cereal crops, as opposed to their market price $P^{\text{market price}}=\left\{p_{m,k}^{\text{m.p.}}\right\}_{m=\overline{1,M}}^{k=\overline{1,K}}$, does not depend on the climatic scenarios, i.e. we will assume that $p_{m,k}^{\text{p.p.}}\equiv p_{m}^{\text{p.p.}}$ for $\forall k=\overline{1,K}$.

Remark 4. The assumption about dependence of the market price of grown cereal crops on climatic scenarios may seem absurd at first glance: after all, quality and price of the products are important to customers, not soil and climatic conditions under which crops were grown, or the difficulties that the manufacturer had to overcome when growing crops. Of course, if we consider a small country (for example, Latvia) with almost the same climatic conditions and relatively uniform soil characteristics, then the assumption that the market price of cereal crops is independent of soil and climatic conditions under which they were grown would be reasonable. However, in our opinion, for some countries with quite sharp climatic and soil differences, the assumption made has the right to exist: in this work, when constructing a mathematical model and its subsequent research, we will proceed from this assumption, however, the results obtained can easily be adapted to the case when the market price of some or all of the grown crops does not depend on climatic scenarios – for this it is necessary (and sufficient) to put in the mathematical model that $p_{m,k}^{\text{m.p.}}=p_{m}^{\text{m.p.}}$ for $\forall k=\overline{1,K}$, as it is done in the example considered in this paper. EOR

Remark 5. It is obvious that instead of N sown fields one could consider only one field. Then, nothing fundamental would have changed: only instead of N areas $\left\{S_n\right\}$ there would be one common area S of the sown field and instead of three-index yields $\left\{q_{n,m,k}\right\}$ there would be two-index $\left\{q_{m,k}\right\}$. However, it seems to us that considering N areas is rational in the sense that an agricultural enterprise may have sown fields that are geometrically quite distant from each other (they may be located in different regions of the country, or even in different countries) and, therefore, it will be more convenient for interested people of the corresponding profile to use the results of this work that can be easily programmed on computers. EOR

III. Mathematical model of the verbally formulated agrarian problem, and its investigation

In order to construct a mathematical model of the problem formulated in the previous section, we denote by $x_{n,m}$ the required area of n-th $\left(n=\overline{1,N}\right)$ field, planted with crops of m-th $\left(m=\overline{1,M}\right)$ kind, and denote by V the required guaranteed total volume of crops grown (which must be maximized) for any of K climatic scenarios, i.e. $V\to\max$. Then using the introduced designations of the original data, we can write that $\sum_{m=1}^{M}q_{n,m,k}x_{n,m}$ is the volume of all crops grown at k-th $\left(k=\overline{1,K}\right)$ climatic scenario on n-th $\left(n=\overline{1,N}\right)$ field. Therefore, the following NK inequalities and N equalities must hold:

$$\sum_{m=1}^{M}q_{n,m,k}\cdot x_{n,m}\geq V,\ n=\overline{1,N},\ k=\overline{1,K};$$

$$\sum_{m=1}^{M}x_{n,m}=S_n,\ n=\overline{1,N}.$$

Further, under the assumption that during the period of sowing and growing crops there was k-th $\left(k=\overline{1,K}\right)$ climatic scenario, yield of crops of m-th $\left(m=\overline{1,M}\right)$ kind, grown in all N fields, is equal to $\sum_{n=1}^{N}q_{n,m,k}x_{n,m}$. Then, it is obvious that the implementation of the procurement contract between the agricultural enterprise and the procurer requires that the following $N\cdot K$ inequalities hold:

$$\sum_{n=1}^{N}q_{n,m,k}x_{n,m}\geq Q_{m}^{\text{p.c.}},\ m=\overline{1,M},\ k=\overline{1,K}.$$

It is also obvious that the company's income from the sale of crops of m-th $\left(m=\overline{1,M}\right)$ kind, grown in all N fields under k-th $\left(k=\overline{1,K}\right)$ climatic scenario, is equal to

$$p_{m,k}^{m.p.}\cdot\left(\sum_{n=1}^{N}q_{n,m,k}x_{n,m}-Q_m^{\text{p.c.}}\right)+p_m^{p.p.}\cdot Q_m^{\text{p.c.}}.$$

Therefore

$$\sum_{m=1}^{M}\left(p_{m,k}^{m.p.}\left(\sum_{n=1}^{N}q_{n,m,k}x_{n,m}-Q_m^{\text{p.c.}}\right)+p_m^{p.p.}\cdot Q_m^{\text{p.c.}}\right)$$

is the gross income of the enterprise from the sale of all M cereal crops, grown in all N fields under the conditions of k-th $\left(k=\overline{1,K}\right)$ climatic scenario. The requirement of maximality of gross income:

$$\sum_{n=1}^{N}\sum_{m=1}^{M}p_{m,k}^{m.p.}q_{n,m,k}x_{n,m}\to\max,\ k\in\overline{1,K}.$$

Hereere we omitted the constant $\sum_{m=1}^{M}Q_m^{\text{p.c.}}\left(p_m^{p.p.}-p_{m,k}^{m.p.}\right)$ due to the fact that it does not play any role in maximizing the gross income function.

Let's introduce new variables $y_j=x_{n,m}$, where:

- $y_{NM+1}=V$;
- for each fixed ordered couple (n,m), in which $n\in\{1,\ldots,N\}$ and $m\in\{1,\ldots,M\}$, index j is calculated by the formula
$$j=M(n-1)+m,\ \ j\in\{1,\ldots,NM\};$$
- for each fixed index $j\in\{1,\ldots,NM\}$ indices $n\in\{1,\ldots,N\}$ and $m\in\{1,\ldots,M\}$ are determined uniquely by the formulas [12]
$$m\equiv j\pmod M,$$
$$n=1+\frac{j-m}{M}.$$

Then, by taking the new variables $y=\{y_j\}_{j=\overline{1,(NM+1)}}$ into account, combining the results obtained above, we can formulate the following multicriteria optimization problem, which is a mathematical model of the considered agrarian problem

$$\begin{cases}\text{maximize}\left\{w_1(y)\overset{def}{\equiv}y_{NM+1}\right\},\\ \text{maximize}\left\{w_{k+1}(y)\overset{def}{\equiv}\sum_{j=1}^{NM}\xi_{j,k}y_j\right\},\ k\in\overline{1,K},\\ \begin{cases}\sum_{m=1}^{M}q_{n,m,k}y_{M(n-1)+m}\ge y_{MN+1},\ n=\overline{1,N},\ k=\overline{1,K},\\ \sum_{n=1}^{N}q_{n,m,k}y_{M(n-1)+m}\ge Q_m^{\text{p.c.}},\ m=\overline{1,M},\ k=\overline{1,K},\\ \sum_{m=1}^{M}y_{M(n-1)+m}=S_n,\ n=\overline{1,N},\end{cases}\\ y_j\ge 0,\ j=\overline{1,NM},\ y_{NM+1}>0.\end{cases}\qquad(1)$$

where $\xi_{j,k}=\xi_{M(n-1)+m,k}=p_{m,k}^{m.p.}q_{n,m,k}$.

Remark 6. In the mathematical model (1), the number of unknown variables is $NM+1$, and all these variables are involved in all K different climatic scenarios, i.e. we have not added an index k $\left(k=\overline{1,K}\right)$ to these variables. It is not a mistake: this is due to the fact that different soil and climatic conditions (climatic scenarios) cannot simultaneously take place for the same sown field. Let us show this using the following simple example [13], for which the mathematical model (1) is greatly simplified and turns into a one-criterion linear programming problem. Let $N=1$ (one sown field with area S), $M=4$ (four kinds of cereal crops), $K=2$ (two climatic scenarios); yields of cereal crops (quintal/ha): $q_{1,1,1}=25$; $q_{1,2,1}=20$, $q_{1,3,1}=30$, $q_{1,4,1}=15$, $q_{1,1,2}=15$, $q_{1,2,2}=20$, $q_{1,3,2}=10$, $q_{1,4,2}=40$. It is required to determine what kinds of crops and in what proportion should the sown field be sown in order to obtain the maximum guaranteed yield, regardless of which of the two climatic scenarios will take place. As mentioned above, for this simple problem, the mathematical model (1) is simplified to a one-criterion optimization model and has the following form:

$$\text{maximize}\left[w(x)\overset{def}{\equiv}y_5\right]$$

subject to

$$\begin{cases}25y_1+20y_2+30y_3+15y_4-y_5\ge 0,\\ 15y_1+20y_2+10y_3+45y_4-y_5\ge 0,\\ y_1+y_2+y_3+y_4=1,\end{cases}$$

where $y_j\ge 0$ is the area of the field sown with crop of j-th $\left(j=\overline{1,4}\right)$ kind. Solving this problem with Danzig's simplex algorithm, we find: $y_1=0$, $y_2=0$, $y_3=\frac{5}{9}S$, $y_4=\frac{4}{9}S$, $y_5=\frac{70}{3}S$. In other words, we obtain that the maximum guaranteed yield is equal to $\frac{70}{3}S$, which is achieved only if the field is sown only with crops of the 3rd

and 4th kinds in proportions 5:4. The reader can independently verify that any other sowing plan will give a worse result. EOR

Model (1) is a linear programming $(K+1)$- criteria problem, therefore, speaking of the solution of model (1), it should be understood as its Pareto-optimal solution, which has the property that any deviation from this solution gives rise to a situation where an improvement in the value of any of the criteria worsens the values of the remaining criteria [14]-[16]. In other words, the Pareto-optimal solution is a trade-off decision: each of the criteria strives to achieve its optimum (maximum or minimum) "while watching the reaction" of the corresponding optimums of all remaining criteria so that they do not deteriorate. Currently, to find the Pareto-optimal solution to the multicriteria optimization problem, there are many different approaches and methods that differ significantly in both idea/concept and implementation complexity [14]-[20]. In the works [12], [21] briefly, but exhaustively from the point of view of the application skill, three main methods for solving the multicriteria optimization problem are described – the weighted sum approach method, the epsilon-constraint method, and the goal attainment method of Gembicki. The paper [22] (see also relevant references given there) discusses in detail the main drawback of the weighted sum approach associated with the lack of scientifically based and objective selection of criteria importance coefficients (these coefficients are also called criteria weights), with which multicriteria optimization problem is reduced to a single-criterion optimization problem with the same limitations of the original multicriteria problem and with one convoluted criterion $w(y)=\sum_{k=1}^{K+1}\lambda_k w_k(y)$, where $\lambda_k>0$ is weighting coefficient of k-th $\left(k=\overline{1,K+1}\right)$ criterion of the original multicriteria problem, and $\sum_{k=1}^{K+1}\lambda_k=1$. For example: (a) if we assume that for the decision maker in model (1) all the criteria are equally important, then instead of the multi-criteria model (1) we get a single-criterion model with convoluted criterion $w(y)=y_{NM+1}+\sum_{k=1}^{K}\sum_{j=1}^{NM}\xi_{j,k}y_j$, which we want to maximize (here we omitted the multiplicative constant $(K+1)^{-1}$ in the right-hand side of $w(y)$ since it does not play any role in maximizing the criterion) when all the same limitations of model (1) are fulfilled, i.e. all $(N+M)K+N$ essential constraints and all $NM+1$ sign constraints; (b) if we assume that for the decision maker in model (1), the importance of the criterion of maximality of guaranteed total volume of grown crops (in any climatic scenario) is p_{pct}% of the cumulative importance of all the criteria, and the importance of the gross income criterion of the enterprise from the sale of all grown crops in all fields, remains unchanged for any of the climatic scenarios that have occurred, then instead of the multicriteria model (1) we get a single-criterion model with a convoluted criterion $w(y)=p_{pct}y_{NM+1}+\frac{100-p_{pct}}{K}\sum_{k=1}^{K}\sum_{j=1}^{NM}\xi_{j,k}y_j$, which we want to maximize (here we omitted the multiplicative constant) 0.01 in the right-hand side of $w(y)$ since it does not play any role in maximizing the criterion) when all the same limitations of model (1) are fulfilled. In particular, if $p_{pct}=50\%$, then $w(y)=y_{NM+1}+\frac{1}{K}\sum_{k=1}^{K}\sum_{j=1}^{NM}\xi_{j,k}y_j$. Obviously, for different sets of weights $\{\lambda_k\}_{k=\overline{1,(K+1)}}$ the corresponding single-criterion problems, to which the original single-criterion problem is reduced, may have different solutions and, moreover, some of them may not have solutions due to the unlimitedness of the minimized criterion from below (if we look for a minimum) or above (if look for a maximum). In the work [22], for finding for finding the weighting coefficients of criteria a new approach based on methods of the theory of inverse and ill-posed problems is proposed. However, for successful application of the proposed approach, special knowledge is needed – knowledge of the theory of inverse and ill-posed problems, which significantly limits the proposed approach.

The epsilon-constraint method, first proposed in [23], has its main insurmountable drawback associated with the lack of an established application procedure, namely, the researcher almost never knows exactly which of the criteria to translate into restrictions, and what values of epsilon to set on the right side of these restrictions [12]. These questions are subjectively decided by the researcher, depending on how much he understands the meaning of the task as a whole and the importance of each criterion in particular. Nevertheless, the epsilon-constraint method has gained some popularity due to the fact that it is very simple and straightforward, and it uses standard mathematical software for computer implementation.

The essence of the goal attainment method of Gembicki, first proposed in [17], is as follows: (a) all the criteria of the original multicriteria problem must be transformed so that their minimization or maximization is required (this is easy to do by multiplying the criteria by -1); (b) one should generate set of desired intentions $\{w_1^*;\ldots;w_{K+1}^*\}$, which is related to criterion vector $(w_1(y),\ldots w_{K+1}(y))$ of the original multicriteria problem (1), for example, as a desired intention w_k^* one can take the optimal value of the corresponding single-criterion problem with the criterion $w_k(y)$ and with all the limitations of the original multicriteria problem (1); (c) a single-criterion problem should be solved in which it is required to find such a minimum value of a numerical parameter $R\in\mathbb{R}^1$, so that new constraints $w_k(y)-\lambda_k R\le w_k^*, k=\overline{1,K+1}$ hold together (here

$\{\lambda_k \geq 0\}_{k=\overline{1,K+1}}$ are weighting coefficients that determine how close each criterion is to its target value) and all the limitations of the original multicriteria problem (1) are satisfied. In the new limitations of the goal attainment method of Gembicki, the value $\lambda_k R \ \left(\sim \Delta w_k = w_k(y) - w_k^*\right)$ can be interpreted as the degree of under-attainment/over-attainment of k-th $\left(k=\overline{1,K+1}\right)$ desired intention w_k^*. In other words, $\lambda_k R$, $k=\overline{1,K+1}$ determine the rigidity of the desired intentions w_k^*, $k=\overline{1,K+1}$. For example [21], [24], [25], if the desired intention w_k^* is unattainable/overattainable, then a small value of the weighting coefficient λ_k will result in the degree of under-attainment/over-attainment Δw_k being small. Finally, let us note that in the case of under-attainment of the desired intentions, the smaller weighting coefficient is associated with the more important criteria, and in the case of over-attainment of the desired intentions, the smaller weighting coefficient is associated with the less important criteria).

In this paper, we will solve the mathematical model (1) by the goal attainment method of Gembicki, the brief essence of which has just been described above. So, the procedure for solving model (1) consists of the following steps.

Step 1. By any standard method (for example, Dantzig's simplex algorithm), we solve the following $K+1$ single-criterion linear programming problems:

$$\underset{y\in\Omega}{\text{minimize}}\left(\tilde{w}_1(y) = -y_{NM+1}\right);$$

$$\underset{y\in\Omega}{\text{minimize}}\left(\tilde{w}_{k+1}(y) = -\sum_{j=1}^{NM}\xi_{j,k}y_j\right),\ k\in\overline{1,K},$$

where the set Ω, called a feasible region, is

$$\Omega \overset{def}{\equiv} \Big\{ y\in\mathbb{R}_+^{NM},\ y_{NM+1}>0:$$

$$\sum_{m=1}^{M} q_{n,m,k}\, y_{M(n-1)+m} \geq y_{MN+1}, n=\overline{1,N}, k=\overline{1,K};$$

$$\sum_{n=1}^{N} q_{n,m,k}\, y_{M(n-1)+m} \geq Q_m^{\text{p.c.}}, m=\overline{1,M}, k=\overline{1,K};$$

$$\sum_{m=1}^{M} y_{M(n-1)+m} = S_n, n=\overline{1,N}\Big\}.$$

As a result of this step, we obtain a set $\tilde{w}_k^{\min} = \min\limits_{y\in\Omega}\tilde{w}_k(y)$, $k\in\overline{1,K+1}$, which we will use as the set of desired intentions $\left\{w_1^*;\ldots;w_{K+1}^*\right\}$, i.e. $w_k^* = \tilde{w}_k^{\min}$, $k\in\overline{1,K+1}$.

Step 2. Solve the following single-criterion problem:

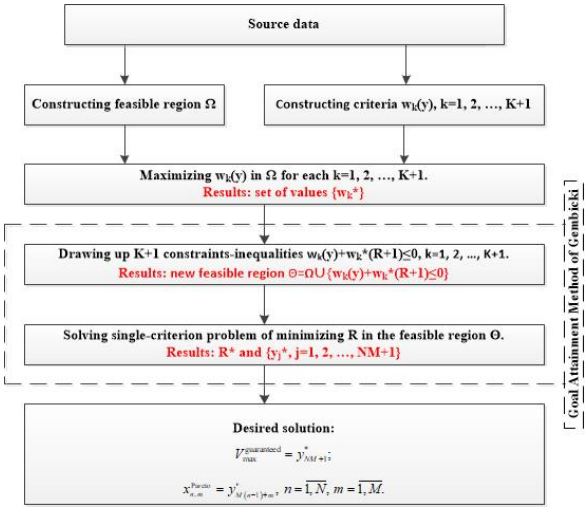
$$\begin{cases} \underset{R\in\mathbb{R}^1,\, y\in\Theta[R]}{\text{minimize}}(R), \\ \Theta[R] = \left\{ y\in\Omega:\ \tilde{w}_k(y) - \tilde{w}_k^{\min} R \leq \tilde{w}_k^{\min} \right. \\ \left. \forall k\in\overline{1,K+1} \right\}, \end{cases} \tag{2}$$

where as weighting coefficients $\{\lambda_k\}_{k\in\overline{1,K+1}}$, which, as stated in the description of the goal attainment method of Gembicki, determine how close each criterion will be to its goal value, we took the desired intentions $\tilde{w}_k^{\min}$, $k\in\overline{1,K+1}$. This means that we want to achieve the same measure of underattainability or overattainability of all $K+1$ criteria.

The results of solving problem (2) are the number $R^{\min} = \min\limits_{R\in\mathbb{R}^1,\, y\in\Theta[R]}(R)$ and numerical vector $y^{\text{Pareto}} = \left(y_1^{\text{Pareto}},\ldots,y_{NM+1}^{\text{Pareto}}\right)^T = \arg\min\limits_{R\in\mathbb{R}^1,\, y\in\Theta[R]}(R)$, the last coordinate of which, we recall, is the desired maximum guaranteed volume (the maximum of the minimum possible) of all M kinds of cereal crops grown in all N fields under any of K climatic scenarios, i.e. $y_{NM+1}^{\text{Pareto}} = V_{\max}^{\text{guaranteed}}$. The remaining coordinates of the resulting numerical vector y^{Pareto} characterize the areas of fields sown with M kinds of cereal crops: $y_{M(n-1)+m}^{\text{Pareto}} = x_{n,m}^{\text{Pareto}}$, $n=\overline{1,N}$, $m=\overline{1,M}$.

So, doing the above two steps gives us a number $V_{\max}^{\text{guaranteed}}$, which is the desired guaranteed yield, and a numerical matrix $x^{\text{Pareto}} = \left\{x_{n,m}^{\text{Pareto}}\right\}_{n=\overline{1,N}}^{m=\overline{1,M}}$, the elements of which are the required areas for sowing, namely, the element $x_{n,m}^{\text{Pareto}}$ is the area of *n*-th field, which must be sown with cereals of *m*-th kind. It remains only to note that since the set $\left\{R^{\min};y^{\text{Pareto}}\right\}$ found by the solution of the single-criterion optimization problem (2) is Pareto-optimal of the multicriteria optimization problem (1) (this statement follows from the theoretical justification of the goal attainment method of Gembicki), then set $\left\{V_{\max}^{\text{guaranteed}};x^{\text{Pareto}}\right\}$ is Pareto-optimal solution of the agrarian problem that we are studying, i.e. a compromise solution in which a compromise occurs between the guaranteed volume of the crop (the maximum of the minimum possible) and the total gross income from the sale of the crop.

The approach described above can be conceptually represented in the form of the following diagram:



IV. Numerical Experiment: Implementation of Mathematical Model

In this section, using a specific example, we illustrate the application of the proposed mathematical model (1) and the chosen goal attainment method of Gembicki to find the Pareto-optimal solution of the considered agrarian problem.

Suppose that the agricultural enterprise "Latvijas labība" Ltd. is going to sow seven sown fields $(N=7)$ in the Jelgava region of Latvia with five kinds of cereals $(M=5)$ – bread wheat (#1), malting barley (#2), common buckwheat (#3), bread rye (#4) and milling oats (#5), the yield of which depends on four types of climatic scenarios $(K=4)$ – warm dry weather (#1), chilly dry weather (#2), warm rainy weather (#3), chilly rainy weather (#4), – which may occur during sowing and growing [1] of these cereal crops. It is assumed that in the corresponding time period in Latvia the demand for each of the above crops will be so high that it can be considered unlimited. According to the procurement contract between the agricultural enterprise "Latvijas labība" and the procurer "Zelta Dzirnavas" Ltd., which purchases the produced crops for further processing, the agricultural enterprise "Latvijas labība" is obliged to sell the bread wheat in amount of not less than 45 quintals, malting barley in amount of not less than 20 quintals, common buckwheat in amount of not less than 25 quintals, milling oats in amount of not less than 20 quintal. It is required to determine what kinds of crops listed above and in what proportions should be sown in order, firstly, to obtain a guaranteed crop (the maximum of the minimum possible) that does not depend on climatic scenarios, and, secondly, the gross income from the sale of the crop was the greatest? The necessary input data are given below (the indicated data are quite realistic data based on the corresponding official statistics on Latvia extracted from the sources [8]-[11] in the period of 2010-2018):

– area of sown fields (ha):

$$S=(20,10,15,25,40,30,60);$$

– purchasing and market prices of grown crops per a quintal (euro):

$$p^{\text{p.p.}}=(17.3,13.2,22.6,10.2,17.4),$$

$$p^{\text{m.p.}}=(18.6,15.9,28,13.6,21);$$

– bread wheat yield (quintal /ha):

$$q_{4\times 7}^{(1)}=\begin{pmatrix}30&25&35&31&29&31&27\\25&20&30&26&24&26&22\\45&40&50&46&44&46&39\\35&30&40&36&34&36&31\end{pmatrix};$$

– malting barley yield (quintal/ha):

$$q_{4\times 7}^{(2)}=\begin{pmatrix}20&22&21&22&20&22&19\\30&35&35&34&32&34&29\\25&21&23&24&22&24&21\\25&19&19&22&20&22&19\end{pmatrix};$$

– common buckwheat yield (quintal/ha):

$$q_{4\times 7}^{(3)}=\begin{pmatrix}8&7&7&8&7&8&7\\10&11&10&11&9&11&11\\9&9&8&9&10&10&8\\9&9&9&10&8&10&9\end{pmatrix};$$

– bread rye yield (quintal/ha):

$$q_{4\times 7}^{(4)}=\begin{pmatrix}20&25&22&23&22&23&20\\40&42&42&42&40&42&36\\35&22&28&29&28&29&25\\30&38&30&33&32&34&29\end{pmatrix};$$

– milling oats yield (quintal/ha):

$$q_{4\times 7}^{(5)}=\begin{pmatrix}10&9&9&10&8&10&9\\15&13&14&15&13&15&13\\20&25&20&22&21&23&19\\25&30&27&28&27&28&24\end{pmatrix}.$$

Now let us establish the following correspondences between indices $n=\overline{1,7}$, $m=\overline{1,5}$, $k=\overline{1,4}$ of the designations in the model (1) and the names present in the considered illustrative case study (names of crops, names of climatic scenarios): index $n=\overline{1,7}$ will correspond to the number of the sown fields; index $m=\overline{1,5}$ will correspond to the number of considered cereal crops, at that $m=1$ will correspond to bread wheat, $m=2$ – to malting barley; $m=3$ – to common buckwheat; $m=4$ – to bread rye; $m=5$ – to milling oats; index $k=\overline{1,4}$ will correspond to climatic scenarios, at that $k=1$ will

correspond to warm dry weather, $k=2$ – to chilly dry weather, $k=3$ – to warm rainy weather, $k=4$ – to chilly rainy weather. Further, variable V stands for sought-for guaranteed crop that does not depend on climatic scenarios; variable $x_{n,1}$ stands for share of area of n-th field sown with bread wheat; variable $x_{n,2}$ stands for share of area of n-th field sown with malting barley; variable $x_{n,3}$ stands for share of area of n-th field sown with common buckwheat; variable $x_{n,4}$ stands for share of area of n-th field sown with bread rye; variable $x_{n,5}$ stands for share of area of n-th field sown with milling oats. Now the correspondence between the variables V, $\left\{x_{n,m}\right\}_{n=\overline{1,7}}^{m=\overline{1,5}}$ and the variables $\left\{y_j\right\}_{j=\overline{1,36}}$ of the model (1) is quite obvious: $V=y_{36}$, $x_{n,m}=y_{5(n-1)+m}$, $n=\overline{1,7}$, $m=\overline{1,5}$.

So, for the considered illustrative computational example, the mathematical model (1) takes the following form:

$$\text{maximize}\left\{w_0\left(y\right)\overset{def}{\equiv}y_{36}\right\}, \tag{3}$$

$$\begin{aligned}&\text{maximize}\left\{w_k\left(y\right)\overset{def}{\equiv}\sum_{n=1}^{7}\sum_{m=1}^{5}p_m^{m.p.}\left(q_{4\times7}^{(m)}\right)_{k,n}y_{y_{5(n-1)+m}}\right.\\&\left.-\sum_{m=1}^{5}Q_m^{\text{p.c.}}\left(p_m^{p.p.}-p_m^{m.p.}\right)\right\},\ k\in\overline{1,4},\end{aligned} \tag{4}$$

subject to

$$\begin{cases}\sum_{m=1}^{M}\left(q_{4\times7}^{(m)}\right)_{k,n}y_{M(n-1)+m}\geq y_{36},\ n=\overline{1,7},\ k=\overline{1,4},\\ \sum_{n=1}^{7}\left(q_{4\times7}^{(m)}\right)_{k,n}y_{5(n-1)+m}\geq Q_m^{\text{p.c.}},\ m=\overline{1,5},\ k=\overline{1,4},\\ \sum_{m=1}^{5}y_{5(n-1)+m}=S_n,\ n=\overline{1,7},\\ y_j\geq0,\ j=\overline{1,35},\ y_{36}>0,\end{cases} \tag{5}$$

where $Q^{\text{p.c.}}=\left(45,20,25,0,20\right)$.

Now we apply the goal attainment method of Gembicki described in the previous section to the constructed five-criterion optimization problem, i.e. we carry out Steps 1 and 2.

Step 1. To specify a set of desired intentions we have to solve the following five single-criterion optimization problems: problem (3), (5); problem (4), (5) for $\forall k=\overline{1,4}$. Having solved these single-criterion linear programming problems by Danzig's simplex algorithm, we find the following set of desired intentions:

$$\begin{aligned}\left\{w_k^*\right\}_{k=\overline{0,4}}&=\left\{\arg\max_{y:\,(6)}\left\{w_k\left(y\right)\right\}\right\}_{k=\overline{0,4}}\\&=\left\{250;\,108676.5;\,107345.4;\,161128.5;\,126880.5\right\}.\end{aligned}$$

Step 2. We have to solve the following single-criterion linear programming problem:

$$\underset{R\in\mathbb{R}^1,\,y\in\Theta[R]}{\text{minimize}}\left[R\right], \tag{6}$$

subject to

$$\begin{cases}w_k\left(y\right)-w_k^*R\geq w_k^*,k=\overline{0,4},\\ \text{Constraints (5)},\\ R\in\mathbb{R}^1.\end{cases} \tag{7}$$

In the framework of this work, the problem (6), (7) was solved by us of the Tikhonov regularization method [26], implemented by the application package Mathcad, version 14.0.0.163. When applying this method, the optimal regularization parameter was found by two methods, both using the generalized residual principle [27] and using the method first proposed and substantiated in [28] (see also [22]): the results obtained coincide with an accuracy not exceeding 10^{-4}.

So, as a result of steps 1 and 2, we obtained the following results: $x_{1,1}=20$, $x_{2,2}=1.35$, $x_{2,4}=8.65$, $x_{3,1}=15$, $x_{4,1}=25$, $x_{5,1}=11.45$, $x_{4,4}=28.55$, $x_{6,1}=30$, $x_{7,1}\approx53$, $x_{7,3}\approx4$, $x_{7,5}\approx3$. In other words, the first, third, fourth, and sixth sown fields should be sown only with bread wheat; the second sown field should be sown with malting barley and bread rye in a ratio of approximately 1:6; the fifth sown field should be sown with bread wheat and bread rye in a ratio of 2:5 approximately; finally, the seventh sown field should be sown with three cereal crops – bread wheat, common buckwheat and milling oats – in a ratio of approximately 99:5:7.

Thus, we can summarize that the agricultural enterprise "Latvijas labība" grows bread wheat on about 154.5 ha of its arable lands of 200 hectares, malting barley – on about 1.5 ha, common buckwheat – on about 4 ha, bread rye – on about 37 ha, and milling oats – on approximately 3 ha. As a result, the volume of the guaranteed maximum harvest of all 5 cereal crops, regardless of which of the four climatic conditions occurs, is approximately 7205 quintals (this is at least, and the maximum possible volume is approximately 94666 quintal), selling of which, taking into account the procurement contract, brings the enterprise approximately 128170 euros (accordingly, this value is the minimum guaranteed income and it can increase to 168441 euros).

In conclusion, we just add that the analysis of the results shows that, within the framework of this illustrative example the desired intentions $w_1^*=10867.5$ and $w_4^*=126880.5$ appeared to be overattainable. By virtue of theory stated in [17] it means that it is possible to improve the model (6), (7) (in the sense of Pareto). This can be achieved by applying one of the modifications of goal attainment method of Gembicki, for example, one of the approaches developed in [29] and [30].

V. Conclusions

In the present paper, one agrarian problem is formulated for finding a guaranteed harvest of cereal crops, the yield of which depends on external factors, in particular, on soil-climatic conditions. For the formulated agrarian problem, a mathematical model is constructed, which is a multi-criteria problem with constraints. Further, the essence of the three main methods for solving the constructed mathematical model is briefly described: the weighted sum approach method, the epsilon-constraint method and the goal attainment method of Gembicki. The main disadvantages of the weighted sum approach and epsilon-constraint method are briefly analyzed and associated with the ambiguity in the selection of criteria's importance coefficients. Then, the goal attainment method of Gembicki is applied to the constructed mathematical model. Besides, in this paper, a computational example is formulated, and its mathematical model is constructed and solved by the goal attainment method of Gembicki. Finally, the authors would like to point out that the agricultural problem considered in this paper, the detailed course of its modelling as well as more or less detailed description of at least one approach to its solving (goal attainment method of Gembicki), in our opinion, may turn out to be a useful template for a wide range of users (not necessarily well-knowing higher mathematics) related to management of growing and production of cereal crops under various possible external factors, in particular, under various soil-climatic factors (which are with increasing frequency occurring even in such a small country as Latvia), under various diseases of cereal crops: infectious diseases (viral and fungal diseases) caused by macro- or micro-organisms; non-infectious diseases caused by inorganic nature, etc. It is important to note that the algorithm proposed in this paper for solving the constructed mathematical model is easily implemented both in Microsoft Excel software and in Mathcad, MATLAB etc. softwares (Mathcad is designed for the engineering environment, while MATLAB betrays its roots as a mathematics tool designed for mathematicians clearly).

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References

[1] Latvian Environment, Geology and Meteorology Centre, "Latvijas klimats." [Online]. Available: https://www.meteo.lv/lapas/laiks/latvijas-klimats/latvijas-klimats?id=1199&nid=562 [Accessed: March 14, 2021]

[2] Ch. Gienapp, D. Dreger, A. Zaharenko, etc., Cereal Crops: Growing, Harvesting, Reworking and Using. Moscow: "DLV AgroDelo" Publishing, 2008.

[3] D. Spaar, H. Kleinhempel, and R. Fritzsche, Getreide, Mais und Futtergräser. Berlin, Germany: Springer-Verlag, 2013.

[4] R. J. Henry and P. S. Kettlewell, Cereal Grain Quality. London: Chapman & Hall, 1996.

[5] V. M. Vazhov, Buckwheat in the fields of Altai. Moscow: Academy of Natural Sciences Press, 2013.

[6] A. Nurbekov, A. Kassam, D. Sydyk, Z. Ziyadullaev, I. Jumshudov, H. Muminjanov, D. Feindel, and J. Turok, Practice of conservation agriculture in Azerbaijan, Kazakhstan and Uzbekistan. Ankara, Turkey: Food and Agriculture Organization of the United Nations Publishing, 2016.

[7] A. Nurbekov, A. Musaev, D. Sydyk, Z. Ziyadullaev, and J. Turok. Conservation Agriculture in Irrigated Areas of Azerbaijan, Kazakhstan and Uzbekistan. Beirut: International Centre for Agricultural Research in the Dry Areas, 2015.

[8] "European Commission. EU prices for selected representative products. Monthly prices for vegetal products." [Online]. Available: https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/farming/documents/market-prices-vegetal-products_en.pdf [Accessed: March 14, 2021]

[9] Ministry of Agriculture of the Republic of Latvia, "Agriculture Annual Reports. Agricultural Report 2019 for 2018." [Online]. Available: https://www.zm.gov.lv/public/files/CMS_Static_Page_Doc/00/00/01/62/36/2019_lauks_gada_zinojums.pdf [Accessed: March 14, 2021]

[10] Latvian Rural Advisory and Training Centre. [Online]. Available: http://new.llkc.lv/ [Accessed: March 14, 2021]

[11] Food and Agriculture Organization of the United Nation, "FAOSTAT: Crops." [Online]. Available: http://www.fao.org/faostat/en/#data/QC [Accessed: March 14, 2021]

[12] R. Aleksejevs, R. Guseinovs, A. N. Medvedev, and Sh. E. Guseynov, "On a Multi-criterion Problem of Planning Maritime Cargo Transportation," Journal of Traffic and Transportation Engineering, vol. 5, no. 3, pp. 124-146, 2017.

[13] S. A. Ashmanov and A. V. Timokhov, Theory of optimization in in tasks and exercises. Moscow: Nauka Publishing, 1991.

[14] A. Chinchuluun, P. M. Pardalos, A. Migdalas, and L. Pitsoulis, Eds., Pareto Optimality, Game Theory and Equilibria. New York: Springer, 2008.

[15] R. L. Keeney and H. Raiffa, Decisions with Multiple Objectives: Preferences and Value Tradeoffs. Cambridge: Cambridge University Press, 1993.

[16] R. E. Steuer, Multiple Criteria Optimization: Theory, Computation, and Application. New York: John Wiley & Sons, 1986.

[17] F. W. Gembicki, "Vector Optimization for Control with Performance and Parameter Sensitivity Indices," Ph.D. thesis, Department of System Engineering, Case Western Reserve University, Cleveland, USA, 1973.

[18] C. A. Coello Coello and G. B. Lamont, Applications of Multi-Objective Evolutionary Algorithms: Advances in Natural Computation. New Jersey: World Scientific Press, 2004.

[19] K. Deb, Multi-objective Optimization Using Evolutionary Algorithms. New York: John Wiley & Sons, 2001.

[20] T. L. Saaty, The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation. New York: McGraw-Hill, 1980.

[21] P. J. Fleming, "Computer-aided control system design of regulators using a multiobjective optimization," Annual Review in Automatic Programming, vol. 13, part 2, pp. 47-52, 1985.

[22] Sh. E. Guseynov, R. Aleksejevs, J. V. Aleksejeva, and Y. S. Gasimov, "Evaluating attractiveness of the Central and the Eastern European countries by using index approach for the strategic decision making process related to expansion of the financial service markets," Advanced Mathematical Models & Applications, vol. 2, no. 3, pp.167-214, 2017.

[23] Y. Y. Haimes, "Integrated System Identification and Optimization," Control and Dynamic Systems, vol. 10, pp. 435-518, 1973.

[24] P. J. Fleming and A. P. Pashkevich, "Application of Multiobjective Optimization to Compensator Design for SISO Control Systems," Electronics Letters, vol. 22, no. 5, pp. 258-259, 1986.

[25] F. W. Gembicki and Y. Y. Haimes, "Approach to Performance and Sensitivity Multiobjective Optimization: The Goal Attainment Method," IEEE Transactions on Automatic Control, vol. 29, no 6, pp. 769-771, 1975.

[26] A. N. Tikhonov and V. Ya. Arsenin, Solutions of Ill-Posed Problems. Washington: Winston and Sons, 1977.

[27] V. A. Morozov, Methods for Solving Incorrectly Posed Problems. New York: Springer-Verlag, 1984.

[28] S. A. Andreyev and Sh. E. Guseynov, Regularizing Algorithms for Diagnosing: Applied to Gas Turbine Engines in Operation. Saarbrucken: LAP Publishing, 2013.

[29] K. Schittkowski, NLQPL. "A FORTRAN subroutine solving constrained nonlinear programming problems," Annals of Operations Research, vol. 5, no. 6, pp. 485-500, 1985.

[30] R. K. Brayton, S. W. Director, G. Hachtel, and L. Vidigal, "A new algorithm for statistical circuit design based on quasi-Newton methods and function splitting," IEEE Transactions on Circuits and Systems, vol. 26, no. 9, pp. 784-794, 1979.

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On the Issue of Planning Sowing Agricultural Crops with the Minimum Risk under the Presence of Various Agroclimatic Conditions

Sharif E. Guseynov
Faculty of Science and Engineering
Liepaja University
Liepaja, Latvia
sh.e.guseinov@inbox.lv

Sergey I. Matyukhin
Department of Technical Physics and Mathematics
Orel State University
Orel, Russia
sim1@mail.ru

Misir J. Mardanov
Institute of Mathematics and Mechanics
Azerbaijan National Academy of Sciences
Baku, Azerbaijan
misirmardanov@yahoo.com

Jekaterina V. Aleksejeva
Institute of Science and Innovative Technologies
Liepaja University
Liepaja, Latvia
Riga Secondary School 34
Riga, Latvia
jekaterina.v.aleksejeva@gmail.com

Olga V. Sidorenko
Department of Accounting and Statistics
Orel State Agrarian University
Orel, Russia
sov1974@mail.ru

***Abstract* - The present paper deals with one problem of quantitative controlling the seeding of the sown area by agricultural crops in different agroclimatic conditions. The considered problem is studied from the standpoint of three strategies: from the seeding planning perspective aiming at minimal risk associated with possible unfavourable agroclimatic conditions (a probabilistic approach is used); from the perspective of obtaining the maximum crops sales profit (a deterministic approach is used); from the perspective of obtaining the maximum crops harvest. For the considered problem, mathematical models are constructed (one probabilistic model and two deterministic models, respectively), their analytical solutions are found, and then, using a specific example, the application of the constructed and solved mathematical models is illustrated as well as the obtained numerical results are analysed..**

Keywords* - *Agricultural crops, agroclimatic conditions, maximum profit, minimal risk

I. Introduction

One of the main branches of agriculture is farming – the use of land for the purpose of growing crops which will be discussed in this paper. Depending on soil and climatic conditions, cropping/farming is divided into the following categories: land reclamation (melioration farming); irrigated cropping; dry farming. Most countries of the European Union, including Latvia, have irrigation farming [1]. The main indicators of soil fertility necessary for the formation of high yields of crops are agrophysical indicators (basic: density, porosity, fine-grained structure, water-strength structure), biological indicators (basic: the presence of organic matter, including humus, phytosanitary state, biological activity, enzymatic activity) and agrochemical indicators (absorption capacity, soil reaction (pH), the presence of nutrients). Crop yields are very sensitive not only to soil fertility indicators, but also to climatic indicators, the main of which are temperature-humidity and temperature-wind (taking into account radiation) indicators. Together these indicators are called soil-climatic indicators (conditions), and it is these conditions that determine the success or failure of all stages of the process of growing crops [2]-[12]. The yield of crops by country, depending on soil and climatic conditions, crop farming, as well as macroeconomic conditions, is quite different. Even in the countries of the European Union, there are noticeable differences both in the yield of crops and in the costs of growing them, and, consequently, in their costs to the final consumer [13]-[17]. In addition,

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different crops respond differently to the same soil and climatic conditions that occur during a particular growing season. Timely and efficient sowing provides the one of principal earnests of a successful harvest of agricultural crops. In its turn, for timely and efficient sowing it is required up-to-date seasonal forecasting information which enables growers to plan their crop production from seeding to harvest. By now, the relevant government departments of the most agriculturally developed countries (which are characterized by so-called high-commodity agriculture) are diligently encouraging scientists to carry out basic research using methods of mathematical modelling into various issues and aspects of the agronomic requirements of crops to provide to crops' growers rigorously scientifically based guidelines on sowing and its timing, on machinery, on environmental conditions, on paddock preparation, etc. [18]-[24] (see also relatively old works [25]-[32] and relevant references therein).

In the present paper, we consider and investigate one agricultural problem staying within the frames of answering the only question: if the agrochemical, landscape-ecological, ecological-genetic, etc. characteristics of the sown field satisfy the necessary requirements for sowing and growing certain kinds of field crops, which crops and in what proportions should be sown in order to obtain the best harvest? This is done regardless of what uncontrollable and/or poorly controlled scenarios (for example, agroclimatic conditions; fight against plant diseases and pests, etc.) will take place at every stage of the sowing process of these crops (the sowing process is a whole set of necessary measures: [33]-[41]). In the present paper, by the term "best harvest" we will alternately (i.e. in the sense of logical disjunction "or") mean three quantitative values: (A) the least risks from a possible loss of harvested crop (for this purpose, the constructed mathematical model has a probabilistic character); (B) the maximum profit from the sale of the harvested crop (for this purpose, the constructed mathematical model has a deterministic nature); (C) guaranteed maximum harvest.

II. Statement of the Considered Problem, its Formalization, and Construction of a Mathematical Model from the Ensuring Minimal Risks Standpoint

Let us suppose that some agricultural enterprise has a sowing field, which according to its' agrochemical, landscape-ecological, ecological-genetic, etc. characteristics is suitable for growing several kinds of field crops, the yield of each depends on uncontrollable and/or poorly controlled factors, which as a whole we will simply call a set of scenarios (for example, climatic conditions; control of diseases and pests; etc.). Provided that the market demand for each of the harvested crop kinds is unlimited, it is required to determine which kind of crop and in what proportions should be sown in order to obtain a guaranteed yield that meets the goal of an agricultural enterprise: as it has been already mentioned in the Introduction section, the goal of an agricultural enterprise will be consistently taken as (A) the lowest risks from a possible loss of crop yields, (B) the maximum crops sales profit, (C) the maximum crops harvest.

Now let us work out in detail and formalize the conceptually formulated problem. For this let us introduce the following designations: S ha is the area of the cultivated field; M is a number of crop kinds that the agricultural enterprise plans for seeding; c_i euro/ha is the total cost for all stages of the cultivation process for the i-th $\left(i=\overline{1,M}\right)$ kind of crop per 1 ha of the sown field; p_i euro/quintal is the forecasting market price for 1 quintal of the future harvest of the i-th crop kind; x_i ha is the required area of the sown field assigned to the i-th kind of crop. In addition, it is assumed that there is empirical data on the harvest (quintal/ha) for each crop kind for a certain period of time: $\left\{q_{i,j,k}\right\}_{j=\overline{1,N_i};k=\overline{1,K}}$ for $\forall i=\overline{1,M}$, where N_i means the number of years for which statistics on the yield by the kind of crop has been collected. Fields (including the current cultivated field under consideration) with more or less similar soil characteristics under different agroclimatic conditions: see [2], [3], [36], [40] are considered. Using statistical methods, having properly processed [42]-[47] the known empirical data $\left\{q_{i,j,k}\right\}_{j=\overline{1,N_i};k=\overline{1,K}}$, it is necessary to determine the following numerical characteristics for each kind of M kinds of crops: sample mean $\left\{m_i\right\}_{i=\overline{1,M}}$, biased sample variance $\left\{\sigma_i^2\right\}_{i=\overline{1,M}}$, unbiased sample variance $\left\{\frac{N_i}{N_i-1}\sigma_i^2\right\}_{i=\overline{1,M}}$. It is important to note that in order to obtain adequate values $\left\{m_i\right\}_{i=\overline{1,M}}$, $\left\{\sigma_i^2\right\}_{i=\overline{1,M}}$, the required proper statistical processing of the available empirical data $\left\{q_{i,j,k}\right\}_{j=\overline{1,N_i};k=\overline{1,K}}$ implies the statistical processing of information on micro- and macro-fluctuations (a) key soil quality indicators (agrophysical, biological and agrochemical indicators: see Introduction); (b) hydro-meteorological parameters (amount of precipitation, moisture reserves in the soil, water evaporation, air humidity, air temperature, soil temperature, wind speed, solar activity, aridity, floods); (c) the spread of diseases and pest proliferation; (d) organizational and technological conditions (seed quality, sowing time, crop rotation and predecessors choice, tillage, mineral fertilizers, crop protection agents, etc.).

Let us begin constructing a mathematical model of a formulated and formalized agrarian problem, in which goal (A) is chosen as the optimized goal – achieving the least risks from a possible loss of productivity of cultivated M kinds of crop species. Using introduced designations, it is possible to write that the total profit (euro) of an agricultural enterprise after the sale of the entire harvested crop is determined by the expression

$$R(x)\overset{def}{\equiv}\sum_{i=1}^{M}\left(p_i m_i-c_i\right)x_i. \qquad (1)$$

From (1) it directly follows that if for any j-th $\left(j \in \{1,\ldots,M\}\right)$ kind of agricultural crop $p_j m_j - c_j \le 0,$ is valid, then seeding of this kind of crop species either is not reasonable (for $p_j m_j - c_j = 0$), or will result in revenue losses (for $p_j m_j - c_j < 0$). However, in the agricultural industry, as in many industries connected with production or mining, there could be faced scenarios where an enterprise must proceed with production, even acknowledging the fact that the sale of goods will not bring any profit or even will incur some losses. For example, if a procurement contract is concluded between an agricultural enterprise and a buyer (for example, the government purchasing agent), under the terms of which the agricultural enterprise is obliged to transfer a certain part of the harvested crop to the buyer-procurer at a different price $\hat{p}_i$ euro/quintal (the so-called a purchasing price), which does not exceed the market price: $\hat{p}_i \le p_i, i \in \{1,\ldots,M\}.$ In this case, instead of formula (1), we have the formula

$$R(x) = \sum_{i=1}^{M} (p_i m_i - c_i) x_i + \sum_{i=1}^{M} (\hat{p}_i - p_i) Q_i, \qquad (2)$$

where $Q_i \ge 0$ denotes the volume (quintal) of the harvested crop for the i-th kind of crop species, which is agreed in the procurement contract between the buyer and agricultural enterprise. Obviously, if for any j-th $\left(j \in \{1,\ldots,M\}\right)$ kind of agricultural crop the inequality $p_j m_j - c_j \le 0$ takes place, then for an agricultural enterprise the following plan will be the best: $x_j = \frac{Q_j}{m_j}.$

Remark 1. If there is no obligation of selling a part of the harvest of any k-th $\left(k \in \{1,\ldots,M\}\right)$ crop species in the procurement contract, then it is obvious that $Q_k = 0$ in formula (2); if there is no such procurement contract concluded, then the second term of formula (2) is identically equal to zero and, therefore, formulas (1) and (2) will coincide. Obviously, the conditions $p_k m_k - c_k > 0$ and $Q_k > 0$ generate an inequality constraint $m_k x_k \ge Q_k$ for the k-th kind of crop species, and the conditions $p_k m_k - c_k \le 0$ and $Q_k > 0$ generate an equality constraint $m_k x_k = Q_k.$ End of Remark (EOR)

Remark 2. In the 50-70s years of the XX century, when the rapid development of computer systems contributed to the unprecedented application of mathematical modelling to real problems of technical, environmental, economic and other systems [48]-[55] having different levels of complexity, there have been published multiple works on various problems of agriculture, in particular, on agro-economic problems (see [28], [30]-[32], [35], [36], [38] and relevant references therein), in almost all of which the harvest distribution density of most agricultural crop species has been a priori considered having a Gaussian distribution. However, according to the numerous results obtained with the help of the "ZONT" aerospace sensing and technology (about 90% of the large-scale predictions made in advance by "ZONT" were later confirmed), the development of which began in the 80s of the 20th century in the Laboratory of Long-Term Forecasts of the Voronezh Agrarian University under the leadership of an authority scientist – Professor Isaak Beniaminovich Zagaytov, now we can state with a high degree of confidence that the series of agricultural crops yields are not subject to the Gaussian probability distribution [56]-[60]. Major portion of the series of agricultural crops yields can be described using semi-stable distribution laws [61], in particular, the Lévy-Zipf's law, which arises, as a rule, when studying complex systems with feedback. Further, considering the seasonally theoretical/true yields of an i-th $\left(i = \overline{1,M}\right)$ kind of agricultural crop as the values of some random variable with a given distribution density $f_i(\text{yield}_i),$ for example, of a Gaussian function $f_i(\text{yield}_i) = \frac{1}{\sqrt{2\pi\sigma_i^2}} e^{-\frac{(\text{yield}_i - m_i)^2}{2\sigma_i^2}},$ we can interpret the parameters m_i and $\sigma_i,$ which, as mentioned above, are found by proper statistical processing of empirical data $\left\{q_{i,j,k}\right\}_{j=\overline{1,N_i};k=\overline{1,K}},$ as a sample mean and biased sample variance of this random variable, respectively. Then, in view of the fact that the total profit of agricultural enterprise

$$R(\text{yield}; x) = \sum_{i=1}^{M} (p_i \text{yield}_i - c_i) x_i + \sum_{i=1}^{M} (\hat{p}_i - p_i) Q_i, \quad (3)$$

which itself is a random variable, appears to be a linear function with respect to theoretical yields $\text{yield} = \{\text{yield}_i\}_{i=\overline{1,M}},$ then it is possible to find the distribution density of the random variable (3) in explicit form [62]. In particular, if we assume that the yields of all M kinds of crops do not depend on each other (in fact, this is not always the case!), then $f_R(\text{yield}) = \prod_{i=1}^{M} f_i(\text{yield}_i).$ It is important to note here that if, on a particular sown field, the cultivation of one of the M kinds of crops affects the cultivation of at least one of the other M kinds of crops, then even if we assume that the yield of each of these two kinds of crops has a normal distribution, the statement about that the linear combination of the yields of these two kinds of crops also has a normal distribution [63] (the well-known Cramér's decomposition theorem for a normal distribution, predicted in [64] and proved in [65], requires that the components involved in this decomposition are independent random variables). In other words, it is impossible to assert that if the yield of each kind of M agricultural crops is distributed normally, then the profit distribution density f_R (3) of an agricultural enterprise has the form of a Gaussian function with a location parameter

$\sum_{i=1}^{M}(p_i x_i)m_i - \sum_{i=1}^{M} c_i x_i$ and a scale parameter $\sum_{i=1}^{M}(p_i x_i)^2 \sigma_i^2$. Taking into account the abovementioned circumstance is all the more important when the yields of agricultural crops M are distributed by other laws (the same or, even more complicated, different laws) EOR

Let us get back to formula (2) and, nevertheless, we will proceed from the fact that all M kinds of agricultural crops considered in this work are such that the value

$$\sigma^2 \overset{def}{\equiv} \sum_{i=1}^{M}(p_i \sigma_i x_i)^2 \tag{4}$$

is the variance of a random variable (3) – the total profit of an agricultural enterprise from the sale of the entire harvest of agricultural crops, taking into account the existing procurement contract (see Remark 1). Since the value (4) can be interpreted as the risks of an agricultural enterprise from the loss of yields, the problem of minimizing these risks is reduced to the problem of minimizing the value (4), but now as a function of variables $\{x_i\}_{i=\overline{1,M}}$, where x_i means the required area (ha) of the cultivated field, which must be allocated under the *i*-th kind of crops species. In other words, we have the following one-criterion constrained optimization problem:

$$\underset{x\in\Omega}{\text{minimize}}\left[\sigma^2(x) \overset{def}{\equiv} \sum_{i=1}^{M}(p_i \sigma_i x_i)^2\right], \tag{5}$$

where

$$\Omega \overset{def}{\equiv} \left\{ x \in \mathbb{R}_+^M : \sum_{i=1}^{M} x_i = S,\ m_i x_i \geq Q_i,\ \forall i = \overline{1,M} \right\},$$

$$\mathbb{R}_+^M \overset{def}{\equiv} \left\{ x \in \mathbb{R}^M : x_i \geq 0,\ \forall i = \overline{1,M} \right\}.$$

Let us apply the Lagrange multipliers method to problem (5). Let us compose the Lagrange functions and find its stationary point using the Karush-Kuhn-Tucker conditions:

– Lagrange function:

$$L(x;\lambda) \overset{def}{\equiv} \sum_{i=1}^{M}(p_i \sigma_i x_i)^2 + \alpha\left(\sum_{i=1}^{M} x_i - S\right) - \sum_{i=1}^{M} \beta_i (m_i x_i - Q_i);\ \alpha \in \mathbb{R}^1;\ \beta_i \in \mathbb{R}_+^1,\ \forall i = \overline{1,M}; \tag{6}$$

– Karush-Kuhn-Tucker conditions for an extremum:

$$\begin{cases} \dfrac{L(x;\lambda)}{\partial x_i} = 0, \forall i = \overline{1,M}, \\ \dfrac{L(x;\lambda)}{\partial \alpha} = 0, \\ \beta_i \dfrac{L(x;\lambda)}{\partial \beta_i} = 0,\ \beta_i \geq 0, \forall i = \overline{1,M} \end{cases} \Leftrightarrow$$

$$\begin{cases} 2p_i^2 \sigma_i^2 x_i + \alpha - \beta_i m_i = 0, \forall i = \overline{1,M}, \\ \sum_{i=1}^{M} x_i - S = 0, \\ \beta_i (Q_i - m_i x_i) = 0, \beta_i \geq 0, \forall i = \overline{1,M}. \end{cases} \tag{7}$$

Having solved this system, we find the coordinates of the sought-for stationary point:

$$x_i^* = \frac{S}{p_i^2 \sigma_i^2 \sum_{j=1}^{M} \frac{1}{p_j^2 \sigma_j^2}} > 0,\ \forall i = \overline{1,M}.$$

By adding to this formula the condition $x_i = \dfrac{Q_i}{m_i}$ if $p_j m_j - c_j \leq 0$, we obtain the final formula for the coordinates of the sought-for stationary point $x^* \in \mathbb{R}_+^M$:

$$x_i^* = \begin{cases} \dfrac{S}{p_i^2 \sigma_i^2 \sum_{j=1}^{M} \frac{1}{p_j^2 \sigma_j^2}} & \text{if} \quad p_i m_i - c_i > 0, \\ \dfrac{Q_i}{m_i} & \text{otherwise} \end{cases} \tag{8}$$

for $\forall i = \overline{1,M}$.

Further, since $\dfrac{L^2(x;\lambda)}{\partial x_i \partial x_j} = \dfrac{L^2(x;\lambda)}{\partial x_j \partial x_i}$ $\forall i, j = \overline{1,M}$ and $\left.\dfrac{L^2(x;\lambda)}{\partial x_i \partial x_j}\right|_{x=x^*} = \begin{cases} 2p_i^2 \sigma_i^2 > 0 & \text{if} \quad i = j, \\ 0 & \text{otherwise,} \end{cases}$ then all of the leading principal minors of the Hessian matrix $H(L) = \left[\left.\dfrac{L^2(x;\lambda)}{\partial x_i \partial x_j}\right|_{x=x^*}\right]$ of the Lagrange function $L(x;\lambda)$ are positive. Therefore, by virtue of Sylvester's criterion [66], the Hessian matrix $H(L)$ is positive-definite. Consequently, in view of the fact that $d^2 L(x;\lambda)\big|_{x=x^*} = \sum_{i=1}^{M}\sum_{j=1}^{M} H(L)_{i,j}\, dx_i dx_j > 0$, we can state that $d^2 L(x;\lambda)\big|_{x=x^*} > 0$. Then, by virtue of the theorem of the second-order sufficient condition for a local extremum [67], the found stationary point $x^* \in \mathbb{R}_+^M$ with coordinates (8) is a point of local minimum for the Lagrange function

$L(x;\lambda)$ and, consequently, this point is a local minimum for the considered original optimization problem (5).

Now let us find out whether the found local minimum $x^* \in \Omega$ of the optimization problem (5) is also its global minimum. For this, we note that the objective function $\sigma^2(x)$ of problem (5), if we consider it as a quadratic form, is a canonical form with positive coefficients, and, therefore, it is a positive definite quadratic form at $\forall x \in \mathbb{R}^M / \{0\}$. Then, by virtue of the well-known theorem [67], the quadratic form $\sigma^2(x)$ is an infinitely growing function on any closed set $X \subset \mathbb{R}^M$, in particular, on our feasible set Ω. We need the following fact [67], [68]: if any function $f(x)$ is a continuous and infinitely growing function on a set $X \subset \mathbb{R}^n$, then a global solution to the problem $\underset{x \in X}{\text{minimize}}(f(x))$ exists. Since our function $\sigma^2(x)$, which, as it has already been shown, is an infinitely increasing function, is also a continuous function, then, by virtue of the above fact, $\sigma^2(x)$ has a global minimum at Ω. In other words, optimization problem (5) has a global solution. On the other hand, the point $x^* \in \mathbb{R}_+^M$ with coordinates (8) is the only stationary point of the function $\sigma^2(x)$. Hence, this point is also that global solution to the optimization problem (5), the existence of which has just been proved.

Remark 3. To avoid possible misunderstandings among readers inexperienced in mathematics who are interested in the agricultural subject matter of the present paper, just in case, we will briefly explain the essence of an infinitely growing function (this is not the same as an upper-unbounded function!). Definition: a function $f(x)$ defined on a set $X \subseteq \mathbb{R}^n$ is called an infinitely growing on X if $\limsup_{k\to\infty} f\left(x^{\{k\}}\right) = \infty$ [69] for any sequence $\left\{x^{\{k\}}\right\}_{k\in\mathbb{N}} \subset X$ such that either $\lim_{k\to\infty} x^{\{k\}} = x \in \overline{X} \setminus X$ or $\lim_{k\to\infty} \left\|x^{\{k\}}\right\| = \infty$. Let us explain the essence of this definition using two examples. Consider a function $f(x) = x_1^2 - x_1x_2 + x_2^2$ on a set $X = \mathbb{R}^2$, and show that this function is an infinitely growing function in $\mathbb{R}^2$. Indeed, using inequality $x_1x_2 \le \frac{x_1^2 + x_2^2}{2}$, we can write: $f(x) \ge \frac{1}{2}\left(x_1^2 + x_2^2\right) = \frac{1}{2}\|x\|^2$, where $x = (x_1, x_2)^T$ is a column vector, $\|x\|$ means Euclidean norm. Therefore, for any sequence $\left\{x^{\{k\}}\right\}_{k\in\mathbb{N}} \subset \mathbb{R}^2 : \lim_{k\to\infty}\left\|x^{\{k\}}\right\| = \infty$, we obtain that $f\left(x^{\{k\}}\right) \xrightarrow{k\to\infty} \infty$. Another example: it is easy to verify that the function $f(x) = x_1^2 + 4x_1x_2 + x_2^2$ (which differs from the function of the previous example only by the coefficient at the term x_1x_2) is not an infinitely growing function on $X = \mathbb{R}^2$. Indeed, since $f(x) = (x_1 + 2x_2)^2 - 3x_2^2$, taking any such sequence $\left\{x^{\{k\}}\right\}_{k\in\mathbb{N}} \subset \mathbb{R}^2 : \lim_{k\to\infty}\left\|x^{\{k\}}\right\| = \infty$, so that the first term in the expression $f\left(x^{\{k\}}\right)$ turns to zero, for example, the sequence $x^{\{k\}} = \left(-2x_2^{\{k\}}, x_2^{\{k\}}\right)^T$, where $x_2^{\{k\}} \xrightarrow{k\to\infty} \infty$ (for example, $x_2^{\{k\}} = k$), we get that $\limsup_{k\to\infty} f\left(x^{\{k\}}\right) = \limsup_{k\to\infty}\left(-3\left(x_2^{\{k\}}\right)^2\right) = -\infty$, that is, the mandatory requirement $\limsup_{k\to\infty} f\left(x^{\{k\}}\right) = \infty$ in the definition of an infinite growing function is not met. Therefore, this function is not an infinitely growing function on the set $X = \mathbb{R}^2$. Finally, let us show that our objective function $\sigma^2(x)$ is an infinitely growing function on a feasible set Ω. As the reader remembers, we already proved this fact before Remark 2, but for the proof we used not the definition of an infinitely growing function, but other considerations. The somewhat unusual proof below, directly using the definition of an infinitely growing function, was kindly provided to us by our colleague Ruslans Aleksejevs from the Faculty of Mechanics and Mathematics, Lomonosov Moscow State University (see Acknowledgments). Statement (R. Aleksejevs): if the set $X \subset \mathbb{R}^M$ is compact (in $\mathbb{R}^M$ this is equivalent to the fact that the set X is bounded and closed), then any function $f(x)$ on X is an infinitely growing function. We carry out the proof of this statement by contradiction of the rule of contraries: suppose that there is a sequence $\left\{x^{\{k\}}\right\}_{k\in\mathbb{N}} \subset X$ such that either

- type I: $\lim_{k\to\infty} x^{\{k\}} = x \in \overline{X} \setminus X$, or
- type II: $\lim_{k\to\infty}\left\|x^{\{k\}}\right\| = \infty$,

but in both types the function $f(x)$ is not an infinitely growing function, i.e. in both types of sequence $\left\{x^{\{k\}}\right\}_{k\in\mathbb{N}} \subset X$ there is valid $\limsup_{k\to\infty}\left\|f\left(x^{\{k\}}\right)\right\| \ne \infty$. Since the set X is closed, then $\overline{X} \setminus X = \varnothing$ which means that type I is eliminated, that is, in X such sequences cannot exist. Therefore, the sequence $\left\{x^{\{k\}}\right\}_{k\in\mathbb{N}} \subset X$, that we assume to exist can only be of type II. However, the set X is also limited and, therefore, any sequence from X must be limited, i.e. there is such a constant $Const < \infty$, that $\left\|x^{\{k\}}\right\| \le Const$ for $\forall k \in \mathbb{N}$ [69]. Therefore, type II also is eliminated, because equality $\lim_{k\to\infty}\left\|x^{\{k\}}\right\| = \infty$ means that the

sequence $\left\{x^{\{k\}}\right\}_{k\in\mathbb{N}}$ is an infinitely large sequence, and any infinitely large sequence is unbounded. Thus, we got a contradiction. In other words, we have proved that our assumption that on a compact set $X\subset\mathbb{R}^M$ the function $f(x)$ is not an infinitely growing function turned out to be wrong. The statement is proven. Since our feasible set Ω is a closed simplex and, therefore, a compact set, it immediately follows from the proved statement: our objective function $\sigma^2(x)$ is an infinitely growing function on Ω. EOR

So, we got that the point $x^*\in\mathbb{R}^M_+$, whose coordinates are calculated by formula (8) is a global solution to the optimization problem (5). Taking into account (8) in (2) and (4) gives us the following results, respectively:

$$R^*\overset{def}{\equiv}R(x^*)=\frac{S}{\sum\limits_{j=1}^{M}\frac{1}{p_j^2\sigma_j^2}}\sum_{i:\,p_im_i>c_i}\frac{p_im_i-c_i}{p_i^2\sigma_i^2}+\sum_{i:\,p_im_i\le c_i}\frac{(\hat{p}_im_i-c_i)Q_i}{m_i}+\sum_{i:\,p_im_i>c_i}(\hat{p}_i-p_i)Q_i; \tag{9}$$

$$\left(\sigma^2\right)^*\overset{def}{\equiv}\sigma^2(x^*)=\frac{S^2}{\left(\sum\limits_{i=1}^{M}\frac{1}{p_i^2\sigma_i^2}\right)^2}\sum_{i:\,p_im_i>c_i}\frac{1}{p_i^2\sigma_i^2}+\sum_{i:\,p_im_i\le c_i}\frac{p_i^2\sigma_i^2Q_i^2}{m_i^2}. \tag{10}$$

It is easy to see that if $p_im_i-c_i>0$ for $\forall i=\overline{1,M}$, then formulas (9) and (10) take a more compact form:

$$R^*=\frac{S}{\sum\limits_{j=1}^{M}\frac{1}{p_j^2\sigma_j^2}}\sum_{i=1}^{M}\frac{p_im_i-c_i}{p_i^2\sigma_i^2}+\sum_{i=1}^{M}(\hat{p}_i-p_i)Q_i;$$

$$\left(\sigma^2\right)^*=\frac{S^2}{\sum\limits_{i=1}^{M}\frac{1}{p_i^2\sigma_i^2}}.$$

Let us interpret the obtained formulas (8)-(10) aggregate. If an agricultural enterprise will be seeding an i-th kind of agricultural crop on an x_i^* ha area (according to the calculation formula (8)) from the available cultivation field with an area of S ha, then the total profit of the enterprise from the sale of the harvested crop while fulfilling the terms of the procurement contract in full scope will be R^* euros (formula (9)), which is guaranteed in the sense that it is achieved with the least risks $\left(\sigma^2\right)^*$ (formula (10)) from a possible loss of yield of cultivated M crop species associated with possible changes in hydro-meteorological conditions.

Along with formulas (8)-(10), the following calculation formulas are also useful from a practical point of view:

– the volume (quintal) of the harvested crop of the i-th $\left(i=\overline{1,M}\right)$ kind of agricultural crop species:

$$m_ix_i^*=\begin{cases}\dfrac{Sm_i}{p_i^2\sigma_i^2\sum\limits_{j=1}^{M}\frac{1}{p_j^2\sigma_j^2}} & if\quad p_im_i-c_i>0,\\ Q_i & otherwise;\end{cases} \tag{11}$$

– the total volume (quintal) of the obtained harvest of all M kinds of agricultural crop species:

$$\sum_{i=1}^{M}m_ix_i^*=\sum_{i:\,p_im_i\le c_i}Q_i+\frac{S}{\sum\limits_{j=1}^{M}\frac{1}{p_j^2\sigma_j^2}}\sum_{i:\,p_im_i>c_i}\frac{m_i}{p_i^2\sigma_i^2}. \tag{12}$$

Finally, let us note that if, for some reason, we are not interested in net results $\left(c_i>0,\ \forall i=\overline{1,M}\right)$ (for example, we do not have the corresponding necessary source data), but only in gross results $\left(c_i=0,\ \forall i=\overline{1,M}\right)$, i.e. results without taking into account the total costs of an agricultural enterprise at all stages of the cultivation process in the sowing field of all M kinds of agricultural crops, then all calculation formulas (8)-(12) will be absolutely valid for this case: it is just needed to take $c_i=0,\ \forall i=\overline{1,M}$ in these formulas, resulting in a more compact form (except for formula (10) – it does not change). For the convenience of use for any persons associated with the cultivation of crops, these calculation formulas are given below:

$$x_i^*=\frac{S}{p_i^2\sigma_i^2\sum\limits_{j=1}^{M}\frac{1}{p_j^2\sigma_j^2}}>0,\ \forall i=\overline{1,M};$$

$$R^*=\frac{S}{\sum\limits_{j=1}^{M}\frac{1}{p_j^2\sigma_j^2}}\sum_{i=1}^{M}\frac{m_i}{p_i\sigma_i^2}+\sum_{i=1}^{M}(\hat{p}_i-p_i)Q_i;$$

$$m_ix_i^*=\frac{Sm_i}{p_i^2\sigma_i^2\sum\limits_{j=1}^{M}\frac{1}{p_j^2\sigma_j^2}},\ \forall i=\overline{1,M};$$

$$\sum_{i=1}^{M}m_ix_i^*=\frac{S}{\sum\limits_{j=1}^{M}\frac{1}{p_j^2\sigma_j^2}}\sum_{i=1}^{M}\frac{m_i}{p_i^2\sigma_i^2}.$$

Let us emphasize once again that the total profit R^* of an agricultural enterprise, determined by formula (9), is not the result of solving either the problem of finding the maximum profit, or the problem of finding the maximum harvest, and is the result of solving the problem of minimizing risks from possible losses in yield capacity due to changes in hydro-meteorological conditions. In other

words, the total profit R^* of an agricultural enterprise, which is calculated according to formula (9), is the result of the implementation of the optimal plan for seeding all M kinds of agricultural crops strictly according to the law (8), and this law, in its turn, is the result of the attaining of a single goal – to ensure that the financial/monetary risks from possible losses in crop yields are kept at minimum. In short, the profit function (2) was driven by the risk function (i.e. by objective function) $\sigma^2(x)$ on the grounds of $\sigma^2(x) \to \min$. There could arise a natural question: how much will the obtained results change if, in the study of the same problem, one proceeds not from the consideration of ensuring the minimum risks, but from the consideration of ensuring the maximum of the obtained profit, or from the consideration of ensuring the maximum harvest? The answer to this question will be discussed in the next section.

III. Mathematical Model of the Considered Problem from the Ensuring Maximum Profit or Maximun Harvest Standpoint

This section considers the same agricultural problem that was formulated and formalized in the previous section, but now this problem will be investigated from the point of view of either maximizing the profit from the sale of the harvested crop (goal (B)), or maximizing the harvest of cultivated crop species (target (C)). Let us note that the notation used in this section has the same meaning as in the previous section.

If we consider the agrarian problem from the point of view of the goal (B), then we get the following model, which is a one-criterion linear programming problem:

$$\underset{x\in\Omega}{\text{maximize}}\left[R(x) = \sum_{i=1}^{M} (p_i m_i - c_i) x_i + \sum_{i=1}^{M} (\hat{p}_i - p_i) Q_i \right], \tag{11}$$

where

$$\Omega = \left\{ x \in \mathbb{R}_+^M : \sum_{i=1}^{M} x_i = S,\ m_i x_i \ge Q_i,\ \forall i = \overline{1, M} \right\}.$$

If we consider the agrarian problem from the point of view of the goal (C), then we get the following one-criterion linear programming problem:

$$\underset{x,V\in\Theta}{\text{maximize}}[V], \tag{12}$$

where

$$\Theta \overset{def}{\equiv} \left\{ x \in \mathbb{R}_+^M : \sum_{i=1}^{M} x_i = S,\ \sum_{i=1}^{M} m_i x_i - V \ge 0,\ m_i x_i \ge Q_i,\ \forall i = \overline{1, M} \right\}.$$

In model (12), V is a new variable meaning the unknown cumulative guaranteed harvest of all M kinds of agricultural crops grown that we want to maximize.

Having solved problems (11) and (12) by some analytical or numerical method, for example, simplex-method, generalized reduced gradient method, etc., we find the desired optimal plans $x^* = \arg\max_{x\in\Omega} R(x)$ and $(x^*, V)^* = \arg\max_{x,V\in\Theta}[V]$, respectively. Obviously, the found optimal plan $x^* = \arg\max_{x\in\Omega} R(x)$ also makes it possible to answer the question about the volume (quintal) $m_i x_i^*$ of the harvested crop of an i-th $(i = \overline{1, M})$ kind of agricultural crop species and, consequently, the question about the total volume (quintal) $\sum_{i=1}^{M} m_i x_i^*$ of the harvested crop of all M kinds of agricultural crops; the found optimal plan $(x^*, V)^* = \arg\max_{x,V\in\Theta}[V]$ also makes it possible to answer both the question about the profit $R(x^*)$ gained by an agricultural enterprise, as well as the question about the volume (quintal) $m_i x_i^*$ of the harvested crop of an i-th $(i = \overline{1, M})$ kind of agricultural crop species.

IV. Results and Discussion

A. Numerical Experiment: Implementation of Mathematical Models

In this section, using a specific example, the application of the developed mathematical models (5), (11) and (12) outlined in the previous two sections is illustrated. As an example, we consider the cultivation of common buckwheat, leguminous crops, grain maize, common oat, common millet, bread wheat, bread rye and common barley in the Orel region of the Russian Federation for the time period 2011-2020. All the necessary source data are real data that we have extracted both from open sources [70]-[76], from the source [77] requiring paid access, as well as through the personal communication channels of the first and third co-authors of this work with experts and competence centers in Orel city. The collected source data are averaged over years and by territorial units, real data (i.e. they are data for the Orel region as a whole for each year of the considered period 2011-2020) of the following kinds: (a) yield (quintal/ha) for each of the abovementioned 8 kinds of crops; (b) cultivated area (ha) allocated for each kind of crop; (c) the market price (RUB/quintal) for each crop species; (d) total costs (RUB/ha) for all stages of cultivation of each kind of crop (except for 2020; see Remark 4); (e) the volume (quintal) of the crop of each kind, which was sold to the procurer at the purchase price in accordance with the terms of the concluded procurement contracts; (f) the volume (quintal) of each crop harvested.

Remark 4. Note that we could not get reliable data on the actual net profit of agricultural enterprises in the Orel region gained from the sale of the total harvest of all 8 kinds of crops for the studied period 2011-2020. However, using statistical data of kinds (a)-(f), it was easy to calculate that the total harvest of all 8 kinds of crops grown on sown

fields with a total area of 8530450 ha amounted to 294148550 quintals, from the sale of which the total net profit of agricultural enterprises in the Orel region for the period 2011-2020, taking into account the fulfilment of the conditions of existing procurement contracts, amounted to 4,947,644,993 roubles. It should also be noted that we could not get reliable information on the total costs (RUB/ha) for all stages of growing all 8 kinds of crops for 2020. However, having calculated the trends in the dynamics of total costs for previous years, using the analytical alignment method applying a polynomial of the second degree (parabolic type), we extrapolated the available and obtained data for the year 2020. EOR

Let us get back to the collected source real data and note the following important circumstance. Before using the available source data (except for data types (b) and (f), since these data are not regarded to be the necessary source data for mathematical models (5), (11), (12), on the contrary, for these mathematical models the data types (b) and (f) are the required unknowns) for the particular example under consideration by applying mathematical models (5), (11), (12), we preliminarily carried out, using the Kruskal's minimum spanning tree algorithm [78], hierarchical clustering of yields (quintal/ha) of agricultural crops of 8 species by year with respect to the following hydro-meteorological signs (daily data for the Orel region during 2011-2020): precipitation, air humidity, air temperature, soil temperature, wind speed, solar activity [79], [80]. As a result, we got 4 clusters: a cluster of yields in 2011, 2014, 2015; cluster of yields in 2012, 2017; cluster of yields in 2013, 2016, 2018; cluster of yields in 2019, 2020. Then, carrying out statistical processing of the source data of the (a), (c)-(e) types corresponding to the years of each of the four clusters, all processed source data of (a), (c)-(e) types were distributed over four clusters (obviously, with the same years), for each of which the radius, diameter and centers were calculated. Finally, using the results obtained, we determined: conditional year; conditional yield (quintal/ha) for each of the 8 kinds of crops: $\{m_i\}=\{12.26; 22.41; 68.16; 23.92; 17.85; 37.99; 30.44; 32.07\}$; conditional market price (RUB/quintal) for the crop of each kind: $\{p_i\}=\{1,551.71; 1,856.59; 713.58; 644.88; 758.02; 765.26; 601.35; 822.65\}$; conditional total costs (RUB/ha) for all stages of cultivation lifecycle for each kind of crops: $\{c_i\}=\{8,739.1; 19,029.6; 33,767.2; 14,705.2; 15,583.1; 25,276.2; 11,813.8; 18,850.9\}$; conditional volume (quintal) for each kind of harvested crop species for sale at the purchase price in accordance with procurement contract: $\{Q_i\}=\{161,300; 165,100; 473,850; 54,400; 900; 4,400,000; 24,750; 1,200,000\}$; conditional purchase price: $\{\hat{p}_i\}=\{1,396.54; 1,670.93; 642.22; 580.39; 682.22; 688.73; 541.21; 740.38\}$; biased sample variance of conditional yields: $\{\sigma_i^2\}=\{8.12; 13.98; 80.97; 12.79; 24.97; 67.49; 91.98; 32.04\}$. In other words, we have reduced the original example to an example in which one conditional agricultural enterprise in the Orel region, which owns one conditional plough land with an area of 853,045 ha (= 8,530,450/10, where 10 is the duration of the considered period 2001-2020), intends to seed this field with 8 kinds of agricultural crops in a conditional year. It is required to determine which kinds of crop species and in what proportions an agricultural enterprise should be seeding in order to:

- to harvest a crop with the least financial risks from a possible loss of crop yields associated with possible changes in hydro-meteorological conditions (i.e. strategy (A) is chosen);
- or the net profit from the sale of the harvested crop would be maximum (i.e. strategy (B) is chosen);
- or the total harvest would reach its maximum (i.e. strategy (C) is chosen).

It should be taken into account that an agricultural enterprise is obliged to comply with the terms of the existing procurement contract, regardless of which strategy of the three strategies listed above it will select.

If an agricultural enterprise chooses strategy (A), then a mathematical model (5) is selected, the implementation of which gives the following results (annual):

- Optimal seeding plan (ha): buckwheat: 27,755; leguminous: 19,388; maize: 131,242; oat: 160,694; millet: 50; wheat: 114,114; rye: 184,800; barley: 98,748.
- The resulting harvest volume (quintal): buckwheat: 340,272.56; leguminous: 434,477.62; maize: 8,945,442.2; oat: 3,843,801.3; millet: 900; wheat: 4,335,197; rye: 5,625,324.6; barley: 3,166,841.5.
- Total harvest volume (quintal): 26,692,256.78.
- Net profit (RUB): 3,458,774,455.96.

If an agricultural enterprise chooses strategy (B), then a mathematical model (11) is selected, the implementation of which gives the following results (annual):

- Optimal seeding plan (ha): buckwheat: 13,156.61; leguminous: 676,560.5; maize: 6,952.02; oat: 2,274.25; millet: 50.42; wheat: 115,819.95; rye: 813.07; barley: 37,418.15.
- The resulting harvest volume (quintal): buckwheat: 161,300; leguminous: 15,161,721.38; maize: 473,850; oat: 54,400; millet: 900; wheat: 4,400,000; rye: 24,750; barley: 1,200,000.
- Total harvest volume (quintal): 15,851,271.38.
- Net profit (RUB): 15,711,408,612.

Finally, if an agricultural enterprise chooses strategy (C), then a mathematical model (12) is selected, the implementation of which gives the following results (annual):

- Optimal seeding plan (ha): buckwheat: 13,156.61; leguminous: 7,367.25; maize: 6,761,453; oat: 2,274.25; millet: 50.42; wheat: 115,819.95; rye: 813.07; barley: 37,418.15.

- The resulting harvest volume (quintal): buckwheat: 161,300; leguminous: 165100; maize: 46,086,063.88; oat: 54,400; millet: 900; wheat: 4,400,000; rye: 24,750; barley: 1,200,000.
- Total harvest volume (quintal): 52,092,513.88.
- Net profit (RUB): 10,554,492,045.

Note that if we average over the years the areas where agricultural crops were actually grown in the Orel region, and the harvested crops, we get that

- Completed seeding "plan" (ha): buckwheat: 72,354; leguminous: 50,772; maize: 50,788; oat: 23,358; millet: 564; wheat: 463,348; rye: 4,754; barley: 187,107.
- The resulting harvest volume (quintal): 806,388; leguminous: 1,100,728; maize: 3,158,961; oat: 544,375; millet: 8,946; wheat: 17,712,353; rye: 123,716; barley: 5,959,388.
- Total harvest volume (quintal): 29,414,855.
- Net profit (RUB): 4,947,644,993.

B. Comparative Analysis of the Obtained Numerical Results

Let us compare the harvest volume $H(\text{Model})$ and profit $R(\text{Model})$ of each model with the actual harvest volume $H(\text{Real})$ and profit $R(\text{Real})$, respectively:

$$\begin{cases} H(5) - H(\text{Real}) = -2,722,598.22, \\ R(5) - R(\text{Real}) = -1,488,870,537.04; \end{cases}$$

$$\begin{cases} H(11) - H(\text{Real}) = -13,563,583.62, \\ R(11) - R(\text{Real}) = +10,763,763,619; \end{cases}$$

$$\begin{cases} H(5) - H(\text{Real}) = +22,677,658.88, \\ R(12) - R(\text{Real}) = +5,606,847,052. \end{cases}$$

Let us interpret the obtained comparison results:

- Application of model (5), the essence of which is a cautious strategy, gives ≈9% and ≈30% less harvested crop volume and profit, respectively, in comparison with the actually obtained harvest and profit;
- Application of model (11), the purpose of which is to ensure the maximum profit, gives ≈46% less harvested crop, but increases the profit ≈3.2 times compared to the real situation;
- Application of the model (12), the purpose of which is to obtain the maximum harvested crop, gives ≈1.77 and ≈2.3 times more harvested crop and profit, respectively, in comparison with the actually obtained harvest and profit.

Despite the foregoing, it must be taken into account that the projection of a multidimensional system to which the studied example belongs (different years; different agricultural enterprises with different technical, financial and other resource capabilities; different cultivated fields with different agrochemical, agrophysical characteristics, etc.), onto a one-dimensional system (one year; one agricultural enterprise; one seeding field, equally suitable for growing 8 kinds of field crops; etc.), and then groundless extrapolation of the results of solving a one-dimensional system to a multidimensional system may lead to false conclusions, much different from the true situation, to overly rosy or, conversely, to overly pessimistic forecasts. In the context of the agricultural problem we are considering, at least it should be borne in mind that for the main agrophysical, agrochemical, landscape-ecological, ecological-genetic, biological, etc. characteristics of agricultural land in the Orel region (over 2030 thousand ha, of which the area of plough-land is about 74% [73], [81]-[88]) are not homogeneous – there are more than 240 soil varieties: over 17 thousand ha of agricultural land are subject to water erosion, and about 21% of them are moderately – and strongly eroded; in terms of qualitative composition, about 8% of plough-land has sod-podzol and pale-gray forest soils with a low level of cultivation, which are characterized by high acidity (4÷4.5 pH), low content of organic matter (1÷2.5 %), insufficient amount of mineral nutrients such as nitrogen, phosphorus, potassium, magnesium and calcium; etc. [81], [86]-[88]. All these circumstances must be taken into account. However, in this section, while applying mathematical models (5), (11), (12) to the considered real example, these circumstances were not considered: the reason for this is not the limitations of the proposed mathematical models, not the impossibility or complexity of the mechanism for taking into account the above listed circumstances, and the reason is only that the authors of this work did not have access to reliable information about agrophysical, agrochemical, landscape-ecological, ecological-genetic, biological, etc. characteristics of plough-lands in the Orel region, on which in 2011-2020 the kinds of crop species we are studying were grown.

In conclusion, the author would like to emphasize that it is possible to combine all these three mathematical models (more precisely, three different strategies of these models) in a compromise way into one: then we get one multicriteria optimization model, the solution of which will give us a Pareto-optimal plan, i.e. we get a trade-off decision.

V. Conclusions

This paper investigates the problem of quantitative control of the seeding of the plough-land by agricultural crops in various agro-climatic conditions. The considered problem is studied from the perspective of three strategies: from the seeding planning perspective aiming at minimal risk associated with possible unfavourable agroclimatic conditions (a probabilistic approach is used); from the perspective of obtaining the maximum crops sales profit (a

deterministic approach is used); from the perspective of obtaining the maximum crops harvest. In this work, mathematical models are constructed for each strategy and their respective solutions are found. In addition, in this work, a specific real example is considered, which illustrates the application of the constructed mathematical models. Computer implementation of these models (using both Mathcad software and Microsoft Excel spreadsheet) makes it possible to find the optimal seeding plan for the crops under consideration for each of the three strategies (A)-(C). Finally, a comparative analysis of the found plans of the best seeding is carried out.

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REFERENCES

[1] Latvian Environment, Geology and Meteorology Centre, "Latvijas klimats." [Online]. Available: https://www.meteo.lv/lapas/laiks/latvijas-klimats/latvijas-klimats?id=1199&nid=562 [Accessed: March 14, 2021]

[2] D. Spaar, H. Kleinhempel, and R. Fritzsche, Getreide, mais und futtergräser. Berlin, Germany: Springer-Verlag, 2013.

[3] J. S. Rayfield, K. L. Smith, T. D. Park, and D. B. Croom, Principles of agriculture, food, and natural resources: Applied Agriscience. Tinley Park: Goodheart-Wilcox Publisher, 2015.

[4] S. Clark, Ed., Sustainable agriculture-beyond organic farming. Basel: MDPI AG, 2016.

[5] A. N. Esaulko, V. V. Ageev, and L. S. Gorbatko, Agrochemical survey and monitoring of soil fertility. Stavropol: Stavropol State Agrarian University, 2013.

[6] R. E. Planant, Spatial data analysis in ecology and agriculture using R. Boca Raton: CRC Press, 2018.

[7] A. V. Kilchevsky and L. V. Khotyleva, Eds., Genetic foundations of plant breeding: General plants genetics. Minsk: Belarusian Science, 2008.

[8] A. V. Kilchevsky and L. V. Khotyleva, Eds., Genetic foundations of plant breeding: Private plants genetics. Minsk: Belarusian Science, 2010.

[9] A. N. Yadav, J. Singh, A. A. Rastegari, and N. Yadav, Eds., Plant microbiomes for sustainable agriculture. Cham: Springer Nature, 2020.

[10] E. I. Koshkin and G. G. Guseinov, Ecological physiology of agricultural crops. Moscow: Prospect Publishing, 2020.

[11] A. Nurbekov, A. Kassam, D. Sydyk, Z. Ziyadullaev, I. Jumshudov, H. Muminjanov, D. Feindel, and J. Turok, Practice of conservation agriculture in Azerbaijan, Kazakhstan and Uzbekistan. Ankara, Turkey: Food and Agriculture Organization of the United Nations Publishing, 2016.

[12] A. Nurbekov, A. Musaev, D. Sydyk, Z. Ziyadullaev, and J. Turok. Conservation agriculture in irrigated areas of Azerbaijan, Kazakhstan and Uzbekistan. Beirut: International Centre for Agricultural Research in the Dry Areas, 2015.

[13] Ch. Gienapp, D. Dreger, A. Zaharenko, etc., Cereal crops: growing, harvesting, reworking and using. Moscow: "DLV AgroDelo" Publishing, 2008.

[14] "European Commission. EU prices for selected representative products. Monthly prices for vegetal products." [Online]. Available: https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/farming/documents/market-prices-vegetal-products_en.pdf [Accessed: March 14, 2021]

[15] Ministry of Agriculture of the Republic of Latvia, "Agriculture Annual Reports. Agricultural Report 2019 for 2018." [Online]. Available: https://www.zm.gov.lv/public/files/CMS_Static_Page_Doc/00/00/01/62/36/2019_lauks_gada_zinojums.pdf [Accessed: March 14, 2021]

[16] Latvian Rural Advisory and Training Centre. [Online]. Available: http://new.llkc.lv/ [Accessed: March 14, 2021]

[17] Food and Agriculture Organization of the United Nation, "FAOSTAT: Crops." [Online]. Available: http://www.fao.org/faostat/en/#data/QC [Accessed: March 14, 2021]

[18] Department of Primary Industries and Regional Development. Goverment of Western Australia, "Agriculture and Food: Sowing." [Online]. Available: https://www.agric.wa.gov.au/crops/production-postharvest/sowing [Accessed: March 14, 2021

[19] O. Diekman, H. Heesterbeek, and T. Britton, Mathematical tools for understanding infectious disease dynamics. Princeton: Princeton University Press, 2012.

[20] J. W. Jones, J. M. Antle, B. Basso, et al, "Toward a new generation of agricultural system data, models, and knowledge products: State of agricultural systems science," Agricultural Systems, vol. 155, pp. 269-288, 2017.

[21] J. H. M. Thornley and J. France, Mathematical models in agriculture: quantitative methods for the plant, animal and ecological sciences. Wallingford: CABI Publishing, 2007.

[22] M. A. Vodounon, "Mathematical models can make farmers more efficient," African Technology Forum, vol. 8, no. 1, 5 p., 2017.

[23] P. Mérel and R. E. Howitt, "Theory and application of positive mathematical programming in agriculture and the environment," Annual Review of Resource Economics, vol. 6, pp. 451-470, 2014.

[24] V. A. Pavljushin and N. N. Semenova, Eds., Mathematical modelling in plant protection. St. Petersburg: All-Russian Research Institute of Plant Protection Press, 2014.

[25] Ch. B. S. Teh, Introduction to mathematical modelling of crop growth. Boca Raton: BrownWalker Press, 2006.

[26] P. K. Thornton and G. Hoogenboom, "A computer program to analyze single-season crop model outputs," Agronomy Journal, vol. 86, no. 5, pp. 860-868, 1994.

[27] C. S. Bernard and J. S. Nix, Farm planning and control. Cambridge: Cambridge University Press, 1980.

[28] P. B. R. Hazell, and R. D. Norton, Mathematical programming for economic analysis in agriculture. London: Macmillan Publishing, 1986.

[29] J. Glen, "Mathematical models in farm planning: A survey," Operations Research, vol. 35, pp. 641-666, 1987.

[30] J. France and J. H. M. Thornley, Mathematical models in agriculture: A quantitative approach to problems in agriculture and related sciences. Boston: Butterworths Publishing, 1984.

[31] R. Beneke and R. Winterboer, Linear programming: Application to agriculture. Ames: Iowa State University Press, 1973.

[32] G. E. Dalton, Ed., Study of agricultural systems. London: Applied Science Publishing, 1975.

[33] V. D. Baranov and I. G. Tarakanov, Crops harvest programming. Moscow: Patrice Lumumba Peoples' Friendship University Press, 1990.

[34] A. N. Polevoy. Theory and calculation of the productivity of agricultural crops. Leningrad: GidroMeteoIzdat Publishing, 1988.

[35] A. N. Polevoy. Applied modelling and forecasting of crops productivity. Leningrad: GidroMeteoIzdat Publishing, 1988.

[36] M. K. Kayumov, Programming the productivity of field crops. Moscow: RosAgroPromIzdat Publishing, 1989.

[37] N. I. Mozhaev, N. A. Serikpaev, and G. Zh. Stybaev, Crops harvest programming. Astana: Foliant Publishing, 2013.

[38] V. V. Gritsenko and V.E.Dolgodvorov, Fundamentals of programming crop yields. Moscow: AgroPromIzdat Publishing, 1986.

[39] S. A. Vorobiev, A. N. Kartashev, A. M. Lykov, and I. P. Makarov, Arable farming. Moscow: AgroPromIzdat Publishing, 1991.

[40] J. Baier, V. Cerny, M. Ferik, et al., Harvest formation of main agricultural crops. Moscow: KOLOS Publishing, 1984.

[41] V. A. Dukhovny, S. A. Nerozin, G. V. Stulina, and G. F. Solodkiy, Crops harvest programming: System approach into applied to amelioration. Tashkent: 2015.

[42] M. G. Kendall and A. Stuart, The advanced theory of statistics: Inference and relationship. London: Charles Griffin & Company, Ltd., 1961.

[43] D. R. Cox and E.J.Snell, Applied statistics: Principles and examples. Boca Raton: CRC Press, 2020.

[44] A. S. C. Ehrenberg, Data reduction: Analysis and interpretation of statistical data. New York: John Wiley & Sons, 1975.

[45] A. S. C. Ehrenberg, A Primer in Data Reduction: An Introductory Statistics Textbook. New York: John Wiley & Sons, 2007.

[46] A. N. Shiryaev, Probability. New York: Springer-Verlag, 1996.

[47] B. V. Gnedenko and I. A. Ushakov, Theory of Probability. Boca Raton: CRC Press, 1988.

[48] A. A. Samarskii and A. P. Mikhailov, Principles of mathematical modelling: Ideas, methods, examples. Boca Raton: CRC Press, 2018.

[49] N. N. Moiseev, Selected works: Interdisciplinary studies of global problems. Moscow: Tydex Co, 2003.

[50] N. N. Moiseev, Numerical methods in the theory of optimal systems. Moscow: Nauka Publishing, 1971.

[51] N. N. Moiseev, Mathematical problems of system analysis. Moscow: Nauka Publishing, 1981.

[52] A. N. Bogolyubov. Fundamentals of mathematical modelling. Moscow: Moscow State University Press, 2001.

[53] O. G. Alekseev, Complex application of discrete optimization methods. Moscow: Nauka Publishing, 1987.

[54] B. Ya. Sovetov and S. A. Yakovlev. Modelling of systems. Moscow: Higher School Publishing, 2001.

[55] S. V. Avrutik, Ed., Solving nonlinear programming problems in a deterministic, discrete, and probabilistic setting: Algorithms and programs. Irkutsk: Siberian Power Engineering Institute of the Siberian Branch of the USSR Academy of Sciences Press, 1976.

[56] I. B. Zagaytov and L. P. Yanovsky, Prediction, foresight, forecast in reproduction planning. Voronezh: Voronezh State Agrarian University Press, 2011.

[57] I. B. Zagaytov, L. P. Yanovsky, V. G. Raskin, and S. N. Dementyev, The 'ZONT' method in forecasting fluctuations of natural harvest conditions. Voronezh: Voronezh State Agrarian University Press, 1996.

[58] I. B. Zagaytov and L. S. Vorobyova, Forecast of fluctuations of the natural conditions of agricultural production, and world statistics of harvests. Voronezh: Voronezh State Agrarian University Press, 1998.

[59] E. V. Zakshevskaya, S. V. Kuksin, and I. B. Zagaytov, "The strategy of state regulation of the Russian grain market based on the grain production forecasts," Herald of the Voronezh State Agrarian University, vol. 4, no. 51, pp. 169-178, 2016.

[60] I. B. Zagaytov, Planning and forecasting the development of agricultural-industrial complex. Voronezh: Voronezh State Agrarian University Press, 2004.

[61] Yu. S. Khokhlov, "Stable distributions and their generalizations, structure and limit theorems," Dr.Sc.Math. thesis, Steklov Mathematical Institute of the Russian Academy of Sciences, Moscow, Russia, 1996.

[62] B. V. Gnedenko, Cours of probability thoery. Moscow: Editorial URSS, 2005.

[63] G. A. Holton, Value at risk: Theory and practice. San Diego: Academic Press, 2003.

[64] P. Lévy, "Propriétés asymptotiques des sommes de variables aléatoires indépendantes ou enchaînées," Journal de Mathématiques Pures et Appliquées, vol. 14, no. 4, pp. 347-402, 1935.

[65] H. Cramer, "Über eine eigenschaft der normalen verteilungsfunktion," Mathematische Zeitschrift, vol. 41, no. 1, pp. 405-414, 1936.

[66] R. A. Horn and Ch. R. Johnson, Matrix analysis. Cambridge: Cambridge University Press, 1985.

[67] F. P. Vasiliev, Methods for solving extremal problems. Moscow: Nauka, 1981.

[68] A. G. Sukharev, A. V. Timokhov, and V. V. Fedorov, A course of optimization methods. Moscow: Nauka, 1986.

[69] V. A. Ilyin, V. A. Sadovnichiy, and Bl. H. Sendov, Mathematical analysis: Basic course. Moscow: Lomonosov Moscow State University Press, 1985.

[70] The Unified Interdepartmental Statistical Information System (UniSIS), "Yield of agricultural crops." [Online]. Available: https://www.fedstat.ru/indicator/31533 [Accessed: March 25, 2021]

[71] The Unified Interdepartmental Statistical Information System (UniSIS), "Gross harvest of agricultural crops." [Online]. Available: https://www.fedstat.ru/indicator/30950 [Accessed: March 25, 2021]

[72] Federal State Statistics Service of the Russian Federation, "Official Statistics." [Online]. Available: https://rosstat.gov.ru/ [Accessed: March 25, 2021]

[73] K. E. Laikam, A. V. Bazarov, N. A. Vorobyova, et. al., Eds., Results of the 2016 All-Russian Agricultural Census, Vol. 1: Highlights, Book 2: The main results of for the constituent entities of the Russian Federation. Moscow: "Statistics of Russia" Information and Publishing Centre, 2018.

[74] T. P. Ustinova, N. E. Dmitrieva, L. I. Akimova, M. V. Andreyuk, and M. Yu. Balakhnev, Eds., Orel region in figures, 2011-2016: Brief statistical collection. Orel: Territorial body of the Federal State Statistics Service for the Orel Region, 2017.

[75] O. V. Sidorenko, "Efficiency of grain production in agricultural organizations: factors and priorities of ensuring," All-Russia Research and Trade Journal of Legums and Groat Crops, vol. 4, no 36, pp. 236-14, 2020

[76] Department of Agriculture of the Orel Region, "Department activities." [Online]. Available: http://apk.orel-region.ru/index.php?cont=97 [Accessed: March 14, 2021]

[77] Expert and Analytical Center of Agribusiness, "AB-Center." [Online]. Available: https://ab-centre.ru/ [Accessed: March 25, 2021]

[78] J. B. Kruskal, "On the shortest spanning subtree of a graph and the traveling salesman problem," Proceedings of the American Mathematical Society, vol. 7, no 1, pp. 48-50, 1956.

[79] Hydro-meteorological Research Center of Russian Federation, "Actual weather archive." [Online]. Available: https://meteoinfo.ru/archive-pogoda/russia/oryol-area [Accessed: March 20, 2021]

[80] Research and Production Centre "Map Maker", "GIS Meteo: Weather diary in Orel region." [Online]. Available: https://www.gismeteo.ru/diary/4432/ [Accessed: March 20, 2021]

[81] T. L. Ivaneha and N. A. Studennikov, "The state of soils in the farms of the Orel region and State support measures of soil fertility," Bulletin of Rural Development and Social Policy: Theoretical and Practical Journal, vol. 4, no. 16, pp. 40-43, 2017.

[82] The Unified Interdepartmental Statistical Information System (UniSIS), "Sown area by agricultural crop kinds." [Online]. Available: https://www.fedstat.ru/indicator/37662 [Accessed: March 23, 2021]

[83] The Unified Interdepartmental Statistical Information System (UniSIS), "The structure of sown areas agricultural crop kinds." [Online]. Available: https://www.fedstat.ru/indicator/37661 [Accessed: March 23, 2021]

[84] K. E. Laikam, A. V. Bazarov, N. A. Vorobyova, et. al., Eds., Results of the 2016 All-Russian Agricultural Census, Vol. 4: Sown areas of agricultural crops and areas of perennial plantings and berry crops, Book 1: Areas of crops and perennial plantings. Moscow: "Statistics of Russia" Information and Publishing Centre, 2018.

[85] K. E. Laikam, A. V. Bazarov, N. A. Vorobyova, et. al., Eds., Results of the 2016 All-Russian Agricultural Census, Vol. 4: Sown area of agricultural crops and areas of perennial plantings and berry crops, Book 2: The structure of sown areas. Grouping of census objects according to the size of sown areas. Moscow: "Statistics of Russia" Information and Publishing Centre, 2018.

[86] N. K. Kruzhkov, V. T. Lobkov, and V. V. Napolov, Agroecological foundations of biologization of husbandry in the Central forest-steppe of the European part of Russia. Orel: Orel State Agrarian University Press, 2018.

[87] V. T. Lobkov, Using soil-biological factors in husbandry. Orel: Orel State Agrarian University Press, 2016.

[88] A. A. Tsvyrko, "High efficiency of the grain market in the post-crisis development of agribusiness," Russian Journal of Agricultural and Socio-Economic Sciences, vol. 11, no 11, pp. 1-8, 2012.

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Sources of Uncertainty and Problems of Increasing the Accuracy of Flow Assesment for the Transboundary Narva River

Artem Iukhno
State Hydrological Institute (SHI)
Saint Petersburg, Russia
artem-ardene@mail.ru

Yakovleva Tatiana
State Hydrological Institute (SHI)
Saint Petersburg, Russia
tiya-ilichovo@yandex.ru

Yaroslav Kobets
Tallinn University of Technology (TalTech)
Tallin, Estonia
yaroslav.kobets@taltech.ee

***Abstract* – The water regime of the transboundary Narva River has always been constantly addressed by the hydrometeorological community. For many years, at the interstate level (the Russian Federation and the Republic of Estonia), there has been a discussion about the accuracy of flow assessment and the correctness of the methods applicable for these purposes. In some years, the discrepancies between the estimates of the average annual water discharge obtained by the Estonian and Russian sides reach values of 20-27%. Sustainable, reliable water use requires updating approaches and achieving greater unambiguity in the flow assessment. In the presented article, various sources of uncertainty in the Narva river flow assessment as hydrodynamic, seasonal factors and imperfection of existing methods are considered.**

Keywords – water discharge, flow assessment methods, transboundary river, hydroelectric power station (HEPS)

I. Brief Description of the Characteristics of the Narva River

The Narva river receives its water from Lake Peipsi and flows into the Baltic Sea through the Narva reservoir and hydroelectric power station (HEPS) and has a length of 76.2km, mean annual runoff about 384m^3/s and the catchment area of 56 200 km^2, located within the territories of three countries (Figure 1 [1]). The width is on average 200-300 m, however, downstream of the Narva HEPS up to 390 m, and the greatest width is observed in the upper reaches of the Verkhovsky Island - about 900 m. The prevailing depth is 3-4 m, in places up to 6 m, below the hydroelectric power station - up to 11 m, before the mouth - up to 15 m. The fall of the river is 30 m and is unevenly distributed: 19% (4-7.5 m) of which falls on the Narva HGS and 16% (5 m) on the Omutskie rapids.

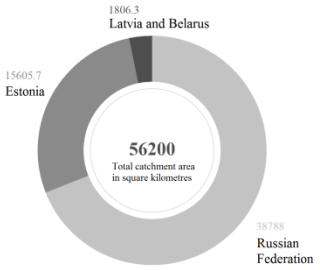

Fig. 1. The Narva catchment area distribution by countries (in square kilometres). [1]

The Narva River, taking on the task of measuring the runoff on the Narva River is initially quite difficult due to the regulation of the flow by the Narva reservoir and the hydroelectric power station on the one hand, and the wind-induced backwater phenomena from the Narva Bay.

II. Hydrological Monitoring in the Study Area

Hydrological monitoring in the catchment area of the Narva river is performed by national hydrometeorological services (and private network gauges) of two countries - the Russian Federation and the Republic of Estonia. The location of the stations is indicated in Figure 2.

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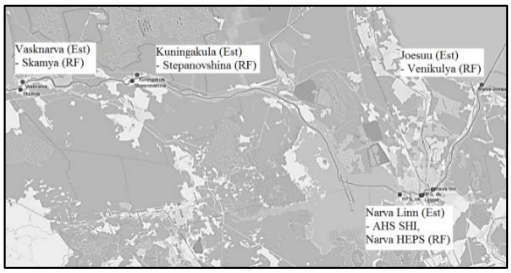

Fig. 2. Hydrological monitoring gauge stations network of Russian Federation and Republic of Estonia.

It should be noted that water discharge is measured only at the gauge station of the Narva river – Narva city (Est) and the Narva river - Narva HEPS (RF), at all other stations only the water level is monitored, Skamya and Venekyulya stations are departmental and access to data from them is quite limited. Nevertheless, potentially the two states have a good unified observation network, confined to important sections of the Narva River.

TABLE 1 RUSSIAN HYDROLOGICAL NETWORK [2]

Gauge station	Period	F, km²	Elevation, mBS	Distance from the mouth, km
Skamya	2003-present	47800	NI	76,2
Stepanovshina	1956 – present	48100	25,35	61,0
Narva HGS	1949 – present	56000	-	16,2
AGS (SHI)	31.07.2019 - present	56000	-	16,04
Venikülya	26.11.2012- present	56200	-0,80	2,05

TABLE 2 ESTONIAN HYDROLOGICAL NETWORK [3]

Gauge station	Period	F, km²	Elevation, mBS[1]/ mEH2000[2]	Distance from the mouth, km
Vasknarva	1902-present	47800	29,00[1]	76,2
Kuningaküla	2011-present	48100	24,68[2]	65,2
Kulgu	1902 – present	55900	25,35[1]	19,5
Narva city	1902-1991 2003 – present	56000	-1,08[1]	14,5
Joesuu	1835 - present	56200	-5,00[1]	0,20

At the same time, the methods used to account the runoff fundamentally differ. Thus, on the Russian side flow assessment of the Narva River is carried out at the Narva hydroelectric generating station (HEPS) by hydraulic calculation (formula 1), summarizing flow through turbines ($Q_{turb.}$) and releases through the ice passes ($Q_{icepass}$), eelway (Q_{eelway}) and shields of the dam (Q_{dam}) [4]:

$$Q = Q_{turb.} + Q_{waste} = Q_{turb.} + Q_{icepass} + Q_{dam} + Q_{eelway} \quad (1)$$

Where:

$$Q_{icepass} = f(H_{HW}, \text{range of openning})$$

$$Q_{dam} = f(H_{HW}, \text{gates rise height})$$

$$Q_{eelway} = 0{,}5 - 1\,\frac{m^3}{s}\,daily$$

And H_{HW} – Narva HEPS headrace water level.

The water flow through the turbines, the assessment of which is the most vulnerable, is recalculated backward depending on the electrical capacity of a hydropower unit (N in kW), gross head of a hydroelectric power station (H in meters) and efficiency factor of a hydropower unit (η in %) values by formula 2 [4]:

$$Q_{turb.} = \frac{1000 * N}{H * \eta * g} \quad (2)$$

Where:

g - free fall acceleration, m/s².

In the Republic of Estonia, a gauge station the Narva river – Narva city (Linn) was opened in 2000, located 14.6 km from the mouth of the river. In the same year, measurements of water flow were started at the stream gauge of the gauge station.

Water level observations were automated in 2002. Hourly data of the water levels for the Narva river – Narva city gauge station is available from 01.01.2003 [3].

Discharges from 2000 to 2005 were measured from a boat.

Prior to 2006, discharges were measured on the «Druzhba» bridge using the «Neva» crane. Discharges were measured using the area velocity method, while the depths in the river cross section were measured using a measuring log line and the «Neva» crane, and the current velocities were measured on pivot points by integration method- using the «IST» mechanical river-based current meter.

Since 2006, water flow measurements have been started using acoustic Doppler current profiler (ADSP). Since 2012, a SonTek HydroBoard II profiler has been used.

Between 2000 and 2014, discharge was measured, covering the full cross section of the Narva River. Since 2015, only partial water discharges have been measured - on the Estonian side to the border line, which is situated approximately in the middle of the river.

Daily discharges for the Narva river – Linn gauge station were calculated only for the period 2003 – 2014.

III. River discharge data comparison and field work results

Average monthly the Narva river – Narva city and Narva river – Narva HGS discharges comparison (m³/s) from 2003 to 2014 (period of the full cross section measures by Estonian side) are given in table 3.

From the table 3 data analysis follows that in the period from 2004 to 2009, the relative discrepancies in the normal annual water discharges according to the data of the Narva river – Narva HEPS and Narva river – Narva city gauge stations do not exceed 6%, and in 2003 and 2010-2014 varied from 16 to 27%, while monthly data can vary by up

to 45% (as in April 2010). For the 2019 and 2020 discrepancies amounts 19.8% and 11.5% resp.

TABLE 3 DISCREPANCY BETWEEN NORMAL ANNUAL DISCHARGES FOR NARVA RIVER – LINN AND NARVA RIVER – NARVA HGS GAUGE STATIONS [5]

Gauge station/ Year	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Narva HEPS	314	469	433	271	341	424
Narva city	392	488	459	287	351	441
Difference, m^3/s	-77	-18	-26	-16	-10	-17
Difference, %	-19.8	-3.8	-5.6	-5.6	-2.8	-3.8
Gauge station/ Year	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Narva HEPS	478	440	431	362	390	300
Narva Linn	495	573	514	435	486	411
Difference, m^3/s	-18	-133	-83	-73	-96	-110
Difference, %	-3.5	-23.2	-16.1	-16.8	-19.8	-26.8

Due to such a high discrepancy in the data obtained by both countries, with allowable errors about 10% for the flow accounting [6], and the importance of further reporting on this parameter (water discharge values) within Helcom (Baltic Marine Environment Protection Commission - Helsinki Commission) [7], additional studies were organized within the ER25 Narva WatMan project «Water Management of the Narva River: harmonization and sustention» [8] aimed at clarification of the flow assessment methodologies and develop common river discharge measurement and calculation methods in order to harmonize the flow estimation to make it comparable for Estonia and Russia.

Within the framework of the project joint river discharge measurements with further data processing and development of harmonized methodologies were performed. From the Russian side of the project the automated hydrological complex (AHC SHI) with a hydrostatic sensor was installed on the right bank of the Narva River, 260 m below the fence enclosing the territory of the Narva HEPS. The choice of this particular location for the sensor predetermined the further improvement of the quality of the Q = f (H) dependences, which cannot be called completely reliable in the gauge station of the city of Narva. During the first 3 periods of the project 53 water discharges (Figures 3-4 for 2019 and 2020 field seasons) in 5 discharge section lines were measured by researchers from the Russian side of the project and 13 – by Estonian researchers, 7 of them can be called a completely synchronous (with an accuracy of 10 minutes, which is important due to fast change of the Narva HEPS operation regimes) (Figure 5). Russian hydrologists used River Ray ADCP from Teledyne Inc. for moving vessel discharge measurements, Estonian - S5 and M9 ADCP from SonTek.

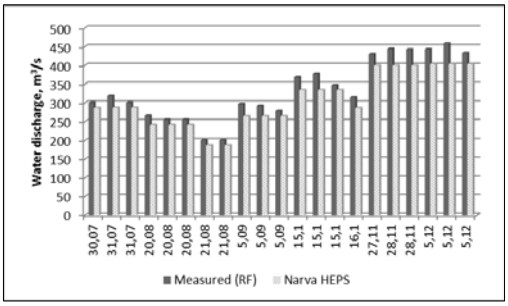

Fig. 3. 2019 field season measured (RF) discharges comparison.

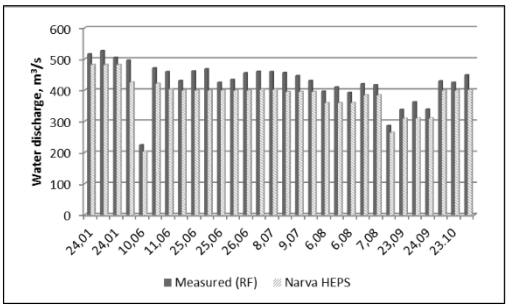

Fig. 4. 2020 field season measured (RF) discharges comparison.

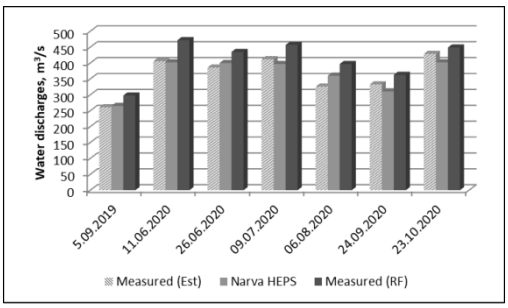

Fig. 5. Synchronous water discharge data.

The discrepancy between the values of water discharge through the hydroelectric units of the Narva HEPS relative to the measurements of the Russian side is on average 10.0%, the Estonian side - 5.87%. In the first case, discrepancy is systematic ($Q_{HEPS} < Q_{meas.RF}$). The maximum discrepancies between the water flow rates measured by the Russian side and those for the hydroelectric power station amounted to 17.3% (June 25, 2020), the Estonian side - 11.1% (November 7, 2019). These indicators show that flow assessment at hydroelectric power plants and direct measurements can be called generally reliable and intercomparable.

IV. Sources of uncertainty and solutions for increasing the accuracy of flow assessment of the Narva river

A. Wind-induced variable backwater effect and influence of HEPS releases waves to the water level regime of the Narva river

Problem: Backwater wind-induced phenomena have a significant impact on the water level regime of the Narva river at a distance of up to 20 km (to the tail water of the Narva HEPS), making rating curves unstable and

unreliable. Discharge/stage points scattering could be caused by the combined effect of the wind and sea "pressure" [9]. This is especially true for the Narva city gauge station rating curve (Figure 6). When the Narva HEPS releases waves are superimposed during waste water discharges period, this effect becomes even more difficult.

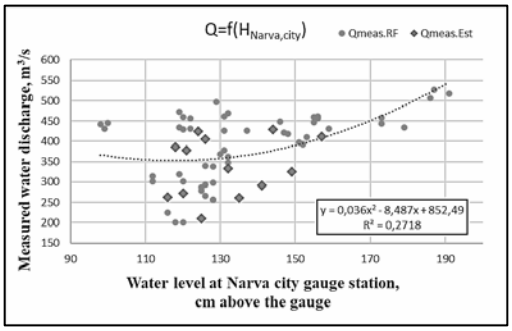

Fig. 6. Rating curve at Narva city gauge station.

Another water level regime influencer is a vertical immobile waves formation during the Narva HEPS releases. When water is released from the HEPS, a hydraulic jump is formed, which subsequently breaks on the downstream spillway apron (15 meters long rubblework). This process affects the level regime of the river, creating standing waves. Unfortunately, the accuracy and discreteness of the data obtained is not enough to unambiguously judge the impact of this factor at the moment.

Solution: Reliable determination of the period of influence of variable backwater. The critical number of the effective component of the wind power W^l (formula 3 [9]), which affects the level regime of the Narva river, should be established:

$$W^l = W * \cos(\beta_w + RV) \qquad (3)$$

Where:

W^l - the effective component of the wind power vector (affects the effective surface);

W- the wind power vector;

β_w - the wind direction in °;

RV- rotation value (The number could be found from the map, as seen in Figure 6)

RV = 90° - 22.3° = 67.7° [9].

All the data on the wind should be processed to derive W^l for every hour using the derived angle value and then intercomparison with the wind speed with further analysis performed. Now this analysis is in deep analytical progress.

Even more important in this field is to choose correct locating for the water level gauge station to install. Consequently, the gauge station in the city of Narva is vulnerable to this phenomenon, and at the temporary gauge station AHC SHI and the level gauge at the Narva river HEPS, this influence, if any, is only insignificant. This is well illustrated by the dependence Q = f (H) for these stations (Figures 6-8).

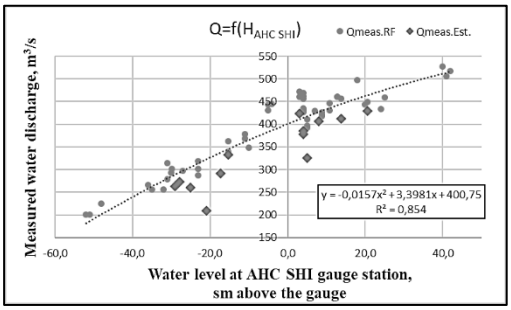

Fig. 7. Rating curve at AHC SHI gauge station.

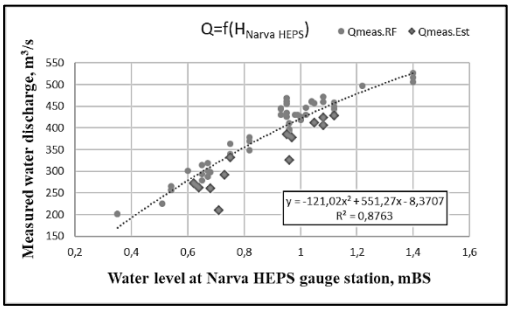

Fig. 8. Rating curve at the Narva river HEPS gauge station.

One of the best solutions to improve these dependences could be the adding of one more variable - the slope of the water surface. And such an attempt was undertaken by both sides of the ER25 project. Thus, Russian researchers obtained the best dependences according to the measurement data in terms of $Q = f(H_{AHC\ SHI}, I_{AHC\ SHI - Narva\ city})$ and $Q = f(H_{Narva\ city}, I_{AHC\ SHI - Narva\ city})$ (Figures 9-10).

The quality of the obtained dependences was assessed according to the characteristics of the series of relative deviations of the measured water discharges $Q_{meas.}$ from those calculated by the equations Q (H_{meas} ; I_{meas}) using formula 4:

$$\tilde{q}_{mes} = \frac{Q_{\text{meas}} - Q(H_{\text{meas}} I_{meas})}{Q(H_{\text{meas}} I_{meas})} \qquad (4)$$

The mean square values $\sigma_{\tilde{q}}$ and mathematical mean value $m_{\tilde{q}}$ of relative regression residuals were estimated.

For the dependence shown in Figure 9 below, the equation is obtained:

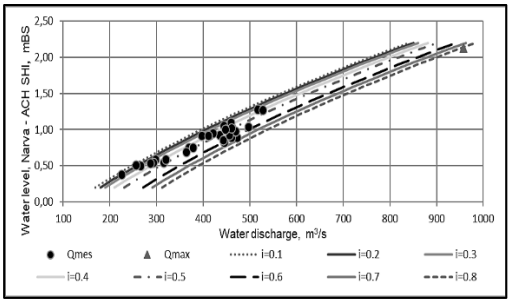

Fig. 9. Slope-and-level curve at AHC SHI gauge station.

$$Q(H_{AHC}, I_{AHC-Narva}) = 100.925 + 230.152H_{AHC} + \\ + 44.047H_{AHC}^2 + 203.682I_{AHC-Narva}$$

With: $m_{\tilde{q}}$= 0.00, $\sigma_{\tilde{q}}$=0.036

For the dependence shown in Figure 10 below, the equation is obtained:

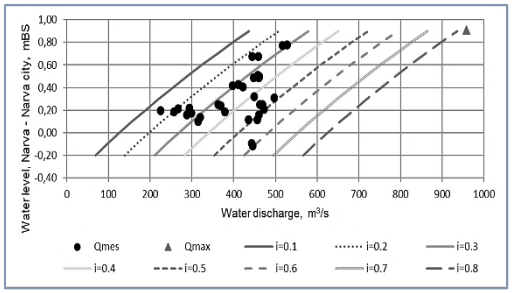

Fig. 10. Slope-and-level curve (RF) at the Narva city gauge station

$$Q(H_{Narva}, I_{AHC-Narva}) = 100.925 + 230.152H_{Narva} + \\ + 44.047H_{Narva}^2 + 203.682I_{AHC-Narva}$$

With: $m_{\tilde{q}}$= 0.00, $\sigma_{\tilde{q}}$=0.048

The equation of dependence Q = f (H_{Narva}, $I_{Narva\ city\text{-}Joesuu}$) is also obtained. The quality of the latter dependence turned out to be significantly worse:

With: $m_{\tilde{q}}$= 0.00, $\sigma_{\tilde{q}}$=0.164

Estonian researchers used WMO techniques [10] and developed dependence (Figure 11):

$$Q_m = 1.6 * 10^{-17}[\frac{(H_{Narva} + 540)^{7.45}}{(H_{Narva} + 11.065)^{0.5}}](H - H_{Joesuu})^{0.5}$$

Using this technique also gives better results compared to using the regular rating curve, but quite limited in the lower part of the curves (which deform in disagreement with the hydraulic physical entity).

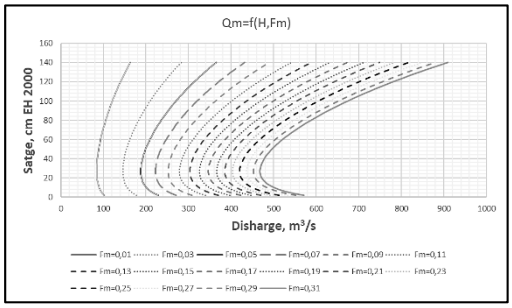

Fig. 11. Slope-and-level curve (Est.) at the Narva city gauge station.

Uncertainties of the flow assessment on the above-described dependencies have several sources:

1 - outside of the range of measuring water discharge and slopes of the water surface, the dependences were obtained by calculation and not confirmed by in-situ data;

2 - random water discharge errors caused by the use of ADSP as a measuring tool (for more details look at subchapter E);

3 - errors in determining the slopes of the water surface at the gauge stations.

The results of the studies performed show that the methodology for assessing water discharge at the Narva city gauge station should be based on reliable observation data of water slopes.

B. Reverse currents during the period of low water levels and discharges through the Narva HEPS

Problem: Water discharge assessment in conditions of negative slopes of the water surface in the section from Narva HEPS to Narva-Joesuu remains as a big problem. This phenomenon is due, as a rule, to the complete or partly shutdown of the operation of the turbines of the hydroelectric power station. At such conditions, reverse currents can occur, and water discharges, in certain surface layers, can be negative. Often, the maximum discrepancies in the data are confined to periods with negative or very low slopes of the water surface

Solution: An analysis of the observational data for slopes for the period from 01.01.2019 to 31.12.2020 (and to 16.06.2020 for the AHC SHI gauge) shows that very low slopes of the water surface are observed in the Narva city gauge station - Narva-Joesuu section (table 4). In 85% of cases, they do not exceed 0.015 ppm.

The uncertainty of the data on the slopes should not exceed 10-15%, which means that the error in determining the difference in water levels at the gauges limiting the sections should not exceed 2-3 cm. Under the existing conditions of the level regime of the Narva River at the estuary, this is a difficult task. Slopes are more reliably determined on the section AHC SHI - Narva city and AHC SHI - Narva-Joesuu, the values of which in most cases have values an order of magnitude higher than on the section Narva city - Narva-Joesuu.

TABLE 4 WATER SURFACE SLOPES DATA ANALYSIS

Section	Section lenght, km	Slop using avg. daily data		Slop using avg. hourly data		Number of hours with negative slopes	
		‰		‰			
		min	max	min	max	2019	2020
AHC - Joesuu	15.84	0.008	0.105	-0.0099	0.122	26	2
AHC - Narva city	1.54	0.01	0.106	-0.151	0.989	119	6
Narva city - Joesuu	14.3	0.00014	0.03526	-0.0173	0.0434	30	107

For a reliable assessment of the slopes of the water surface, it is necessary to organize additional automated water level gauges above and below the Narva city gauge station. At the same time, the issue of determining representative locations for their placement must be resolved. Thus, in the section between Narva HEPS and the Narva city, the AHC should be located outside the zone of possible formation of vertical immobile waves.

C. The problem of the influence of the discreteness of the obtained data on the accuracy of the flow characteristics

Problem: Uncertainties that arise when calculating water discharge at HEPS are largely due to the choice of

the method for calculating the average daily water discharge Fundamentally little differing from one another, methods of determining the average daily water discharge can be used.

The first most accurate way is that for each hour of the day, electrical capacity of a hydropower unit N (kW), gross head of a hydroelectric power station H (m) are determined. According to these data, using the operational characteristic, according to the formula (1), the water discharge for each hour Q_h (m^3/s) is calculating. Average daily discharge is defined as:

$$Q_{avg.daily} = \frac{\sum_1^{24} Q_{hourly\ using\ F.1}}{24} \qquad (5)$$

When using the second method, the average daily electrical capacity of a hydropower unit $N_{avg.daily}$ (or hydraulic units, if the calculation is carried out for all hydraulic turbines at once) is determined by the formula 6:

$$N_{avg.daily} = \frac{Э}{24} \qquad (6)$$

Where:

Э - generation of electricity by a hydraulic unit (all hydraulic units) for a calculated time interval (day), kWh.

Based on the data of individual measurements of the levels of the headwaters and tailwaters, the average working gross head per day is determined. For the obtained average values of capacity N and gross head H according to the flow characteristic of the hydraulic unit, the average daily water discharge through the hydraulic turbines is calculating.

The second method gives satisfactory results only with a uniform round-the-clock load of the hydraulic units.

If during the day the hydraulic unit was stopped or operated in the synchronous compensator mode, then the determination of the average daily load by dividing the output by 24 hours will inevitably lead to a decrease in the average daily load and, consequently, the flow rate. The error will be the greater, the less the hydraulic unit was in operation. For example, when a hydraulic unit is stopped for only 1 hour, the average daily flow rate determined by the second method will be reduced by 1/24 part, or 4%.

For more reliable flow assessment at hydroelectric power plants, it is necessary that under the conditions of daily regulation, only the first method of calculating the average daily water discharge is used and the values of the operating characteristics of the turbines are regularly updated. This is required by the regulatory documents of the Russian Joint-Stock Company of Energy and Electrification [11].

Solution: measure all of the described above characteristics with a discreteness of no more than 1 hour for further calculations of water discharge and use the first daily averaging approach (formula 5).

D. Accuracy of the flow assessment by Narva HEPS

Problem: systematic discrepancies between the measured water discharges and calculated at the HEPS within 10%. In this case, the reasonable question is - which of the estimates is true? The measured ADCP flow discharges have objective errors (subchapter E), and flow assessment at HEPS has always been recognized as the most reliable method in turbulent conditions. In-depth measurements (including pulsation flow velocities measurements) carried out in 1989 by SHI researchers [12] at the headrace revealed only a small (<5%) systematic negative ($Q_{meas.}>Q_{HEPS}$) discrepancy between the water discharges measured by traditional flow metering instruments and an ultrasonic unit and calculated by HEPS. Such a low discrepancies indicate the high quality of flow metering at hydroelectric power plants.

Solution: new calibration of a hydroelectric power plant is an expensive procedure in which Narva HEPS itself cannot be interested, as a water discharge in comparison with electricity generation is not a main value. The accuracy obtained at the moment can be considered high.

E. Moving vessel ADCP as a water discharge instrument

Problem: random errors in water flow measurement by moving-vessel ADCP, two main reasons for which are: (1) the boat's speed exceeding while measuring the current velocities in this section; (2) inaccurate determination of the distance to the left bank when moving the Q-boat; (3) boat displacement due to high turbulence and related inaccuracies in the determination of the cross-section characteristics.

Solution: under these conditions, none of the modern measuring instruments can operate correctly. Accuracy can be increased by using river bank-based immersible ADCP (solution of the first problem). The second and third problems can be solved by good post-processing of the measurement data. To solve the 3rd problems, there are special software solutions described in [13].

CONCLUSION

The problems discussed in this article can be consider as a case study in the field of flow assessment in conditions of turbulence and variable backwater effects at medium and large rivers.

Acknowledgements

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REFERENCES

[1] The Narva river-basin project. The 1st Book "Environmental assessment and key problems of the river basin of the Narva river"

[2] Materials of the USSR State Water Cadastre. "Basic hydrological characteristics" Volume 2. River basins of the Baltic Sea, Ladoga and Onega lakes for 1963-1970 years.

[3] Official web-site of the Estonian Environment Agency [Web-site. Online]. Available: https://www.keskkonnaagentuur.ee/en/hydrology [Accessed March 4, 2021].

[4] The Narva HEPS (Heps-13) operational water flow assessment instruction

[5] Materials of the Water Cadastre of the Russian Federation. "Rivers and lakes of the Russian Federation (resources, regime and water quality)" for the 2003-2020 years.

[6] Russian national technical Code SP 33-101-2003 "Determination of design hydrological performance"

[7] HELCOM Baltic Marine Environment Protection Commission Report, "Nutrient loads to the Baltic Sea from Leningrad Oblast and transboundary rivers". [Web-resource. Online] Available: https://helcom.fi/media/publications/Nutrient-monitoring-in-Leningrad-Oblast_BASE-Project-Final-Report.pdf [Accessed February 26, 2021].

[8] ER25 Narva WatMan project "Water Management of the Narva River: harmonization and sustention" official web-site. [Web-site. Online]. Available: https://www.narvawatman.com/t-ru-ru [Accessed March 5, 2021].

[9] Yaroslav Kobets, "Comparison and analysis of water discharge estimation methods for the Narva river", Master thesis, Tallinn University of Technology, Rep. of Estonia, 2020.

[10] Manual On Stream Gauging, vol. II, Geneva: World Meteorological Organization, 2010, pp. II.1-1-II.3-20.

[11] Russian technical directive document. RD 153-34.2-21.563-00. "Requirements for Metering Wastewater at Hydroelectric Generating Stations"

[12] The State Hydrological Institute-based report on the work to clarify the characteristics of water flow and calibration of culverts of the Narva HPP on topic II.14.3 (1989).

[13] Jongkook Lee, Hongjoon Shin, Jeonghwan Ahn and Changsam Jeong, "Accuracy Improvement of Discharge Measurement with Modification of Distance Made Good Heading", Advances in Meteorology, Vol. s/n, p.1-9, 2016.

[14] Official web-site of the Estonia-Russia Cross Border Cooperation Programme. [Web-site. Online]. Available: https://www.estoniarussia.eu/ [Accessed December 12, 2020].

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Structural Investigation of a High-Chromium Material Used as an External, Working Layer of a Bimetallic Mill Roller

Peter Ivanov
"CENTROMET" JSC
Vratza, Bulgaria
petarv@abv.bg

Ivan Georgiev
Institute of Metal Science, Equipment and Technologies with Centre of Hydroaerodynamics "Acad. A. Balevski"
Bulgarian Academy of Sciences
Sofia, Bulgaria
ivan_georgiev51@abv.bg

Angel Velikov
Institute of Metal Science, Equipment and Technologies with Centre of Hydroaerodynamics "Acad. A. Balevski"
Bulgarian Academy of Sciences
Sofia, Bulgaria
anmabg61@gmail.com

***Abstract* - The bimetallic mill roller has been produced by the method of vertical axis centrifugal casting. The processes, accompanying the formation of the structure of the external (working) layer from high chromium material of the bimetallic roller have been investigated. A mathematical model for the geometry of the working layer was created. By using the MAGMA Soft software package, simulations of the processes of casting and crystallization have been made. A metallographic assessment of the microstructure has been made.**

Keywords* - *metallographic assessment, simulation, thermodynamic state

I. INTRODUCTION

The development of construction worldwide requires the introduction of new characteristics for the materials used in the construction of buildings. This in turn increases the challenges facing the ceramic industry - new raw materials (combinations of different types of clay) are introduced into production, which have radically different abrasive parameters than traditionally used ones.

Mixtures for production of roof- tiles and bricks are ground by machines similar to the one shown in Fig. 1.

Manufacturers of ceramic construction products have to constantly look for a trade-off between durability and peripheral roller speed to maximize the productivity of the technological process.

In the manufacture of rollers for machines for the ceramic industry through stationary (bottom) casting, the currently optimal option has been found by using cast iron with a high chromium content (over 20%) and a hardness exceeding 700 HV, and as a result the rollers made of such material has a significantly higher wear resistance than the rollers made of the widespread chilled, chilled spheroidal-graphite (ductile) and bainitic cast irons, while maintaining the same peripheral speed of 20 m/sec [1,2,3].

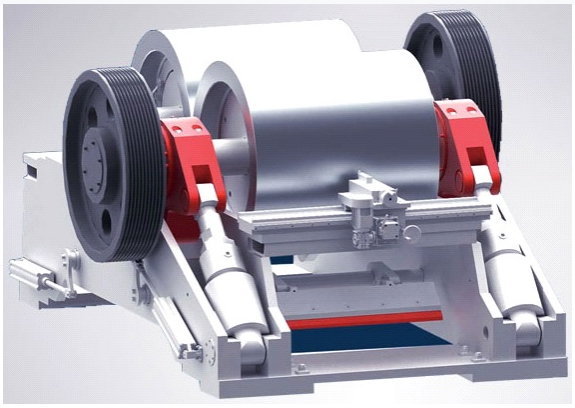

Fig. 1. Grounding machine

The final structure of each cast material is bearer of the physical parameters of the casting. The requirements for the exploitation properties of the casting of a type " roller" are that the external work surface must be of high hardness and wear resistance, while the internal connecting and base surface must be with a good workability and to withstand the heavy workloads. It is these requirements that lead to the idea that the casting must be made of two types material: the external work surface of a durable cast iron (in this case, high Cr content) and internal of a grey cast iron. Having in mind the difficulties at machine

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processing, an additional requirement is set - the external surface to be in shape and dimensions as close as possible to those of the finished roller. This type of two-layer casting can be accomplished by applying the method of vertical axis centrifugal casting by successive pouring of the melt .

II. MATERIALS AND METHODS

In the production of "CENTROMET" JSC, a successfully working prototype of a bimetallic mill roller with a vertical axis of and an external working layer of cast iron with a high content of chromium (over 20%), was produced.

For this purpose a special moulding equipment was constructed and made according to the desired configuration of the casting. The parameters of the casting mould are internal diameter 1,24m and height of the cavity in the mould 0,96m.

The values of the technological parameters for forming the cast were determined, namely: the amount of the melt for the first and second layer, the mass rates of melt pouring into the cavity of the metal mould, the type and thickness of the heat-resistant and thermally insulating coating on the working surfaces of the vertical shape, the pouring temperatures of the two types of melt, the angular velocity of the mould at forming of the casting (300 s^{-1}) , and the pause after the end of pouring of the first layer and the beginning of pouring of the second one (table 1). A mathematical model of the geometry of free surface of the first layer of melt at a constant angular velocity of formation , volume of the melt and pressure of the liquid metal on the solidified layer of the casting, has been created.

TABLE 1 TECHNOLOGICAL PARAMETERS

layers	***m, kg***	***ρ, kg/m³***	***casting/flooding time, s***	***pause of flooding, s***	***number of steps***
1	2100	6835	30	0	40
2	1900	6897	27	280	30
3	1300	6897	23	307	30
4	2676	6897	100	350	30

Specialized software has been developed for calculation the free surfaces at a multilayer system and applying the method of sequential pouring of the melt (Fig.2 and Fig.3).

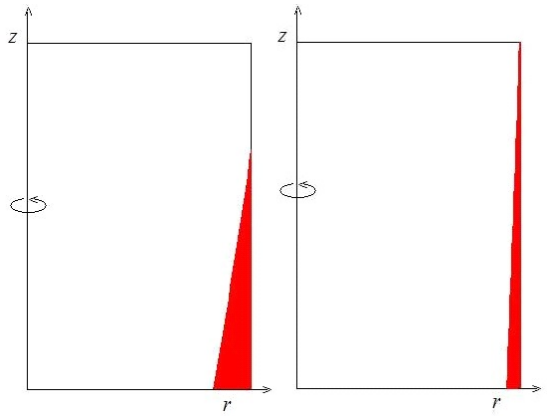


Fig. 2. Calculation the free surfaces at a multilayer system

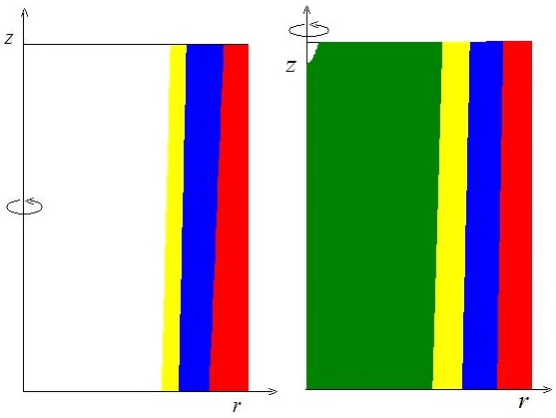
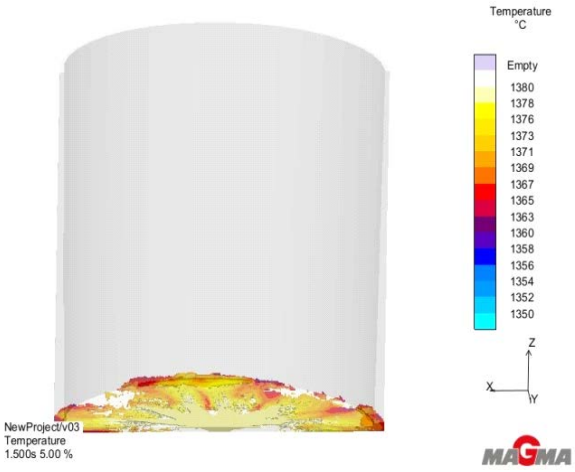


Fig. 3. Calculation the free surfaces at a multilayer system and applying the method of sequential pouring of the melt

III. RESULTS AND DISCUSSION

A. MAGMA Soft simulation

Simulation of crystallization and arising stresses was made by the help of (Fig.4).



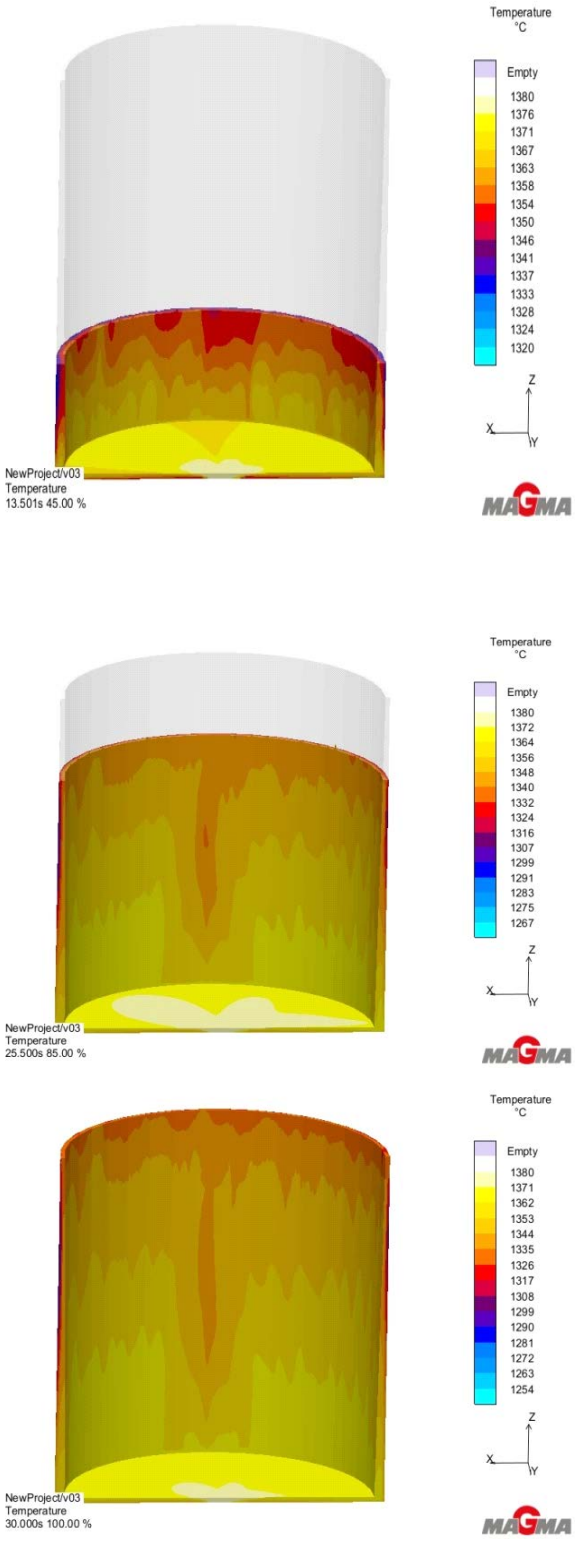


Fig. 4. Simulation of crystallization and arising stresses

Simulation of the thermodynamic state of the system in the different stages of casting was performed.

A simulation of the processes of structure formation was performed.

B. Microstructure of the external (working) layer made of material with high chromium content

From the cast, a sample was cut, which was prepared according to the standard methodology for metallographic observations. The metallographic analysis was performed with an OPTON metallographic microscope.

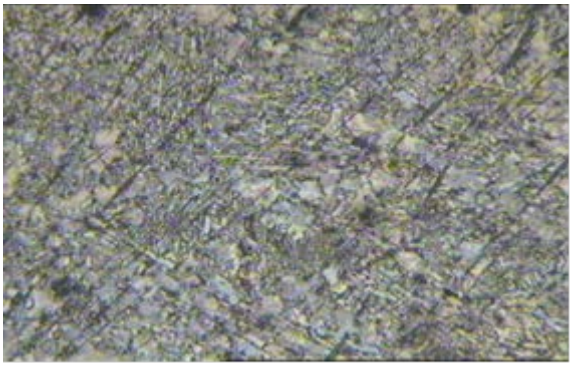


Fig. 5. I layer - Chromium carbides + metal base - x50

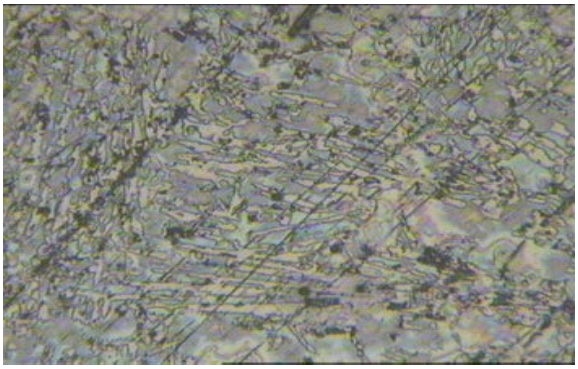


Fig. 6. I layer - Chromium carbides + metal base – x100

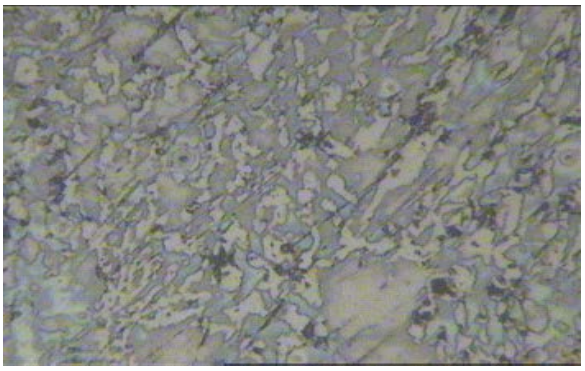


Fig. 7. I layer - Chromium carbides + metal base – x200

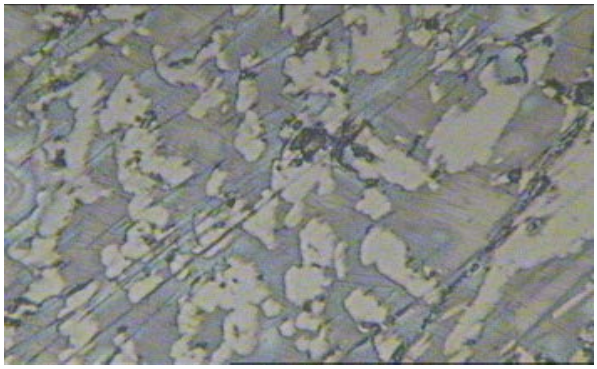


Fig. 8. I layer - Chromium carbides + metal base – x500

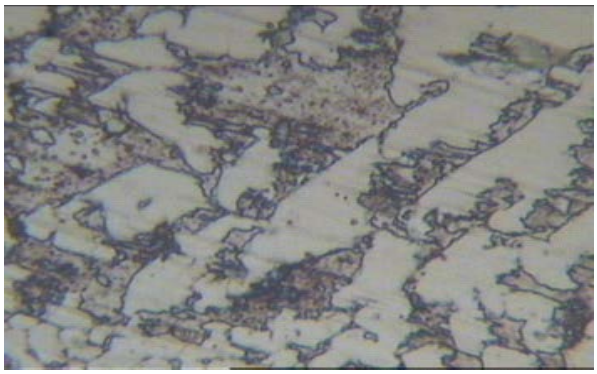


Fig. 9. I layer - Chromium carbides + metal base – x1000

IV. CONCLUSIONS

1. A material with a hardness of 730 ± 30HV was obtained.

2. The structure confirms that the working layer of such material will have the necessary wear resistance, which is the aim of this research.

3. The working properties of the obtained material are confirmed by testing the mill roller in real, production conditions.

ACKNOWLEDGMENTS

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REFERENCES

[1] G.Georgiev and I.Georgiev, "Mathematical modelling and computer simulation of two-component moulding", *Scientific Proceedings*, year XXIII, vol. 2(165), June 2015.

[2] G. Georgiev, I. Georgiev, P.Ivanov, St. Tsenov and I.Panayotov, "Mathematical modelling and optimization of technology for the formation of two-layer casting by the method of centrifugal casting", *XXIV International Scientific and Technical Conference : FOUNDRY 2017 proceedings*, April 5-7, 2017, Pleven, Sofia, Scientific-technical union of mechanical engineering "Industry-4.0", 2018, pp 23-28.

[3] I. Georgiev, S. Valkanov, I. Murdgeva, S. Bushev, "Structures and Phases – Heat Treatment of Centryfugally Cast Alloy ", *XXIV International Scientific and Technical Conference : FOUNDRY 2017 proceedings*, April 5-7, 2017, Pleven, Sofia, Scientific-technical union of mechanical engineering "Industry-4.0", 2018, pp 47-49.

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Primary Assessment of the Degree of Torrefaction of Biomass Agricultural Crops

Serhii Yermakov
Educational and Scientific Laboratory "DAK GPS", State Agrarian and Engineering University in Podilia,
Kamianets-Podilskyi,Ukraine
dakgps@pdatu.edu.ua

Taras Hutsol
Institute of Energy, State Agrarian and Engineering University in Podilia,
Kamianets-Podilskyi,Ukraine
pro-gp@pdatu.edu.ua

Szymon Glowacki
Institute of Mechanical Engineering Warsaw University of Life Sciences – SGGW
Warsaw, Poland
glowackisz@gmail.com

Vadym Hulevskyi
Faculty of Energy and Computer Technology Dmitry Motornyi Tavria State Agrotechnological University,
Melitopol, Ukraine

Viktoriia Pylypenko
Agrobiological Faculty, National University of Life and Environmental Science,
Kyiv, Ukraine

Abstract **- Biomass energy is an important component in the overall structure of renewable energy and has the greatest potential for increasing volumes. However, the peculiarities of the properties of agro-industrial residues are a significant disadvantage of their widespread use. The process of torrefaction allows to bring the characteristics of biofuel as close as possible to thermal coal. Different degree of heat treatment of biomass leads to a product with different heating value. Therefore, it is important to know the optimal mode of torrefaction, which will provide the best energy parameters of biofuels.**

Researches of torrefaction were carried out on the basis of educational and scientific laboratory "DAK GPS" of the State Agrarian and Engineering University in Podilia. The kinetics of the relative mass of different types of biomass at different processing temperatures was considered. The dependence of the degree of torrefaction on the heat treatment temperature is revealed. As shown by studies for most biomaterials of plant origin, we can distinguish the beginning of intensive transformation and its end, after which there is a sharp slowdown in weight loss, and, accordingly, and the energy density of the samples.

Keywords - biomass, torrefaction, thermal treatment, energy intensity biofuels, thermal decomposition, thermogravimetric investigation.

I. INTRODUCTION

The growth rate of the bioenergy sector in the world is constantly growing, which requires the expansion of opportunities and improvement of technologies in existing areas of renewable energy. From this point of view, one of the most promising renewable energy sources is biomass.

The main sources of biomass are agricultural waste and residues (straw, stalks and rods of corn, stalks and husks of sunflower), as well as energy crops (willow, poplar, miscanthus), which are grown specifically for this purpose. Increasing the volume of such raw materials is an agronomic issue, and in the field of improving the energy properties of biomass there are already significant successes, but scientific research is still underway. The main obstacles to the use of plant biomass as a solid fuel are then some of its physical characteristics: low energy density, heterogeneity, particle size, etc. The peculiar chemical-physical properties, which appear as highly variable shape, size, moisture content, density, chemical composition (different proportion and nature of the hemicellulose, cellulose and lignin) and high concentrations of minor species, such as chlorine, alkali metals, nitrogen and sulphur, strongly modify the reactivity of both the starting material and the intermediate products of the decomposition and gasification processes.

The production of standardised upgraded biomass with low cost technology will definitively constitute a

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prerequisite to produce biofuels rather than the use of raw biomass.

One of the ways to obtain a product with such properties from biomass is its torrefaction - the process of "soft" pyrolysis of biomass, heating without access of air, which takes place at temperatures of 200-320 °C and atmospheric pressure for 15-30 minutes.

The torrefaction process is aimed at improving the properties of biomass as a fuel. It consists of a slow heating of biomass in an inert atmosphere to a maximum temperature of 300 °C. The treatment results in a solid uniform product with lower moisture content and higher energy content compared to those in the initial biomass. The solid product retains approximately 70% of the initial weight and 80-90% of the original energy content [1-3].

The following property changes can be achieved by torrefaction:

• Increase of the heating value per weight unit.

• Improved hydrophobic nature. Torrefied biomass is hydrophobic and contains a very low moisture content. It does not egain humidity during storage and therefore it can be stored outside.

• Improved grinding properties [4]

• Increased uniformity and durability. The composition of torrefied biomass is uniform. The production process is controllable. This makes it a suitable solid fuel for combustion and gasification applications.

One of the big advantages of the torrefaction technology is that it converts biomass feedstocks, which generally do not have uniform qualities, into more uniform materials with predictable and controllable fuel properties [5, 6].

Torrefied products can substitute charcoal in various applications.

The thermogravimetric method of analysis is widely used to study the torrefaction process. This method allows not only to obtain quantitative characteristics of the process of term decomposition, but also to describe this process with sufficient accuracy in the form of kinetic equations [7]. Although such studies are the most accurate, they are not so common in the literature [8,9], which is due to the high complexity of the experiments and the need to have the appropriate equipment.

For production conditions it is important first of all qualitative characteristics of the final product which depend on modes of thermal processing of biomass. This is due to the fact that in the process of torrefaction is not only the removal of moisture from the raw material (drying), but also the partial thermal destruction of the organic component of biomass. It is accompanied by changes that can be detected and evaluated not only by complex laboratory analysis, but also by simple measurements, weighing or even organoleptic evaluation of samples. According to the parameters that characterize the level of thermal transformations of biomass can be a change in color, weight loss, change in shape and size, the acquisition of new properties (fragility, hardness, etc.).

II. Materials and Methods

It continues the work on the scientific topic "Agrobiomass of Ukraine as an energy potential of Central and Eastern Europe" (registration number 0119U103056) at the State Agrarian and Engineering University in Podilia, the joint Ukrainian-Polish educational and scientific laboratory "DAK GPS"[10-17]. The main activity of the laboratory is to improve the energy performance of biomass by thermal treatment (torrefaction), which results in torrefied products. Investigations of the primary signs of the state of heat-treated raw materials were carried out on a plant for torrefaction of tape-type biomass with passive interaction with the material. This method minimizes the physical and mechanical effects on the raw material, and the flow of the process allows to get the most homogeneously processed product.

Selected biomass samples using laboratory scales were divided into equal-weight portions of 50-100 g, which were alternately subjected to heat treatment at seven temperature regimes: 180, 200, 220, 240, 260, 280 and 300 °C. The temperature range 180-300 fully meets the conditions of the torrefaction process.

To bring the data to a more traditional form, it is necessary to build thermogravimetric curves in addition to the weight loss curves. To construct the curves, the loss in mass of the substance during heating to high temperatures is determined. The curve of the dependence of mass loss on temperature is plotted in the coordinates of the abscissa - temperature, ordinate - mass loss in grams or percent (Fig. 1). Such a curve called simple or integral shows all the mass loss from the beginning to the end of heating.

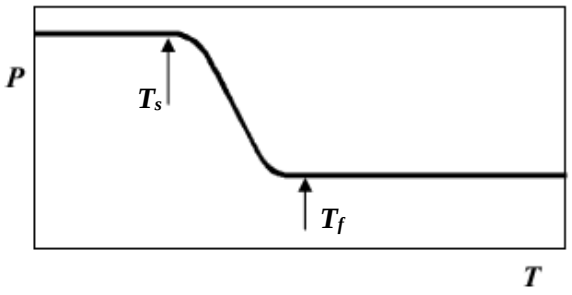

Fig. 1. Characteristics of the thermogravimetric curve in the case of a one-stage reaction

In Fig. 1 shows the characteristics of the curve of mass reduction in the case of a single-stage reaction. For any one-stage non-isometric reaction, you can choose two characteristic points on the thermogravimetric curve: a) the initial decomposition temperature T_s, ie the temperature at which the total change in mass reaches the sensitivity of thermobalances; b) the final temperature T_f, ie the temperature at which the total change in mass reaches a maximum value corresponding to the completion of the reaction. The difference T_f - T_s is called the reaction

interval. These threshold values will determine the start and end modes of torrefaction.

III. RESULTS AND DISCUSSION

Any heat treatment of organic matter is primarily associated with the removal of moisture and thermally unstable elements, as well as with the transformations caused by the action of temperature. The basic classification of the bonds between moisture and material is usually a scheme where all bonds are divided into chemical, physicochemical (adsorption and osmotic) and physico-mechanical (wetting fluid and contained in capillaries). Chemically bound moisture has the highest binding energy to the material and is in a certain quantitative ratio with the dry matter. This moisture can be removed from the wood at temperatures above 180 °C, but the molecular structure of the material will change.

At a temperature of about 190 °C, pyrolysis reactions begin to take place in the surface layers of the wood, the front of which moves into the material as it heats up (Fig. 1). This causes the decomposition of the least heat-resistant components of wood, which is accompanied by the release of monoxides of carbon and nitrogen, chemically bound moisture and other products [18, 19]. The component composition of wood begins to change.

Biomass consists of three main polymer structures: cellulose, lignin and hemicellulose. Hemicellulose begins to decompose at a temperature of about 190 °C, Its decomposition begins with the loss of moisture and the formation of volatile products. It is believed that the main destructive processes take place at a temperature of 220-280 °C, with the maximum rate of weight loss corresponds to 240 °C. [20].

Cellulose and lignin are more heat-resistant, so the decomposition of cellulose occurs in the temperature range 280-370 °C, the maximum speed of this process is at 335 °C. Thermal decomposition of the main part of lignin occurs in the temperature range 200-540 °C, with the maximum rate of weight loss is observed at 420 °C [20]

Thus, the decomposition of certain components will affect the overall weight loss, and in parallel will determine the degree of torrefaction. In order to identify the boundary points of this process, it is necessary to construct appropriate thermogravimetric curves, the analysis of which will allow us to talk about the optimality of processing in a particular mode.

To determine the parameters of weight loss at different processing temperatures, a number of studies were conducted for different types of raw materials. The results of measurements of relative weight loss are shown in Fig.2. And to bring them to the classical form of such studies, integral thermogravimetric curves are shown in Fig.3.

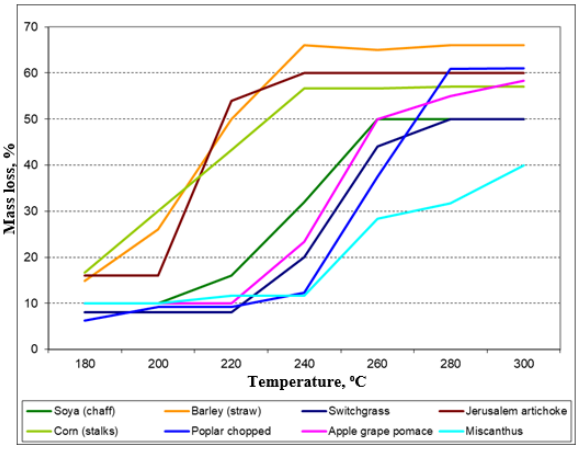

Fig. 2. Relative weight loss of some types of raw materials.

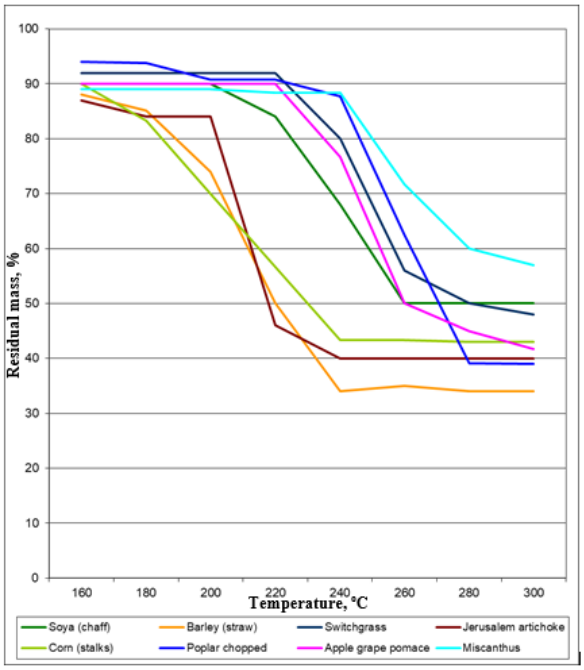

Fig. 3. Integral thermogravimetric curves of torrefaction of different types of biomass.

Analyzing the graphs, we see that the dynamics of changes in weight loss depending on the thermal treatment temperature for different biomass occurs on similar principles. At the initial stage, the curve is almost horizontal, or with a slight slope toward growth, depending on the initial humidity of the material. Obviously, as in the case of thermogravimetric curves (Fig. 2, 3) at this stage is the removal of free moisture and drying of the material. Further, there is a sharp increase in weight loss, which is apparently due to the internal destruction of organic matter of biomass and the removal of volatile substances. After some period of temperature, the curve stabilizes again, which indicates the end of the active phase of thermal transformations. This interval can be considered as temperature modes of torrefaction. As can be seen from the graphs, this interval has different values for different crops, but given that their definition does not require complex

techniques and expensive equipment, this method can be a way of initial assessment of the parameters of torrefaction and the quality of torrefaction).

IV. CONCLUSIONS

Thus, in the process of torrefaction, the potential energy of biomass is compacted by removing moisture from the wood, as well as volatile substances formed during the decomposition of hemicellulose and partial decomposition of cellulose and lignin. As shown by studies for most biomaterials of plant origin, we can distinguish the beginning of intensive transformation and its end, after which there is a sharp slowdown in weight loss, and, accordingly, and the energy density of the samples.

Thus, the control of weight loss and discoloration of biomass subjected to thermal treatment can be parameters of the initial assessment of the modes of torrefaction and the quality of torrefaction. And this in turn will allow without the presence of complex equipment in the production environment with sufficient accuracy to determine the necessary modes of torrefaction.

REFERENCES

[1] J. Arcate, "New process for torrefied wood manufacturing". Bioenergy update. vol. 2, 2000.

[2] A. Knapczyk, S. Francik and M. Jewiarz, "Robust optimization in production engineering-methods and application". E3S Web of Conferences, 2019, pp.132. https://doi.org/10.1051/e3sconf/2019

[3] K. Mudryk, M. Wróbel and M. Jewiarz, "Innovative Production Technology of High Quality Pellets for Power Plants". Renewable Energy Sources: Engineering, Technology, Innovation. Cham, Switzerland: Springer. 2018, pp. 701–712, https://doi.org/10.1007/978-3-319-72371-6_69

[4] B. Arias, C. Pevida and J. Fermoso, Eds., "Influence of torrefaction on the grindability and reactivity of woody biomass", Fuel Processing Technology, 89, 2008, pp. 169-175.

[5] T.G. Bridgeman, J.M. Jones and P-T. Williams, "Torrefaction of reed canary grass, wheat straw and willow to enhance solid fuel qualities and combustion properties", Fuel 87, 2008, pp. 844-856.

[6] P.C.A. Bergman and J.H.A. Kiel, "Torrefaction for biomass upgrading", Published at 14 th European Biomass Conference and Exhibition, Paris, France, ECNRX-05-180, 2005.

[7] P.A. Mar'yandyshev, E.I. Popova, A.A. CHernov and V.K. Lyubov, "Izotermicheskoe issledovanie drevesnogo topliva i ego organicheskih koponentov" (Isothermal study of wood fuel and its organic components). Vestnik Cherepoveckogo gosudarstvennogo universiteta, № 2 (71), 2016, pp. 15-18.

[8] Z.B. Jankovich and M.M. Jankovich "Pyrolysis of pine and beech woodsamples under isothermal experimental conditions". The determination of kinetic Cellulose Chemistry and Technology, 2013, Vol.47, pp. 681-697

[9] A. Knapczyk and S. Francik, "Analysis of research trends in the fieldof mechanical engineering". Tehnologija. Resursi - Environment, Technology, Resources, Vol. 2, 2019, https://doi.org/10.17770/etr2019vol2.4170

[10] S. Yermakov, T. Hutsol and S. Slobodian, Eds., "Possibility of using automation tools for planting of the energy willow cuttings". Renewable Energy Sources: Engineering, Technology, Innovation. 2018. pp. 419-429.

[11] S. Yermakov, K. Mudryk and T. Hutsol, Eds., "The analysis of stochastic processes in unloadingthe energywillow cuttings from the hopper". Environment. Technology. Resources. Rezekne, Latvia. Proceedings of the 12th International Scientific and Practical Conference. Vol. III. 2019. pp. 249-252, https://doi:10.17770/etr2019vol3.4159.

[12] M. Korchak, S. Yermakov and V. Maisus, Eds., "Problems of field contamination when growing energy corn as monoculture". E3S Web of Conferences. Krynica, Poland. 6th International Conference – Renewable Energy Sources. Vol.154, 2020.

[13] V. Ivanyshyn, S. Yermakov and T. Ishchenko, Eds., "Calculation algorithm for the dynamic coefficient of vibro-viscosity and other properties of energy willow cuttings movement in terms of their unloading from the tanker". Proceedings of 6 th International Conference – Renewable Energy Sources, vol. 154, E3S Web of Conferences. 2020. pp. 04005, https://doi:10.1051/e3sconf/202015404005.

[14] S. Yermakov, T. Hutsol, O. Ovcharuk and I. Kolosiuk "Mathematic simulation of cutting unloading from the bunker". Independent journal of management & amp; production (IJM&P). Vol. 10, No. 7, 2019. pp. 758-777.

[15] T. Hutsol, S. Yermakov and Ju. Firman, Eds., "Analysis of technical solutions of planting machines, which can be used in planting energy willow". Renewable Energy Sources: Engineering, Technology, Innovation. 2018. pp. 99-111.

[16] A. Tryhuba, T. Hutsol and S. Glowacki, Eds. "Forecasting Quantitative Risk Indicators of Investors in Projects of Biohydrogen Production from Agricultural Raw Materials". Processes 2021, 9, pp/ 258. https://doi.org/10.3390/pr9020258

[17] A. Tryhuba, T. Hutsol and I. Tryhuba, Eds. "Risk Assessment of Investments in Projects of Production of Raw Materials for Bioethanol". Processes. 2021; 9(1):12, https://doi.org/10.3390/pr9010012

[18] V.M. Zajchenko, V.V. Kosov and V.A. Sinel'shchikov, "Torrefikaciya — sposob uluchsheniya potrebitel'skih harakteristik granulirovannogo topliva iz biomassy". (Torrefaction is a way to improve the consumer characteristics of pelleted biomass fuel.) Energotekhnologii i resursosberezhenie (Energy technologies and resource conservation). 2012. № 5. pp. 37-41.

[19] V.K. Lubov, E.I. Popova and K.S. Bolotova, Eds., "A study of wood torrefaction". Bulletin of the Cherepovets State University, 2017, no. 3 (78), pp. 38-45.

[20] P.A. Mar'yandyshev, A.A. Chernov and M.K. Eseev, Eds., "Issledovanie processa izotermicheskogo razlozheniya drevesiny", Himiya tverdogo topliva. №6, 2016. pp. 51–59.

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Impact of Cultivation Technologies on Soybean Production and Quality

Inga Jansone
dept. of Plant breeding and Agroecology
Institute of Agricultural Resources and Economics
Dižstende, Latvia
inga.jansone@arei.lv

Vita Sterna
dept. of Plant breeding and Agroecology
Institute of Agricultural Resources and Economics
Dižstende, Latvia
vita.sterna@arei.lv

Veneranda Stramkale
dept. of Plant breeding and Agroecology
Institute of Agricultural Resources and Economics
Vilani, Latvia
veneranda.stramkale@arei.lv

Aldis Stramkalis
dept. of Plant breeding and Agroecology
Institute of Agricultural Resources and Economics
Viļani, Latvia
aldis.stramkalis@arei.lv

Arnis Justs
dept. of Plant breeding and Agroecology
Institute of Agricultural Resources and Economics
Viļani, Latvia
arnis.justs@arei.lv

Sanita Zute
dept. of Plant breeding and Agroecology
Institute of Agricultural Resources and Economics
Dižstende, Latvia
sanita.zute@arei.lv

Abstract **- Legumes are considered the second most important food source after cereals. One of high protein legume – soybeans is new species for growing in Latvia. Biochemical composition of soybeans is variable dependent on varieties, and highly affected by environmental factors, including fertilisation and the presence of *Rhizobium* bacteria. Therefore, the present study was conducted to evaluate a chemical composition of soya (*Glycine max* L) differently fertilized and grown in different places in Latvia. In this study was evaluated protein, fat, fibre content and yield of soybean variety 'Laulema' grown at different (F1-F6) fertilisation background in Stende and Vilani. Overall results of a three-year analysis (2018-2020) showed that the protein content of soybean 'Laulema' ranged from 31.0 to 38.9%, values of total crude fat ranged from 19.4 to 22.4, but crude fibre 10.5-13.7%. Significant difference was observed among fertilisation background, year and climatic conditions. Soybean productivity depends to a large extent on climatic conditions. Providing favourable conditions for the development of *Rhizobium* bacteria and the availability of balanced nutrients for plants, soybean yield can reach 2 - 3 t ha^{-2} also in Latvia**

Keywords - soybean, feed, food, fertilisation, protein.

I. INTRODUCTION

Soybean seed is one of the most important protein sources for human and livestock all over the world. In the EU this crop is produced mainly in Italy (33%), Romania (18%), Croatia (14%), Austria, Hungary and France (all 9%) [1].

Safety and sustainability of the food system can be guaranteed by increasing the locally grown raw material and thus allowing to reduce the amount of imported soy products (which is not always GMO free). Soybean adaptation in Baltic / Nordic region is a new opportunity and challenge resulting from climate change. This is evidenced by the increase in soybean sown areas in recent years in Lithuania to 2,100 and in Latvia - 298 ha [2]. The EU green policy emphasizes the efficient and sustainable use of plant genetic resources to reduce soybean imports and increase the self-sufficiency of this crop. Currently, EU countries produce only 5-7% of total soy protein consumption [3]. There is a great demand for GMO-free soy, especially soy that is grown using organic farming practices.

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Several factors influence the chemical composition present in soybean seeds, such as climatic changes, genetics, and soil fertility [4],[5]. Next to the climatic factors, adverse soil conditions are major constraints for soybean production. Board and Kahlon [6] suggested thad recent yield gains in the USA are 50% due to cultivar genetic improvement and 50% to improve cultural practices.

Therefore aim of this study was evaluate different cultivation technologies for improwing soybean yield and quality.

II. MATERIALS AND METHODS

The field trials were set up at the Research Center of the Institute of Agricultural Resources and Economics in Stende (57˚11'20"N, 22˚33'43"E) and at the Latgale Agricultural Research Center Ltd. in Vilani (56˚34'10"N, 26 ˚58'01"E) from 2018 to 2020 year.

Experimental design and treatments. Two soybean cultivars were used in the experiment (corresponding to 000 group by vegetation period) - 'Laulema' (Estonia) and 'Lajma' (Poland). Field experiments were carried out using a block design with four replicates and plot size was 20m^2. The sowing rate used was 50 germinating seeds per m^2, row party distance 25 cm. The seeds were treated with Rhizobium bacterial product HiStick® before sowing.

The soil type and characteristic of experimental fields assumed in table 1.

TABLE 1 THE SOIL TYPE AND CHARACTERISTIC IN EXPERIMENTAL FIELDS IN STENDE AND VIANI

Viļani				
Year	***soil type –loam***			
	pH KCl	***Organic matter, %***	***K_2O mg kg^{-1}***	***P_2O_3 mg kg^{-1}***
2018	6.6	4.1	112	83
2019	6.5	2.6	104	56
2020	6.1	3.5	94	51
Stende				
Year	***soil type – clay sand***			
	pH KCl	***Organic matter, %***	***K_2O mg kg^{-1}***	***P_2O_3 mg kg^{-1}***
2018	5.6	3.1	216	166
2019	6.3	2.8	244	125
2020	7.0	2.2	151	361

The conditions for growing soybeans were more favourable in Vilani - the soils have a significantly higher organic matter content, cly structure and optimal soil acidity. In Stende, soils have a lower content of organic matter, clay sand structure, soil acidity varies from year to year, 2018 - significantly below optimal.

Evaluation of soybeans yield and quality was made at four different fertilization backgrounds: Control - without additional fertilization, PK - basic fertilizer NPK 0- 45-75 (without nitrogen), NPK - basic fertilizer NPK 15-45-75, NPK+N20 - basic fertilizer NPK 15-45-75 and additional fertilizer N20 pure kg ha^{-1}. The fertilizer is applied to the soil before sowing by cultivating the soil.

Climate data

Sum of monthly precipitation showed in table 2. and temperature at both locations during the growing season showed in Figure 1.

TABLE 2 MONTHLY PRECIPITATION DURING THE GROWING SEASON AT THE EXPERIMENTAL SITES FROM 2018 TO 2020

Year	**April**	**May**	**June**	**July**	**August**	**September**
Sites	***2018***					
Stende	47.7	14	28.5	32.6	94.1	52.8
Vilani	27.5	13.6	42.3	35.4	93.0	29.4
	2019					
Stende	8.4	30.7	52.1	117	21.1	50.7
Vilani	0.0	69.8	48.4	92.9	105.4	63.2
	2020					
Stende	20.3	37.3	42.7	60.2	33.9	32.4
Vilani	27.1	84.7	73.1	66.3	60.0	43.3
Long term date						
Stende	36	50	71	89	88	62
Vilani	32	52	75	81	71	62

In all three vegetation seasons, the sum of active temperatures was similar - close to 2000°C, however, for example, in 2018 this amount was reached in 117 days, and in 2019 - in 135 days.

In 2018, soybean productivity was adversely affected by the lack of precipitation (in Stende, the amount of precipitation during the growing season reaches only 157 mm). In 2019, the development of soybeans was limited by temperatures, which were significantly below the norm in several periods of soybean development (especially during germination and flowering). Several later soybean varieties suffered from autumn frosts before ripening.

Very low air temperatures were observed in May of 2020, which hindered the development of soybeans, and some of the soybean seedlings died. The growing season from August to October was favourable for the development of soybeans..

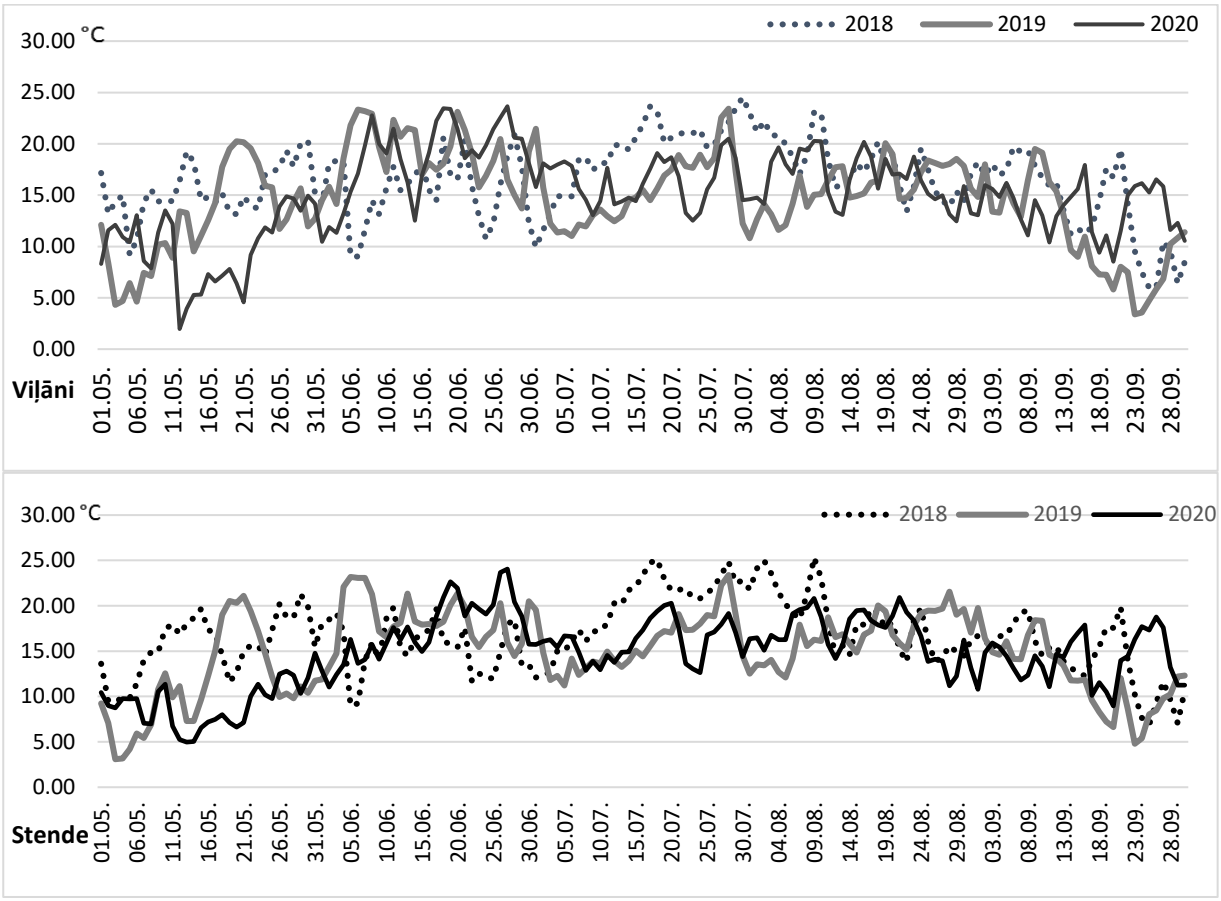

Fig. 1. Mean air temperature (2m above ground level) in the experimental sites.

The vegetation period from sowing to maturity in Stende varied from 108 days ('Laulema', 2018) to 142 days ('Lajma', 2019) and from 120 days ('Laulema', 2018) to 161 days ('Lajma', 2019). The sum of active temperatures of vegetation period assumed from 1889°C ('Laulema', 2018) to 2173°C ('Lajma', 2018) in Stende and from 2003°C ('Laulema', 2020) to 2231°C ('Lajma', 2018) in Vilani. The sum of precipitation from sowing to maturity in Stende varied 156mm ('Laulema', 2018) to 263 mm ('Lajma', 2019) and from 186 mm ('Laulema', 2018) to 426 mm ('Lajma', 2019) in Vilani.

Soybeans was harvested at the GS90-99, using compact gain harvester Wintersteiger, then dried and cleaned using MiniPetkus equipment, determined humidity. Yield was calculated as t ha^{-1} at humidity 14% and 100% purity. Impact of cultivation technologies was evaluated comparing yield, thousand grain weight, number of pods per plant, number of plants per $1m^2$, and chemical composition of seeds based on average values of both cultivars. Number of pods per plant was determined as average of 20 plants from each replications. Indicators of productivity was measured for each of 4 replications and mean value was calculated.

For quality traits 0.5kg soybean seeds was complected. Test weight, protein, fat and fibre of harvested soybeans were made in duplicate. Measures of quality traits are given in dry matter.

The chemical analyses were carried out at the Laboratory of Cereal Technology and Agricultural Chemistry of the Institute of Agricultural Resources and Economics. Collected soybean seed samples of each replicates were dried at 60°C, ground in mill with a 1.0 mm sieve and collected for further analysis. Protein content was determined by the Kjeldahl method, and conversion factor 6.25 was used to convert total nitrogen to crude protein. Fat was extracted with petroleum ether (boiling range of 40–60°C) by the Soxhlet extraction method and determined gravimetrically. Content of fibre was determined by ISO 5498:1981[7].

Statistical analysis. The obtained results were statistically processed using methods of descriptive statistics (sample mean and standard deviation) and factor analysis (Anova: Two-Factor Without Replication and General Linear Model – Univariate) at MS Excell IBM SPSS 20 programs. Statistical significance was declared at $p < 0.05$.

III. Results

The results of study confirms that climatic conditions significantly affected amount and productivity of soya

bean yield. According to most of studies [8], [9], [10] the site conditions primarily the amount and distribution of rainfall significantly modify harvested quantity and quality of soybeans. Among other factors including cultivation technology, these climatic conditions are the most difficult to control and they are greater limiting factors in the maximum yield [8].

Yield of harvested soybeans from all trials in Vilani in different years are showed in Figure 2, but in Stende in Figure 3.

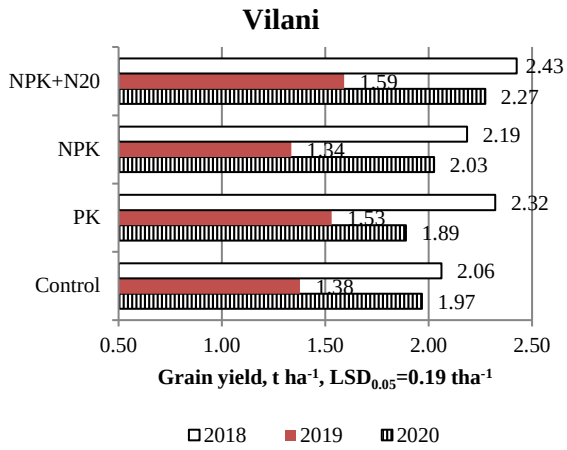

Fig. 2. Yield of soybeans of experimental site Vilani

The soil of experimental fields in Vilani characterized with higher level of organic matter, therefore fertilizers do not have an effect on productivity. Significant increase of soybean yield was obtained from variant PK (2.32 t ha^{-1}) in 2018 year when was relatively few precipitation, providing plants with phosphorus and potassium fertilizers. Additional increase of nitrogen NKP+N20 resulted in the increase of yield (2.32 t ha^{-1}) in comparison with control (2.06 t ha^{-1}) but not with yield from fields where fertilizer background was PK (without additional nitrogen).

Climatic conditions in 2019 – rainfall prior maturity and early autumn frosts - significantly effected harvesting of soybeans and caused additional crop losses, as a result insignificant differences among variants were calculated ($p>0.05$), although trends were the same as in 2018, described above. The results of year 2020 showed significant difference of yield from control fields (1.97 t ha^{-1}) and variant NPK+N20 (2.27 t ha^{-1}).

Summarizing the above – additional nitrogen not always is important in fields with high content of organic matter (as in Vilani). It is important to evaluate provision of other nutrients and additional provision of soil with phosphorus and potassium fertilizers also could give significant increase of yield.

Many field data showed that the total amount of N assimilated in a plant shoot is highly correlated with the soybean seed yield [10], [11]. Morshead et. al. concluded that nitrogen application progressively and significantly increased the yield of soybean up to the N rate of 26.45 kg ha^{-1} where the highest seed yield of soybeans was obtained [11]. Fertilizing with 30 kg N/ha was the optimal rate both in terms of quality and quantity of the yield, as well as economically. The varieties of 'Aligator' and 'Lissabon' proved the best suited to the climate and environment of Głubczyce region, regarding significant LSD coefficients [10].

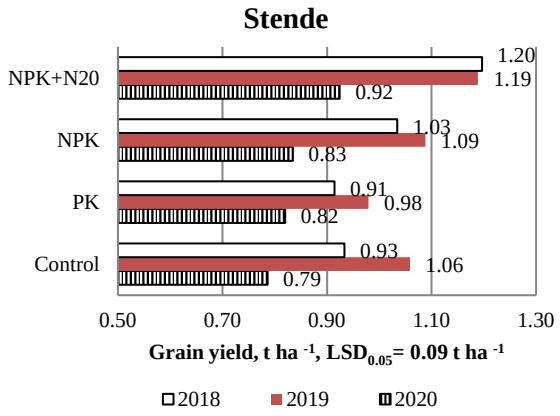

Fig. 3. Yield of soybeans of experimental site Stende

Experimental fields in Stende organized in fields with soil characterized with relatively low content of organic matter, but relatively high content of phosphorus and potassium. Additional nitrogen amount could significantly increase soybean yield especially in less fertile soils [11], [12] and especially in the early stages of plant development when on roots were not developed *Rhizobium* bacteria.

Soil type - clay sand, like in Stende, characterized with relatively low soil pH (5.6 - 6.3). Weakly acidic soil reaction, low soil temperatures or drought were main factors negatively affected operation of *Rhizobium* bacteria. Additional nitrogen in this kind of conditions showed significant impact on soyabean yield. The results of field trials in Stende in 2018 and 2020 showed significantly higher yield of soybeans in variants NPK (1.03 t ha^{-1} in 2018 and 0.83 t ha^{-1} in 2020) and NPK+N20 (1.20 t ha^{-1} in 2018 and 0.92 t ha^{-1} in 2020) in comparison with control where yield was 0.93 t ha^{-1} in 2018 and 0.72 t ha^{-1} in 2020, respectively. Evaluation of yield in 2019 showed significant difference just in variant NPK+N20 (1.19 t ha^{-1}) in comparison with control (1.06 t ha^{-1}).

Summarizing the results in Stende – additional nitrogen dose has been useful if environmental conditions are not favorable for development of nodules on the soybean roots, but additional phosphorus and potassium in soil rich with them was not effected yield significantly.

Since crop productivity indicators determines TGM, number of pods per plant and number of plants per $1m^2$, these parameters of soya bean harvested in this study showed in table 3.

TABLE 3 SOYBEAN PRODUCTIVITY INDICATORS AGAINST THE BACKGROUND OF DIFFERENT FERTILIZER RATES

Indi-cators	Variant s	2018	2019	2020	Mean
TGM, g	***Stende, LD $_{0.05}$=5.9 g***				
	Control	158.3	172.0	162.8	164.7
	PK	156.5	173.7	160.5	164.2
	NPK	165.5	174.1	163.0	167.5
	NPK+N20	171.9	181.1	163.9	172.3
	Vilani, LD $_{0.05}$=5.4 g				
	Control	154.1	159.4	158.2	157.3
	PK	163.1	166.0	157.2	162.1
	NPK	169.2	166.7	162.6	166.1
	NPK+N20	166.1	172.9	166.2	168.4
Number of pods per plant	***Stende, LD $_{0.05}$=6.2 plants***				
	Control	23.1	44.9	20.4	29.5
	PK	24.9	42.9	20.2	29.4
	NPK	26.5	47.3	24.0	32.6
	NPK+N20	26.8	57.1	23.0	35.7
	Vilani, LD $_{0.05}$= 3.7 pods				
	Control	22.6	30.5	27.8	27.0
	PK	21.7	31.3	27.6	26.8
	NPK	21.0	31.6	33.8	28.8
	NPK+N20	23.3	31.0	29.7	28.0
Number of plants per 1 m^2	***Stende, LD $_{0.05}$=2.4 plants***				
	Control	25.8	15.4	30.5	23.9
	PK	28.1	15.4	29.6	24.4
	NPK	26.0	17.3	31.0	24.7
	NPK+N20	25.9	14.4	31.5	23.9
	Vilani, LD $_{0.05}$=5.2 plants				
	Control	49.5	43.5	39.5	44.2
	PK	47.5	46.5	41.5	45.2
	NPK	42.5	41.5	43.0	42.3
	NPK+N20	49.5	44.0	39.5	44.3

The sowing rate was 50 germinating seeds per m^2. Number of productive plants per m^2 among years differed. It was significantly affected by climatic conditions. After sowing in the 2018 prolonged drought, in 2019 and 2020 years prolonged low temperatures of air and soil. The lowest germination was in Stende, for example in 2019 it was 31% of planned – average 15.6 plants per m^2.

Next indicator characterized a productivity of soya beans are number of seeds per pod and 1000 grain weight. An increase of nitrogen amount was not significantly affected number of pods per plant. The number of pods, along with increasing fertilizer rate was increased in Stende from 29.4 (PK) to 35.7 (NPK+N20) and from 26.8 (PK) to 28.8 (NPK) in Vilani, but analysis of variance showed that critical value is higher than differences among variants. This indicator was significantly affected by climatic conditions of year – determination coefficients in Stende R^2 = 92%, in Vilani R^2 = 79%. Variation of years in Stende was average from 21.9 (2018) to 48.1 (2019) and in Vilani from 22.1 (2018) to 31.1 (2019).

Similar data obtained evaluating average number of seeds per pod. It was significantly affected by year (number of seeds per pod in Stende varied from 2.82 to 3.4, determination coefficients in Stende R^2=79%, in Vilani it was lower and varied from 1.38 to1.53, R^2=69%) but differed insignificantly by fertilizer rates ($p>0.05$).

Increase of fertilizer rate was significantly increased TGM of soybeans in both sites. TGM was obtained significantly higher ($p<0.05$) in Vilani in all years in variants NPK (169.2g, 166.7g and 162.6g) and NPK+N20 (166.1g, 172.9g and 166.2g) in comparison with control fields – 154.1g, 159.4g and 158.2g, respectively. This indicator was significantly higher also in 2018 (163.1g) and 2019 (166.0g) in samples of fields where fertilizer rate was PK (without surplus nitrogen) in comparison with control, but then it was insignificantly differed from averages of samples from fields with mentioned fertilizer rates with using of addition nitrogen.

TGM was determined significantly higher – 171.9g, 181.1g and 163.9g in samples of fields with the highest fertilizer rate NPK+N20 (15+20 kg N ha^{-1}) ($p<0.05$) in comparison with control – 158.3g, 172.0g, 162.8g relatively. The average TGM obtained in Stende was higher as obtained in Vilani, but total yield of harvested soybeans was not higher because significantly smaller number of plants per m^2. From other side smaller competition among plants in Stende give higher number of pods per plant and higher TGM, but it was not compensate decrease of yield caused by unsprouting plants.

Our results of variant with higher nitrogen fertilizer rate (NPK+N20) were in line with results of Morshed et.al., who concluded from a pot experiment that nitrogen application progressively and significantly increased the yield of soybean [11]. Bobrecka-Jamro *et. al.* study also observed that plants from the control treatment (without nitrogen fertilizer) were characterized by smallest number of pods and TGW [12].

The chemical composition of soybeans significantly differed ($p<0.05$) among years at both experimental sites, but impact of cultivation technologies was not expressed. The same conclusion was reported by Vollmann et.al., after evaluation of 60 soybean genotypes of early maturity groups – average to high protein content (range 399-476 g kg^{-1}) was found in years with high air temperature and moderate rates of rainfall during the seed filling period, whereas seed protein content was drastically reduced (range 265-347 g kg^{-1}) in seasons of insufficient nitrogen

fixation or higher amount of precipitation during seed filling [13].

Protein content of soybeans harvested at Stende and Vilani showed at figure 4.

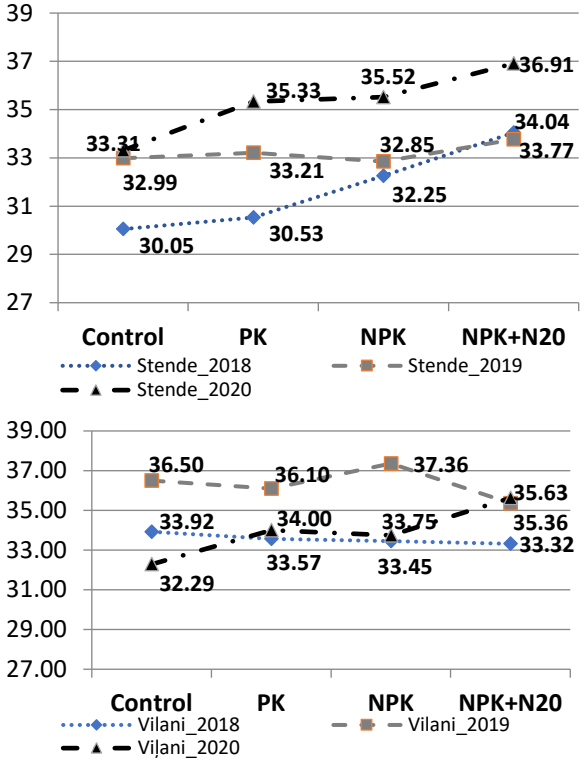

Fig.4. Protein content of soybeans grown in Stende and Vilani from 2018 to 2020 year.

There was observed tendency when protein content of samples from fields with fertilization background NPK+N20 was higher than protein content of soybeans from control group. Significant difference among fertilizer rates was determined at Stende (p-=0.04<0.05), but not in Vilani (p=0.90>0.05). The results in Stende was significant in 2018 when protein content of samples from fields with additional nitrogen dose determined 34.04% in comparison with control 30.05% (p<0.05) (13% higher) and in 2020 when protein content determined 36.9% and 33.31% (p<0.05) (11% higher as control), respectively. Same tendency was observed in Vilani just in 2020 where protein content of control group samples determined 32.29% but protein content of samples from fertilization background NPK +N20 with additional nitrogen (35 kg per ha) – 35.63% (10% higher) and this difference was significant (p<0.05).

These results regarding on protein content was in line with investigation of Bobrecka-Jamro et.al., where concluded that high doses of nitrogen increased the content of total protein in seeds and decreased the content of crude fat, as well as causing a significant decrease in the content of ash and fibre in seeds [12]. Obtained protein content of control group (additional nitrogen N= 0 kg ha^{-1}) soybean seeds in mentioned study was 35.42%, but protein content of experimental groups 36.3% (N= 30 kg ha^{-1}) and 36.96% (N= 60 kg ha^{-1}). Difference of protein content in control group soybeans and experimental group was 2-4% in the study of Bobrecka-Jamro et.al. Morshed et al. concluded that nutrient uptake and protein content in seeds increased with increasing levels of N (up to rate 26.45 kg N ha^{-1})[8]. In contrast, results of Ferreira *et.al.*, showed that fertilization with nitrogen no effect and Valinejad *et.al.* studies finded insignificant effect on total protein and crude fat in soya beans [14], [15]. The results of soybeans fat and fibre content of our study assumed in table 4.

TABLE 4 THE FAT AND FIBRE CONTENT OF SOYBEAN GROWED IN STENDE AND VIANI

Indi-cators	Variant s	2018	2019	2020	Mean
Fat, %	***Stende***				
	Control	23.11	19.08	20.33	20.84
	PK	22.73	18.89	20.64	20.75
	NPK	21.58	19.00	20.97	20.51
	NPK+N20	21.74	16.79	20.92	19.82
	Vilani				
	Control	20.18	17.28	19.14	18.87
	PK	20.71	17.18	18.81	18.90
	NPK	20.36	17.23	19.54	19.04
	NPK+N20	20.48	17.96	19.42	19.29
Fibre, %	***Stende***				
	Control	12.68	10.76	10.83	11.42
	PK	12.59	11.15	10.72	11.49
	NPK	12.93	11.16	10.91	11.67
	NPK+N20	10.87	13.25	10.78	11.63
	Vilani				
	Control	11.52	11.33	9.68	10.85
	PK	11.39	11.54	9.94	10.96
	NPK	11.23	11.64	7.94	10.27
	NPK+N20	11.25	11.75	9.13	10.71

Evaluation of soybean fat and fibre content in both experimental sites showed that there is not significant difference among fertilizer rates in our study. Regarding fat content observed tendency when fat content decrease with increasing nitrogen fertilizer in samples of Stende, similar with results of other studies [8], [12], [13]. This tendency was more pronounced in 2018 year when fat content of control determined 23.11%, but fat content of soybean samples from variant NPK+N20 – 21.74% (6% lower than control). The impact of year on fat content of soybeans was significant (p<0.05) as in Stende, same as in Vilani. Vollmann *et.al.*, reported that fat content in years with high protein content varied from 17.44% to 19.67% ,

but in years with lower protein content from 21.13% to 24.84% [13].

The results of soybeans fibre content significantly differed ($p<0.05$) among years, but did not show any tendency. Average fibre content in Stende for all fertilization backgrounds were 11.42%, 11.49%, 11.67% and 11.63%. There are few reports regarding fibre content of soybean seeds and factors affected it, but data mentioned in USDA data base reported average fibre content 9.7% [16]. Bobrecka-Jamro et.al., reported, that fibre content decreased from 5.81% to 5.49% if nitrogen fertilizer increased from 0 (control) to N=60 kg ha^{-1}) [12]. Our conclusion is that fibre content is much stronger affected by other factors, for example precipitation and humidity of soil than nitrogen content.

IV. CONCLUSIONS

The results of study confirms that soybean productivity is significantly affected by meteorological conditions during the growing season, soil fertility and cultivation technology. Additional nitrogen fertilizers (up to 30 kg N ha^{-1}) significantly affected soybean yield if the soil is low in organic matter content, or environmental conditions are not favourable for the activity of *Rhizobium* bacteria.

The application of additional fertilizer significantly affected the increase of soybean 1000 seed weight (TGM), but did not affect such plant productivity indicators as the number of pods per plant, the number of seeds per pod.

The addition of fertilizer had a positive effect on the protein content of soybeans in less fertile soils, but did not have a significant effect in the soybean trial, which was set up in soils with high organic matter content in Vilani. The fat and fibre content of soybeans was not affected by applied fertilizer rates.

REFERENCES

[1] EIP AGRI report, 2014.

[2] https://www.lad.gov.lv/lv/statistika/platibu-maksajumi/periods-2004-2016/statistikas-dati-par-2019-gadu

[3] Eurostat, 2019.[online] Available : https://ec.europa.eu/eip/agriculture/en/publications/eip-agri-focus-group-protein-crops-final-report

[4] C. M. Grieshop and G. C. Fahey. “Comparison of quality characteristics of soybean meals,” J. Agric. Food Chem., vol. 60, pp. 437–442, 2001.

[5] C. M. Grieshop, C. T. Kadzere., G. M. Clapper, E. A. Flickinger, L. L. Bauer, R. L. Frazier and G. C. Fahey Jr.. “Chemical and nutritional characteristics of United States soybeans and soybean meals,” J. Agric. Food.Chem., vol. 51, pp.7684–7691, 2003.

[6] J. Board and C. S. Kahlon , Soybean yield formation: What controls it and how it can be improved in Soybean Physiology and Biochemistry, pp. 1-36, November, 2011. https://www.researchgate.net/publication/221918892_Soybean_Yield_Formation_What_Controls_It_and_How_It_Can_Be_Improved [Acessed Marth 20, 2021] DOI: 10.5772/17596

[7] ISO 5498:1981. Agricultural food products. Determination of crude fibre content. ISO/TC34, ICS: 67.050, ed.1, 8 pp.

[8] A. M. H. de Avila., J. R. B. Farias, H. S. Pinto, F. G. Pilau, “Clmatic restrictions for maximizing soybean yields,” in A comprehensive Survey of International Soybean Research-Genetics, Physiology, Agronomy and Nitrogen Relationships pp.367-375, January 2, 2013. eBook (PDF) ISBN: 978-953-51-4259-1. https://www.intechopen.com/books/a-comprehensive-survey-of-international-soybean-research-genetics-physiology-agronomy-and-nitrogen-relationships/climatic-restrictions-for-maximizing-soybean-yields [Acessed Marth 20, 2021]

[9] V. Popovic, M.Tatič, V. Sikora, J. Ikanovic, G. Drazic, V.Dukič, B. Mihailovic, V. Filipovic, G.Dozet, L. Jovanovic and P. Stevanovic “Variability of yield and chemical composition in soybean genotypes grown under different agroecological conditions of Serbia” Romanian Agr.Res., No 33, pp. 29-39, 2016.

[10] M. Bednarczyk, I. Pisarek “Sustainable development for soya production based on the field research carried out at the Variety assessment experimental station of Glubczyce in the years 2015-2017”, Economic and Environmental Studies, vol 18, no 4., pp.1219-1234, April 2019, https://www.researchgate.net/publication/332555939 [Acessed Marth 20, 2020] DOI: https://doi.org/10.25167/ees.2018.48.3

[11] R. M. Morshed, M. M. Rahman and M.A.Rahman “Effect of nitrogen on seed yield, protein content and nutrient uptake of soybean (*Glycine max* L.),” J.Agric Rural Dev, vol. 6 (1&2), pp.13-17, June 2008. http://www.banglajol.info/index.php/jard [Accessed Marth 15, 2021] DOI: 10.3329/jard.v6i1.1652

[12] D. Bobrecka-Jamro, W. Jarecki and J. Buczek ”Response of soya bean to different nitrogen fertilization levels,” J. Elem., vol. 23 (2), pp. 559-568, 2018. Ūtiski DOI: 10.5601/jelem.2017.22.3.1435

[13] J.Vollmann, C. N. Fritz, H. Wagentristi and P. Ruckenbauer “Environmental and genetic variation of soybean seed protein content under Central European growing condtions” J. Sci. Food Agric. Vol 80, pp.1300-1306, 2000.

[14] A. S. Ferreira, A.A., Balbinot Jr., F. Werner, C. Zucareli, J. C. Franchini and H.Debiasi “Plant density and mineral nitrogen fertilization influencing yield, yield components and concentration of oil and protein in soybean grains,” Bragantia vol.75 (3), pp. 362-370, June 23, 2016. https://www.scielo.br/scielo.php?script=sci_arttext&pid=S0006-87052016000300362 [Acessed Marth 20, 2021] https://doi.org/10.1590/1678-4499.479

[15] M. Valinejad, S. Vaseghi, and M. Apzali, “Starter nitrogen fertilizer impact on soybean yield and quality,”int. J. Eng. Adv. Tech., vol. 3(1), pp.333-337, October2013. https://www.ijeat.org/wp-content/uploads/papers/v3i1/A2250103113.pdf

[16] USDA (2018) United States Department of Agriculture Food Composition Databases. [Online]. Available: https://www.nal.usda.gov/fnic/databases. [Acessed 30.04.2020.]

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Extrusion Technology of Soybeans and Obtained Product Feeding Effect on Lactating Sows and Their Offsprings Productivity.

Imants Jansons
Department of Plant Breeding and Agroecology
Institute of Agricultural Resources and Economics
Latvia
imants.jansons@arei.lv

Lilija Degola
Institute of Animal Sciences
Latvia University of Life Sciences and Technologies,
Latvia
lilija.degola@llu.lv

Vita Sterna
Department of Plant Breeding and Agroecology
Institute of Agricultural Resources and Economics
Latvia
vita.sterna@arei.lv

Abstract **- The aim of study was to estimate the processing technology of soybeans produced in Latvia and to compare the possibilities of using the obtained soybean cake with imported soybean meal in the feeding of lactating sows and their offspring. From soybeans, which were processed into animal feed, we obtained a product with a high content of protein. The control group of sows and fattening pigs received the imported soybean meal mixed into the compound feed, but the trial groups compound feed was mixed with soybean cake grown and processed in Latvia. Fattening pigs were weighed regularly. Feed consumption was counted and feed conversion was calculated. Was determined meat quality, carcases weight, carcases length. The chemical composition of the manure was analysed. Statistical analysis of data was performed with SAS / STAT 9.22 software package. The inclusion of soy cakes grown and processed in Latvia in lactating sow feed increased sow milk yields traits by 3.9% at 21 day of piglet age. At the end of experiment higher live weight by 3.42% were found in the trial group. Carcass quality indicators and chemical composition of meat did not show significant differences. Was observed a tendency to decrease in manure the content of organic matter in the trial group by 3.25%, decrease levels of total phosphorus and ammonium nitrogen compared to the control group. Using soybean cakes grown and processed in Latvia is possible to develop feed rations that showed similar pig growth results to imported soybean meal.**

Keywords - extrusion technology, soybean cakes, pig feeding.

I. INTRODUCTION

Soybean cultivation in Latvia is a new industry with many challenges. On 2019 in Latvia were declared 320 ha with soybean sowings. In Latvia soybeans is used for oil production, food and livestock feeding. Soybean meal is one of the most important protein sources in animal nutrition and is widely used in pig feeding. It has high biological value and digestibility, and considerable energy content. Unfortunately, in recent years, soybean meal has become so expensive [1], [2], [3], [4]. In Latvia, opportunities are being sought to grow soybeans and process them into feed to provide pigs with high-quality protein and reduce feed costs.

Even though they are a great source of amino acids the impairment of legumes' nutritional value is attributed in part to the presence of different compounds classically known as toxic and/or antinutritional factors, which act as direct or indirect antagonists of nutrient availability [4], [5]. For soybean seeds, trypsin inhibitor and lectin are considered to be the major proteins responsible for poor nutritional value [6], they cannot be consumed raw. The reason for that is because they also consist of anti-nutritional factors such as trypsin inhibitors, urease and lectins that adversely affect digestive efficiency. To reduce the anti-nutritional factors to minimum levels acceptable to your livestock, poultry, pet food or aqua species, the soybean needs to be processed [7].

Trypsin inhibitors are sensitive to denaturation by heat treatment. The vast majority of soybean products used for livestock feeds are heat-treated in order to eliminate any anti-nutritional effects associated with feeding raw soybeans [8].

Extrusion may be used to increase the nutritional value of feed ingredients or diets fed to pigs [9], [10]. The use of

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a combination of heat, pressure, and moisture that is applied to the feed during extrusion may gelatinize starch and improve apparent ileal digestibility of starch in feed ingredients [11] although duration of the extrusion procedure may influence the degree of gelatinization. Extrusion of cereal grains also increased concentrations of metabolizable energy in corn, and sorghum and extrusion may increase the apparent total tract digestibility of gross energy in high fiber diets [10] indicating that the increase in energy digestibility may be caused not only by increased starch digestibility but also by solubilization of fiber[11].

There are many factors that go into extruding soybeans properly such as using the correct temperature, equipment, resources, etc. With proper extrusion of soybeans, there are multiple additional benefits aside from already reducing anti-nutritional factors such as: reducing bitter flavors, denatures protein, frees the oil by rupturing plant cell walls, deactivating fat enzymes to promote stability/ shelf life [7].

Extrusion is a unique processing operation that uses high temperature and pressure over a short time, in which high shear forces are applied to produce a feed product with distinct physical and chemical characteristics. Extrusion as the most efficient energy intensive feed process gives better cooking effect of the starch and proteins than any other commercial processes. [12].

The aim of study was to estimate the processing technology of soybeans produced in Latvia and to compare the possibilities of using the obtained soybean cake with imported soybean meal in the feeding of lactating sows and their offspring.

II. MATERIALS AND METHODS

The study was conducted on a commercial farm at year 2020. In the extrusion process were include complete all soybean processing steps – separation of soybean husks, separation of oil from full-fat soya, extrusion the core of soybean and, cooling of soybean cakes. Soybeans were processed in the working body of the extruder 25 to 40 seconds the pressure generated heat in the extruder barrel was 130-140°C. Production volume was 500 kg per hour.

The estimations of lactating sows were based on the ethical guidelines. Research was carried out in accordance with the Pig welfare requirements Regulations of the Cabinet of Ministers No. 743 [13]. Were completed 2 groups control group and trial group 18 sows in each. In both groups were included pregnant sows inseminated with the following: 8 sows Yorkshire x Landrace (M1), 2 Yorkshire and 4 Landrace inseminated with a Pietren boar and 4 Landrace sows inseminated with a Yorkshire boar.

In the control groups diet was included imported soybean meal mixed with compound feed, and the experimental group included soybean cakes grown and extruded by the local farm. The other feed additives and feed nutrients were the same. In the experiment were calculated and prepared diets for each group similar in crude protein content and to be isoenergetic for metabolizable energy. The rations contained barley, wheat, canola or soybean oil, soybean meal or soybean cakes, salt and trace element vitamin premix, phytase. The compound feeds were fed to the sows in a dry, flowing manner.

The chemical composition of feed was determined with follows methods; protein content was determined (LVS NE ISO 5983-2:2009).Fat content was ISO 6492:1999. Amino acids detected using amino acids analyzer. The identity and quantitative analysis of the amino acids were assessed by comparison with the retention times and peak areas of the standard amino acid mixture. Ash were determined using ISO 5984: 2002/Cor1: 2005, calcium determined using LVS EN ISO 6869:2002, phosphorus using ISO 6491:1998, crude fibre determined using ISO 5498: 1981, methods [14].

During the study, the live weight of the piglets was regularly monitored by weighing on days 1, 21 and when they were weaned from the sows on the day 28, the dead piglets were counted.

In order to evaluate the impact of imported soybean meal and local soybean cake on the growth and quality indicators of fattening pigs, two groups were completed with 40 animals in each. Piglets were taken from sows in a previous experiment. Pigs were regularly weighed at 28, 66, 115, and at the end of the experiment at 168 days of age, when they reached the realization end weight. Feed consumption was counted and feed conversion was calculated.

Carcasses weight was determined and carcasses length from the anterior tip of the aitch bone to the anterior edge of the first rib and next to the vertebra was measured [15]. The lean meat content in the carcases was detected by the ZP two-point method [16]. For quality testing 24 hours after slaughter meat samples were taken from the *musculus longissimus lumborum et thoracis*. Amino acids in meat samples were determined by ISO 13903: 2005, total protein LVS ISO 937: 1978, total fat content LVS ISO 1443: 1973IC-UV, cholesterol, BIOR-T-012-132-2011, moisture LVS ISO 1442: 1997, pH LVS ISO 2917: 2004, tryptophan (total) EU 152/2009, LC-FLD methods[17].

Manure samples were taken from each group included in the study. The chemical composition of manure was determined by standard methods in the laboratory of SIA "Vides audits"; dry matter LVS EN 13040: 2008, total nitrogen LVS EN 13654-1: 2003 / NAC: 2004, total potassium LVS ISO 11466: 1995, LVS ISO 9964-3: 2000, total phosphorus LVS 398: 2002, environmental reaction, pH (KCl) pH LVS ISO 10390: 2006, organic matter content LVS EN 13039: 2012, ammonium nitrogen LVS ISO 5664: 2004 L / NAC: 2007, pH level LVS EN 13037: 2012 methods.

Statistical analysis of data was performed with SAS / STAT 9.22 software package. Standard errors of the means (SEM) was calculated. The results of the study was compared using a t-test. Statistical significances was assessed at ($P < 0.05$).

III. RESULTS AND DISCUSSION

The geographical area of production of the soybeans might affect the protein quality and nutrient content of the corresponding soybean meal. However, the feed compound industry has paid little attention to the influence of the country of origin of the beans on the chemical composition, amino acid (AA) profile and protein quality of the SBM [18].

Comparing the chemical composition of average indicators of soybeans grown and extruded in Latvia with the research results of Ibáñeza et al., where was included the data obtained from 18 published papers from 2002 to 2018 with a total of 1944 samples in which the chemical composition and protein quality of soybean meal of different origins were compared [18], we found that Latvian soy cakes had lower protein, starch calcium and phosphorus contents, higher content of crude fiber than those presented by Ibáñeza et al (Table 1).

Data from the meta-analysis suggest that the chemical composition, protein quality and nutritive value of the soybean meal depend on the country of origin of the bean. Consequently, different matrices should be used in feed formulation for commercial SBM obtained from beans of different origins [18].

TABLE 1 SOYBEAN CAKE AND SOYBEAN MEAL CHEMICAL ANALISES

Traits	Soybean products		
	Full fat soybean cakes	***Soybean cakes***	***Soybean meal****
Protein, %	36.44	42.94	46.4
Fat, %	19.59	7.02	16.6
Ash, %	6.67	7.12	6.51
Crude fiber, %	5.53	5.43	4.65
Starch, %	2.80	3.27	4.34
Calcium, %	0.21	0.22	0.35
Phosphorus, %	0.53	0.57	0.64

*Ibáñeza et al. 2020. [18]

The energy and nutrient requirements of the lactating sows depends on her weight, milk yield and composition, and to a lesser extent, the environmental conditions under which she is housed. [19]. Lactation is the most demanding stage of the reproductive cycle, and milk production requires significantly more energy, which has a negative effect on the short- and long-term productivity of sows and affects the growth and development of piglets. Lactating sows should be full-fed during lactation to obtain maximum milk production, minimize weight loss and improve rebreeding performance [20]. During our study, the growth rates of suckling piglets were similar in both groups (Table 2), were not observed significant differences ($P > 0.05$).

TABLE 2 PIGLET GROWTH AND RETENTION RATES (MEAN ± SEM)

Traits	Groups	
	Control group	***Trial group***
Birth weight, kg	1.42 ± 0.25	1.38 ± 0.29
Live weight in 28 days, kg	6.99 ± 0.60	7.07 ± 1.15
Live weight gain per day, kg	0.198 ± 0.019	0.203± 0.035
Number of live born piglets per litter	10.70 ±1.13	11.00±1.08
Number of piglets per litter at the age of 28 days	9.40±1.77	9.50±1.42
Retention of piglets at the age of 28 days, %.	87.5	86.4

Between live born piglets per litter, number of piglets per litter at the age of 28 days and retention of piglets at the age of 28 days were no significant differences ($P > 0.05$).

The relative milk yield of sows was determined based on litter weight at 21 days old (Table 3). The milk yield of sows depends on the number of piglets and their individual weight at 21 days old, and is correlated directly with litter weight at birth.

TABLE 3 IMPACT OF MILK YIELDS ON PIGLETS AT 21 DAY (MEAN ± SEM)

Traits	Groups	
	Control group	***Trial group***
Number of piglets in a litter at the age of 21 days.	9.60±1.45	9.70±1.41
Piglet live weight at 21 days of age, kg	5.51±0.59	5.70±1.12
Litter weight of piglets at 21 days of age, kg	53.60±10.96	55.7±13.64

The careful management of sow feeding during lactation can markedly increase feed intake and facilitate greater milk yields.

This represents an opportunity commercially to maximize the weaning weights of all piglets, including low birth weight piglets. Furthermore, improved sow lactation nutrition can significantly reduce pre weaning mortality of low birth weight animals. This, in turn, will greatly increase the number of animals weaned, improving output and profitability at farm level [21]. Therefore, by weighing all litters at 21 days of age, sows' milk can be monitored. The inclusion of soy cakes grown and processed in Latvia in lactating sow feed increased sows milk yield traits by 3.9% at 21 day of piglet age. There were no significant differences between groups. That indicated that the sows were fed with similar nutrients, soybean cakes and soybean

meal were equally absorbed in the digestive tract of both groups of sows. Were provided all the nutrients and produced similar amounts of milk. Local soybean cakes and imported soybean had a similar feeding efficiency to suckling piglets.

Feed effects on fattening pig growth traits and carcasses performance was made in this study. The study lasted 140 days from weaning of piglets at 28 days of age until the end of the fattening period. Live weight rates for pigs in both groups at 28, 66, and 115 days of age were similar (Table 4).

TABLE 4 PIGS LIVE WEIGHTS AND LIVE WEIGHT GAINS (MEAN ± SEM)

Traits	Groups	
	Control group	***Trial group***
Live weight at the age of 28 days, kg	9.50±0.14	9.10±0.15
Live weight at the age of 66 days, kg	27.05±0.57	27.58±0.55
Live weight at the age of 115 days,kg	64.46±1.15	64.94±1.25
Live weight at the age of 168 days, kg	100.95±1.95	104.40±2.33
Live weight gain per day for the period from 28 to 66 days of age, kg	0.48±0.02	0.47±0.02
Live weight gain per day for the period from 66 to 115 days of age, kg	0.76±0.03	0.76±0.03
Live weight gain per day for the period from 115 to 168 days of age, kg	0.69±0.04	0.70±0.04
Live weight gain per day for the period from 28 to 168 days of age, kg	0.66±0.04	0.68±0.02
Live weight gain, kg	92.28±2.36	94.92±2.02

The final weight of pigs at the trial group was 104.4 kg, which was 3.4% higher than the control group pigs but it is not significant difference (P > 0.05) between live weights in pigs groups.

Live weight gain per day for the period from 28 to 66 days, 67 to 115 days, and 116 to 168 days were similar between groups and showed no significant differences (P > 0.05) Throughout the fattening period from the age of 28 days until the end of the fattening period at the age of 168 days, was found 3.42% higher live weight of the pigs in the trial group. No significant differences (P > 0.05) were found between live weight gains in pigs groups.

The feed consumption of fattening pigs, which were fed with soy cakes bred and processed in Latvia, was 3.48% lower compared to the control group (Table 5). On average, one animal from the trial group consumed 70 grams less feed per day than the control group of pigs.

TABLE 5 FEED CONSUMPTION AND CONVERSION

Traits	Groups	
	Control group	***Trial group***
Feed consumption per animal, kg	314.9	304.3
Feed consumption per day, kg	2.24	2.17
Feed conversion kg, kg	3.41	3.21

Accordingly, feed conversion, feed consumed per kg of live weight gain in the trial group was by 200 grams or 5.87% better than in the control group of pigs.

The carcass weight of the trial group pigs was on average 2.57 kg or 3.3% higher than the control group pigs (Table 6). The lean meat content and carcases length were similar between the groups. Carcases quality indicators did not show significant differences (P > 0.05) between the groups of imported and locally produced soy products.

When evaluating the results of chemical analyzes of muscle tissue, the observed amino acid content was similar, significant differences were not observed between the groups. Content of all determined amino acids was slightly higher in the samples of the trial group. The amount of intramuscular fat in the muscle tissue of the trial group of pigs was 4.15%, which was 2.6% lower than in the muscle tissue of the control group of pigs. The cholesterol content in the muscle tissue of the experimental group pigs was 16.9% lower. The pH of the muscle tissue was similar.

Feeding fattening pigs, with feed were included soybeans cakes grown and processed in Latvia, was observed a tendency to decrease the organic matter content in the trial group by 3.25%, (Table 7) as well as lower levels of total phosphorus, ammonium nitrogen (N / NH4) in manure compared to the control group.

TABLE 6 PIGS CARCASES TRAITS AND CHEMICAL COMPOSITION OF MEAT (MEAN ± SEM)

Traits	Groups	
	Control group	***Trial group***
Carcass weight, kg	74.57±1.56	77.14±1.85
Lean meat content,%	61.30±0.18	60.82±0.19
Carcass length from the first rib, cm	80.50±0.74	80.80±0.85
Hydroxyproline <0.05 (LOQ) g 100 g^{-1};	<0.05	<0.05
Alanine, g 100 g^{-1}	1.26	1.30
Arginine, g 100 g^{-1}	1.38	1.43
Aspartic acid, g 100 g^{-1}	2.06	2.11
Cysteine + Cystine, g 100 g^{-1}	0.23	0.24
Phenylalanine, g 100 g^{-1}	0.94	0.95
Glycine, g 100 g^{-1}	0.98	1.09

Traits	Groups	
	Control group	***Trial group***
Glutamic acid, g 100 g^{-1}	3.23	3.35
Histidine, g 100 g^{-1}	0.92	0.94
Isoleucine, g 100 g^{-1}	0.99	1.02
Leucine, g 100 g^{-1}	1.80	1.85
Lysine, g 100 g^{-1}	1.94	1.99
Methionine, g 100 g^{-1}	0.57	0.57
Proline, g 100 g^{-1}	0.81	0.89
Serine, g 100 g^{-1}	0.88	0.90
Threonine, g 100 g^{-1}	1.01	1.02
Valine, g 100g^{-1}	1.06	1.07
Cholesterol, mg 100g^{-1}	81.50	67.75
Total fat content,%	6.75	4.15
Humidity,%	71.10	72.55
Protein, %	21.30	21.95
pH	5.47	5.44
Tryptophan, g 100 g^{-1}	0.29	0.29
Ornithine <0.01 (LOQ) g 100 g^{-1}	<0.01	<0.01
Hydroxyproline <0.05 (LOQ) g 100 g^{-1};	<0.05	<0.05

TABLE 7 CHEMICAL COMPOSITION OF MANURE

Traits	Groups	
	Control group	***Trial group***
Dry matter, %	22.95	24.45
Total nitrogen, (N)%	0.90	0.99
Total potassium, (K2O)%	0.26	0.27
Total phosphorus, (P2O5)%	0.75	0.67
Environmental reaction pH, (KCl) pH unit.	6.86	6.55
Organic matter content,%	19.36	16.16
Ammonium nitrogen, N / NH4%	0.18	0.17
Environmental reaction pH, (H2O) pH unit.	6.75	6.52

By feeding local soy cakes to fattening pigs was possible to reduce environmental pollution.

IV. CONCLUSIONS

The inclusion of soybean cakes grown and processed in Latvia in lactating sow diet increased sow milk yields traits by 3.9% at 21 day of piglet age, piglet weaning weights at age of 28 days were similar between groups, retention of piglets was 1.1% lower. Local soybean cake using in the diet of lactating sows showed insignificant differences on the growth rates of piglets compared with imported soybean meal diets.

Live weights and live weight gain of weaned piglets and fattening pigs showed similar rates between groups. Pigs fed soybean cakes grown and processed in Latvia found a 3.48% lower feed consumption and feed conversion was 5.87% better. The carcass weight of the trial group was on average 3.3% higher. Carcass quality indicators did not show significant differences between groups. The amino acid content of muscle tissue was similar. The muscle cholesterol content of the pigs of the trial group was 16.9% lower. Feeding local soybean cakes to fattening pigs reduce environmental pollution by organic matter, total phosphorus and ammonium nitrogen.

Using soy cakes grown and processed in Latvia, it was possible to develop feed rations for lactating sows and fattening pigs, which showed similar results for the use of imported soybean

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REFERENCES

[1] Navicha, W.B., Y. Hua, K. Masamba and C. Zhang. ” Effect of roasting temperatures and times on test parameters used in determination of adequacy of soybean processing“. Adv. J. Food Sci. Technol. 13, 2017, pp. 22-28. [Online]. Available: https://www.researchgate.net/publication/318254957_Optimization_of_soybean_roasting_parameters_in_developing_nutritious_and_lipoxygenase_free_soymilk [Accessed March 16, 2021]

[2] P. Florou-Paneri, E. Christaki, I. Giannenas, E. Bonos, I. Skoufos, A. Tsinas, A. Tzora and J. Peng. “Alternative protein sources to soybean meal in pig diets”. Journal of Food, Agriculture & Environment . Vol.12 (2): 2014, pp. 655-660. [Online]. Available: https://www.cabdirect.org/cabdirect/abstract/20143310441. [Accessed March 18, 2021].

[3] H. H. Stein, J. A. Roth, K. M. Sotak and O. J. Rojas. “Nutritional Value of Soy Products Fed to Pigs”. University of Illinois, Urbana-Champaign 'Swine Focus'. 01 August 2013 [Online]. Available. https://www.thepigsite.com/articles/nutritional-value-of-soy-products-fed-to-pigs [Accessed March 16, 2021].

[4] N. Javed, M. T. Javed, M. A. Mirza, G. Saleem, B. Aslam, F. Manzoor, A. Rehman, M. Aslam, M. N. Bhutta, S. Faizan “Pathological effect of replacement of solvent extracted soybean meal with expeller extracted soybean meal in broilers”. Chemistry Pakistan Journal of Agricultural Sciences. V. 57(4); 2020, pp. 969-973.

[5] G. S. Gilani, K. A. Cockell, E. Sepehr. “Effects of antinutritional factors on protein digestibility and amino acid availability in foods”. J. AOAC Int.; 88.1989, pp.967–987. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/16001874/ [Accessed March 16, 2021].

[6] G. Grant. ”Antinutritional effects of soybean a review”. Prog. Food Nutr. Sci. (Oxford) 1989; 13(3-4) :317–348. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/2699045/ [Accessed March 17, 2021].

[7] M. Ramos. Why Extrude Soybeans. November 3, 2016. [Online]. Available: https://www.insta-pro.com/en/blog/nutritionandtechnologies/why-extrude-soybeans/ [Accessed Mart 10, 2021].

[8] R. Yasothai. “ Antinutritional factors in soybean meal and its deactivation”. International Journal of Scie nce, Environment and

Technology. ISSN 2278-3687 (O), Vol. 5, No 6, 2016, pp. 3793 – 3797.

[9] Y. Liu, O. J. Rojas, and H. H. Stein. “Effects of extrusion of corn and oats on the digestibility of energy and nutrients in diets fed to pigs”. J. Anim. Sci. 93(Suppl. 2): 2015, pp.134–135. [Online]. Available: https://nutrition.ansci.illinois.edu/node/1014 [Accessed March 15, 2021].

[10] O. J. Rojas, E. Vinyeta and H H Stein. “Effects of pelleting, extrusion, or extrusion and pelleting on energy and nutrient digestibility in diets containing different levels of fiber and fed to growing pigs”. J. Anim. Sci. 94: 2016, pp.1951–1960. [Online]. Available: Oxford Academic Online ttps://academic.oup.com/jas/article-abstract/94/5/1951/4701614 [Accessed March 18, 2021].

http;//doi:10.2527/jas.2015-0137.

[11] D. A. Rodriguez, S. A. Lee, M. R. C. de Godoy, H. H. Stein. “Extrusion of soybean hulls does not increase digestibility of amino acids or concentrations of digestible and metabolizable energy when fed to growing pigs”. Translational Animal Science, Volume 4, Issue 3, July 2020, txaa169.

[Online]. Available: Oxford Academic Online, https://academic.oup.com/tas/article/4/3/txaa169/5903553. [Accessed March 18, 2021]. https://doi.org/10.1093/tas/txaa169

[12] D. Miladinovic. Optimising the extrusion process. 20-05-2019. [Online]. Available: https://www.allaboutfeed.net/author/dejan-miladinovic/

[Accessed March 18, 2021].

[13] Pig welfare requirements Regulations of the Cabinet of Ministers No. 743. [Online]. Available: https://likumi.lv/ta/id/194745-cuku-labturibas-prasibas [Accessed March 16, 2021].

[14] L. Degola, V. Sterna, I. Jansons, S. Zute. “The nutrition value of soybeans grown in Latvia for pig feeding”. Agronomy Research 17(5), 2019, pp. 1874–1880. [Online].Available:

http://dspace.emu.ee/xmlui/handle/10492/5099 [Accessed March 18, 2021].

https://doi.org/10.15159/AR.19.158

[15] B. Grisdale, , L. L. Christian.; H. R Cross; D. J. Meisinger, M. F. Rothschild and R. G. Kauffman. "Revised Approaches to Estimate Lean of Pork Carcasses of Known Age or Days on Test". Animal Science Publications. 1984, pp. 312.

[16] Rules for the classification of animal carcase. Regulations of the Cabinet of Ministers No. 416. [Online]. Available https://likumi.lv/ta/id/300432-dzivnieku-liemenu-klasifikacijas-noteikumi [Accessed March 16, 2021].

[17] I. Jansons, L. Degola, V. Sterna and S. Zute. “Influence of local extruded soybean cake and imported soybean meal on fattening pig productivity and pork quality”. Agronomy Research, 18 (Special Issue 2) 2020, pp. 1307-1315. [Online]. Available: https://dspace.emu.ee/xmlui/handle/10492/5700 [Accessed March 16, 2021]. https://doi.org/10.15159/AR.20.102

[18] M. A. Ibáñeza, C. de Blasb, L. Cámarab, G. G. Mateosb. “Chemical composition, protein quality and nutritive value of commercial soybean meals produced from beans from different countries: A meta-analytical study”. Animal Feed Science and Technology. Volume 267, September 2020, 114531. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0377840120304351 [Accessed March 16, 2021].

https://doi.org/10.1016/j.anifeedsci.2020.114531

[19] F. Aherne. Feeding the lactating sow. Pork Information Gateway Factsheet PIG 07-01-05. 2005. [Online]. Available: https://porkgateway.org/resource/feeding-the-lactating-sow-2/ [Accessed March 15, 2021].

[20] , D. E. Reese, R. C. Thaler, M. C. Brumm, A. J. Lewis, P. S. Miller, and G. W. Libal. "Swine Nutrition Guide". Faculty Papers and Publications in Animal Science . 69. 2000. [Online]. Available: https://digitalcommons.unl.edu/animalscifacpub/694 [Accessed March 16, 2021].

[21] S. J. Hawe, N. Scollan, A. Gordon, E. Magowan. “Impact of sow lactation feed intake on the growth and suckling behavior of low and average birthweight pigs to 10 weeks of age” Translational Animal Science, Volume 4, Issue 2, April 2020, pp. 655–665. [Online]. Available: Oxford Academic Online, https://academic.oup.com/tas/article/4/2/655/5835298 [Accessed March 12, 2021]. https://doi.org/10.1093/tas/txaa057

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Energy Efficiency Assessment of the Housing Stock in Belarusian Regions

Volha Kameka
Department of Economics
Polotsk State University
Novopolotsk, Belarus
o.kamecko@psu.by

Svetlana Izmailovich
Department of Economics
Polotsk State University
Novopolotsk, Belarus
s.izmailovich@psu.by

Alena Lisichonak
Department of Economics
Polotsk State University
Novopolotsk, Belarus
l.lisichonok@psu.by

Abstract **- The need to ensure energy efficiency of the Belarusian economy at the present stage is justified. Indicators characterizing the level of fuel energy consumption and the impact of fuel consumption on the environment for the Belarusian regions are calculated. The authors found that Vitebsk region is characterized by high heat capacity Gross regional product. Also, Vitebsk region is characterized by a high volume of pollutant emissions into the air. We are talking about the emissions generated from fuel combustion for the production of heat and electricity. It has been substantiated that the main directions of regional development should be to reduce the consumption of fuel resources and the volume of emissions. The authors analyzed the structure of final consumption of fuel and energy resources by sectors of consumption, which showed that the main consumers of fuel and energy resources in Belarus are industry and housing sector.**

In this article the highest priority has been given by authors to energy efficiency in housing sector. It is noted that improving the energy efficiency of the housing stock can reduce the energy load on the region. It is proposed to use a system of indicators to assess the level of energy efficiency. The scientific novelty is in the application of a systematic approach to assessing energy efficiency. Previous studies were limited to considering individual energy efficiency indicators, rather than their systems. It is proposed to include the following groups of indicators in the system: technical, financial and economic, environmental. In contrast to the previously proposed groups of indicators, the system developed by the authors includes environmental indicators. The relevance of their study is due to regional characteristics, which is especially important for the Vitebsk region.

The proposed system of indicators is able to give a holistic view of the level of energy efficiency of the housing stock. Thus, it becomes possible to identify reserves for the growth of energy efficiency in the housing sector in Belarus.

Keywords – Energy efficiency, housing stock, region

1. INTRODUCTION

Specific conditions for the functioning of economic systems, features of the development of the energy sector and current trends in the development of the world economy against the background of global fuel, energy and environmental problems ensure the relevance of the problem of ensuring energy efficiency at various levels of the economy. The state policy of Belarusian transition to the path of innovative resource-saving and energy-saving development, which allows the implementation of the strategy of energy efficiency, energy conservation and energy substitution in these conditions is completely justified and has no alternative. This is enshrined in a number of regulatory legal acts, including the Concept of the National Strategy for Sustainable Development of the Republic of Belarus for the period up to 2035 [1], the Law of the Republic of Belarus "On Energy Saving" [2], etc.

The priorities of resource-saving and energy-saving development were selected based on quite obvious arguments [3, 4]:

- in terms of the GPD energy intensity (in terms of purchasing power parity), Belarus was among the countries with an inefficient economy;
- electrical energy has taken a key place in the material foundation of modern society;
- thermal energy in the required amount is a fundamental condition for a comfortable life of the population;
- sustainable growth in the welfare of society is possible only with a decrease in the growth rate of specific volumes of energy consumption;
- large-scale replacement of non-renewable mineral energy resources with renewable ones, and traditional technologies for the production of electric and thermal energy with advanced ones allows extending the availability of traditional energy resources, reducing man-made pressure on the environment.

A number of scientists are developing the theory and

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methodology, specific methodological tools for ensuring the energy efficiency of the Belarusian economy: T.G. Pospelova, N.A. Haustovich, T. Kh. Gulbrandsen, L.P. Padalko, V.L. Chervinsky, V.L. Ganzha, I.V. Galuzo, I.N. Potapov, V.A. Baydakov [5-9] and other scientists.

Due to the high degree of relevance, the problem of improving energy efficiency is being studied by different scientists and scientific teams: AH Rosenfeld, M. Patterson, R. Haas, TR Lakshmanan, S. Ratick, H. Herring, S. Sorrel, V. V. Efremov, G.Z. Markman, I. A. Bashmakov, R. F. Araslanov, A. A. Tupikina, A. S. Gorshkov, A. A. Gladkikh and others [10-20].

Most of these scientists consider this concept as a category that determines the efficiency of the fuel and energy complex in the context of reducing the consumption of fuel and energy resources. The housing stock, due to the use of various types of energy, can affect the volume of its output, thereby indirectly affecting the process of consumption of fuel and energy resources. A number of researchers consider energy efficiency as a characteristic of production processes, including: output of products by evaluating the efficiency of energy costs to the production result. Within the framework of the housing stock, it is possible to conduct a reverse assessment related to the economy of energy resources through the production of measures that improve the quality of life of the population, including the quality of functioning of the housing stock. For example, to determine the need for heat energy after the implementation of major repairs in the housing stock. This will allow us to determine the energy savings required for heating a residential space, both for the end user and for the production process of the heat generating plant. Thus, the derived category should include the most rational ideas of the above and take into account the scope of application (housing stock) as the final factor.

The results of the research carried out by the World Bank, the United Nations Development Program and other international organizations are of great practical and scientific importance. The research in the field of energy efficiency in various countries and regions is carried out by leading international organizations: the European Commission, the International Energy Agency, etc.

For example, the World Bank actively contributes to the implementation of programs to improve the energy efficiency of the world's regions, including their housing stock. “Despite the huge potential, the potential for energy efficiency is still not fully realized due to political, technical and financial difficulties”. [21]

Countries and development organizations, such as the World Bank Group, have realized that long-term efforts are needed to successfully implement large-scale energy efficiency programs. Financing needs to be tailored to the needs of local markets, while relying on effective policy measures, regulatory measures and, in some cases, incentives.

Countries are currently developing next-generation programs to realize this huge potential, including through combined purchases of energy-saving devices and equipment, creating revolving funds, and improving national standards.

The policy of the European Union in the field of energy efficiency of the housing stock is based on regional characteristics.

Countries with cold climates traditionally pay more attention to general energy efficiency issues compared to countries with more favorable climatic conditions, which mainly focus on reducing the energy consumption spent on air cooling. Germany, France, and the United Kingdom are among the leaders in implementing a consistent energy policy, and Denmark and some new EU members, such as Slovenia, are also very active in these issues. [22]

As areas that require special attention in the context of energy efficiency of the housing stock, it is possible to determine the level of energy consumption of various engineering networks, the energy characteristics of buildings, the share of renewable energy sources, etc. In order to improve the energy efficiency of housing facilities, European CEN standards have been developed.

National Academy of Sciences of Belarus, Ministry of Energy, Ministry of Architecture and Construction, Ministry of Housing and Utilities, Ministry of Industry, Ministry of Natural Resources and Environmental Protection, the Ministry of Economy deal with the problems of sustainable development of the energy sector and energy efficiency by types of economic activity, increasing social stability, economic development, as well as issues of state regulation of energy efficiency at the level of the Republic of Belarus. Research institutes and institutions of higher education make a significant contribution to the development of these issues.

II. MATERIALS AND METHODS

The purpose of the study is to develop a system of indicators for assessing the energy efficiency of the housing stock of Belarusian regions.

More specifically, the study aims to analyse the regional characteristics to substantiate directions for increasing energy efficiency to study the housing stock as the main consumer of energy in Belarus; to form groups of indicators for assessing the energy efficiency of the housing stock.

In the process of the research, the authors used the following methods: analysis, synthesis, observation, comparison, a systematic approach, as well as special methods and techniques of economic analysis.

In order to identify regional characteristics of consumption of fuel and energy resources and its impact on the environment, the authors have calculated indicators based on official data of the National Statistical Committee of Belarus. The choice of indicators is determined by many years' experience of assessment at the national level and the possibility of

their adaptation to the regions.

Comparison of the indicators obtained for the regions of Belarus allowed revealing the peculiarities of resource consumption in the Vitebsk region.

III. RESULTS AND DISCUSSION

There are seven regions in Belarus: Brest, Vitebsk, Gomel, Grodno, Minsk, Mogilev regions and Minsk – the capital city. Reasons for the considerable attention to the Vitebsk region:

- unfavourable environmental situation due to significant amounts of pollutants emitted into the atmosphere;
- the region is located in a colder climatic zone than other regions, which affects the performance of the housing stock and the consumption of fuel and energy resources.

To improve energy efficiency, it is necessary to take into account regional characteristics that have a direct impact on it. To do this, we will calculate the indicators characterizing the level of consumption of fuel and energy resources and the impact of fuel consumption on the environment of the Belarusian regions based on the data of the National Statistical Committee of Belarus in 2019 (Table 1).

The gross regional product of Gomel region is the most power-consuming, and the gross regional product of Vitebsk region is heat-consuming. Most of all electricity is consumed per capita in Gomel region, and the least - in Brest region.

The emissions of pollutants into the air from fuel combustion in the process of heat and electricity production per capita are the most significant in 2019 in Vitebsk region. The value of this indicator per unit of territory is the highest in Minsk region. Vitebsk region has a lower level of this indicator, slightly inferior to Minsk region.

TABLE I. INDICATORS CHARACTERIZING THE LEVEL OF CONSUMPTION OF FUEL AND ENERGY RESOURCES AND THE IMPACT OF FUEL CONSUMPTION ON THE ENVIRONMENT

Indicator name	Indicator value by region					
	Brest	Vitebsk	Gomel	Grodno	Minsk	Mogilev
1. Electricity of the gross regional product, kilowatt-hours per 1 ruble	0,26	0,49	0,63	0,41	0,23	0,42
2. Heat capacity of gross regional product, gigacalories per 1,000 rubles	0,45	0,86	0,78	0,71	0,37	0,69
3. Electricity consumption per capita, thousand kilowatt-hours	2,42	4,29	6,10	4,33	3,78	3,76
4. Emissions of pollutants into the atmosphere from fuel combustion in the process of heat and electricity, kilogram per capita	6,52	20,87	8,07	7,11	7,42	8,00
5. Emissions of pollutants into the air from fuel combustion in the process of heat and electricity, per unit of territory, kilogram per square kilometer	268	591	277	291	646	282

Thus, it can be concluded that Vitebsk region is distinguished by a high level of heat capacity of the gross regional product and the volume of emissions of pollutants into the air from fuel combustion in the process of heat and electricity production. Consequently, the main directions for the development of the region should be to reduce the consumption of fuel resources and reduce the volume of emissions.

In order to identify the ways for reducing the consumption of fuel and energy resources, it is necessary to consider the structure of the final consumption of fuel and energy resources by consumption sectors in 2010 and 2019 (Table 2).

So, the main consumer of fuel and energy resources in Belarus is industry. The next major consumer is the housing sector. These sectors account for more than 60 % of all final consumption of fuel and energy resources. Transport also accounts for a significant share in final consumption. All the above-mentioned sectors of consumption account for 4/5 of the total volume of final consumption. At the same time, noteworthy is the fact that, if the share of consumption in industry and the housing sector decreased in 2019 compared to 2010, then in transport it increased significantly.

TABLE II. STRUCTURE OF FINAL CONSUMPTION OF FUEL AND ENERGY RESOURCES BY CONSUMPTION SECTORS IN 2010 AND 2019 (IN PERCENTAGE OF THE TOTAL)

Consumption sector	Share of consumption, percent		Change in the share in 2019 compared to 2010, percentage points
	2010	2019	
1. Industry	34,5	33,1	-1,4
2. Agriculture, forestry and fisheries	5,9	6,3	0,4
3. Service sector	10,1	9,8	-0,3
4. Construction	1,7	0,9	-0,8
5. Transport	19,8	23,2	3,4
6. Housing sector	28,0	26,7	-1,3

Thus, in order to reduce the consumption of fuel and energy resources, it is necessary to focus on the following sectors of the economy in Belarus: industry, transport and housing sector.

In this article, the authors take a closer look at energy efficiency in the housing sector.

The housing stock is one of the objects with the greatest potential in terms of energy efficiency. Based on the works of different scientists, it is clear that high indicators of real economic growth require consistent and rational measures to create industrial enterprises of a new formation, as well as to improve the existing production capacities in various sectors of the economy. The central place here is occupied by the state program "Energy Saving", which has been developed in the Republic of Belarus for a five-year period. Currently, a program for 2021-2025 is being prepared. It aimed at improving the energy efficiency of the housing stock.

It should be noted that the housing sector is a specific field of activity, which has a number of features. This area is directly related to the level and quality of life of people. An important task of the housing stock is to provide the population with living space. Also, the housing stock is located at the junction of two areas of activity: housing construction and housing and communal services. At the initial stage of the residential buildings are residential, and the phase of the object relate to housing and utilities. Among other things, this sector requires efficient operation and timely maintenance, which is also a feature.

Along with other subjects of the national economy of Belarus, the housing stock is one of the largest energy consumers. The process of improving the energy efficiency of residential sector is possible by reducing the amount of energy consumed, which entails a significant reduction in the consumption of fuel and energy resources for energy production.

Improving the quality of energy production and usage (primarily electricity and heat) is the basis for determining the energy efficiency of the housing stock. For a rational assessment of the energy efficiency of objects, we suggest using energy efficiency indicators.

According to the Law of the Republic of Belarus "On energy saving", the energy efficiency indicator is a scientifically validated absolute or specific consumption of fuel and energy resources (including their normative losses) on the unit of production (works, services) for any purpose set of technical normative legal acts in the field of technical regulation and standardization [2].

The task of determining the optimal energy efficiency indicators is relevant for the development of energy consumption standards that adequately reflect the technological process or the chain of successive technological processes [16]. However, in the issue of housing stock, not only the technologies of production and development of heat and electricity are important, as well as the condition and energy demand of the fund's facilities themselves, the effectiveness and economic effect of measures to improve the energy efficiency of residential buildings.

The environmental issue is also important: namely the influence of the weather and natural features of the region on the volume of energy production and consumption, as well as the impact of energy producers and consumers on the environment. Thus, the most rational approach is to form a system of indicators for assessing energy efficiency in relation to the functioning of the housing stock.

Based on the research of R. Kaplan and D. Norton [23], the balanced scorecard provides management with a universal mechanism that interprets the company's worldview and strategy through a set of interdependent indicators. Within the framework of the functioning of the housing stock, this kind of indicator system demonstrates the versatility of energy efficiency, claiming that all its indicators are inherently interdependent. Thus, they can be divided into three main groups: technical, financial and economic, and environmental. Also, if necessary, it is possible to allocate related groups: technical-economic and economic-environmental indicators.

The group of *technical* indicators combines indicators of the technical condition of housing facilities and energy supply systems for these facilities, as well as parameters related to the technological process of production and consumption of various types of energy. This group of indicators takes into account the efficiency of consumption of fuel and energy resources, energy efficiency of power transfer, energy intensity of its production, energy consumption standards, thermal characteristics of housing facilities, etc. The calculation of technical indicators gives an idea of the volume of energy consumption, expressed in natural units of measurement (units of the volume of conventional fuel, etc.), as well as the state and characteristics of the housing stock objects under consideration.

Financial and economic indicators are designed to reflect the economic effect of measures to improve the energy efficiency of housing facilities. These indicators include net profit, profitability and payback period of measures (simple and discounted), resource savings (expressed in monetary units), the impact of reducing energy consumption by the housing stock on the level of gross domestic product in the country, and other indicators that are necessary for the purposes of the study.

Within the framework of the system of energy efficiency indicators, *the environmental issue* of the functioning of the housing stock is also considered. This group of indicators shows the impact of the production and use of various types of energy on the environmental situation in the region, and also allows to evaluate the effectiveness of measures to improve the energy efficiency of the housing stock in the region. The group of environmental indicators includes: the specific indicator of emissions, discharges, pollutants into the atmosphere; the indicator of the use of renewable energy sources for housing stock; indicator of the efficiency of the use of natural resources, etc.

TABLE III. COMPOSITION OF ENERGY EFFICIENCY INDICATORS OF THE HOUSING STOCK (BY GROUPS)

Name of the group	Indicators
Technical	- account the efficiency of consumption of fuel and energy resources; - energy efficiency of power transfer; - energy intensity of its production; - energy consumption standards; - thermal characteristics of housing facilities, etc.
Financial and economic	- net profit; - profitability and payback period of measures; - resource savings (expressed in monetary units); - the impact of reducing energy consumption by the housing stock on the level of GDP, etc.
Environmental	- the specific indicator of emissions, discharges, pollutants into the atmosphere; - the indicator of the use of renewable energy sources for housing stock; - using of natural resources, etc.

Such formation of groups of energy efficiency indicators allows us to take into account all stages of the life cycle of energy consumed by the housing stock: to take into account the conditions and technology of production of energy resources, to reflect the financial side of this issue.

IV. CONCLUSIONS

The authors substantiate the need to take into account regional peculiarities in the management of energy efficiency of housing sector. For example, Vitebsk region is characterized by a high level of heat capacity of the gross regional product and a significant amount of emissions of pollutants into the atmosphere from the combustion of fuel in the process of heat and electricity production. This determines the need to develop specific recommendations for improving energy efficiency in this region.

It is proved that one of the main consumers of fuel and energy resources in the Republic of Belarus is the housing sector. Therefore, it is necessary to look for reserves to improve energy efficiency in the region.

The need to increase the level of energy efficiency of the housing stock determines the need for its assessment. The authors propose a system of indicators for assessing the energy efficiency of the housing stock, which, in contrast to the approaches proposed by other authors, includes 3 groups of indicators: technical, financial, economic and environmental. At the same time, the authors focus on the need to take into account regional characteristics when assessing energy efficiency.

The proposed system of indicators will allow not only to comprehensively assess the energy efficiency of the housing stock, based on regional characteristics, but also to develop the most accurate recommendations for each individual region, taking into account its strengths and weaknesses.

REFERENCES

[1] Concept of the National Strategy for Sustainable Development of the Republic of Belarus for the period up to 2035 [Online]. Available: https://www.economy.gov.by/uploads/files/ObsugdaemNPA/Kontseptsija-na-sajt.pdf [Accessed January 21, 2021].
[2] Law of the Republic of Belarus “About energy saving” [Online]. Available: http://energoeffekt.gov.by/downloads/laws/act/201501_law.pdf [Accessed January 21, 2021].
[3] E. Volkov and V. Kostuk, “New technologies in the Russian electric power industry,” Bulletin of the Russian Academy of Sciences, vol.79, no. 8, pp. 675-686, 2009.
[4] S. Voronin and A. Kalinin, “Energy saving”, Zernograd, Azov Black Sea State Agroengineering Academy, 256 p., 2009.
[5] I. Galuzo, I. Potapov and I. Baydakov, “Experimental elective course “Fundamentals of Energy Efficiency” for schoolchildren,” Energy Efficiency, no. 8, 24 p., 2005.
[6] V. Ganzha, “Fundamentals of efficient use of energy resources: theory and practice of energy saving,” Minsk, Belarusian. Science, 451 p., 2007.
[7] T. Gulbrandsen, L. padalko and V. Chervinsky, “Energy efficiency and energy management: study guide,” Minsk, BGATU, 240 p., 2010.
[8] T. Pospelova, “Fundamentals of energy saving,” Minsk, UP "Technoprint", 353 p., 2000.
[9] N. Khaustovich, “Energy efficiency as an important condition for sustainable development of the country's economy,” Belarusian Economic Journal, no. 3, pp. 15-23, 2006.
[10] R. Haas, “Energy efficiency indicators in the residential sector,” Energy Policy, no. 25 (7–9), pp. 789–802, 1997.
[11] H. Herring and S. Sorrel, “Energy Efficiency and Sustainable Consumption: The Rebound Effect,” Hampshire, Palgrave Macmillan, 272 p., 2009.
[12] T. R. Lakshmanan, P. Nijkamp and S. Ratick, “Integrated Models for Economic-Energy-Environmental Impact Analysis. Economic-Environmental-Energy Interactions: Modeling and Policy Analysis,” Springer Netherlands, pp. 7–39, 1980.
[13] M. Patterson, “What is energy efficiency?” Energy Policy, no. 24(5), pp. 377-390, 1996.
[14] A. H. Rosenfeld, “The Art of Energy Efficiency: Protecting the Environment with Better Technology,” Annual Review of Energy and Environment, no. 24, pp. 33–82, 1999.
[15] A. H. Rosenfeld, “Real Prospects for Energy Efficiency in the United States, Chaired by Lester Lave and Maxine Savitz, America's Energy Future Panel on Energy Efficiency Technologies,” National Academy of Sciences, Academy of Engineering; The National Academies Press., 203 p., 2009.
[16] V. Efremov, G. Markman “"Energy saving" and "energy efficiency": clarification of concepts, the system of balanced indicators e "energy efficiency",” Bulletin of the Tomsk Polytechnic University, no. 4, pp. 146-148, 2007.
[17] A. Araslanov, “Formation of the mechanism of energy efficiency management of socio-economic systems of the region” [Online]. Available: https://esstu.ru/library/free/ Avtoreferat /% d0% 90% d1% 80% d0% b0% d1% 81% d0% bb% d0% b0% d0% bd% d0% be % d0% b2_% d0% a0_% d0% a4.pdf. [Accessed January 11, 2021].
[18] I. Bashmakov, “Energy efficiency: from rhetoric to action” [Online]. Available: https://www.abok.ru/?controller=article AuthorView&id=1467 [Accessed December 12, 2020].
[19] A. Gorshkov and A.Gladkikh, “Measures to improve energy efficiency in construction,” Construction sciences: building telophysics and energy saving, no. 3, pp. 246-250, 2010.
[20] A. Tupikina, “Energy saving and increasing energy efficiency: a history of concepts,” Business. Education. Right. Bulletin of the Volgograd Institute of Business, no. 2, pp. 90-95, 2014.
[21] “Energy efficiency” [Online]. Available: https://www.vsemirnyjbank.org/ru/results/2017/12/01/energy-efficiency [Accessed March 1, 2021].
[22] O. Seppanen, “Energy efficiency requirements for buildings in the EU” [Online]. Available: https://www.abok.ru/for_spec/articles.php?nid=4739 [Accessed February 19, 2021].
[23] R. S. Kaplan and D. P. Norton, “A balanced scorecard. From strategy to action,” Moscow, Olimp-Business, 304 p., 2003.
[24] Energy balance of Belarus, 2020: statistical bulletin [Online]. Available: https://www.belstat.gov.by/ofitsialnaya-statistika/realny-sector-ekonomiki/energeticheskaya-statistika /statisticheskie-izdaniya/index_17875/ [Accessed December 21, 2020].

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Study of Changes in Currant During Fast Freezing

Serhii Kiurchev[1]
[1]Dmitry Motornyi Tavria State Agrotechnological University, Melitopol, Ukraine
serhii.kiurchev@tsatu.edu.ua

ValentynaVerkholantseva[1]
[1]Dmitry Motornyi Tavria State Agrotechnological University, Melitopol, Ukraine
valentyna.verkholantseva@tsatu.edu.ua

Lyidmila Kiurcheva[1]
[1]Dmitry Motornyi Tavria State Agrotechnological University, Melitopol, Ukraine
lyidmila2007@ukr.net

Taras Hutsol [2]
[2]*State Agrarian and Engineering University in Podilia,* Kamianets-Podilskyi,Ukraine
pro-gp@pdatu.edu.ua

Iryna Semenyshyna [2]
[2]State Agrarian and Engineering University in Podilia, Kamianets-Podilskyi,Ukraine
dakgps@pdatu.edu.ua

Abstract **- Frozen berries have a number of undeniable advantages: they do not require additional preparation costs, are almost ready to eat, and most importantly, thanks to modern technologies, they retain almost twice as much nutrients as with other canning methods. Increasingly, there are risks associated with internal and external factors, as well as problems with excess yields that threaten not to sell the product fresh. short shelf life immediately after harvest, which increases the critical dependence on market prices. One of the progressive technological methods of processing fruit and berry products is quick freezing. The use of such freezing gives, first of all, a low degree of product damage, minimally reduces the biological value and taste characteristics, and the use of freezing does not significantly affect the quality of the thawed product.**

The main task of an industrial or commercial line for shock freezing of berries is to ensure almost instantaneous preservation of the product, which will retain all its nutritional value and taste. This is usually achieved by rapidly chilling the berries to -18 °C. By far the best option for extending the shelf life of freshly cooked food is to freeze it quickly. There are various options, but the best known is the freezing technology. For instant freezing without crystallization, it is necessary to provide a temperature of -5 ...-18 °C. Experimental data were obtained during research. The temperature regime of storage of currants with the preservation of quality indicators using a freezing device is also considered. When frozen quickly, the berries should be blown from all sides or literally float in a stream of frosty air of the appropriate temperature.

The duration of this process depends on the type and size of the berries, as well as on the intensity of the cooling air flow. The current direction in the field of research of frozen berries is the preservation of consumer properties of berries after freezing.

Keywords - berries, currant, freezing, storage.

INTRODUCTION

The blast freezing technology, which is similar for any foodstuff, differs in detail for each type of food. Depending on size, consistency, firmness, maturity, variety and other characteristics, different food products are exposed to different effects of artificial cold using different freezing equipment.

Deep freezing technology for delicate products such as berries requires the use of special refrigeration equipment. Wet and sticky, they easily stick together into lumps, deform even under the influence of their own weight, losing their appearance and consumer qualities. Therefore, freezing of berries can be carried out qualitatively only in fluidizing quick freezers in bulk [1,2].

Currant is a very valuable berry. It contains many vitamins that our body requires every day. The use of black and red currants strengthens the immune system, and vitamin C, which is found in large quantities in black currants, is not destroyed even when frozen [3].

This berry tolerates freezing well if the freezing technology is properly followed. In this case, her physical and chemical properties, as well as taste characteristics, remain unchanged. Such fruits can be stored all winter and longer, until the next harvest appears.

MATERIALS AND METHODS

In order to preserve the external and internal properties of the berries, the technology is strictly observed. If there is a lot of ice and frost on the berry, then it will lose its taste. And when using such fruits in baking, the dough will get wet and sink.

The choice of berries is important. Crumpled and overripe will stick together into one unattractive mass.

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Unripe, due to the low sugar content, will change color, lose aroma and taste.

Black and red currants are the most attractive as source of ascorbic acid versus other berries and fruits. Pronounced the seasonality of berry production makes you think about ways to save them. One of the most environmentally friendly clean ways -
freezing berries. However, according to biochemical value frozen berries different from fresh ones. After defrosting in berries there is a decrease in the content of ascorbic acids, soluble solids and titratable acids [3,7].

RESULTS AND DISCUSSION

Before freezing, the berries should be properly prepared. It is necessary to sort them, removing bad berries and removing debris.

Depending on what kind of currants you freeze, there are some peculiarities.

Red currants should be frozen only with twigs. Black can be whole berries [2,6].

After you wash it, you need to spread it on a towel to dry the berries. Drops of water on the berries turn to ice and can destroy the integrity of the skin.

Foodstuffs retain useful substances better if quick freezing is applied to them. Its peculiarity lies in the fact that the liquid contained in the tissues of berries or other product does not have time to expand.

This effect leads to rapid hardening and, as a result, good preservation of the product over a long period of storage. The exact same preservation method should be applied to all types of berries.

Before storage and during storage, we have determined the main indicators of quality. In the course of using the technology, we checked, that is, the following indicators were investigated: mass fraction of sugars, mass fraction of vitamin C, mass fraction of titratable acids, mass fraction of soluble solids [6, 12].

Creation of a fluidization layer of production in the course of its high-temperature processing can be carried out at use of such schemes of executive bodies of cars as: in a fluidization gutter or a tray,in the pneumomechanical system which carries out pulse supply of the refrigerant to a product surface, in a fluidizing rigid container; in the semifluidization conveyor system [4,5,13].

The use of a fluidizing device freezes in the range from 10 ... 25°C by installing an additional fan with a guide nozzle can improve the movement of the product to be frozen, namely the horizontal movement of the upper layers of the product that do not touch the mesh vehicle, which in turn increases the intensity of heat transfer in the upper layers of the pseudo-liquefied stream and the productivity of the freezing process as a whole [8-11].

In the course of the experiment, a biochemical assessment of the berries was made before freezing and after defrosting (Tab.1)

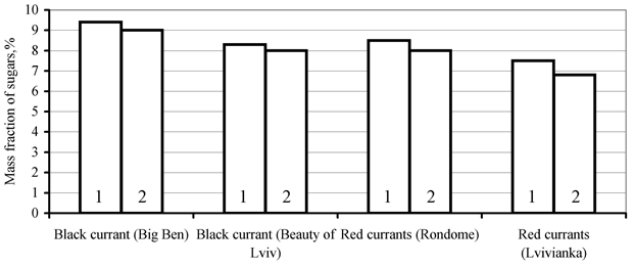
For each indicator of biochemical assessment, diagrams were plotted (Fig.1-Fig.4).

TABLE 1. BIOCHEMICAL EVALUATION OF BERRIES BEFORE FREEZING AND AFTER DEFROSTING

Name of berries	Mass fraction of sugars,%		Mass fraction of vitamin C, mg per 100g		Mass fraction of titratable acids,%		Mass fraction of soluble solids,%	
	before freezing	*after defrosting*	*before freezing*	*after defrosting*	*before freezing*	*after defrosting*	*before freezing*	*after defrosting*
Black currant (Big Ben)	9,4	9,0	175,4	160,3	2,5	2,6	15,3	14,2
Black currant (Beauty of Lviv)	8,3	8,0	153,0	145,5	2,63	2,7	13,2	12,7
Red currants (Rondome)	8,5	8,0	52	45	2,6	2,8	13,1	11,8
Red currants (Lvivianka)	7,5	6,8	43,6	38,6	2,2	2,65	11,3	12,6

For each indicator of biochemical assessment, charts were built. We offer to consider the mass fraction of sugars for the storage stages for black and red currants in two varieties (Fig.1).

We observe that in both types of currants of different colors, the indicators are normal, but in black currants they are better than in red.

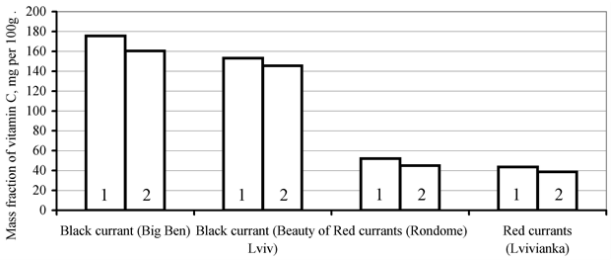


1- before freezing; 2- after defrosting

Fig. 1 Mass fraction of sugars depending on the stages of storage currant berries of various sorts

Fig. 2 shows the results for the mass fraction of vitamin C from the storage stages. As we can see, vitamin C in black currant (Big Ben) has significantly decreased,

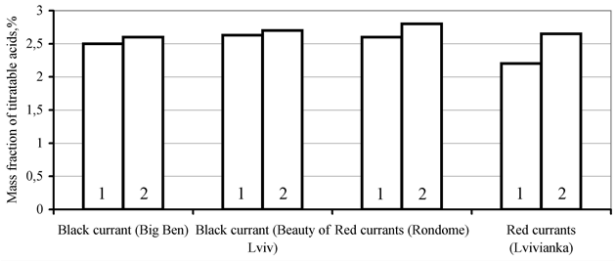
and vitamin C in red currant (Lvivianka) has decreased less.



1- before freezing; 2- after defrosting

Fig. 2 Mass fraction of vitamin C depending on the stages of storage currant berries of various sorts

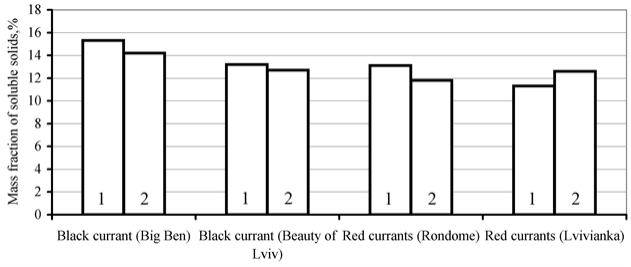
As for the mass fraction of titratable acids, then the indicator for red currants (Lvivianka) became 0.45% worse, while for black currants it changed from 0.07 ... 0.1% (Fig. 3)



1- before freezing; 2- after defrosting

Fig. 3 Mass fraction of titratable acids depending on the stages of storage currant berries of various sorts

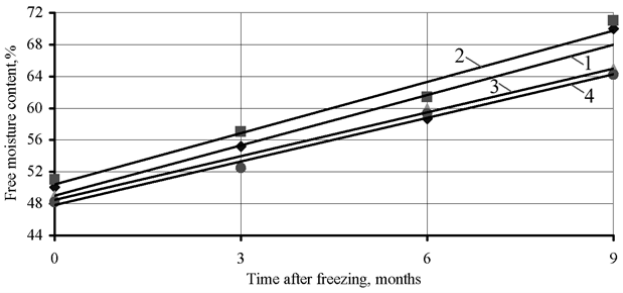
The mass fraction of soluble dry substances from the storage stages was also determined (Fig. 4). In black currant **(**Beauty of Lviv) it fell slightly by 0.5%, but in red currant (Lvivianka)it increased by 1.3%.



1- before freezing; 2- after defrosting

Fig. 4 Mass fraction of soluble solids.depend-ing on the stages of storage currant berries of vari-ous sorts

The free moisture indicator is very important during storage, and even more so during freezing(Fig.5-Fig.8).



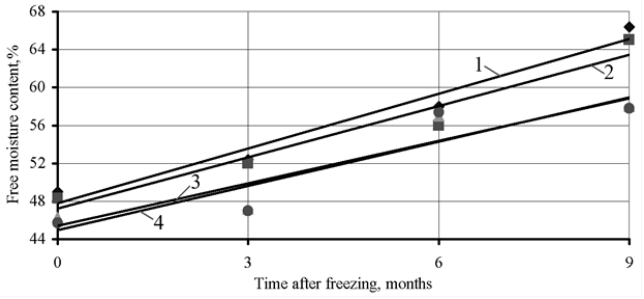
1– Black currant (Big Ben); 2 – Black currant (Beauty of Lviv); 3 – Red currants (Rondome); 4 – Red currants (Lvivianka)

Fig.5. Change in free moisture content during storage of currant berries (freezing temperature (-10^{0}C))

We observe the most free moisture at a temperature of (-10^{0}C) (Fig.5).

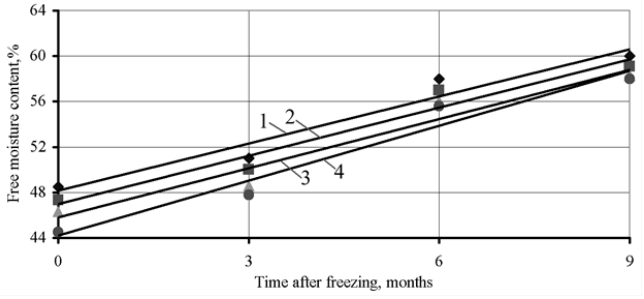
With each decrease in temperature in our case, for every (-5^{0}C) to a temperature of (-25^{0}C), the free moisture content decreased for each variety of currants (Fig.6- Fig.8).

Thanks to these graphs, we can see how the free moisture changes during storage at different temperatures.



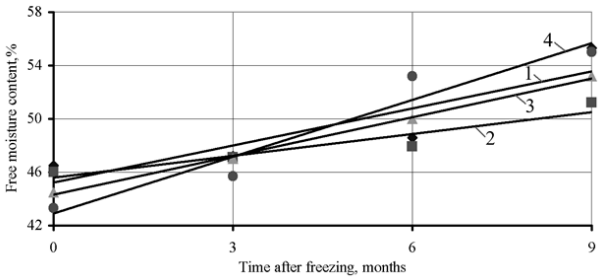
1– Black currant (Big Ben); 2 – Black currant (Beauty of Lviv); 3 – Red currants (Rondome); 4 – Red currants (Lvivianka)

Fig.6. Change in free moisture content during storage of currant berries (freezing temperature (-15^{0}C))



1– Black currant (Big Ben); 2 – Black currant (Beauty of Lviv); 3 – Red currants (Rondome); 4 – Red currants (Lvivianka)

Fig.7. Change in free moisture content during storage of currant berries (freezing temperature (-20^{0}C))



1– Black currant (Big Ben); 2 – Black currant (Beauty of Lviv); 3 – Red currants (Rondome); 4 – Red currants (Lvivianka)

Fig.8. Change in free moisture content during storage of currant berries (freezing temperature (-25^{0}C))

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We truly thank you for the opportunity to publish our scientific work in your collection of scientific papers.

CONCLUSION

Shock freezing of currants allows you to preserve the geometry, properties and vitamin composition. After thawing, the product looks fresh and juicy. It is these properties that are so valued, for which special equipment is being developed. It can have different modifications, but in general, the principle of operation remains the same. The design has a cold generator and a chamber, inside which low temperatures are created, leading to instant freezing of food.

The advantages of the technology of using a blast chiller include the following features: with the help of fast freezing, the time for preparing food for storage is significantly reduced; all vitamins and useful components are preserved; the appearance of each berry is also preserved.

REFERENCES

[1] Yalpachik V.F., Zagorko N.P. and Kiurchev S.V., Eds., Optimization of technology for frozen fruit and vegetable products: Monograph. Melitopol: Vidavnichy booth Melitopolskiy Myskoy Drukarniy, 2018.

[2] Postolski J. and Gruda Z. Freezing of food products. Moskow: Food industry. 1978.

[3] Kiurchev S., Glowacki S. and Verkholantseva V. “An innovative approach for storing berries in the modern”. Innovations in technology and equipment of hotel and restaurant, food and processing industries: international

[4] scientific-practical Internet conference, November 24, 2020. Melitopol: TSATU, 2020. pp. 62-64.

[5] Kiurchev S.V., Verkholantseva V.O., Kiurcheva L.M. and Samoychuk K.O. Goal. ed. prof. V. M. Kyurchev. Vip. 20, vol. 2. Melitopol: TDATU, 2020. pp. 115-123.

[6] Kiurchev S., Verkholantseva V., Yeremenko O. and Al-Nadzhar F. ”Research and changes in berries using technology of freezing during storage” Latvia University of Sciences and Techologies Faculty of Engineering. Jelgava, May 2020. pp. 997 -1002.

[7] Fikin A. and Dichev S. The main parameters characterizing the process of fluidization of the layer of fruits and vegetables. Refrigeration № 11 1976.

[8] Yalpachik V.F. Technological equipment for the processing of products Roslinnstva: Laboratory workshop. Melitopol: Vidavnichy Budynok of Melitopolskiy Miskoy Drukarny, 2017.

[9] Ivanyshyn V., Yermakov S. and, Ishchenko T., Eds. “Calculation algorithm for the dynamic coefficient of vibro-viscosity and other properties of energy willow cuttings movement in terms of their unloading from the tanker”. Proceedings of 6 th International Conference – Renewable Energy Sources, vol. 154, E3S Web of Conferences. 2020. pp. 04005. https://doi:10.1051/e3sconf/202015404005

[10] Yermakov S., Hutsol T., Ovcharuk O. and, Kolosiuk I. “Mathematic simulation of cutting unloading from the bunker”. Independent journal of management & amp; production (IJM&P). Vol. 10, No. 7. 2019. pp. 758-777

[11] Yermakov S., Mudryk K. and Hutsol T., Eds. “The analysis of stochastic processes in unloadingthe energywillow cuttings from the hopper”. Environment. Technology. Resources. Rezekne, Latvia. Proceedings of the 12th International Scientific and Practical Conference. Volume III. 2019. pp. 249-252, https://doi:10.17770/etr2019vol3.4159

[12] Samoychuk K.O., Kiurchev S.V. and Yalpachik V.F., Eds. “Innovative technologies and equipment of the industry”. Processing of crop products: workshop manual. Melitopol: Publishing and printing center "Lux", 2020.

[13] Tryhuba A., Hutsol T. and Glowacki S., Eds. “Forecasting Quantitative Risk Indicators of Investors in Projects of Biohydrogen Production from Agricultural Raw Materials”. Processes 2021, 9, 258. https://doi.org/10.3390/pr9020258

[14] Tryhuba A, Hutsol T. and Tryhuba I, Eds. “Risk Assessment of Investments in Projects of Production of Raw Materials for Bioethanol”. Processes. 2021; 9(1):12. https://doi.org/10.3390/pr9010012

Environment. Technology. Resources. Rezekne, Latvia
Proceedings of the 13th International Scientific and Practical Conference. Volume 1, 117-121

Deformation Transverse Shear Bending State of a Thin Plate Layer of an Anisotropic Geological Medium from the Action of Concentrated Energy Impulses

Ilya Kolesnikov
Geophysical Center of Russian Academy of Sciences
Moscow, Russia
kol@wdcb.ru

Viktor Tatarinov
Geophysical Center of Russian Academy of Sciences
Moscow, Russia
victat@wdcb.ru

Tatiana Tatarinova
Geophysical Center of Russian Academy of Sciences
Moscow, Russia
t.tatarinova@gcras.ru

***Abstract* – A method is proposed for study the structural stability of the deformation state of structural blocks of the earth's crust, approximated in the form of plate layers of the geological medium when transverse shear bending from the action of concentrated energy impulses. Advances here are carried out in the two directions. First, in contrast to the previous article, the physical and mechanical model of the geological medium is endowed with anisotropic properties, which makes it possible to increase the adequacy of the obtained numerical results to the specifics of the real problem. Secondly, instead of the simplest bilinear 4-node finite elements, the special spectral non-algebraic 8-node finite iso-parametric finite elements are used, the use of which significantly increases both the accuracy of calculations and their reliability in the sense of ensuring the robustness of calculations for relatively small values of the plate thickness. It should be noted that the Finite Element Method uses exclusively only algebraic finite elements (power polynomials in the h-version and orthogonal polynomials in the p-version). It is known from approximation theory that the use of spectral non-algebraic approximations improves the quality of approximations. Therefore, their introduction into the structure of finite element calculations can improve the quality of modeling in the study of the strain-stress-state (SSS) of the geological medium. A structural block (SB) is understood as a plate layer with plan dimensions exceeding the thickness by more than 10 times. The identification of hazardous zones in the rock massive due to stress concentration is complemented by the development of mechanical, mathematical and computational tools for modeling the curvature of the earth's crust during bending based on the classical theory of Kirchhoff and refined Reissner-Mindlin theory. Test calculations have shown that the accuracy of the calculation and the quality of geometric modeling of fragments of an anisotropic geological environment based on the refined 8-node spectral finite element is significantly better than for the 8-node algebraic finite element.**

Keywords – stability of geological environment, radioactive waste, bending of a Reissner-Mindlin plate of medium thickness, finite element method.

I. INTRODUCTION

In our case, the structural block (SB), in which it is planned to place the radioactive waste, can be represented in the first approximation as a plate of finite thickness (with the ratio of its thickness to characteristic length less than 1/20) using the classical Kirchhoff model or the refined Reissner-Mindlin model [1] for plates with a relatively thicker thickness (with a ratio greater than 1/20, which are called medium-thickness plates). In addition, an analysis of the deformation of the surface upper layer is introduced, idealized using a refined (allowing to take into account the effect of a small parameter of relative thickness and transverse shear deformation) bending model for very thin plate layers with a ratio of the average size to thickness of about 10000. This leads to finite element modeling for very stiff computational schemes that require appropriate approaches to obtain a reliable solution. In this regard, the identification of hazardous zones in the rock mass due to the stress concentration caused by the nature of the change in SSS is complemented by the development of mechanical-mathematical and computational algorithms and modeling tools based on the theories of

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Kirchhoff and Reissner-Mindlin formulations [2].

II. RESULTS AND DISCUSSION

Spectral Shape Functions for an 8-Node Finite Element

In a rectangular Cartesian coordinate system xy, consider a curvilinear finite element (Fig. 1), all nodes of which are numbered from 1 to 8.

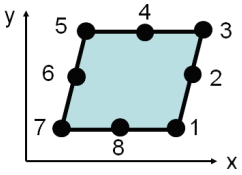

Fig.1. Iso-parametric 8-node finite element in the physical plane with the numbering of nodes.

In another rectangular Cartesian coordinate system $\xi\eta$, we introduce an auxiliary square with side 2 (Fig. 2). On the sides of this square, select eight points in accordance with the number of nodes of the finite element.

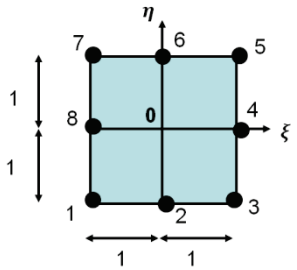

Fig. 2. Generating (Master) 8 – node element in the computational plane.

The constructed non-algebraic shape functions ψ_r (ξ, η) for r = (1, 8) take the form [11-13]

$$\psi_r = \psi_r^{(1)} + \psi_r^{(2)} \quad (r = \overline{1,8})$$

$$\psi_1^{(1)} = (1-t)(1-z), \qquad \psi_3^{(1)} = (t)(1-z),$$
$$\psi_5^{(1)} = (t)(z), \psi_7^{(1)} = (1-t)(z),$$
$$\psi_r^{(1)} = 0, (r = 2,4,6,8)$$
$$\psi_2^{(2)} = \chi_{11}(z)\sin\pi t, \qquad \psi_4^{(2)} = \chi_{21}(t)\sin\pi z,$$
$$\psi_6^{(2)} = \chi_{21}(z)\sin\pi t,$$
$$\psi_8^{(2)} = \chi_{11}(t)\sin\pi z,$$
$$\psi_1^{(2)} = -1/2(\psi_2^{(2)} + \psi_8^{(2)}), \psi_3^{(2)} = -1/2(\psi_2^{(2)} + \psi_4^{(2)}),$$
$$\psi_5^{(2)} = -1/2(\psi_4^{(2)} + \psi_6^{(2)}), \psi_7^{(2)} = -1/2(\psi_6^{(2)} + \psi_8^{(2)}),$$
$$\chi_{11}(z) = -e^{-\alpha}c_1 + e^{-\alpha z}c_{21}, \chi_{21}(z) = e^{-\alpha(1-z)}c_{21} + e^{-\alpha z}c_{11},$$
$$c_{11} = -e^{-\alpha}c_{21}, c_{21} = (1 - e^{-2\alpha}\alpha = 2\sqrt{2},$$
$$\alpha = 2\sqrt{2}, t = (1+\xi)/2, z = (1+\eta)/2 \qquad (1)$$

Non-algebraic solution method

A plate SB is understood as a layer with plan dimensions **a** exceeding the thickness **h** by more than 10 times. The calculation is based on the previously developed original problem-oriented finite element software complex together with a set of programs for modeling the SSS of a heterogeneous medium [5], supplemented by the methodology of energy analysis of stress concentration for the problems of geodynamic zoning for the model of the plane problem of the theory of elasticity (generalized plane stress state) [6]. In this case, the problem is solved for a thin plate layer and a layer of a plate of medium thickness, which is a transitional option for further approximation to the 3D formulation of the solution to the problem of predicting the stability of the SB. An analysis of our earlier calculations of hazard levels using four criteria for a plane problem showed that the determining factors here are not the stress values themselves (which for the elastic model at the tops of cracks and faults can take any large values), but the integral characteristics of the stress concentration. The scheme for solving these problems is reflected in [4, 6-7].

It is required to find the components of the stress strain tensors in the plate layer.

The results are, within the framework of the accuracy of the involved mechanical and mathematical modeling, recommendations are formed on the stability and safety of the insulating properties of the medium within the investigated SB.

Modeling the action of an energy impulse

The case of the impact of an instantaneous point energy impulse is described in detail in [1]. The superposition principle makes it possible to consider the solution of the problem of plate bending from the action of a point energy impulse under the simply supported boundary conditions. To simulate (within the framework of the formulation of the boundary value problem) the action of an instantaneous energy impulse on the plate, we will use the energy-force analogy due to the law of conservation of energy. For this, we first solve the following problem of plate bending due to the action of a unit concentrated force 1 (ξ, η) applied at a point (ξ, η).

As a result of the action of a concentrated unit force, the internal forces in the plate will produce work equal to the work of the applied external force on the displacement caused by it:

$$A_1 = 1/2 \times 1 \times \omega(\xi,\eta) \qquad (2)$$

This work, according to the law of conservation of energy, will transform into the potential energy of deformation of the plate

$$U_1 = A_1 \qquad (3)$$

Let an energy impulse with amplitude J (ξ, η) act at some point on the plate (ξ, η).

We introduce the ratio of energy quantities

$$\Lambda = J(\xi,\eta/U_1) \qquad (4)$$

Then the magnitude of the impulse will be expressed through the magnitude of the potential energy:

$$J(\xi,\eta/U_1) = \Lambda \times U_1 \qquad (5)$$

If the value of the concentrated force at the point (ξ, η) is equal to Λ, then the value of the accumulated potential energy of deformation will be U_Λ:

$$U_\Lambda = \Lambda \;\; U_1 \qquad (6)$$

From (2) - (6) it follows that the concentrated force of the quantity Λ at the point (ξ, η) accumulates in the plate an energy equal to the energy impulse acting at the same point. As a result, the stress-strain state of the plate is found from the action of a point energy (for example, seismic) impulse. Thus, an energy-force analogy is

realized, which allows simulating concentrated energy impulses using concentrated shear forces during bending of simply supported polygonal plates [1].

Refined Reissner-Mindlin theory for anisotropic plates

The initial formulation of the problem of bending of medium and small thickness h under the action of transverse loads and instantaneous energy impulse with Reissner-Mindlin kinematics, which correspond to the occurrence of vertical displacement ω and two rotation angles $\theta_i (i = 1,2)$ of the normal to the original undeformed median plane of the plate: $\{\omega, \theta_i\}$ is reflected in [2]. In the refined Reissner-Mindlin theory [2], three independent degrees of freedom are used: ω - deflection; θ_x , θ_y – rotations angles. Here: $\{w, \theta_i\ (i = 1, 2)\} = \{w, \theta_x, \theta_y\}$ are the required field functions.

According to the Reissner-Mindlin formulation, the displacements are:

$$u_x = z\theta_x(x, y), u_y = z\theta_y(x, y), w = w(x, y) \quad (7)$$

Represent field functions by using shape functions

$$w = \sum_{r=1}^{8} \psi_r(\xi, \eta) w_r,\ \theta_x = \sum_{r=1}^{8} \psi_r(\xi, \eta)\theta_{xr},\ \theta_y = \sum_{r=1}^{8} \psi_r(\xi, \eta)\theta_{yr}, \quad (8)$$

Here w_r , θ_{xr} , θ_{yr} – degrees of freedom. Using the iso-parametric approach, we associate each point of the computational square (Fig. 2) with some point of the original finite element (Fig. 1), putting

$$x = \sum_{r=1}^{8} \psi_r(\xi, \eta) x_r,\ y = \sum_{r=1}^{8} \psi_r(\xi, \eta) y_r, \quad (9)$$

where x_r, y_r are corresponding coordinates of the nodes.

A typical block of the stiffness matrix of the element $[K_{rs}^e]$ will be written as the sum of the bending and shear parts [11-13]

$$[K_{rs}^e] = [K_{rs}^e]\text{b} + [K_{rs}^e]\text{s}$$

$$[K_{rs}^e]\text{b} = \int_{-1}^{1}\int_{-1}^{1} D_1 [\beta_r] b^T [\kappa] b [\beta_s] b |[J(\xi, \eta)]| d\xi d\eta$$

$$[\beta r]_b = \begin{bmatrix} 0 & \partial\psi_r/\partial x & 0 \\ 0 & 0 & \partial\psi_r/\partial y \\ 0 & \partial\psi_r/\partial y & \partial\psi_r/\partial x \end{bmatrix}$$

$$[\beta r]_s = \begin{bmatrix} \partial\psi_r/\partial x & \psi_r & 0 \\ \partial\psi_r/\partial y & 0 & \psi_r \end{bmatrix}$$

$$[\kappa] = \begin{bmatrix} 1 & \mu_2 & 0 \\ \delta_2\mu_1 & \delta_2 & 0 \\ 0 & 0 & \delta_G(1 - \mu_1\mu_2) \end{bmatrix}, \quad (9)$$

where

$$D_1 = \frac{E_1 h^3}{12(1 - \mu_1\mu_2)}$$

$$\delta_2 = \frac{E_2}{E_1},$$

$$\delta_G = \frac{G}{E_1},$$

$$\mu_2 = \delta_2\mu_1 \quad (10)$$

Here E_1, E_2 – young's moduli for tension-compression in the main directions *x, y* [14]; G – shear modulus; μ_1 – poisson's ratio, characterizing the contraction in the *y* direction when stretching-compressing in the *x* direction; *h* is the thickness of the plate; | [J (ξ, η)] | - modulus of the determinant of the Jacobi matrix [2]; the top "T" symbol stands for transposition.

The shape functions for the corner points of the constructed eight-node finite element are represented by the sum of bilinear and non-polynomial terms (for intermediate nodes, there are only non-polynomial functions). However, it is known [2] that a bilinear finite element can lead to "locking" when the plate becomes thinner due to a strong shear stiffening of the resolving system of finite element equations. Therefore, it seems appropriate to express the shear part of the stiffness matrix (9) as a sum of four terms, the first three of which contain integrals of bilinear functions or their products by non-polynomial functions, and the last term is an integral of only a non-polynomial function:

$$[K_{rs}]s = \sum_{i=1}^{2}\sum_{j=1}^{2} \delta_G E_1 \int_{-1}^{1}\int_{-1}^{1} h[\beta_r^{(i)}][\beta_s^{(j)}]^T |[J]| d\xi_i d\eta_j \begin{bmatrix} \frac{\partial\psi_r^k}{\partial x} & \psi_r^{(k)} & 0 \\ \frac{\partial\psi_r^k}{\partial y} & 0 & \psi_r^{(k)} \end{bmatrix} \quad (11)$$

The fundamental difference between the obtained representation (11) and the original (9) lies in the important possibility to perform integration for each of the four terms separately - according to its specially constructed quadrature formulas.

The variation formulation of the problem consists in finding a solution that satisfies the conditions of equality to zero of the first variation of the total potential energy of the plate and the strict positivity of the second variation:

$$\delta\Pi = 0;\ \delta^2\Pi > 0 \quad (12)$$

Here P = U + A is the total potential energy of the plate, U is the potential energy of deformation, A is the work of external forces.

The calculation of anisotropic plates will be carried out using the example of square plates with homogeneous (Fig. 3, a) and mixed (Fig. 3, b) boundary conditions.

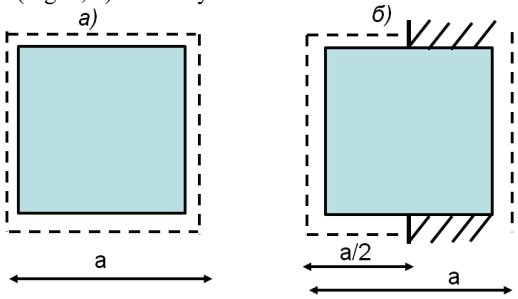

Fig. 3. Plates with different boundary conditions:
a) a simply supported plate; b) mixed: partially supported.

Results of finite element analysis of an anisotropic Reissner-Mindlin plates

The calculation of thin Reissner-Mindlin plates by the finite element method causes significant computational difficulties associated with the rigidity (stiffening) of the resolving system of linear algebraic equations and

leading to the "locking" of the sought solution at the displacement and potential energy levels [2] close to zero.

The following conclusions can be drawn that with an increase in the number of finite elements:

1) For plates of medium thickness, the values of the solution are obtained, although they differ from the desired deflections, but do not tend to zero and partially reflect the change [2] of the exact solution depending on the thickness of the plate.

2) With a further decrease in thickness, solution values are obtained that rapidly tend to zero.

The general conclusion here is that exact integration of stiff matrix for the finite elements of the Reissner-Mindlin plates does not allow obtaining satisfactory values for the desired solution in the case of sufficiently thin plates. In order to improve the quality of the solution, finite element calculations were performed on the same mesh using reduced (non-exact) integration. The calculation results show that the reduced integration scheme, in contrast to the exact integration scheme, gives rather good results approaching the exact value on the meshes. It is essential that in this case it is possible to take into account the effect of thickness on the parameters of plate deformation. However, such a scheme is not robust: for weakly coupled boundaries, it leads to zero energy modes, to eliminate which stabilizing finite elements were built [2, 8-10].

Finally, in order to further increase the accuracy of finite element calculations, we use a selective-reduced integration scheme with decomposition [11], where the bending part of the potential energy is integrated according to the 4-point Gauss-Legendre quadrature formula ("exact integration"), and the shear part - according to the one-point quadrature formula ("approximate integration") with the decomposition of shear stiff matrix [11-13].

Numerical experiments for an 8-node spectral finite element confirmed the reliability of the proposed decomposition of the shear stiffness matrix and revealed the following effective numerical integration scheme: for the first three integrals in (11), one should use the one-point Gauss-Legendre formula (1x1), and for the latter, the four-point (2x2). Since the application of such a procedure for the bending part of the stiffness matrix did not lead to practical results, the traditional integration over nine (3x3) Gauss-Legendre points was used there. Attempts to construct other numerical integration schemes for the considered non-algebraic finite element were unsuccessful: the element was "locked" with the plate refinement (the proposed procedure turned out to be completely useless for an eight-node quadratic algebraic serendipity finite element due to the fundamental impossibility of such a division in polynomial shape functions).

This is illustrated by the results for composite plate layers of an anisotropic layered material composed of orthogonally oriented fibers with mechanical parameters corresponding to the properties structure of a composite type of glass fibers impregnated with resin with the following stiffness parameters [14]: $E_1 = 1.6 \times 10^{11}$ Pa, $E_2 = 2.6 \times 10^{11}$ Pa, G= 0.42×10^{11} Pa.

Figure 4 shows curves characterizing the value of the maximum dimensionless deflection $W_C/(\frac{Pa^2}{D_1})$ of a square, simply supported anisotropic plate, which is under the action of a concentrated energy impulse P, depending on the parameter of the relative thickness. The dotted lines represent the solutions obtained on a 4 x 4 finite element mesh, and the solid lines represent the 6 x 6 mesh.

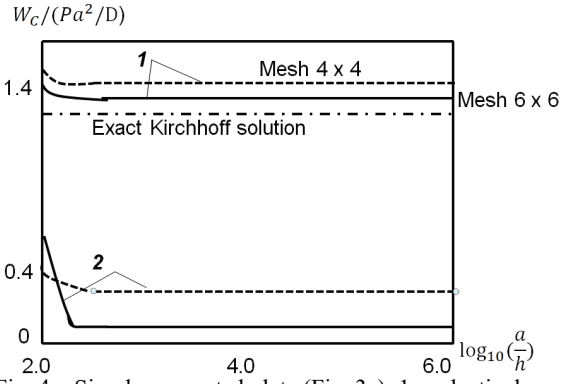

Fig. 4. Simply supported plate (Fig. 3a): 1 - selectively reduced integration with decomposition stiff matrix; 2 - exact integration.

Number 1 corresponds to the use of the proposed scheme of selectively reduced integration with preliminary decomposition of the shear part of the stiffness matrix, and number 2 corresponds to the solutions obtained using the well-known integration scheme [2]: 3 x 3 points for the bending part and 2 x 2 points for the shear part stiffness matrices. The dash-dotted line here corresponds to the value of the exact solution for the classical Kirchhoff theory of bending as applied to a simply supported square plate, obtained using double Fourier sine series and having the next form:

$$\frac{(w_c)}{Pa^2/D_1} = \frac{4}{\pi^4} \sum_{m=1,3,5,\ldots}^{\infty} \sum_{n=1,3,5,\ldots}^{\infty} (-1)^{m-1}(-1)^{n-1} \frac{1}{(m^4 + 2\delta_3 m^2 n^2 + \delta_2 n^4)}$$

$$\delta_3 = \mu_2 + 2\delta_G(1 - \mu_1\mu_2$$

Fig. 5 reflects the dependence of the dimensionless central deflection for a plate with mixed (discontinuous) boundary conditions (Fig. 3b): when plate is clamped along the halves of two opposite sides and simply support on the remaining sections of the boundary. Here, the solid line corresponds to the use of the generated non-polynomial shape functions for the proposed scheme of selectively reduced integration with preliminary decomposition of the shear part of the stiffness matrix, and the dashed line to the use of an eight-node algebraic serendipity finite element with the known scheme of selectively reduced integration. The results were obtained on a 6 x 6 finite element mesh and are similar to the previous results (Fig. 3). For a quadratic algebraic serendipity finite element, usually effective selectively reduced integration does not exclude shear "locking" for

very thin plates with a complex nature of the boundary conditions, what is consistent with [2]. The dot-and-dash line presents the solution obtained by the analytical method of dual equations for Kirchhoff model [14].

Comparison of the above results testifies to the efficiency of using the constructed 8-node non-polynomial finite element based on the proposed selective-reduced scheme with preliminary decomposition of the shear part of the stiffness matrix and the implementation of the possibility of adjustable selection of quadrature points in numerical integration.

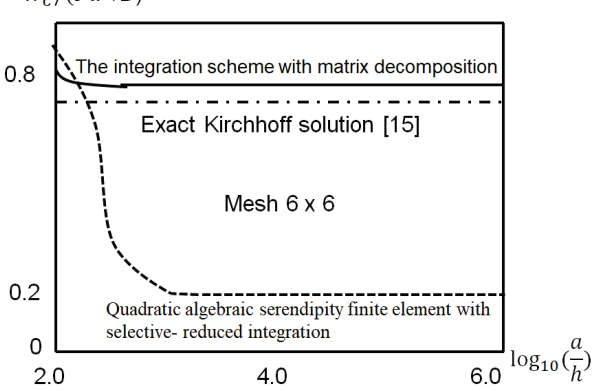

Fig. 5. Partially supported plate: Fig. 3b.

III. CONCLUSION

As a result of the research:

- effective refined finite elements of the Reissner-Mindlin plates under the action of an instantaneous energy impulse have been implemented, which expand the capabilities of the previously created software for calculating the stress-strain state of a heterogeneous anisotropic geological medium and can form the basis of the new software packages for applications;
- computational finite element tools for calculating very thin plates and nano-films (the ratio of the side length of the plate to its thickness of the order of: ten thousand, one hundred thousand and one million) in bending;
- the accuracy of the calculation and the quality of geometric modeling of complex fragments of the geological medium on the basis of an 8-node spectral non-algebraic finite element have been significantly increased.

IV. ACKNOWLEDGMENTS

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REFERENCES

[1] Kolesnikov I.Yu., Tatarinov V.N. Stability of the geological environment under the action of bending loads and concentrated energy impulses. GIAB. Mining Information and Analytical Bulletin, 2019 (9): 149-159.

[2] O.C. Zienkiewicz, R.L. Taylor. The Finite Element Method. Vol. 1, 1989; Vol.2, 1991. McGRAW-HILL BOOK COMPANY. London-New-York.

[3] Babenko K.I. Fundamentals of Numerical Analysis. Moscow: Nauka, 1986. 744 p.

[4] Anderson E.B., Belov S.V., Kamnev E.N., Kolesnikov I.Yu., Lobanov N.F., Morozov V.N., Tatarinov V.N. Underground isolation of radioactive waste. Moscow: Gornaya Kniga Publishing House, 2011.592 p.

[5] Kolesnikov I.Yu., Morozov V.N., Tatarinov V.N. Program for calculating the stress-strain state in a rock mass based on heterogeneous finite element modeling "GEODYN 1.0": Reg. No. 2011614290. 2011.

[6] Kolesnikov I. Yu., Morozov V.N., Tatarinov V.N., Tatarinova T.A. Stress-deformed energy zoning of the geological environment for the placement of ecological infrastructure facilities. Innovatics and Expertise. No. 2 (20), 2017, pp. 77-88.

[7] Tatarinov V.N., Morozov V.V., Kolesnikov I.Yu., Kagan A.I., Tatarinova T.A. Stability of the geological environment as the basis for safe underground isolation of radioactive waste and spent nuclear fuel. Reliability and Safety of Power Engineering. 2014. No. 1 (24), pp. 25-29.

[8] Zhang Y., C. Yang. Recent developments in finite element analysis for laminated composite plates. Composite structures. 2009 (88): 147-157.

[9] Wan D., Hu D., Long T. A linear smoothed quadratic finite element for the analysis of laminated Reissner-Mindlin plates. Composite Structures. 2017 (180): 395-411.

[10] Sprague M., Purkayastha A. Legendre spectral finite element for Reissner-Mindlin plates. Finite Elements in Analysis and Design. 2015 (105): 33-43.

[11] Gorshkov A.G., Kolesnikov I.Yu. Finite Elements Based on the Complete Family of Nonpolynomial Defining Shape Functions for an Arbitrary Number of Boundary Nodes. Izv. RAS. Solid mechanics. No. 1. 1998, pp. 116-129.

[12] Kolesnikov I.Yu. Kirchhoff coordination of field functions in finite elements of Reissner-Mindlin plates by controlling the spectral functions of the shape. Proceedings of the XXI All-Russian Conference "Theoretical Foundations of Designing Numerical Algorithms and Solving Problems of Mathematical Physics" dedicated to the memory of K.I. Babenko. Moscow: Institute of Applied Mathematics, RAS named by M.V. Keldysh, 2016, pp. 43-44.

[13] Kolesnikov I.Yu. Expansions into finite series on complete systems of spectral non-algebraic shape functions and applications. Proceedings of the International Conference "Analytical and numerical methods for solving of hydrodynamics, mathematical physics and biology problems", dedicated to the 100th of KI Babenko (Pushchino, 26–29 August, 2019), Keldysh Institute of Applied Mathematics RAS, 2019, pp. 86-87.

[14] Tseitlin A.I., Glikman B.T. The bending of an elastic rectangular plate with mixed boundary conditions. Trudy TsNII Stroitel'nykh Konstruktsii, Vol. 17, 1971, pp. 123-143.

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Features of Weediness of the Field by Root Residues of Corn

Mykola Korchak
Faculty of Engineering and Technology
State Agrarian and Engineering University in Podilia,
Kamianets-Podilskyi, Ukraine
korchak_nikolay@ukr.net

Serhii Yermakov
Educational and Scientific Laboratory "DAK GPS",
State Agrarian and Engineering University in Podilia,
Kamianets-Podilskyi, Ukraine
dakgps@pdatu.edu.ua

Taras Hutsol
Institute of Energy,
State Agrarian and Engineering University in Podilia,
Kamianets-Podilskyi, Ukraine
pro-gp@pdatu.edu.ua

Lesya Burko
Agrobiological Faculty,
National University of Life and Environmental Sciences of Ukraine,
Kyiv, Ukraine

Weronika Tulej
Institute of Mechanical Engineering
Warsaw University of Life Sciences – SGGW
Warsaw, Poland

***Abstract* - The presence of a large amount of root residues after harvesting corn creates problems for the processing of the field. On the basis of field and laboratory studies, the character of weediness and the main physical and morphological characteristics of rhizomes were revealed. Analysis of the variation curves of the dimensional characteristics of root residues and the mass graphical dependences of rhizomes made it possible to develop a general approach to freeing fields from plant residues of corn.**

Keywords - weediness of the field, root residues, corn, ground part, rhizome.

I. INTRODUCTION

The existing knowledge regarding the use of plant residues of maize for energy purpose gives reason to determine the urgent tasks of research on this problem. The main ones are:

– development of a yearbook for the study of the nature of weediness of the field by plant residues of corn and methods for processing experimental data;

– development of methods for the efficient use of plant residues in energy production;

– the development of field processing methods after harvesting corn and other thick-stemmed crops;

– development and creation of appropriate agricultural machinery.

Common shortcomings in the work of research institutions conducting research on the effective use of plant residues are insufficiently comprehensive research, as well as, insufficient effectiveness of coordination of scientific work.

The capacity of the corn root system largely depends on the nature of the soil and its moisture: on loosened and moderately moist soils the root system develops better than on dense and very moist, as well as excessively dry soils.

Scientific research is devoted to processing problems [3, 4]. They have proposed a mechanized technology the essence of which lies in multi-pass disking in different directions with heavy disk tools.

Milling solid is considered more efficient [5,6]. Scientists of NRC (National Research Center) "Institute for Mechanization and Electrification of agriculture" (settlement of town type Glevakha) after to pre-crush surface leaf and stem mass by forager drums.

The only rational recommended mechanized technology of grinding leaf-stem and root mass before the tillage of the soil is absent in Ukraine. Therefore there is an acute production problem that requires a scientific and applied solution.

In solving this problem at the first stage, we see the classical scheme, namely:

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– study of the processing object;

– analysis of existing methods and studies of studying the contamination of the field by root residues;

– – conducting research on fixing the quantitative and qualitative characteristics of rhizomes and ground parts of corn;

– – data processing and search for solutions to free the field from corn residues.

Some studies of the state of weediness of the field after harvesting corn were considered by the authors earlier [7-9].

The main purpose of field contamination is: a study of the processing object of root residues as elements that need to be crushed in time and embedded into the soil.

The list of issues under study includes: determination of the dimensional characteristics of rhizomes and ground parts, study of corn rhizomes to determine the location of their bulk and the required depth of processing.

The results obtained will be the basis for further engineering decisions for developing machine designs, selecting a technological scheme; determining technological parameters.

II. MATERIALS AND METHODS

To find ways and means of solving this problem you should carefully examine the state of the field.

Stubble after corn harvesting was chosen as the field littered by root residues of thick-stem crops.

The technique of conducting research into the nature of the field contamination by root residues of corn is shown in Figure 1.

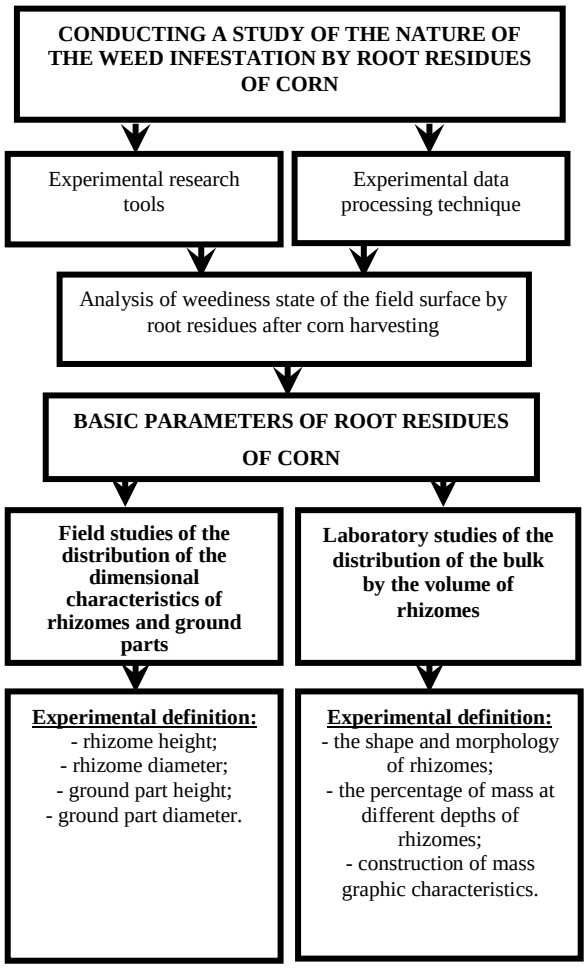


Fig. 1. Methods of researching the nature of the field contamination by root residues of corn

Experimentaly there were determined (Figure 2):

1. Plant residues diameters:
– rhizomes diameters $d_к$;
– ground parts diameters $d_н$;
2. Plant residues height:
– rhizomes height (provisionally) $h_к$;
– ground parts height (provisionally) $h_н$.

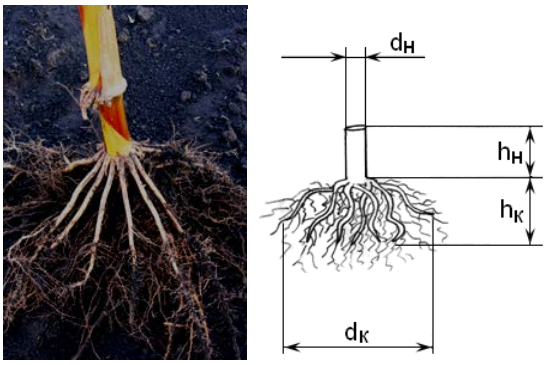


Fig. 2. Measurements scheme rhizomes: dк – rhizome diameter, dн – ground part diameter, hk – rhizome height; hg – ground part height.

Planning tests and processing the results obtained was carried out according to the existing techniques of field and engineering experiments [8]. Measurement variability of the object studied was determined by variant rows and variant curves.

III. RESULTS AND DISCUSSION

Useful experimental studies of the weediness of the field by root residues of thick-stem crops were carried out on the experimental field of Podolsky state agrarian and technological university.

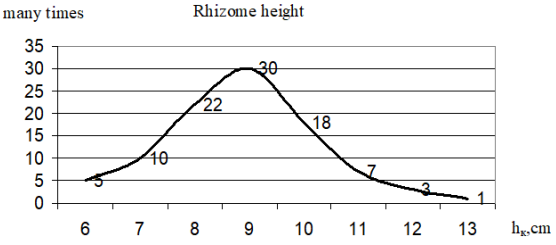
Soil type – chernozem (black earth zone) ordinary, slightly humus. Background – stubble after corn harvesting.

Processing the experimental data according to the method described above, a series of variation curves was obtained from which above given parameters were calculated.

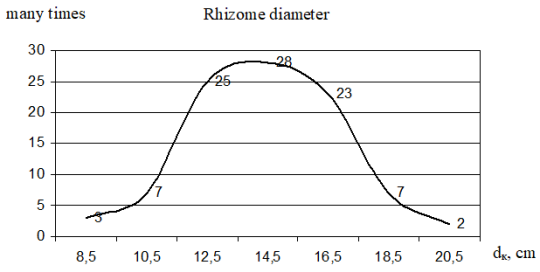
The research results are as follows:

a) Results of the distribution of dimensional characteristics of rhizomes and ground parts.

– Characteristics of the height and diameter of the rhizome (Fig. 3).



a)



b)

Fig. 3. Research results: a) rhizome height (Mc = 8,9 cm; σ = 1,4 cm); b) rhizome diameter (Mc = 14,4 cm; σ = 2,5 cm)

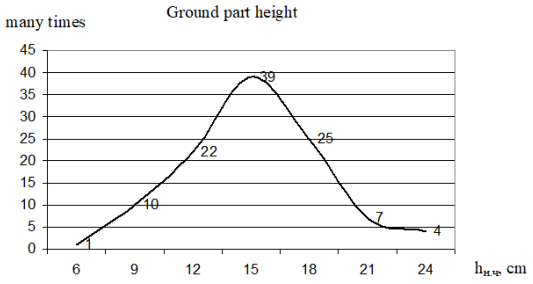
Examining the research data found: $h_{к\ max}$, $h_{к\ min}$, $d_{к\ max}$, $d_{к\ min}$.

h_{max} = 13cm, h_{min} = 6cm, d_{max} = 20cm, d_{min} = 8,5cm.

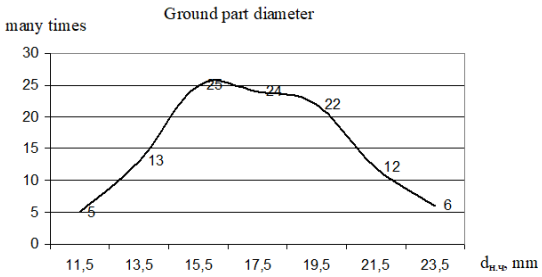
– Characteristic of the height and diameter of the ground part (Fig.4).

When examining research data there were found: $h_{н.ч.\ max}$, $h_{н.ч.\ min}$, $d_{н.ч.\ max}$, $d_{н.ч.\ min}$.

$h_{н.ч.\ max}$ = 24 cm, $h_{н.ч.\ min}$ = 6 cm, $d_{н.ч.\ max}$ = 24 mm, $d_{н.ч.\ min}$ = 11 mm.



a)



b)

Fig. 4. Figure 4. Research results: a) ground part height (Mc = 15,2 cm; σ = 3,7 cm); b) ground part diameter (Mc = 17,5 mm; σ = 3,0 mm)

b) Research of maize rhizomes to determine their main mass location and the required depth of cultivation was carried out in laboratory conditions on samples taken on separate experimental plots.

Calculations were carried out according to the formula:

$$m_{(0...n,\%)} = \frac{m_{(0...n)}}{m_{кор}} \cdot 100 \qquad (1)$$

where $(m_{0...n}, \%)$ – the percentage of mass at a depth of *0* to *n* cm, %;

$m_{(0...n)}$ – rhizomes mass for each centimeter from 0 to n cm, g;

m_{tot} – total mass of a rhizome, g.

The results of calculations are shown in Fig. 5.

1-st sample

Rhizome mass $m_{кор}$=42 gr.

2-nd sample

Rhizome mass $m_{кор}$=38 gr.

$m_{(0-8см)} = 37 гр; m_{(9-18см)} = 5 gr$

$m_{(0-8см,\%)} = \frac{m_{(0-8см)}}{m_{кор}} \cdot 100 = \frac{37}{42} \cdot 100 = 88\%$

$m_{(9-18,\%)} = \frac{m_{(9-18см)}}{m_{кор}} \cdot 100 = \frac{5}{42} \cdot 100 = 12\%$

3-d sample

$m_{(0-8см)} = 31 гр; m_{(9-18см)} = 7 gr$

$m_{(0-8см,\%)} = \frac{m_{(0-8см)}}{m_{кор}} \cdot 100 = \frac{31}{38} \cdot 100 = 82\%$

$m_{(9-18,\%)} = \frac{m_{(9-18см)}}{m_{кор}} \cdot 100 = \frac{7}{38} \cdot 100 = 18\%$

4-th sample

Rhizome mass $m_{кор}$=34 gr.

Rhizome mass $m_{кор}$=32 gr.

$m_{(0-8см)} = 29 гр; m_{(9-18см)} = 5 gr$

$m_{(0-8см,\%)} = \frac{m_{(0-8см)}}{m_{кор}} \cdot 100 = \frac{29}{34} \cdot 100 = 85\%$

$m_{(9-18,\%)} = \frac{m_{(9-18см)}}{m_{кор}} \cdot 100 = \frac{5}{34} \cdot 100 = 15\%$

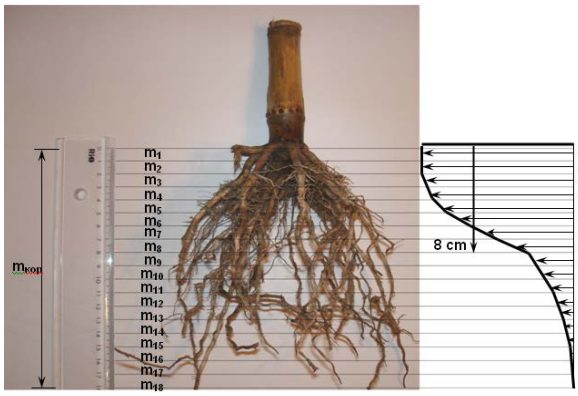
$m_{(0-8см)} = 26 гр; m_{(9-18см)} = 6 gr$

$m_{(0-8см,\%)} = \frac{m_{(0-8см)}}{m_{кор}} \cdot 100 = \frac{26}{32} \cdot 100 = 81\%$

$m_{(9-18,\%)} = \frac{m_{(9-18см)}}{m_{кор}} \cdot 100 = \frac{6}{32} \cdot 100 = 19\%$

Fig. 5. Corn rhizomes during research in the laboratory

After calculations a mass diagram was constructed for each centimeter of rhizomes distribution (Fig. 6).



a) b)

Fig. 6. Study of corn rhizomes to determine the location of the main mass and the required processing depth: a – rhizome, b – a mass diagram

Experimental data of rhizomes showed that the bulk of the roots is at a depth of 8 cm. So, the depth of processing when conducting useful research is chosen in the range from 2 to 8 cm.

On the basis of studies of the state of contamination a method has been developed for cultivation a field clogged with plant residues of thick-stem crops and shredder for its implementation [10-15]. The novelty of technical decisions was confirmed by patens of Ukrainian invention [16, 17].

IV. CONCLUSIONS

As a result of the research conducted on the state of the field weediness by rhizomes and their ground part the following was revealed:

- the variance or standard deviation of all measurements is quite significant that is significant variation of parameters (within M = 3±σ);

- the medium-arithmetic development of height of the rooster (rhizome) M_c = 8,9 cm with with variation curve is visible that the basic part of the heights lies in the limits of 7,5 – 10 cm. This indicates that for treatment (cultivation) of the rooting system considering the degree of crushing, it is enough to enhance the working body in 8…9 cm;

- average arithmetic deviation of the diameter of the rhizome M_c = 14,4 cm, and the main part of measurements lies within 12,5…18,5 cm; therefore the required row cultivation width is at least 20cm;

- diameter of the ground part varies widely the main part of measurements is 15…20cm and reaches a maximum of 24cm. This should be considered when choosing the method of grinding and the working body;

- the average value of the height of the ground part (cutting height) is 15,2cm which meets the agrotechnical requirements of corn harvesting.

2. Considering the obtained statistical quantitative data of debris and their quantitative characteristics:

- the presence of a large amount of crop residues makes it difficult to cultivate the soil and worsen the further use of the field which requires carrying out operations to free the fields from coarse plant residues, more over, given the fibrous structure of corn stalks, it can be concluded that for grinding the corn crop residues it is necessary to use working bodies that cut rather than break the stems, provide a sufficient degree of grinding, good sealing and mixing with the soil.

- processing to free the field from root residues, as noted above, must be carried out to the depth of the main roots. Since the energy consumption of the process is directly proportional to the processing depth, the processing depth must be taken within 7...9cm.

REFERENCES

[1] Boyko P.I. Corn (Maize) in intensive crop rotation. Kyiv: Urozhay, 1990.

[2] Godulyan I.S. Maize in crop rotations. Kyiv: Urozhay, 1977.

[3] Godulyan I.S. Rational crop rotations – basis of high yield. Dnepropetrovsk: Promin', 1972.

[4] Ilchenko V.Yu., Nagirny Yu.P. Machine use in agriculture Kyiv: Urozhay, 1996.

[5] Lystopad G.E., Demidov G.K. and Zonov B.D. Agricultural and land reclamation machines. Moskow: Kolos, 1976.

[6] Korchak M.M. and Yermakov S.V. "Study of the nature of the field weediness with leafy and root residues after harvesting corn". Collection of scientific papers of the Podolsky State Agrarian and Technological University. Kamenets-Podolsky, 2007. pp. 498 – 504.

[7] Korchak M., Yermakov S. and Maisus V., Eds. "Problems of field contamination when growing energy corn as monoculture". E3S Web of Conferences. Krynica, Poland. 6th International Conference – Renewable Energy Sources. Volume 154. 2020.

[8] Sheichenko V., Marynchenko I. and Dudnikov I., Eds. "Development of technology for the hemp stalks preparation". Independent Journal of Management and Production // State

agrarian and engineering university in Podilia. – V. 10, № 7, p. 687 – 701 (ISSN: 2236-269X)

[9] Korchak M.M. "Development of a combined method and a grinder for soil littered by plant residues" Visnyk of Lvivsky national agrarian university: Agrarian and engineering research. № 13, volume 1. Lviv, 2009 pp.155 – 163.

[10] Korchak M.M. "Substantiation of the technological functional model of the method of tillage after harvesting rough-stem crops". Collection of scientific and research works. Podilsky Agrarian and Engineering University. Edition 24, part 2. Kamyanets-Podilsky, 2016. pp. 165 – 174.

[11] Korchak M., Dudchak T., Vilchinska D. "Theoretical substantiation of the working body for soil alignment". Zhytomyr State Technological University. Series: Engineering, V. 1, 2019. pp. 69-75.

[12] Yermakov S., Mudryk K. and Hutsol T., Eds. "The analysis of stochastic processes in unloadingthe energywillow cuttings from the hopper". Environment. Technology. Resources. Rezekne, Latvia. Proceedings of the 12th International Scientific and Practical Conference. Volume III. 2019. pp. 249-252, https://doi:10.17770/etr2019vol3.4159

[13] Ivanyshyn V., Yermakov S. and, Ishchenko T., Eds. "Calculation algorithm for the dynamic coefficient of vibro-viscosity and other properties of energy willow cuttings movement in terms of their unloading from the tanker". Proceedings of 6 th International Conference – Renewable Energy Sources, vol. 154, E3S Web of Conferences. 2020. pp. 04005. https://doi:10.1051/e3sconf/202015404005

[14] Tryhuba A., Hutsol T. and Glowacki S., Eds. "Forecasting Quantitative Risk Indicators of Investors in Projects of Biohydrogen Production from Agricultural Raw Materials". Processes 2021, 9, 258. https://doi.org/10.3390/pr9020258

[15] Tryhuba A, Hutsol T. and Tryhuba I, Eds. "Risk Assessment of Investments in Projects of Production of Raw Materials for Bioethanol". Processes. 2021; 9(1):12. https://doi.org/10.3390/pr9010012

[16] The way of releasing field from plant residues of rough-stem crops. Patent 90538, Ukraine, № a2008 04264; application 04.04.2008; published 11.05.2010, Bulletin № 9.

[17] Combined grinder of plant residues of rough-stem crops. Patent 90535, Ukraine, № a2008 03070; application 11.03.2008; published 11.05.2010, Bulletin № 9.

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Ecological and Economical Substatiation of Production of Hydrogen

Nataliia Kovalenko
Faculty of Agrarian management
National University of Life and Environmental Sciences of Ukraine
Kyiv, Ukraine
n.kovalenko@it.nubip.edu.ua

Taras Hutsol
Institute of Energy,
State Agrarian and Engineering University in Podilia,
Kamianets-Podilskyi,Ukraine
pro-gp@pdatu.edu.ua

Oleksander Labenko
Economical Faculty
National University of Life and Environmental Sciences of Ukraine
Kyiv, Ukraine
labenko@nubip.edu.ua

Szymon Glowacki
Institute of Mechanical Engineering
Warsaw University of Life Sciences – SGGW
Warsaw, Poland
glowackisz@gmail.com

Dmytro Sorokin
Department of Electrical Engineering, Electromechanics and Electrotechnology
National University of Life and Environmental Science of Ukraine
Kyiv, Ukraine
sdima.asp@gmail.com

Abstract **- Hydrogen production from biomass may become one of the leading areas of bioenergy in Ukraine soon. Currently, the main direction of biomass energy production in Ukraine is the production of thermal energy for distributed heat supply of enterprises and private households by burning biomass of wood and agricultural origin. Nowadays in Ukraine, there is a technology for the production of biohydrogen. We calculated the environmental and economic effects of hydrogen production as a source of energy. We have come up with the following conclusion that if there is a demand for the final product, hydrogen production will be attractive from economic standpoint and will not require a green tariff or other support from the government. The market price of biohydrogen will be $ 4-5 per kg and will be comparable to that which the European Union aims to achieve. We assume that hydrogen may be a cleaner source of energy for end users, especially in the transport sector in the future.**
One of the main issues of Ukraine's possible participation in Europe's hydrogen energy program as a supplier and producer of renewable hydrogen is the possibility of its technically safe and cost-effective transportation to EU countries.
As the main hypothesis considered transportation of hydrogen using the gas transmission system of Ukraine as part of a mixture with natural gas. Calculations show that, of course, obtaining energy from hydrogen, even in mass production, will be more expensive than alternative traditional and non-traditional methods. The development of this technology, in any case, is promising in terms of the development of energy independence and environmental development of states. The effect of scale in mass production of hydrogen energy should also work, which will significantly reduce the cost of this technology.

Keywords - hydrogen, ecology, bioenergy, biohydrogen, natural gas.

1. INTRODUCTION

The Integration of Ukraine's economy into the European and world economy and the high level of its dependence on the external supply of traditional energy sources (oil and gas) due to the deficit of its own, necessitates the introduction of strategic directions of the domestic bioenergy market. Adoption of legislation aimed at creating favorable conditions for increasing the use of renewable energy sources while identifying strategic priorities in the development program of domestic bioenergy, will achieve the goals of sustainable development of society through the system "man-economy-nature". Ultimately, such an approach will not only allow not to violate the principles of ensuring the energy balance of Ukraine, but also help to preserve the environment and solve social problems.

The development of hydrogen technology is gaining popularity around the world. Currently, the main direction

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of biomass energy production in Ukraine is the production of thermal energy for district heating of enterprises and private households by burning biomass of wood and agricultural origin. The hydrogen economy remains a matter of the future, but hydrogen technologies for energy, such as hydrogen storage of renewable energy, hydrogen storage for autonomous and distributed generation, refueling for ever-increasing quantitative and qualitative hydrogen transport, are actively introduced into the economies of developed countries [1,2] .

Hydrogen energy includes a set of technologies for the production, transportation, accumulation and use of a universal secondary energy source - hydrogen. In the concept of hydrogen energy, hydrogen complements the most important secondary energy source - electricity, energy use of hydrogen is determined by the possibility of environmentally friendly electricity generation and long-term storage without losses, including large-scale. The problem of using hydrogen as a promising environmentally friendly and universal energy source and energy accumulator in various sectors of the economy was formulated in the early 70s of last century after the first oil fuel crisis. It became clear that it is necessary to develop new environmentally friendly energy technologies based on the use of renewable energy sources, nuclear energy, coal and universal environmentally friendly energy sources that can replace non-renewable energy resources as they become depleted and more expensive [3,4].

From an ecological point of view, the concept of "green hydrogen" is not always environmentally friendly. Technological processes associated with the manufacture of equipment for hydrogen production are completely non-ecological. This is still an ecologically dirty chain of processes, starting from the stage of extraction of rare earth metals. Thus, the "dirty" part of the technological processes that ensure the production of "clean" electricity from renewable energy sources, simply taken (with all their negative environmental and climatic effects) far beyond the EU - mainly in Asian countries. But the global climate problem is not regional but global.

According to the new "Green Course" of the European Commission (Green New Deal), the main bet is made on the use of renewable energy sources and decarbonized gases, primarily hydrogen. In this case, hydrogen is considered both as an energy source and as a means of accumulating excess electricity from renewable energy sources during periods of active sun and wind, when their production exceeds consumer demand and can be preserved.

According to the nomenclature used by the research firm Wood Mackenzie, most of the gas, which is already widely used as an industrial chemical, or brown, if it is produced by gasification of coal or lignite; or gray, if it is carried out by steam conversion of methane, which usually uses natural gas as a raw material. None of these processes are completely safe in terms of carbon emissions. Presumably a cleaner option is known as blue hydrogen, where the gas is produced by steam conversion of methane, and emissions are reduced by capturing and storing carbon. This process can halve carbon emissions, but it is still a long way from carbon-free production. On the other hand, green hydrogen can almost completely eliminate harmful emissions by using renewable energy - fast-growing and often generated in less favorable periods of time - to power water electrolysis [5].

2. Materials and methods

For our analytical study on the prospects for the development of biohydrogen projects in Ukraine, we used materials from existing bioenergy foundations in Ukraine and Europe. Among the domestic organizations – the Bioenergy Association of Ukraine (UAIBO,) which includes the well-known Scientific and Technical Center "Biomass", Accord Ltd and the public association "Agency for Renewable Energy".

The methodological support of the study was based on a systematic approach, which allowed to reflect the state of research on hydrogen technology, to justify the need to develop energy from hydrogen, taking into account the environmental approach, to calculate and analyze the economic components of hydrogen development. They also used a graphical and analytical method, which allowed to summarize and visualize the studied processes.

3. Results and discussion

One of the main issues of Ukraine's possible participation in Europe's hydrogen energy as a supplier and producer of renewable hydrogen is the possibility of cost-effective production and technically safe transportation to EU countries. At the moment, it makes no sense to approach hydrogen production only from an economic point of view. Traditional types of energy production are certainly much cheaper and proven. But traditional fuels are non-renewable and often environmentally polluting, which is why humanity has turned to renewable sources.

Environmental component of hydrogen production

Negative environmental consequences of the use of petroleum fuels are already visible in large industrial centers, primarily due to transport [6]. Thus, in a city with a population of about 1 million inhabitants, the share of vehicles accounts for almost 70% of the total amount (several hundred tons per day) of environmentally harmful, including toxic emissions. Common forecasts say that by 2030 the number of cars on the planet will double to 1.6 billion.

Whether hydrogen production is environmentally friendly depends on the presence or absence of CO2 emissions at the end of the process. Today, the vast majority of hydrogen in the world is from the gray category. It is extracted from fossil fuels such as natural gas or coal. And such hydrogen is harmful to the environment, because the process of its production causes huge emissions of CO2. Natural gas is a fossil fuel whose entire life cycle is accompanied by greenhouse gas emissions, and renewable energy sources produced from renewable raw materials are biomass. By replacing

natural gas with biohydrogen, we reduce greenhouse gas emissions and thus prevent environmental catastrophe.

Therefore, the transition to the use of hydrogen as a motor fuel in transport is a promising task. The undeniable advantages of the new fuel, firstly, are that with any release of energy using hydrogen (fuel cell, conventional heating, internal combustion engine) we have a favorable energy / mass ratio. That is, hydrogen is an extremely energy-intensive fuel. Thus, when it is burned per unit mass, almost 3.5 times more heat is released than when burning hydrocarbon oils or coal. It is especially important that in the case of hydrogen use there will be almost no emissions of harmful substances, especially carbon dioxide. After all, when hydrogen is burned, only water is formed.

Hydrogen fuel also has its drawbacks: the probability of explosion of the system when the normalized pressure in it is exceeded; it is not always possible to find hydrogen cylinders within walking distance (it is not natural propane gas). The technology has not been fully tested, it takes time to refine and experiment.

Economic component of hydrogen production

During the swift development of solar and wind energy among experts and politicians is growing awareness of the need to use a new gaseous carrier of renewable energy, which would allow not only to compensate for seasonal unevenness and poor predictability of solar and wind generation, but also to completely decarbonize other sectors of the economy - heat, transport, metallurgy, chemical industry and others.

"Green" hydrogen produced without any use of fossil fuels was almost unanimously recognized as such an energy carrier.

Green hydrogen production requires large-scale production of a wide range of new related equipment and infrastructure elements. Electrolyzers and fuel cells, hydrogen engines and specialized vehicles, gas stations and means of transportation and storage.

A direct competitor to hydrogen, natural gas today costs around $ 220 per 1,000 cubic meters, containing 40,000 MJ of energy. The equivalent volume of hydrogen is ~ 3700 m3. That is, to be competitive in the domestic market with natural gas, 1000 m3 of hydrogen must cost ~ $ 60, which corresponds to $ 0.67 / kg. To begin with, biohydrogen needs to be produced by investing considerable funds in the construction of biohydrogen complexes. At the same time, as mentioned earlier, the approximate cost of biohydrogen production will be, on average (according to Akkord Ltd), $ 600 per 1000 m3, which is 10 times more expensive than gas and will be $ 6.7 / kg.

Let's see what is happening with the price of natural gas in the markets in recent years and what are the forecasts for the future.

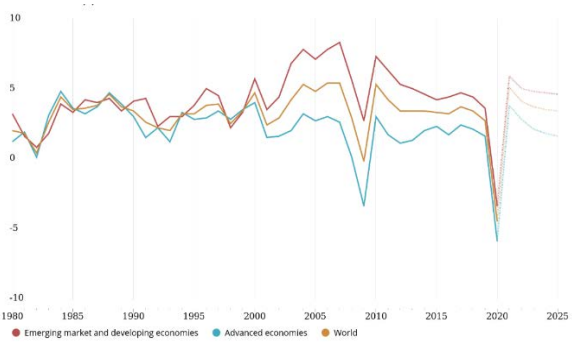

Fig. 1. Real GDP growth (annual percent change) [7].

According to experts in the longer term, the EU GDP growth is projected to slow down to 1.7% per year between 2020 and 2030.

Thus, to produce hydrogen to replace natural gas - it is possible, but economically - it's impractical now and the situation will change little in future, if we consider only the economic approach.

In Europe and the United States, it's predicted that the cost of hydrogen is projected to decline when considering several technology development scenarios and increased production. According to the forecast of the first scenario, it is assumed that the cells are connected to the grid and can produce hydrogen with a power factor of 100%. The minimum price in Europe is expected to fall from $ 4.83 / kg now to $ 3.21 / kg by 2050. In the US, the lowest price of hydrogen production in 2050 is expected to be almost a dollar higher - $ 4.15 / kg (at $ 6.06 / kg at present). According to the forecast of the second scenario, it is assumed that the cells are not connected to the grid, but instead are connected directly to power plants that generate electricity from renewable energy sources. In this scenario, the average price of hydrogen production in the United States will fall from the current $ 10.61 / kg to $ 5.97 / kg, and the minimum price will fall from $ 4.56 / kg to $ 2.44 / kg. It is expected that in Europe the minimum price will be even lower - $ 2.23 / kg (at $ 4.06 / kg at present), and the average price will decrease from $ 19.23 / kg - to $ 10.02 / kg in 2050 [8].

In terms of electricity substitution, hydrogen may also be attractive in Ukraine to participate in European hydrogen technology projects.

1 m³ of hydrogen weighs 89.8 g (44.9 mol), so to obtain 1 m³ of hydrogen will be used 12832.4 kJ of energy. 1 kWh = 3600 kJ, so we get 3.56 kWh of electricity. The feasibility of switching to hydrogen fuel can be assessed by comparing the existing tariff per 1 kWh of electricity and, for example, the cost of 1 m³ of gas or the cost of another energy source.

As we received earlier, the cost of hydrogen is currently $ 6.7 / kg, but experts aim to reduce it to the European ~ 4.83 / kg ($ 430 per 1000 m3), $ 0.43 per 1 m3 (which will be 3.56 kWh of electricity). Therefore, the cost of 1 kWh of electricity will cost $ 0.15 or 0.13 euros.

Compared to the current tariff in Ukraine - 0.05 euros, the calculations are not profitable. But 0.13 euros is the cost of hydrogen that Europe is counting on in its hydrogen strategy and with which it can start synergies.

Regarding the attractiveness of using hydrogen for transport

1 kg of natural gas (55.6 mJ) is 1.39 m3, currently it costs $ 0.37 / kg in Ukraine. Per 100 km requires 10-12 kg of gas, which will average $ 4.07.

A hydrogen supply of 5-7 kg is enough for a mileage of about 500 km - on average, the developers promise to achieve hydrogen consumption, which will be about 1 liter per 100 km, but in reality the flow is 1.1-1.3 kg per 100 km [9]. We have such a high efficiency of hydrogen use due to the efficiency of internal combustion engines: the efficiency of gas combustion - 10-42%, the efficiency of hydrogen combustion - 75-85%.

1 kg of hydrogen - 11.1 cubic meters (142.43 mJ), take the minimum projected cost of $ 2.23-4.3 / kg or it will be $ 2.7-5.5 per 100 km. Even in a more expensive scenario, the cost of 100 km is economically comparable and, of course, environmentally efficient.

What then hinders the development of this technology. Fuel cells and volumetric hydrogen cylinders are the "heart" of the entire hydrogen car system. With cylinders, everything is simple and clear: multilayer composite materials; today they already have a relatively low cost; good resistance to destruction; they take the place of the fuel tank and the trunk pallet. But with fuel cells, everything is much more complicated: they are expensive to produce (used platinum coating) and can be easily destroyed. The cost of such an engine will be many times more expensive than those we have today and there aren't many consumers who are willing to buy a car more expensive just to save the environment. But we believe that this technology is very promising for large industries in transport, such as aircraft, large water transport, trains.

4. Conclusion

After conducting preliminary calculations, we came to the following conclusions. Projects to replace natural gas with hydrogen, today, from an economic point of view are not profitable. The process of adding hydrogen to the gas system of Ukraine requires additional research, in terms of a safe maximum ratio of gas and hydrogen. Some scientists talk about the limit range of 5-10%, others push it to 20%. All in one - the inevitability of hydrogen corrosion and increased brittleness of the metal when using traditional carbon steels, due to the penetration of very small hydrogen molecules into their crystal lattice. Each individual situation requires painstaking research and largely depends on the condition and wear of the system. For this reason, in many countries around the world are building special separate water pipelines, which transport pure hydrogen, suitable for further use in fuel cells. According to average estimates, the cost is approximately 60-70% higher than the cost of construction of standard gas pipeline systems. The necessary infrastructure is also undergoing the necessary changes in this case.

Regarding the production of electricity from hydrogen, while achieving a reduction in the cost of hydrogen production to 4.83, we will get a result that is currently attractive for Europe and will attract potential investors.

The most attractive are the calculations for the use of hydrogen in the transport system, which is perhaps the largest polluter of the ecosystem. An obstacle to development is the increase in the cost of cars if they switch to hydrogen technology, but this does not diminish the importance of technology for major transport.

REFERENCES

[1] Dudnikov, D., etal., Hydrogen energy techmologies.M.: OIVT RAN, 2017. Rel. 1. 190 c.

[2] Perederiy, N., Kuzmenko, S., Labenko, O., Energy-saving technologies in agriculture of Ukraine. Quantitative methods in economics.Volume XVII, No. 4, 2016, p. 89-100. [Online]. Available: https://www.ceeol.com/search/article-detail?id=473655. [Accessed Jan. 24, 2021].

[3] Kovalenko, V., Kovalenko, N., Labenko, O., Faichuk, O. and Faichuk, O. ,Bioenergy sustainable development: achieving the balance between social and economic aspects. E3S Web of Conferences 154, 2020, 07008. [Online]. Available: https://www.e3s-conferences.org/articles/e3sconf/abs/2020/14/e3sconf_icores2020_07008/e3sconf_icores2020_07008.html. [Accessed Jan. 21, 2021].

[4] Malyshenko, S.P., Borzenko, V.I., Dunikov, D.O., Nazarova, O.V., Metal hydride technologies of hydrogen energy storage for independent power supply systems constructed on the basis of renewable sources of energy. Thermal Engineering, 2012, T. 59, № 6. p. 468-478.

[5] Energy club. [Online]. Available:https://iclub.energy. [Accessed Jan. 25, 2021].

[6] The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs. National Research Council and National Academy of Engineering. 2004. [Online]. Available: https://www.nap.edu/read/10922/chapter/1#ii. [Accessed Jan. 25, 2021].

[7] International Monetary Fund. [Online]. Available: https://www.imf.org/external/datamapper/NGDP_RPCH@WEO/OEMDC/ADVEC/WEOWORLD. [Accessed Jan. 25, 2021].

[8] Tsina vodniu z VDE vyroblenoho v YeS ta SShA mozhe buty zmenshena maizhe vdvichi do 2050r. [The price of hydrogen from RES produced in the EU and the US could be reduced by almost half till 2050]. [Online]. Available:

[9] https://expro.com.ua/novini/cna-vodnyu-z-vde-viroblenogo-v-s-ta-ssha--buti-zmenshena-mayje-vdvch-do-2050r. [Accessed Jan. 26, 2021].

[10] Mohut li vodorodnye avtomobili sostavit konkurentsiiu elektromobiliam? [Can hydrogen cars compete with electric cars?].[Online]. Available: https://e-move.com.ua/mogut-li-vodorodnye-avtomobili-sostavit-konkurenciyu-elektromobilyam/. [Accessed Jan. 31, 2017].

[11] Tryhuba, A.; Hutsol, T.; Tryhuba, I.; Pokotylska, N.; Kovalenko, N.; Tabor, S.; Kwasniewski, D. Risk Assessment of Investmentsin Projects of Production of Raw Materials for Bioethanol. Processes 2021, 9,12, doi:10.3390/pr9010012.

[12] Tryhuba, A.; Bashynsky, O.; Hutsol, T.; Rozkosz, A.; Prokopova, O. Justification of Parameters of the Energy Supply System of Agricultural Enterprises with Using Wind Power Installations. In Proceedings of the 6th International Conference – Renewable

Energy Sources (ICoRES2019), E3S WebConf, 2020, Volume154, 06001, doi:10.1051/e3sconf/202015406001.

[13] Huber, G.W.; Dumesic, J.A. Anoverviewofaqueous-phasecatalyticprocessesforproductionofhydrogenandalkanesinabiorefinery. Catal. Today 2006, 111,119–132,doi:10.1016/j.cattod.2005.10.010.

[14] Zhou, C.; Xia, X.; Lin, C.; Tong, D.; Beltramini, J.Catalyticconversionoflignocellulosicbiomasstofinechemicalsand fuels.Chem. Soc. Rev. 2011, 40,5588–5617,doi:10.1039/C1CS15124J.

[15] Kayfeci, M.; Keçebaş, A.; Bayat, M. Hydrogenproduction. Solar Hydrog. Prod. Process. Syst. Technol. 2019,45–83,doi:10.1016/B978-0-12-814853-2.00003-5.

[16] Nikolaidis, P.; Poullikkas, A. Acomparative overview of hydrogen production processes. Renew. Sustain. Energy Rev. 2017, 67,597-611, doi:10.1016/j.rser.2016.09.044.

[17] Ishaq, H.; Dincer, I. Comparative assessment of renewable energy-based hydrogen production methods. Renew. Sustain. Energy Rev. 2021, 135, 110192, doi:10.1016/j.rser.2020.110192.

[18] Golub, G.; Skydan, O.; Kukharets, V.; Yarosh, Y.; Kukharets, S. The estimation of energetically self-sufficient agroecosystem' smodel. J. Cent. Eur. Agric. 2020, 21, 168–175, doi:10.5513/JCEA01/21.1.2482.

[19] Meng Ni, M.;Leung, D.Y.; Leung, M.K.; Sumathy, K. An overview of hydrogen production from biomass. Fuel Process. Technol. 2006, 87, 461–472, doi:10.1016/j.fuproc.2005.11.003.

[20] Diachuk, O.; Chepeliev, M.; Podolets, R.; Trypolska, G.; oth.Transition of Ukraine to the Renewable Energyby 2050. In Heinrich Boell Foundation Regional Office in Ukraine; Publishing house "ArtBook" Ltd.: Kyiv, Ukraine, 2017; Volume 88. Available online: https://ua.boell.org/sites/default/files/transition_of_ukraine_to_the_renewable_energy_by_2050_1.pdf (accessed on 1 November 2017).

[21] Tryhuba, A.; Hutsol, T.; Glowacki, S.; Tryhuba, I.; Tabor, S.; Kwasniewski, D.; Sorokin, D.; Yermakov, S. Forecasting Quantitative Risk Indicators of Investors in Projects of Biohydrogen Production from Agricultural Raw Materials. Processes 2021, 9, 258. https://doi.org/10.3390/pr9020258

[22] Mohammad, T.A.; Aqsha, A.; Mariam, A.; Ain, S.; Hellgardt, K.; Sumaiya, Z.A.; Farooq, S. Catalytic reforming of oxygenated hydrocarbons for the hydrogen production: Anoutlook.Biomass Conv. Bioref. 2020, 127, 109852, doi:10.1007/s13399-020-01081-6.

[23] Yermakov, S.; Hutsol, T.; Mudryk,K.; Dziedzic, K.; Mykhailova, L. The analysis of stochastic processes in unloading the energy willow cuttings from the hopper. Environment, Technology, Resources. In Proceedings of the 12th International Scientific and Practical Conference, Rezekne, Latvia, 2019; pp.249–252, doi:10.17770/etr2019vol3.4159

[24] Dziedzic, K.; Mudryk, K.; Hutsol, T.; Dziedzic, B. Impact of Grinding Coconut Shell and Agglomeration Pressure on Quality Parameters of Briquette; Engineering for Rural Development: Jelgava, Latvia, 2018; pp.1884–1889, doi:10.22616/ERDev2018.17.N461.

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Research of Biomass Micro-Cogeneration System Integration With a Solar PV Panels in Zero-Energy Family Building

Jānis Kramens
Institute of Energy systems and Environment, Riga Technical university
Riga, Latvia
digiteks.info@gmail.com

Edgars Vīgants
Institute of Energy systems and Environment, Riga Technical university
Riga, Latvia
edgars.vigants@rtu.lv

Ivars Liepiņš
Institute of Energy systems and Environment, Riga Technical university
Riga, Latvia
ivars.liepins@komforts.lv

Viktorija Terjanika
Institute of Energy systems and Environment, Riga Technical university
Riga, Latvia
viktorija.terjanika@rtu.lv

***Abstract* - Nowadays, any economic development is based on its sustainability. On the other hand, sustainability of the economy is no longer conceivable without efficient use of resources. Climate change and environmental degradation affects everybody and have no borders. It is essential, that all countries, regardless of their existing resources, are involved in environmental matters. The European Union (EU) has taken the initiative and has seen the possibility of transforming climate change into a guiding theme for sustainability and development in the economy. The EU has developed a green policy in order to transform all economic sectors into sustainable use of resources. EU is planning to achieve climate neutralisation in all sectors of the economy by year 2050. In order to achieve this objective, only the transformation of the industrial, transport and energy sectors will not be sufficient. The activity and willingness of each individual to achieve these objectives at their own household level will be crucial. It should change habits in all sectors important for households: food, transport, waste management and decreasing energy consumption in all mentioned sectors. Solar PV panels traditionally are used to reach zero balance, but taking in to account climatic conditions and seasonable solar irradiation activity, they can operate successfully during the summer and partly during the spring and autumn season. During the heating season, the efficiency of solar PV panel systems is very low. Use of innovative micro-cogeneration equipment producing both heat and electricity is more efficient during heating season in Latvia.**

In this paper case study of innovative biomass Stirling engine micro-cogeneration system integration with a solar PV panels in zero-energy family building will be present.

Keywords* - *Efficiency, environmental impact, micro-cogeneration, off-grid, sustainability

I. INTRODUCTION

If we look at the structure of Latvian households and their potential to use biomass micro cogeneration (mCHP) equipment for heat and electricity production in combination with solar panels for self-consumption, we must first assess the number of households that could use this type of equipment. As with high-capacity biomass cogeneration (CHP), in the case of mCHP, the primary factor for its efficient operation is the efficient and effective use of heat, in the case of households it will be heat for heating and hot water for domestic use. If we compare the amount of heat consumed for heating and hot water

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preparation, then on an annual basis heating requires on average twenty times more heat, so the data obtained during the heating season should be used for mCHP calculations. In turn, the solar panel system must be viewed from the structure of household electricity consumption. Household electricity consumption also varies with the time of year and the season, but the change in consumption in this case is not so much related to the start of the heating season as to the decrease in daylight hours in winter and the increase in electricity consumption for lighting. On average, these fluctuations in household electricity consumption between winter and summer season do not fluctuate by more than 50 %. This seasonal fluctuation in electricity consumption is the opposite of the fluctuation in solar panel production, which is several times higher in the summer season than in the winter season. At present, combined heat and power solutions are not popular in the household sector, and while such fossil fuel based mCHP solutions are still available, solutions based on biomass fuels are rare and not widespread. It is generally accepted that the most successful solution for households to achieve Zero Climate Balance (NET) is the installation of solar panels. According to the authors, such a theory is also closely related to the development of solar panel technology, because until recently it was considered that solar panels can be successfully used only in southern countries such as Italy and Spain, where in households electricity is as primal energy type and thermal energy – as secondary. With the development of solar panel technology, their efficiency indicators improved, and accordingly it became economically justified to use solar panels in Northern European countries, where heat consumption is the primary energy balance in households. Accordingly, in regions where heat consumption is significant or even higher than household electricity consumption, it is not appropriate to compensate for this increase in energy consumption with a larger area of solar panels. The northern regions also have more pronounced changes in solar intensity during the winter and summer, so in order to cover the increase in household energy consumption, the area of solar panels needs to be increased several times, which creates a significant surplus of energy in the summer and additional load on energy supply grid. In Northern European countries, including Latvia, forest areas are on average twice as large as the European average, therefore it would be useful to compensate with this renewable energy sources (RES) the increase in the consumption of seasonal energy resources (wood). Seasonal changes in the consumption of these household-critical resources, climatic conditions and the availability of RES provide good evidence for the usefulness of the study presented in this article.

There are 817 900 households in Latvia (in 2019), of which more than 56.4 % are connected to the district heating (DH), but the rest (356 600) are provided with individual heat supply equipment – wood, pellet, gas or other resource heating boilers, various types of heat pumps and heating using electricity from the grid [1].

The majority (60 %) of households that provide individual heat supply are located in rural areas. If the most optimal development scenario for a household with individual heat supply in an urban area would be connection to the District heating (DH) in the future, then in rural areas, in most cases, such option will not be economically justified. Assuming a scenario that in the future these households in rural areas with individual heat supply, which is 212 429 units, or 26 % of all Latvian households [2], will use efficient heat production equipment together with mCHP and solar panels, this will have a significant effect on achieving Latvia's Green Deal goals, promoting the country's energy independence and efficient use of local renewable energy resources. Households are one of the largest and most inefficient consumers of energy resources in the country, as well as one of the largest emitters, so any effective solution to achieve these goals is essential for achieving climate goals. biomass heating system with integrated mCHP Stirling engine in combination with a solar panels would be the most effective solution taking into account the geographical position of Latvia and the availability of biomass (wood) resources in rural areas.

Objectives of the research:

- Household Electricity Calculation (NET) system solution with a smooth production and consumption curve.
- Achieving CO_2 neutrality in the supply of heat and electricity to households

II. SYSTEM DESCRIPTION

A. System Components

As mentioned in the introduction, the system for investigation consists of a micro-cogeneration unit based on external combustion Stirling engine and a solid biomass gasification boiler and a solar photovoltage panels (PV).

B. mCHP System

A prototype of a solid biomass micro-cogeneration unit was used for the experiments. An “A” class solid biomass heating boiler Magasro 31 kW [3] was used to create the prototype. This boiler was chosen due to the latest available technologies in the field of household biomass boilers. According to the Stirling engine performance [4], the boiler must be able to heat the engine head to at least 550 ºC in order to achieve maximum Stirling engine efficiency. This head temperature can be ensured by the combustion of the gas obtained from the wood gasification process of the used boiler in the combustion chamber (Fig. 1).

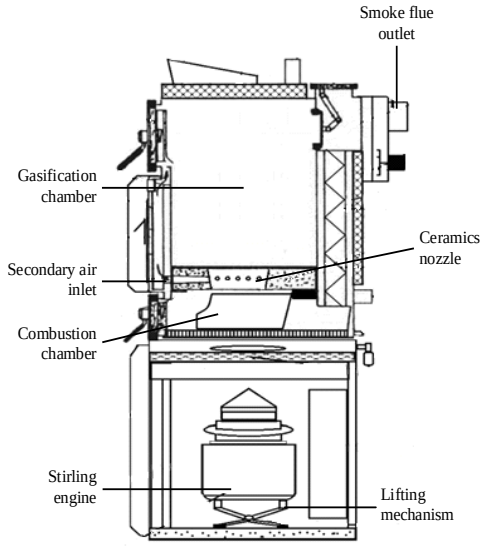

Fig. 1. Schematic representation of the experimental equipment with the lifting mechanism.

C. Solar PV System

For the research, a solar PV panel system was created on the roof of the building 14º in relation to the horizon with a south-facing position, the installed total panel power is 1200 W, Fig. 2.

Fig. 2. experimental PV solar panel system.

Stirling engine micro-CHP equipment parameters are shown in Table 1.

TABLE 1. MCHP SYSTEM DESCRIPTION

mCHP system description	
engine model	Microgen 1.0 kW
engine type	external combustion
engine alternator electrical power	1.0 kW
cooling type	fluid
boiler model	Magasro 30
boler type	solid biomass gasification
boiler heating power	31 kW

TABLE 2. PV SYSTEM DESCRIPTION

PV system description	
number of panels	4
panel electrical power	300 W
panel model	Canadian Solar
Inverter	Solar Inverter (Bimle solar)

III. MATERIALS

A. Household Loads and System Description

The system runs continuously, following typical electrical and thermal demand profiles in households. The installation is able to apply real thermal and electrical loads according to set demand profiles. Data of the main operating parameters of the system is collected on tests that run without errors for 24 h (whole days). The monitored variables include meteorological conditions (radiation, temperature, humidity, etc.), electrical production and consumption, water temperatures and flow rate in all the water circuits and the Stirling engine system variables. To evaluate the system, the main results from each day are further analysed, according to the methodology described below.

B. Household Thermal Loads

According to Latvian construction standards, the heat energy consumption of residential houses is allowed up to 90 kWh/m^2 per year [5]. The current situation in the Baltic States, which is related to heat energy consumption, is significantly worse. It is shown that in Latvia and Lithuania it exceeds 200 kWh/m^2 per year [5]. Most residential buildings were built before the adoption of the existing building codes, so based on the reports of energy audit data collection [6], it can be concluded that in fact the heat consumption of households exceeds the permissible level of building standards. According to these reports, it averages at least 150 kWh/m^2 per year. For future calculations, we use these data as the total heat consumption of households, which also includes the energy required for hot water preparation.

According to statistical data, the average household size in rural areas of Latvia, where firewood is mostly used for heating, is 93.9 m^2 [4]. It is taken into account that this value is the average size of households, which also includes buildings without district heating, the area of which is below average. For further calculations, in this study the minimum heating area is taken to be 200 m^2, as this area is recommended in the technical documentation of the boiler manufacturer [4]. According to previously accepted data on household size and average heat energy consumption, it is determined that a household with a heated area of 200 m^2 consumes 39 MWh of heat energy during a calendar year.

In order to ensure a zero balance with the help of PV and mCHP technologies, their seasonal activities are taken into account, the activity of mCHP is directly related to climatic conditions, or heating season. Fig. 3 shows the typical heat energy demand during a calendar year.

According to the regulations of the Cabinet of Ministers, the heating season in Latvia begins when the daily average air temperature is below +8 ° C for three consecutive days [7], [8]. Evaluating the data of the Latvian Environmental Geology and Meteorology Center [9], it appears that the Latvian heating season begins in the second half of September and ends at the end of April, as well as the amount of precipitation, which increases heat loss.

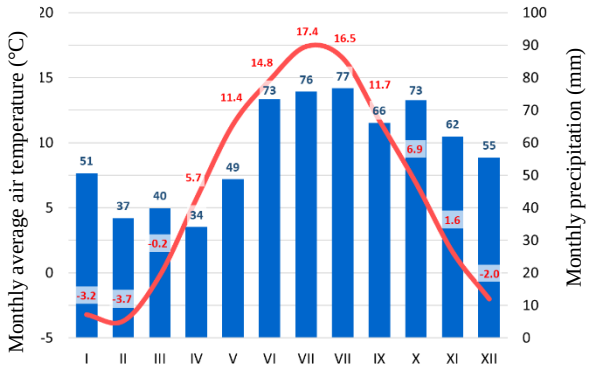

Fig. 3. Avarage temperature and moisture precipitation monthly [9].

C. *Households Electrical Loads*

Households vary in both area and annual electricity consumption [8]. A study [10] found that the average household in Latvia consumes 293 kWh of electricity per month, which is in line with the Latvian Bureau of Statistics [5], that the largest share of 36.3 % of households' annual electricity consumption is over 2000 kWh per year, leading to further calculations. that the monthly electricity consumption of Latvian households is 293 kWh.

D. *Solar PV Panel Productivity*

The efficiency of solar PV panels is directly related to solar radiation entering the ground. The intensity of solar radiation in Latvia can be seen in Fig. 4.

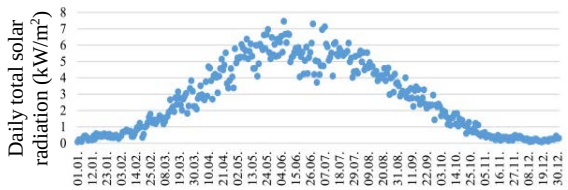

Fig. 4. Solar radiation in Latvia [9].

The amount of electricity obtained from solar PV panels, calculated on the area of the installed panels, depends on both their efficiency and installation features. Reviews [10], [11], [12] show that under optimal installation conditions, a 1 kW installed PV solar panel system produces about 800 kWh of electricity annual.

E. *System Connection*

The study is performed on a system connected to an external Public electricity grid, Fig. 5.

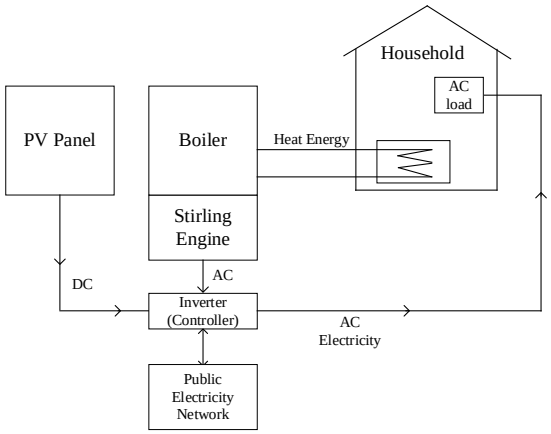

Fig. 5. System connection diagram.

The system is controlled by a control unit with a current inverter, which regulates the flow of electricity when transmitting or receiving it from the grid.

Heat energy is produced only for own consumption and is not connected to external grids.

IV. METHODS

A. *Electrical and Thermal Energy Production*

Operation of the equipment used in the experiment.

1. *Thermal and elecrical energy produced by mCHP*

Based on monthly changes in average air temperature [9], the intensity of heating equipment use is changing during the year. The electricity generation of the mCHP plant used in the study is directly related to the thermal energy production of the boiler. Electricity generation as a function of mCHP Stirling engine head temperature is shown in Fig. 6.

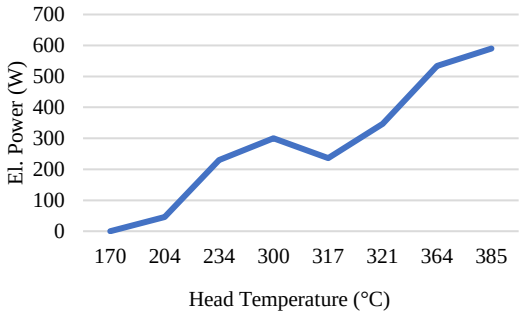

Fig. 6. Power generation capacity depending on Stirling engine head temperature .

In the course of the study, 9 experiments were performed, the aim of which was to find out how much heat and electricity the mCHP unit is able to produce in cogeneration mode.

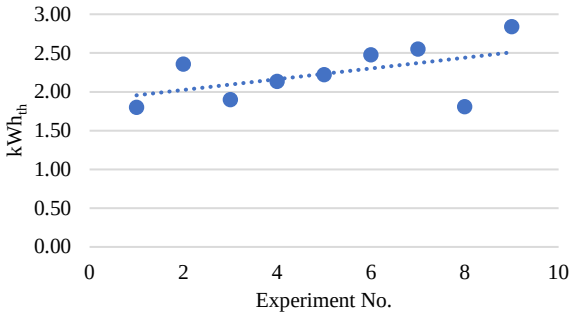

Fig. 7. Produced thermal energy from 1 kg of wood.

Experiment series ware done to determinate mCHP system electricity production (Fig. 8), and thermal energy (Fig. 7) from burning 1 kg of wood, first 3 experiments was done running experimental unit in thermal mode, 4–9 experiments in cogeneration mode.

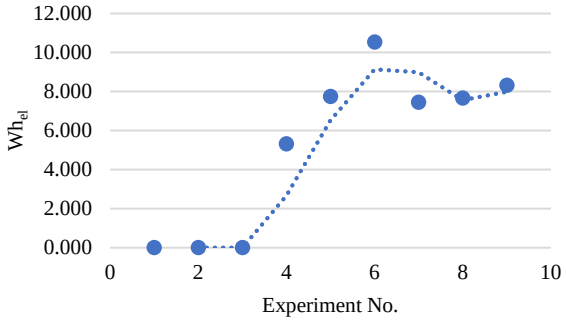

Fig 8. Produced electrical energy from 1kg of wood.

2. Electricity Produced from PV Panel System

To determine the actual amount of electricity produced by PV panels, data was collected from the experimentally installed 1.2 kW solar panel system Table 2. Given that the experimental PV system was installed off-grid, it does not count the electricity produced without consumption, or if the battery system is fully charged. Based on the above, data on other solar panel systems installed in Latvia and Northern Europe, which are connected to the grid and all electricity generated is accounted for and transferred to the grid, ware analyzed. Data from grid tied systems were used for further calculations [13].

According to the experimental results in Fig. 8, we calculate that when the plant is operating in cogeneration mode, 1014 kWh of electricity would be produced per year.

B. Measurement methods and accuracy

Analytical equipment was used:
Heat energy counter *Sontex supercal 739*, providing +/–3 % accuracy.
VEXON 140D meter used for accounting for electricity transferred to the public network, providing +/–1 % accuracy.
Stirling Engine el. generator instantaneous power and produced el. energy to network data collection was done with Stirling engine *Data Viewer software* and build in thermal sensors with precision of +/–1 %.
Calibrated 200 kg mechanical weights with an accuracy of +/–3 % have been used to determine the weight of the loaded fuel.
The fuel temperature has been accepted identical to the room temperature as the fuel has long been located in the same room as the heating plant, a digital thermometer, *Sonex*, an accuracy of +/–2 % was used for measurement.
The humidity of wood was measured with the portable humidity meter *iCcraft*, checking each wood log, accuracy +/–5 %.
Flow/return temperature fixated with boiler in build in temp sensors an accuracy of +/–2 %.
Flue gas temperature read from the boiler's built-in sensors, accuracy +/–3 %.
Flue-gas composition measured by calibrated analyser *Testo 340*, margin of error 0.2 % by volume.
To minimize impact of analytical equipment inaccuracy to data offset, during each experiment measurements ware performed each 15 min. In average 15 measurements ware performed per experiment, so we conclude that data accuracy is less than equipment max. inaccuracy range.

V. Results

A. Household Energy demand

In section III we calculated household average annual heat and electrical demand. In this section we try to model how to cover those loads to reach zero NET balance of electrical and thermal energy demand. Primary calculation shows (section III) annual head energy demand is about 39 MWh and 3,516 MWh of electricity annual

B. Produced Electricity From mCHP

As pointed out in the chapter (IV A, 1.), the electricity generation of the mCHP system directly depends on the heat energy of the boiler, as result total annual electricity produced with mCHP system is tightly depending on household heat energy demand. During the recalculation, it was determined that on average 0.026 kWh electricity (Fig. 8) and 2.53 kWhth (thermal energy) (Fig. 7) was obtained from burning 1 kg of wood. According to Chapter III (A), a household with these parameters consumes 39 MWh of thermal energy annual. Correspondingly recalculating the capacity of the mCHP unit to produce electricity from the mentioned annual heat energy demand, we obtain that 1,014 MWh of electricity would be produced.

C. Produced Electricity From PV Panels

As it was mentioned on section III (C) from 1 kW of installed solar panels annual production is around 800 kWh. Our experiment installation is 1.2 kW, so it could produce 960 kWh electricity annual.

D. Annual Electricity Demands Coverage

As it was described on section III (C) monthly electricity demand on average household is 293 kWh, 3 516 kWh annual.

From mCHP annual electricity production would be1014 kWh, section (B).

To cover annual electricity demand increase of PV panels installed power, compare to experimental installation, is necessary. To cover total demand of 3 516 kWh, of what 1014 kWh could be covered by mCHP system, 2 412 kWh is necessary to cover by installed PV panels. As it was described before, 1 kW of installed PV panels can produce in average 800 kWh electricity annual. To cover annual electricity demand of the household, 3 015 W of installed PV power is necessary, it means 10 solar panels of 300 W each as mentioned on Table 2.

E. Electricity NET Balance Calculation

NET settlement system in Latvia is specified in the regulations of the Cabinet of Ministers [14]. Smooth grid balancing is this study objective

F. Public Grid Disbalace

Scientific paper [15] and public reviews [16], [17] identify the problem that NET Zero solutions based on PV panel systems only makes overload risks to public electricity grid due to seasonal its productivity. Current policy for NET settlements in Latvia is based solely on PV systems that are highly seasonal in the region. In this paper research was done how combination of mCHP and PV panels system decrease risk of seasonal public grid overload.

G. NET Zero Calculation Scenarios

Experimental based calculations ware done to define household annual electricity supply of consumption (SOC) by using combination of PV systems with mCHP to reach NET Zero balance. Results of those calculations are shown in Fig. 9.

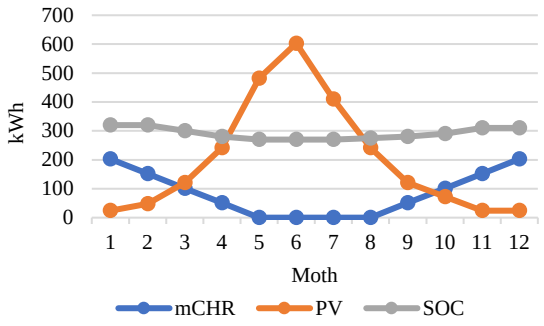

Fig. 9. Annual produced electricity with mCHP and PV systems for household Supply of Consuption (SOC).

As alternative scenario ware calculated to cover (SOC) by using PV panels system only to reach NET Zero balance.

In order to determine how much electricity a PV panel system is able to produce during a calendar year, an inventory was made from the experimental equipment Fig. 1, as well as a review of the literature on the operation of similar PV systems in Latvia [10].

Comparison of those two alternatives, NET balance providing the household electricity supply with PV panels only (Scenario 2) and combination of PV+mCHP (Scenario 1), is shown in Fig. 10.

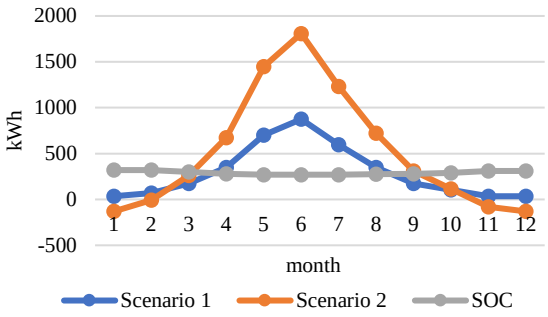

Fig 10. NET Zero energy balance with public grid.

VI. CONCLUSIONS

In this paper, the first experimental results from the joint operation of a novel mCHP installations are presented. The system is composed by an External Combustion Microgen Stirling Engine micro-CHP unit and PV panels. All the energetic needs – both thermal and electrical – in a household are tried to achieve via experiments, using experiment data to interpolate it to annual heat and electricity demand. Reverse interpolation was done to set up minimum PV panels installed power to achieve annual NET Zero energy balance. This objective is subject to the generation capacity and the synchronization between the energy production and consumption profiles.

Synchronization process is depending on mCHP and household heat energy demand. As the test results shows mCHP can produce only about ¼ of the total annual electricity demand and fully supply with heat energy demand. From the Figure 8, we can conclude that during heating season it still need to receive electricity from grid, as result we have to install much more solar panels installed capacity as we thought before. It was far not enough with 1.2 kW of installed PV panels. Calculations show about 3 kW of installed PV panels capacity should be installed to reach zero NET balance.

Optimum calculation software method was used to find NET balance between household heat energy supply, electricity production from mCHP+PV (scenario 1) and PV panels only with heat from conventional biomass boiler. Results of the NET balance calculations are present on Fig. 10. On the graph we can clearly detect positive result to minimize public grid disbalance over the year using Scenario 2. Public grid peak load was minimized by almost 40 %, compare to system with electricity production with PV panels only, (scenario 2). It was detected, that more less grid disbalance would be possible if also during summer period mCHP would be used, for example, for hot water preparation. We conclude also that by installing heat energy storage tank lower Public grid disbalance could be reached, but for detailed results additional research is necessary.

As the secondary objective was to achieve full CO_2 neutrality of the household heat and electricity demand.

Carbon footprint calculation method was used to determinate household carbon neutrality.

Calculations shows, that by using wood for space heating household is carbon neutral in this aspect.

Electricity production from biomass mCHP and PV panels itself is carbon neutral. Using electricity from public grid is option to choose carbon neutral electricity, but this is actually more virtual aspect than practical, while with that choice is possible to support electricity production from renewable resources, but still most part of power is produced from fossil fuel.

Our calculation shows that use of PV and mCHP systems combination for household energy supply CO_2 neutrality could be reached.

ACNOWLEGEMENTS

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Thanks to Microgen LTD for the opportunity to use a micro-cogeneration unit for research and Dainis Seržants for responsiveness and quality work by connecting the research unit to the boiler house infrastructure

REFERENCES

[1] Central Statistical Bureau, "Environment and Energy, Energy - Household Energy Consumption" [Online]. Available: http://data1.csb.gov.lv/pxweb/en/vide/vide__energetika__energ_pat/ [Accessed: Mar. 08, 2021].

[2] R. Padinger, et al, Best practise report on decentralized biomass fired CHP plants and status of biomass fired small- and micro scale CHP technologies. IEA Bioenergy, 2019.

[3] MAGA, "Wood-gasifying boilers MA" [Online]. Available: https://magasro.sk/en/wood-and-brickets-boilers-d/wood-gasifying-boiler [Accessed: Mar. 10, 2021].

[4] Microgen Engine, "Microgen's compact gas fired Heater-Generator," Techn. Paper. [Online]. Available: http://stirling-tech.com/wp-content/uploads/2018/05/ThermoGen1.0kW.pdf [Accessed: May 15, 2018].

[5] Central Statistik Bureau Databases, "Overall description of dwellings (%)" [Online]. Available: http://data.csb.gov.lv/pxweb/en/sociala/sociala__majapst/MTG020.px/ [Accessed: Mar. 15, 2021].

[6] D. Kostova, et al, "D2.2 Report on EPC best practices," QualDelEPC, Goteborg, Sweden, Rep., 2020.

[7] Cabinet of Ministers Republic of Latvia, "Cabinet Regulation No. 280. Regulations Regarding the Latvian Construction Standard LBN 002-19, Thermotechnics of Building Envelopes," Latvijas Vēstnesis, vol. 135, 2019.

[8] Cabinet of Ministers Republic of Latvia, "regulation No. 204. On the conditions of heat supply," Latvijas Vēstnesis, vol. 125, 1994. (in Latvian)

[9] LVGMC, "Latvian climate" [Online]. Available: https://videscentrs.lvgmc.lv/lapas/latvijas-klimats [Accessed: Mar. 15, 2021]. (in Latvian)

[10] L. Rozentale, D. Lauka, D. Blumberga, "Accelerating power generation with solar panels. Case in Latvia," Energy Procedia, vol. 147, pp. 600–606. https://doi.org/10.1016/j.egypro.2018.07.077

[11] I. Pakere, D. Blumberga, "Solar power or solar heat: What will upraise the efficiency of district heating? Multi-criteria analyses approach", Energy, vol. 198, pp. 117291, May 2020.

[12] A. Simola, et al, "Optimal dimensioning of a solar PV plant with measured electrical load curves in Finland," Solar Energy, vol. 170, pp. 113–123, Aug. 2018.

[13] J. Telicko, D. Heincis, A. Jakovics, "A study of solar panel efficiency in Latvian climate conditions," Proceedings of the 12th Nordic Symposium on Building Physics, vol. 172, pp. 16007, Jun. 2020.

[14] Cabinet of Ministers Republic of Latvia, "Facilitated conditions for net system users," April 2020 [Online]. Available: https://www.mk.gov.lv/lv/jaunums/atviegloti-nosacijumi-neto-sistemas-lietotajiem [Accessed: Mar. 14, 2021]. (in Latvian)

[15] K. N. Nwaigwe, P. Mutabilwa, E. Dintwa, "An overview of solar power (PV systems) integration into electricity grids," Materials Science for Energy Technologies, vol. 2, iss. 3, pp. 629–633, Dec. 2019.

[16] The Weekend Australian, A. Hepworth, "Rooftop solar panels overloading electricity grid," October 2011 [Online]. Available: https://www.theaustralian.com.au/news/rooftop-solar-panels-overloading-electricity-grid/news-story/5ea583571dde0830ec34d3cd8c32b9dc [Accessed: Mar. 01, 2021].

[17] BUILD, "Rapid increase in solar installations potentially overloading the grid" [Online]. Available: https://build.com.au/rapid-increase-solar-installations-potentially-overloading-grid [Accessed: Mar. 14, 2021].

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The Development Problems of Biological Beekeeping

Ilga Krampuža
Rezekne Academy of Technologies
Faculty of Economics and Management
Rezekne, Lavia
ilga.krampuza@rta.lv

Abstract **- Beekeeping is an integral part of the European agricultural production. More than 620 000 beekeepers work in the beekeeping branch of the European Union. Beekeeping is recognised to be an activity, which has an essential significance in the sustainable development of the rural areas, in the job-creation, the conservation of the ecosystem's biological diversity, and in the maintenance of ecological balance. The basic principle of biological beekeeping is the production of as natural produce as possible.**

The study uses the analytical method to explore the current situation in the biological beekeeping sector. The analytical and comparative method helped to identify the problematic issues concerning the implementation of the beekeeping process and support measures. To study different views on the problems of biological beekeeping, the following methods for interpretation of legal norms were used: grammatical, systemic, teleological, and historical. The inductive and deductive scientific research methods were used to draw conclusions regarding current normative regulations and to recommend possible solutions.

Keywords - biological beekeeping, beekeeper, bees, honey.

I. INTRODUCTION

Beekeeping can be classified as follows: 1) hobby, a good way to spend time while getting additional benefit – honey; 2) conventional beekeeping; 3) biological beekeeping.

The definition of the term *biological beekeeping* is found in connection with the interpretation of the term *organic production*. Organic production implies a comprehensive farm management and food production system which involves: 1) best environmental protection practices, 2) protection of biodiversity, 3) conservation of natural resources, 4) application of high animal welfare standards and production methods following the desire of a specific consumer group to use products manufactured using natural substances and processes.[2] *Biological* means acquired through organic production or related to it.[2] Thus, the essence of biological beekeeping involves: 1) providing people with biological beekeeping products, 2) promoting agricultural development, 3) environmental protection and conservation of natural diversity, 4) important ecosystem and agricultural services when pollinating flowers.

The development of biological beekeeping faces a range of problems, including the threats to the preservation of biological beekeeping product manufacturing, which will be reviewed further.

II. MATERIALS AND METHODS

The research aim is to identify and analyse the main problems of biological beekeeping development. The research methods are based on the analysis of data, documents, and normative regulations. The provisions of the European Council regulations were analysed in terms of the issues related to the necessity to create a state support system for the development of biological beekeeping, as well as the *Report on prospects and challenges for the EU apiculture sector*. The analytical method was used in the study to explore the current situation in the biological beekeeping sector. Using the analytical and comparative method, problematic issues were identified in the implementation of the beekeeping process as well as in the realisation of support measures.

III. RESULTS AND DISCUSSION

Basic regulations for biological beekeeping are determined by the general principles, which dictate the main requirements for the manufacturing methods, the use of natural resources, and limitations regarding the use

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of chemicals. From Council Regulation No. 834/2007 [2] it follows that biological beekeeping should respect: 1) Specific principles applicable to processing of organic food. These principles involve the requirement to produce honey and other beekeeping products from organic agricultural ingredients, as well as the prohibition to use non-organic ingredients, prohibition to use substances and processing methods that might mislead customers and that might imitate organic production, as well as the permission to only use organic, mechanical and physical methods for the preparation of the final product. 2) Specific principles applicable to processing of organic feed. These set the requirement to use only organic materials for the production of winter feed for bees and provide for the restriction of the use of feed additives and processing aids, so that they are used to a minimum extent and only in case of essential technological or zootechnical needs or for particular nutritional purposes.[2]

These requirements are integrated in the biological beekeeping certification process. For example, the *Beekeeping Production Plan* [3], which is required in the certification process, already provides for the following requirements: 1) register the beekeeping products produced by the company, 2) present the bee feed planned to be used, 3) state from the start that the bees are going to be fed with a specific product, 4) specify how much of this product is going to be used and its origin.

The requirement for detailed documentation of the biological beekeeping process, on the one hand, partly corresponds to the task set for the state under Commission Regulation No. 889/2008 to develop requirements for the production, preparation, and realisation stages of organic products. On the other hand, setting overly detailed bureaucratic requirements for accounting in addition to recording the organic production procedure involves the investment of large amounts of time and financial resources.

This is why justified criticism is heard from biological beekeepers that every year they have to fill in a total of 25 different report sheets, beginning with the hive placement plan.[4] Obviously, this requires that each of these reports is filled in and that a variety of information is accumulated, processed, and reflected. The bureaucratic procedures also include, for example, an obligatory requirement to notify the controlling authority within seven days of any changes in the numbers of hives in the apiary.

Biological beekeeping is subject to the special requirement set in Article 13 of Commission Regulation No. 889/2008 that the siting of the apiaries shall be such that, within a radius of 3 km from the apiary site, nectar and pollen sources consist essentially of organically produced crops and/or spontaneous vegetation and/or crops treated with low environmental impact methods. [5] Thus, apiaries must be placed in such a way that would prevent any chemicals used to treat agricultural fields from entering beekeeping products and would ensure the preservation of bee health. Following these requirements poses bigger and bigger problems.

Also, when the beekeeper brings hives to pastures, apart from submitting a report to the controlling authority (reporting the dates when specific hives are moved), there is also the requirement that pastures be organic.

The extent of intensive agriculture is growing, simultaneously reducing the area available for biological beekeeping. For example, in the period from 2000 until 2013, the crop sowing area in Latvia increased 1.39 times, reaching 584.0 thousand hectares, and rapeseed sowing area increased 17.1 times, reaching 128.2 thousand hectares.[6]

Whereas intensive agriculture, the spread of monoculture is associated with the use of chemicals throughout the entire agricultural production cycle. This includes the use of herbicides to kill unwanted plants, the use of fungicides against fungal diseases, repeated use of chemicals to promote growth, the use of insecticides against insects, the use of substances to reduce lodging, the use of chemicals intended for the ripening of the crops.

Synthetic pesticides used by industrial farmers to treat their fields not only exclude huge areas from biological beekeeping, but also kill bees. For example, in the spring of 2020, a biological beekeeper in Drabeši parish had half of the 240 colonies sheltered for winter perish. In the territory of Gauja National Park where Suda swamp reserve is located, an industrial farmer ploughed up the natural meadows next to the reserve and used synthetic pesticides for dusting rapeseed fields.[7]

Beekeepers understand that natural reduction is possible when bees die, for example, due to the spread of varroasis or from any other understandable cause. However, in the recent years, the so called “disappearing disease” has been observed when bees leave the hive and after intoxication by pesticides are unable to return to the hive. Specialists have termed this the *Colony Collapse Disorder (CCD)*. Disappearance of bees is common in the USA, Europe, Australia and other parts of the world.

In 2019 and 2020, approximately 400 beekeepers were surveyed and spoke of the necessity to create pesticide-free areas.[7] The Regulations Regarding the Use of Plant Protection Products [8] provide for the obligation for farmers, before using plant protection products that are toxic to bees, to warn the owners of apiaries whose colonies are registered and located within a two-kilometre radius about the use of such pesticides three days in advance. However, the implementation of this condition is not going as well as it might seem because farmers look for various excuses not to inform apiary owners, for example, saying that they did not

know about the placement of the apiary. In the survey, only 10.2% of the beekeepers responded that they had received a warning about the use of pesticides. Hence, the Regulations Regarding the Use of Plant Protection Products have justly been called a "paper law". Thus, in the future, beekeeping in Latvia in accordance with the provisions for biological beekeeping will only be possible in very limited areas.[9]

We have to agree that "in biological beekeeping, the production system needs to be created in such a way that would eliminate all pollution risks as much as possible, which is not easy at all." [10] However, in practice, if a rapeseed field is sown in the vicinity of a biological beekeeper's apiary at the distance where the bees can reach it, then, most likely, the bee colonies will have to be moved. It is in the interests of the public and specific beekeepers to reach a mutual understanding and reasonable management in order to be able to offer healthy ecological products on the market.

How seriously violations of pesticide use are treated in the world can be seen, for example, from an incident in Australia. After a fruit plantation owner sprayed pesticides over trees that were still flowering, which resulted in the death of fifty nearby colonies belonging to local beekeepers, the court in the city of Klagenfurt in Austria sentenced the fruit grower to one year in prison and ordered him to pay a 20-thousand-euro compensation for deliberately poisoning the bees. The court concluded that a professional fruit grower must have known how pesticides can harm bees and the people who were going to consume the "poisoned" honey. Whereas Denmark, to fight against excessive use of pesticides in agriculture, implemented a pesticide tax to encourage a reduction of pesticide usage.[7]

Beekeeping will always be closely related to the availability of ecological nectar plants required for bees. Of course, there are also good examples of cooperation between farmers and beekeepers, for example, in the production of rapeseed or buckwheat honey. Some seed growers also collaborate with beekeepers so that when plants are flowering, the bees deliberately placed in the fields can pollinate clover or other plants, allowing to obtain a higher yield of seeds. From the point of view of public interest, conservation of biological natural environment is very important. This would enable us to maintain the amounts of beekeeping products and to conserve the populations of bees.

It is impossible to obtain an organic bee product from materials contaminated with chemicals.

In biological beekeeping, special regulations are in place which provide for procedures for fighting bee diseases and pests. It is clear that an increase of bee mortality and decrease of bee populations in Europe can have a very negative effect on agriculture, food production, biological diversity, sustainability of the environment and the ecosystems. This is why we have to agree with the statement in the *Report on prospects and challenges for the EU apiculture sector* [1] that emergency measures are required at the national level to implement a broad long-term strategy to restore bee health and populations and thus conserve the population of wild bees in the EU, whose size is currently decreasing, which is why agricultural environment measures are required in order to support the creation of bee colonies. At the same time, if veterinary medication is required, a biological beekeeper must keep very detailed records of the treatment process in a special journal. The records must include the duration of the use of the medication, the active pharmaceutical ingredient, detailed information on the diagnosis, dosage, method of administration of the medication, and the duration of treatment. Whereas before selling the final product, information must be provided to controlling authorities and product testing must be performed to verify that the product is organic.

It is clear that the purpose of the special regulations for disease prevention and veterinary treatment in beekeeping is to protect frames, hives and honeycombs, especially from pests, for example, Varroa mites. Only substances suitable for biological beekeeping are allowed. For example, for apiary disinfection, physical treatment is allowed, such as using vapour or open flame. If preventive measures are ineffective, these are followed by treatment measures or even placement of specific colonies in isolated apiaries. Limited use of medication in biological beekeeping is allowed in terms of amounts as well as the restrictions allowing the use of, for example, formic acid, lactic acid, acetic acid, and oxalic acid, as well as menthol, and thymol. Usually, after the use of chemically synthesised substances, all the wax in the apiary must be replaced with organically produced wax within a specific time period. These measures require significant resources.

Additional costs in biological beekeeping result from the requirements concerning the tools and hives used. Hives must be made only from natural materials to eliminate the risk of pollution to the environment and the final product. The creation of honeycombs also requires the use of only natural materials. Moreover, only natural products may be used in hives, such as propolis, wax, and plant oils.

Obviously, the requirement in biological beekeeping to leave in the hives, at the end of the production season, enough honey and a reserve of pollen for the bees to spend the winter requires increased investments.[2] Moreover, artificial feeding of bee colonies is only allowed if their survival is threatened due to the climate and only after the last harvest of honey and 15 days before the beginning of the next nectar or honeydew collection season. Artificial feeding should be done using organic honey, organic sugar syrup, or organic sugar, [5]

which is relatively more expensive than using ordinary sugar for preparing the feeding syrup. Moreover, an apiary journal must be completed on a regular basis, which must reflect information about the feeding of the bees, specifying when each hive was fed and the type and amount of the feed. The procedure for the supervision and control of organic farming is provided for in Cabinet Regulation No. 485. [11]

Beekeeping development prospects are also associated with the cultivation of bee species and the development of queen bee selection in the state. Admittedly, currently we need to restore the local bee species appropriate to the Latvian climate in particular, which are better able to adapt to our meteorological conditions and would be best at using the plants that are common in Latvia for collecting nectar. It is obvious that the selection process requires big financial investments. Latvia does not have any geographically isolated queen bee insemination areas – mountain regions or islands isolated from other bee colonies –, but the use of the nearest ones (for example, the islands in Estonia) is economically unprofitable because the distance disproportionately increases the transportation and tending costs. Hence, the creation of an artificial queen bee insemination system is considered more justified, which would allow queen bee breeders and selectionists to use the instrumental queen bee insemination service as close to the location of the apiary as possible. [12] Most likely, the creation of such a system would require the EU and national investments, which would undoubtedly provide a return, but of course, it can only be expected in the course of several years.

Since 1 July 2010, the use of the EU logo on organic food products has been mandatory, as has been an indication of the provenance of raw materials used in the product. This indication must be shown in the same field of vision as the EU logo.[13]

Manufacturing or the purchase of honeycombs requires significant investments. Non-organic bee wax can only be used when creating a new apiary or during a conversion period. In any other case, an opportunity and means must be found to use organic wax. Moreover, the rules for the movement of honeycombs must also be observed. Biological beekeepers must also register the removal of honey frames and extraction of honey in the apiary journal.

Biological beekeeping implies that apiary owners must comply with special controls, which are, moreover, paid for by the beekeepers. Control is performed at any production, processing, or distribution stage [14] in order to ensure the traceability of the movement of food products. Unexpected, surprise checks are practiced, which also put mental pressure on the beekeeper.

The traceability of honey and other beekeeping products starts with identification of each hive, i.e., marking each hive with a colony number; a pillow used for insulation in winter, filling in with natural materials, and the prohibition to use synthetic materials.

The beekeeping product cycle ends with the sale of the final product. Products may only be sold in specially labelled containers. Also, only special food-grade containers and special clothing must be used throughout the entire production cycle.

Realisation of the final product involves another problem – import of honey to Latvia for a disproportionately low price, which makes it difficult for local beekeepers to sell honey and other products produced in Latvia for a price that would cover all investments and allow the beekeeper to earn a living for their family. Thus, the findings in the *Report on prospects and challenges for the EU apiculture sector* that in 2015 more than a half of the honey imported to the EU — approximately 100 000 tons or twice as much as in 2002 — was imported from China appear to be justified. Regardless of the fact that in other parts of the world the numbers of bee colonies have decreased, professionals in the beekeeping sector believe that a large part of the honey imported from China might be counterfeit and contain sugar acquired from sugarcane or corn. Not all member states are able to perform testing to discover violations regarding imported honey at the external border control points of the European Union. [1] Thus, Latvian beekeepers find themselves in the circumstances of unfair competition. Everyone can see honey-like liquids in supermarkets where the prices alone show that it cannot be real honey. Generally, the movement of biological farming products is strictly regulated in the European Union. The products offered by biological beekeepers are, of course, also subject to the general quality requirements, for example, honey packaging and storage requirements, which are not directly related to the requirements for biological farming only.[9]

Making national authorities understand the importance of the beekeeping sector and its irreplaceable contribution to the public has an important role in ensuring the protection of the interests of beekeepers. The limited understanding that our authorities have is seen even in the fact that Latvia has achieved an EU investment for state beekeeping programmes in 2021 in the amount of 207 500 euro; whereas, for example, Lithuania has achieved 487 114 euro respectively. [15] These numbers are a bright illustration of the situation with support for beekeeping.

Overall, such a level of support from the European Union and Latvia is required that would ensure fair competition when selling final products for an adequate price. Without political support, the bee perishing process cannot be stopped, for example, due to excessive use of pesticides, and the production of honey and other bee products will likely be impossible.

CONCLUSIONS

Beekeeping is an integral part of the European agricultural production. More than 620 000 beekeepers work in the beekeeping branch of the European Union. Beekeeping is recognised to be an activity, which has an essential significance in the sustainable development of the rural areas, in the job-creation, the conservation of the ecosystem's biological diversity, and in the maintenance of ecological balance. The basic principle of biological beekeeping is the production of as natural produce as possible.

Biological beekeeping prescribes particular requirements:1) for the location of apiary, for example the distance until the fields where chemical treatment agents are used; 2) the usage of medicinal products for the illnesses 'combat; 3) food to feed bees additionally; 4) he turnover of the produce is also strictly regulated, therefore sale requires additional expenses

It is banned to use plant protection products and animal health products, which have a negative impact on the produce in biological beekeeping. However, it becomes more and more complicated to ensure that bees could have pastures in natural environment, as larger and larger areas are accommodated for agricultural activities, where chemicals for the flushing of plants' growing, eradication of pesticides and against lodgings are used repeatedly during the season.

The conformance to particular requirements requires additional expenses in the biological bee-keeping. It is difficult to recover the costs, selling the finished produce. Large investments are necessary for the production development of the current beekeeping produce's medical aims. Therefore, new biological beekeepers' aid schemes are necessary, involving more new participants and minimising bureaucratic procedures for receiving of the aid.

The conservation of bees' genetic heritage, which is characteristic and appropriate to Latvia's conditions is one of the beekeeping activities' challenges in order to ensure the bee-population's ability to adjust to the environmental changes and their health's hazards.

The study uses the analytical method to explore the current situation in the biological beekeeping sector. The analytical and comparative method helped to identify the problematic issues concerning the implementation of the beekeeping process and support measures. To study different views on the problems of biological beekeeping, the following methods for interpretation of legal norms were used: grammatical, systemic, teleological, and historical. The inductive and deductive scientific research methods were used to draw conclusions regarding current normative regulations and to recommend possible solutions.

REFERENCES

[1]Ziņojums par ES biškopības nozares perspektīvām un izaicinājumiem (2017/2115(INI)), 2018. Available: https://www.europarl.europa.eu/doceo/document/A-8-2018-0014_LV.html#title2[Accessed March 11, 2021]

[2] Padomes Regula (EK) NR. 834/2007(2007. gada 28. jūnijs) par bioloģisko ražošanu un bioloģisko produktu marķēšanu un par Regulas (EEK) Nr. 2092/91 atcelšanu. Available:https://eur-lex.europa.eu/eli/reg/2007/834/oj/?locale=LV [Accessed March 11, 2021]

[3]Ražošanas plāns biškopībā. Available: http://www.videskvalitate.lv/index.php?asad=20. [Accessed March 11, 2021]

[4]Bioloģiskā biškopība Briģos, Available: https://ludzaszeme.lv/biologiska-biskopiba-brigos/.[Accessed March 11, 2021]

[5] KOMISIJAS REGULA (EK) Nr. 889/2008. Available: https://eur-lex.europa.eu/eli/reg/2008/889/oj/?locale=LV. [Accessed March 11, 2021]

[6] Bioloģiskās biškopības saimniecību pastāvēšanas iespējas LAP 2014-2020 kontekstā. Available: https://www.lbla.lv/wp-content/uploads/2015/01/Biologiskas-biskopibas-pastavesanas-iespejas-LAP_2014-2020_LBLA_22012015_Publiski.pdf. [Accessed March 11, 2021]

[7] I.Pēttersone. Bitenieki jūtas bezspēcīgi. Kas apturēs bišu slepkavas? Available: https://www.la.lv/bitenieki-jutas-bezspecigi-kas-aptures-bisu-slepkavas. [Accessed March 11, 2021] [8] Augu aizsardzības līdzekļu lietošanas noteikumi. Ministru kabineta noteikumi No 950, 2011, Available: https://likumi.lv/ta/id/241853-augu-aizsardzibas-lidzeklu-lietosanas-noteikumi. [Accessed March 11, 2021]

[9] Medus neredzamā puse: pesticīdi-drauds biškopības nozares nākotnei. Available:https://biologiski.lv/zinas/medus-neredzama-puse-pesticidi-drauds-biskopibas-nozares-nakotnei. [Accessed March 11, 2021]

[10] IEVA ŠTĀLE. Bioloģiskajā biškopībā dravniekam jāparedz visi riski. Available: https://www.diena.lv/raksts/videunturisms/videsdiena/biologiskaja-biskopiba-dravniekam-japaredz-visi-riski-14173498. [Accessed March 11, 2021]

[11] Bioloģiskās lauksaimniecības uzraudzības un kontroles kārtība. Ministru kabineta noteikumi No 485, 2009. Available: https://likumi.lv/ta/id/193115-biologiskas-lauksaimniecibas-uzraudzibas-un-kontroles-kartiba. [Accessed March 11, 2021]

[12] Latvijas Biškopības Programma 2020–2022. Gadam. 2019. Available:https://www.lad.gov.lv/files/ladDocument/1832/LV_biskopibas_programma_2020-2022.pdf. [Accessed March 11, 2021]

[13] Bioloģisko produktu ražošana un marķēšana, Dokuments 32007R0834. Available:https://eur-lex.europa.eu/legal-content/LV/LSU/?uri=celex:32007R0834. [Accessed March 11, 2021]

[14] Pienācīgu pārtikas un dzīvnieku barības pārbaužu nodrošināšana. Available: https://eur-lex.europa.eu/legal-content/LV/TXT/?uri=LEGISSUM:f84005. [Accessed March 11, 2021]

[15] Komisijas īstenošanas lēmums 2020.-2022.gadam. Available:https://www.zm.gov.lv/lauksaimnieciba/statiskas-lapas/lopkopiba-un-ciltsdarbs/biskopibas-nozare?nid=588. [Accessed March 11, 2021]

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The Methodology for the Creation of an Adapted Model for the Transition to the Circular Economy for the Small and Medium Enterprises of Latvia in a Long Term Perspective

Ivo Lemss
Faculty of Economics and Management
Ventspils University of Applied Sciences
Ventspils, Latvia
ivo.lemss@venta.lv

Una Libkovska
Faculty of Economics and Management
Ventspils University of Applied Sciences
Ventspils, Latvia
una.libkovska@venta.lv

Abstract **- Research will focus on investments for the development of the company. Transition to the circular economy is understood in many cases only as an unnecessary obstacle, not as the new business model. Production based on the linear model "take, make, dispose of" is not possible anymore based on decreased environmental quality. Increased production efficiency could help promote the company's prestige, gain tax allowances, create optimistic co-operation with the state, municipality, and maintain sustainability in terms of the balance achieved between economic, environmental and social interests. Although the research until now is in an early stage, the research purpose is to create an adapted model for the implementation of the circular economy for the small and medium enterprises (from now on – SMEs) of Latvia in a long-term perspective. Research will focus on the following qualitative data analysis methods – SWOT, factor, economic contribution, structured interviews at expert level, overall structured interview in the form of the questionnaire. From quantitative methods, hierarchical cluster or partial cluster method will be used in this research, analysing 3966 organisations in the Eco-Management and audit scheme (from now on – EMAS) at the European level that ensure compliance with the essential environmental requirements under EMAS Regulation No.1221/2009 . Until now within the research, the number of EMAS organisations have been selected between 29 different countries (total number of observations) in 5 sectors (energy, water, waste management, food industry, port terminals), allowing to make the cross-country comparison and describe the involvement level of EMAS in each country. Before using the cluster method, it is essential to assess the cluster trend and whether the cluster method is suitable for research data. The next step will involve using a hierarchical cluster or partial cluster method (a certain number of clusters will be created). It is necessary to use different techniques to evaluate and interpret the created cluster results in future work. Until now, the main conclusion from the literature study is that Latvia has no organisation registered under EMAS and the term "circular economy" is a prevalent trend nowadays worldwide, which can be justified with 114 different terms of the circular economy. Expected results will be the following – issued new criteria for SMEs, issued the adapted model and issued recommendations and suggestions for developing the eco-innovation market.**

Keywords - circular economy, eco-innovations, industrial production, quality standards.

I. INTRODUCTION

It is an axiom that industrial production ensures the society with products and goods necessary for daily life; unfortunately, necessary investments for the development of the company, transition to the circular economy is understood in many cases only as an unnecessary obstacle (not opportunity), postponing, or even ignoring these issues. Production based on the linear model "take, make, dispose of" is not possible anymore based on decreased environmental quality (see Fig.1). Increased efficiency of the industrial production processes can help promote the company's prestige, gain tax allowances, create optimistic co-operation with the state, municipality sector and maintain sustainability (the balance between economic, environmental, and social interests) of the company activities.

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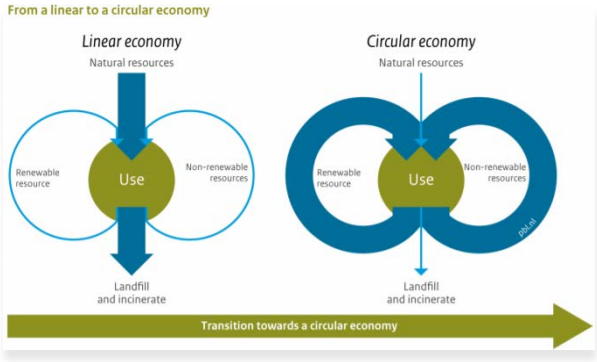

Fig.1. Circular economy concept [4].

The subject of the research is the different models of the circular economy. The object of the research will be SMEs in different economic sectors. The research hypothesis can be defined as the transition to the circular economy is the essential element to achieve high production efficiency in the companies in the long term perspective. The research aims to create an adapted model for the transition to the circular economy for Latvia's SMEs. Until now, the research covers five different essential sectors (electricity and heat production; water and sewage sector; waste management; food production; port terminals) for Latvia's economy, which can be justified with the significance of the infrastructure in each sector (see TABLE 1).

TABLE 1 GENERAL DATA SET IN EACH SECTOR [5], [6]

Sector	**Total number of companies in Latvia (general data set) by NACE codes**	**Infrastructure / activity**
Electricity and heat production	741 (NACE: 35)	Central heat energy supply systems
Water and sewage sector	198 (NACE: 36; 37)	Central water supply and sewage systems
Waste management	368 (NACE: 38; 39)	Collecting, transportation, sorting, regeneration, landfilling
Food production	1481 (NACE: 10)	Production technologies
Port terminals	68 (NACE: 49.5; 52.1)	The infrastructure of the bulk and liquid cargos

Tasks of the research are the following: 1. To analyse literature in the field of environmental and circular economy and eco-innovation technologies; 2. To prepare the methodology and organisation of the research; 3. To compare the different elements of the circular economy (including EMAS and ISO); 4. To research small and medium enterprises based on different economic parameters in each of the sectors; 5. To create and do a comprehensive questionnaire regarding the environmental policy implemented in a company for direct (companies, municipalities, state authorities) and indirect (students, citizens, NGOs) stakeholders; 6. To create and do structured expert interviews in order to assess the "portfolio" of the company, its aims, plans, development strategies, environmental policy; 7. To analyse and interpret data; 8. To create an adapted model of the circular economy for SMEs; 9. To create recommendations for the implementation of an adapted model of the circular economy.

The research topic will remain actual at least until 2025, which fully corresponds to Latvian "Action Plan for the Transition to a Circular Economy 2020-2027" and contributing to the implementation of the European Green Course and the global goals of sustainable development and stresses "(..) investment in research and innovation and support for the adaptation of industry and infrastructure (..)". The missing investments by 2025 are estimated at €320 billion [7].

Although several circular economy good practices have already implemented through eco-innovative projects in Latvia (treatment of the different type of the construction waste, plastics recycling etc.), there is still free capacity for many other projects. The research will use existing circular economy methodologies (for example, different checklists and questions) to strengthen both qualitative and quantitative methods.

II. MATERIALS AND METHODS

The research will use both qualitative and quantitative methods. The following qualitative methods will be used in research: 1. SWOT analysis (identification of the strength, weakness, opportunities, and threats of the circular economy); 2. FACTOR analysis (it is important to understand to what extent one factor can affect others if changes happen in one or another production process); 3. Economic contribution analysis (the gross changes in a region's existing economy can be attributed to a given industry, event, or policy [8]. In this research, economic contribution analysis could be used to analyse and assess whether after implementing some circular economy element, there occurs or there are not any changes in some particular sector; 4. Structured interviews at an expert level (at least three in-depth peer interviews in each sector to identify the most important and crucial points from SMEs point of view in terms of a possible implementation of at least one or more circular economy elements – what do they need? What are the main reasons/factors or obstacles that hinder the implementation of the circular economy? What should be done? et al.); 5. Overall structured interview in the form of the questionnaire (the aim is to ask the same questions to different stakeholders – companies, municipalities, state authorities, students, citizens, NGOs). After analysing the responses received, there will be clear in which questions there is consensus, but in which questions there are doubts, anger, negative emotions, different opinions. From quantitative methods, a hierarchical cluster or partial cluster method could be used in this research, analysing 3966 organisations in the Eco-Management and Audit Scheme (from now on – EMAS) at the European level that ensure compliance with the essential environmental requirements under EMAS Regulation No.1221/2009 [1]. Until now, within the research, the number of EMAS organisations have been

selected between 29 different countries (total number of observations) in five sectors (energy, water, waste management, food industry, port terminals), allowing to make the cross-country comparison and describe the involvement level of EMAS in each country. Before using the cluster method, it is important to assess the cluster trend, whether the cluster method is suitable for the data used in research. If so, how many clusters could be formed? The next step will involve using a hierarchical cluster or partial cluster method (a certain number of clusters will be created). In future work, it is necessary to use different techniques to evaluate and interpret the created cluster results. If one chooses to use the cluster method in one's study, they will need to determine the optimal number of clusters to use, taking into account the statistical error [9]. Creating "K-medium" clusters is one of the simplest and most popular machine learning algorithms. Using an unknown algorithm, it is typical that conclusions are drawn from input vector datasets ("inputs") without reference to known or labelled results ("outcomes"). AndreyBu, who has more than five years of a machine learning experience, says that "The goal of K-means is simple: to the group, the same (with the same characteristics) data points together and discover the basic models. The K-mean uses fixed cluster numbers (k) from the entire data set to achieve this goal. Defining the cluster numbers (k) will record the number of centroids required throughout the data set. A centroid is an imaginary or real cluster centre. Each data point is assigned to each set by reducing the sum of the clusters' inner squares. In other words, the number of the centroid is identified (k). In other words, the K-means algorithm identifies the *k* number of centroids and then allocates every data point to the nearest cluster while keeping the centroids as small as possible. The *'means'* in the K-means refers to averaging the data, finding the centroid. To process the learning data, the K-means algorithm in data mining starts with the first group of randomly selected centroids, which are used as the beginning points for every cluster, and then performs iterative (repetitive) calculations to optimise the positions of the centroids. It halts creating and optimising clusters when: the centroids have stabilised – there is no change in their values because the clustering has been successful; the defined number of iterations has been achieved [10]. Other quantitative methods as calculation of the internal rate of return (IRR) and other economic factors will be used in the research phases. The Likert scale method will be used to prove the hypothesis using respondents' attitude using an assumption that modernisation and development of the production are not possible without investments. Likert scales are the most broadly used method for scaling responses in survey studies. Survey questions that ask one to indicate their level of agreement, from strongly agree to disagree, use the Likert scale strongly. The data in the worksheet are five-point Likert scale data for two groups [11].

III. RESULTS AND DISCUSSIONS

With the circular economy's topic rapidly becoming popular in 2017, there are currently 114 different definitions found in various literature sources. One of the most popular definitions of the circular economy is that it is a production and consumption model that includes the extraction and distribution of resources, re-use, repair, refurbishment, and recycling of equipment to maximise the use of resources [12].

Selecting and getting acquainted with various scientific publications, exciting findings can be found in J.Tirole's research on innovations published in the Journal of Public Economics. At the same time, it should be emphasised that J.Tirole is considered to be a developer of the industrial economy. The research will substantiate the interdisciplinarity of the research with exciting findings from various articles on environmental issues and innovations; for example, J.Tirole concludes that the continuation of an existing activity without new investments is cheaper than new investments in new technologies because, in the last one, there is no state support in terms of different kind of allowances [13].

Expected results of the research will be the following – issued new criteria for SMEs for the transition to the circular economy in long term perspective, issued the adapted model for SMEs for the transition to the circular economy and issued recommendations and suggestions for developing the eco-innovation market.

IV. CONCLUSIONS

The main conclusion from the literature study is that Latvia has no organisation registered under EMAS [2], [3], and the term "circular economy" is a prevalent trend nowadays worldwide, which can be justified with 114 different terms of the circular economy.

In the following research, the author can conclude that it could be necessary to decrease the number of the sectors chosen because the circular economy's central sector is waste management, and other sectors where circular economy elements could be most appropriate is food production.

Practical application of the adapted model could be described as possible IT green market tool where wide range of the eco-innovations (technologies, standards, costs etc.) will be collected and sorted. Waste management and food production SMEs can use such tool for the appropriate analysis and decision making before investing.

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VI. REFERENCES

[1] Access to European Union Law, "Regulation (EC) No 1221/2009 of the European Parliament and of the Council of November 25, 2009, on the voluntary participation by organisations in a Community eco-management and audit scheme (EMAS), repealing Regulation (EC) No 761/2001 and Commission Decisions 2001/681/EC and 2006/193/EC", EUR-Lex-32009R1221-EN, 2009. [Online]. Available: EUR-Lex - 32009R1221 - EN - EUR-Lex (europa.eu). [Accessed: March. 14, 2021].

[2] Access to State Environmental Bureau. [Online]. Available: Vides pārraudzības Valsts birojs - EMAS - Reģistrs (vpvb.gov.lv). [Accessed: March. 14, 2021].

[3] Access to European Commission EMAS Register. [Online]. Available: Emas register (europa.eu). [Accessed: March. 14, 2021].

[4] J. Potting, M. Hekkert, E. Worrell. "Circular Economy: Measuring Innovation in the product chain" PBL Netherlands Environmental Assessment Agency, Hague, Netherlands, Policy Rep. p.9, 2017. [Online]. Available: https://www.pbl.nl/sites/default/files/downloads/pbl-2016-circular-economy-measuring-innovation-in-product-chains-2544.pdf. [Accessed: March. 14, 2021].

[5] Access to Lursoft databases of enterprises. [Online]. Available: Lursoft - databases of enterprises. [Accessed: March. 14, 2021].

[6] Access to Enterprise Register. [Online]. Available: https://www.ur.gov.lv/en/register/. [Accessed: March. 14, 2021].

[7] Access to the Latvian policy planning document database [Online]. Available: Rīcības plāns pārejai uz aprites ekonomiku 2020.–2027.gadam | POLSIS (mk.gov.lv). [Accessed: March. 14, 2021].

[8] P. Watson, J. Wilson, D. Thilmany, S. Winter, "Determining Economic Contributions and Impacts: What is the difference and why do we care?" The Journal of Regional Analysis&Policy, vol. 37(2), pp. 1-15, 2007. [Online]. Available: https://www.ntc.blm.gov/krc/uploads/74/Watson,%20et%20al%20Impacts%20vs%20Contribution%2037-2-6.pdf. [Accessed: March. 14, 2021].

[9] A. Kassambara, "Practical Guide to Cluster Analysis in R," Multivariate analysis, vol.1, p.14-15, 2017. [E-book]. Available: STHDA, https://www.datanovia.com/en/wp-content/uploads/dn-tutorials/book-preview/clustering_en_preview.pdf [Accessed March 14, 2021].

[10] M. Garbade, "Home page - Dr., Michael J.Garbade", September 2018. [Online]. Available: Understanding K-means Clustering in Machine Learning | by Dr. Michael J. Garbade | Towards Data Science [Accessed March 14, 2021].

[11] J. Winter, D. Dodou, "Five-Point Likert Items: t-test versus Mann-Whitney-Wilcoxon (Addendum added October 2012)," Practical Assessment, Research, and Evaluation: Vol. 15, 2010, Article 11. DOI: https://doi.org/10.7275/bj1p-ts64 Available: https://scholarworks.umass.edu/pare/vol15/iss1/11 [Accessed March 14, 2021].

[12] J. L. Ruiz-Real, J. Uribe-Toril, J. P. Valenciano, J. C. Gázquez-Abad, "Worldwide Research on Circular Economy and Environment: A Bibliometric Analysis," Int J Environ Res Public Health, 2018 November 29;15(12):2699 2018. DOI: 10.3390/ijerph15122699 Available: https://pubmed.ncbi.nlm.nih.gov/30501129/ [Accessed March 14, 2021].

[13] J. Laffont, J. Tirole, "Pollution permits and environmental innovation", Journal of Public Economics, 1996, Volume 62, Issues 1–2, Pages 127-140, https://doi.org/10.1016/0047-2727(96)01576-9 Available: http://www.sciencedirect.com/science/article/pii/0047272796015769 [Accessed March 14, 2021].

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Critical Thinking as Grounds of Socially Responsible Communication

Iveta Linina
Turiba University
Riga, Latvia
iveta.linina@turiba.lv

Velga Vevere
EKA University of Applied Sciences
Riga, Latvia
velga.vevere@gmail.com

***Abstract* - Companies and individuals are willing to introduce the principles of social responsibility in their everyday working practices, still, in order to accomplish this and to have real gains for the company and society, the concept of social responsibility has to be understood in the broadest sense. This understanding is based on critical information processing or critical thinking. Information can be obtained through reflection, observation, communication, experience, etc. The aim of the research is to study the factors that influence the basic principles of critical thinking formation, which are the basis of socially responsible communication. The authors employ the monographic method for charting the theoretical framework, the survey to research respondent's' ability to evaluate information critically and to make socially responsible decisions. As the result of research the authors conclude that development of the critical thinking competences can raise the level of social responsibility on the individual and societal level.**

Keywords* - *Communication; socially responsible communication; critical thinking; critical information processing

I. INTRODUCTION

Communication process, in general, is playing more and more significant role in contemporary society. The process is facilitated by the advancement of new technologies and increasing competition within global business environment. Responsible communication is most often associated with conveying the truth in a manner which does not try to manipulate [1]. The responsible communication presupposes such aspects as accessibility, responsiveness and transparency. However, conducting a responsible communication process actually means much more and should also focus on information selection, processing and relaying it others in the appropriate form. A company which strives to become an excellent communicator should carefully manage its entire range of customer touch points and focus on increasing both the actual and the perceived value of its communication process. It pertains any company regardless its size and legal status (private, public, et.), to every management level – from client managers to company CEOs. This brings forth the question of business education, namely, teaching students the responsible communication fundamentals. The novelty of our approach is to relate students' business communication competence to their critical thinking ability.

The role of critical thinking in the contemporary society is as significant as never before since with the process of globalization the speed of business operations increases immensely, that, in its turn involves complex flow of information and necessity to make decisions on all managerial levels, often without the previous experience in the field. This calls for a special type of skills, the one of critical thinking – the mental process of analysis and evaluation information, recognition of the fake content, misleading data, etc. The source of information can be experience, reflection, observation, communication, etc., as well as study process. According to the research of Pearson Education [2], the highest rated skills today are the following: good analysis and problem-solving skills; good judgment and decision making; good overall job performance; the ability to evaluate the quality of information presented; creativity; job knowledge; and the potential to move up within the organization. Critical thinking, perhaps more than any other business skill set, can make the difference between success and failure. Particularly the business world has increasingly stressed the need for critical thinking in graduates for handling large volumes of information in decision-making, with increased competition and pace of change leading to a need for a more strategic outlook and more innovative approaches to processes and products. The business education plays a special role in developing critical thinking skills. In

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addition, the critical thinking becomes a matter of a special importance during the crisis situation, such as Covid-19 pandemic, when many unconventional and nontrivial decisions are to be made, the information are to be sorted out; the new learning and communication methods are to be acquired. Besides that, more than ever there exists necessity for skills to detect the fake news and different conspiracy theories, to check the information sources. The authors of the current research are daily involved with these issues being professors at the private universities in Latvia, teaching such subjects as critical thinking, problem solving, international marketing and research methodology to business students of the bachelor, master and doctoral levels. The aim of the current research is to study the factors that influence the basic principles of critical thinking formation, which are the basis of socially responsible communication.

II. MATERIALS AND METHODS

Communication is an integral feature of human activities. Communication can be described as the process of transmitting and receiving ideas, information and messages. It is used to persuade; to influence relationships; to inform; and to share, discover and uncover information. It is important to recognize that it is a critical thinking fosters the communication and collaboration competence (i.e., information processing, fact checking, communication content, etc.), on one hand, while, on the other hand – the communication competence enhances the critical thinking; this is because communication is a dynamic interactive process that involves the effective transmission of facts, ideas, thoughts, feeling and values. Thus, it follows that development of communication skill is not a separate activity from problem solving, creativity, or collaborative learning, because the students will use communication skills for logical presentation of facts in oral or written form [3]. The concept of responsible communication in the current research is defined through the prism of values as defined in the ground breaking book by Mary C. Gentile " Giving Voice to Values: How to Speak Your Mind When You Know What's Right" [4] and summarized by D. L. Remund [5]. Responsible communication means taking ownership of, and accountability for clear, candid, and consistent dialogue about values-based decisions. The ground rules of such communication include sincerity, relevance, continuity, clarity, prudence, tolerance, openness, prompt resolution, balance, and optimal timing [6]. All in all, the responsible communication, according to this approach means basically three things – accessibility, responsiveness and transparency. Accessibility breeds trust, and trust builds relationships,. In short, accessibility is often about information – receiving and sharing. Being accessible means staying adaptable to changing circumstances and sharing information as freely as possible. Responsiveness, on the other hand, stresses the dynamic character of communication – interaction with stakeholders regarding important issues and moral based decisions. Finally, the third concept of transparency describes sharing information, not having hidden agendas, and being forthright. In the example of information or data, being visible would mean being easily located and complete; being inferable, then, would mean being thorough enough to draw verifiable inferences. We can state that there exists distinct correlation between critical thinking and communication skills – the indicators of critical thinking are skills of formulating and analysing problems; providing viable arguments based on scientific evidence and developing a concise explanation; implementing evaluation which is accompanied by facts, principles or existing guidelines and drawing conclusions. Each and every of these indicators involves communication – relying information; responsible content formation and use of the means and techniques [7].

There is a variety of definitions of critical thinking depending on the field of application and its functions. Some value the reasoning process specific to critical thinking, while others emphasize the outcomes of critical thinking, such as whether it can be used for decision making or problem solving. Thus, for, example, D. F. Halpern [8] focuses on the outcome or utility aspect of critical thinking, in that critical thinking is conceptualized as a tool to facilitate decision making or problem solving in everyday life and business.

Other authors put their stress upon teaching and educational aspects and inclusion of the dedicated course in the curriculum. Because success in our technically advanced society requires critical thinking competence, and because education is the principal means of preparing students for an active and responsible life, it is imperative that educational establishments focus on fostering and developing the critical thinking skills. Nonis and Hudson [9] write about the developing skills of marketing students by the means of including specific themes and practical tasks in different courses (such as, marketing, management, market research, etc.). Among the recent studies we can mention the ones by R. Andrews [10], R. Barnett [11], K. Thomas and B. Lok [12].

Yet other researchers are engaged in the problem of assessment of the level of students' critical thinking, for example such authors as, A. S. Ünsar and E. Engin [13]; M. Karakoc [14]; B. Critchley [15]; A. Khalifa [16]; T. Laurer [17] and many others.

For the purpose of the current research we employ a definition proposed by the Foundation for Critical Thinking that describes the critical thinking as the "intellectually disciplined process of actively and skilfully conceptualizing, applying, analysing, synthesizing or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication, as a guide to belief and actions" [18]. This definition comprises, in our opinion, the vital characteristics of this thinking mode, namely, the acquired (taught) abilities to work with information and apply results of reflection in the practice. In addition, the critical thinking involves the art of argument creation. This process is thoroughly described by T. Bowel and G. Kemp in their joint book "Critical thinking: a concise guide" [19]. The authors argue that it is very important to tell whether an

argument is being given, exactly what the argument is about, and whether one ought to be persuaded by it.

R. Paul and L. Elder [20], on the other hand, presents a list of the characteristics of critical thinkers. These characteristics include the following activities: raising vital questions and problems, formulating them clearly and precisely; gathering and assessing relevant information, using abstract ideas to interpret it effectively; coming to well-reasoned conclusions and solutions, testing them against relevant criteria and standards; thinking open-mindedly within alternative systems of thought, recognizing and assessing as need be, their assumptions, implications, and practical consequences; and, finally, communicating effectively with others in figuring out solutions to complex problems. Moreover, critical thinking requires the use of self-correction and monitoring to judge the reasonableness of thinking as well as reflexivity. Thus, critical thinking ability can be viewed as one of the most important components in 21st century skill roadmap alongside with communication and collaboration, innovation, media literacy, technology literacy, productivity and accountability, leadership and responsibility [21].

The focus of the current article particularly is the relation between critical thinking and responsible communication.

Within the framework of this study, in order to find out respondents' use of critical thinking in evaluation of information, a traditional method was used - a survey was organized with the help of a questionnaire. Additional aspects researched were the following: students' ability to distinguish false information from true; their views on responsibility for disseminating false information. The respondents were full and part-time students from three Latvian universities, aged between 19 and 40. Preparation of the survey involved the following steps:

(1) Determining the standardization and degree of openness of the questionnaire. Taking into account the purpose of the survey and the characteristics of the respondents, the authors of the paper chose a standardized open questionnaire. This meant that all respondents were offered the same questions in the same order, which ensured an objective comparison of answers. The questions were selected with one answer variant according to the Likert scale in the 10-point system and other answer variants in the system.

(2) Determining the survey method. The authors of the paper chose the following option - the survey was created on the website "Google forms". The questionnaire was sent to the respondents via e-mail using the personal contacts of the authors. The questionnaires were filled out and 387 responses were recognized as valid for the current research. Students of all Latvian higher education institutions in 2020 were taken as census altogether 78548 students. At the 95% confidence level and 5% error margin, the minimum sample size was calculated - 383 respondents [22].

(3) Determining the acquisition of the necessary information. For this purpose two focus group discussions were organized, as well as a pilot research. Taking into account the pilot study results, the questions on students' self-assessment regarding information evaluation and questions that allow to assess his / her true skills were prepared.

(4) Question wording. To avoid problems, the authors followed recommendations of the experts [23], [24], [25]: to use simple words and sentences; to avoid ambiguous words and questions; to avoid prompting questions; to avoid hidden alternatives; to make the questions are concrete.

(5) Sequence of questions. The sequence of questions is also an important step, as it affects the respondents' interest in answering questions accurately. In order to avoid such mistakes, the authors of the paper followed special recommendations: general questions were asked at the beginning, but specific questions were later; relatively difficult questions were placed in the second half of the questionnaire; questions on one topic were completed before moving on to the next topic.

(6) Determining the form of the answer. In order to be able to provide a quantitative assessment and perform an appropriate analysis in the case of one possible answer, the authors used a Likert scale with a ten-point rating, where 0 was no rating and 10 was very high. But in order to assess the respondents' true skills and social responsibility in case of providing false information, the ranking of students' agreement with a particular statement was performed.

(7) Statistical methods of processing and analysis of the survey results. Extensive statistical analysis was possible for the given questions. Using the SPSS program, the authors calculated the following indicators: the arithmetic mean ($\bar{X}$); the arithmetic mean standard error; median (Me); mode (Mo); amplitude of variation; standard deviation. For questions with possible multiple choice answers, the percentage of answers in the total sum of answer options was calculated. In order to find out whether there is a correlation between respondents' self-assessment and other factors, correlation coefficients were calculated.

III. RESULTS AND DISCUSSION

The responses were further processed and analysed. First, the main sources for information obtaining were clarified. In the authors' opinion, the information sources particularly can serve as one of the indicators for the truthfulness of information. After processing the answers, it could be seen that the main sources of information for respondents were the internet news portals (44%), followed by the social networks (36%), TV (13%), information from peers (5%) and other unidentified sources (2 %). When asked about the existence and number of accounts in social networks, the answers were the following: existence of one account was admitted by 3%, two accounts by 21%, three accounts by 18% of all respondents, but more than three by 58% of respondents. Social networks make it possible for users to share information, that, in its turn, can serve as an information source for followers. The shared information

in some (or many) cases can be deemed as fake, still, sharing fakes does not presuppose any responsibility to society. Next, the issue of the students' self-assessment in recognizing false information was discussed (see Table 1). In this question, students rated their skills in recognizing false messages on a 10-point scale, where 0 meant that the student could not distinguish between a false message and a real one at all, and 10, where they could always do so.

TABLE 1 STUDENTS SELF-ASSESSMENT IN FAKE NEWS RECOGNITION

Criterion	Arithmetic mean	Standard error	Median	Mode	Amplitude of variation	Standard deviation
Students' self-assessment in recognition of fake news	7.22	0.85	8.00	8.00	8.00	2.54

Analysing the obtained data, it can be concluded that students evaluated their skills in recognizing fake messages quite highly, because the arithmetic mean was 7.22. But if we looked at the range of variations, it was large, which showed that there were students who regarded themselves as being able to objectively assess their skills, namely, their low ability of false news recognition. As the median showed, the most common value was 8, no student rated himself with 0 and 1.

In order to find out whether there was a correlation between the respondents' self-assessment and the factors that indicated the reasons for not recognizing false information, a correlation coefficient was calculated. The authors' calculations of the correlation coefficient between the respondents' self-assessment (on a 10-point scale) and three factors - limited sources of true information, belief in distinctly populist personalities and recognition of world-renowned Latvian scientists showed that the correlation existed, but it was not always very pronounced. A negative correlation coefficient indicates that when increasing one indicator, the other decreases, but positive, increasing one, the other increases. Very weak and weak correlation means that the level of the students' self-assessment is irrelevant to the factors that may affect the ability to recognize false information or the students' ability to objectively assess themselves in relation to the recognition of false information (see Table 2).

TABLE 2 CORRELATION COEFFICIENTS THAT SHOW THE RELATIONSHIP BETWEEN A STUDENT'S SELF-ASSESSMENT IN RECOGNIZING FALSE INFORMATION AND FACTORS THAT INDICATE A LACK OF ABILITY

Indicators of fake news	Students' self-assessment in fake news recognition
Number of information sources used	-0.156
Belief in populistic personalities	0.104
Ability to recognize Latvian scientists	-0.121

The calculation of the correlation coefficients showed that the higher the students' self-esteem, the less information sources they use. As well as belief in highly populist well-known personalities, there was a weak but positive correlation with high self-esteem. A similar situation was observed with the recognition of scientists. The fewer scientists were recognized, the higher their skills in recognizing false news. These correlation coefficient calculations showed that students had major problems in objectively assessing their ability to distinguish false information from true information.

Respondents were also asked how much they agreed with the statement that they share information on social networks without being convinced of its truthfulness (see Figure 1).

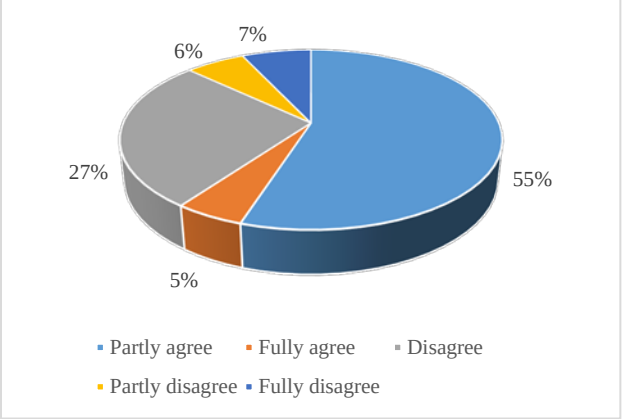

Fig. 1. Responses to the statement regarding sharing information without fully checking information.

The answers to this question made it clear that the majority, i.e., a total of 60% of respondents, partially or fully agreed with the statement that they shared news on social networks without being convinced of its truthfulness. Only 7% of respondents said they completely disagreed with the statement that they always share news without being sure of its content.

Finally, the respondents were asked whether the distributors of false information should be responsible for the consequences caused by this information (see Figure 2).

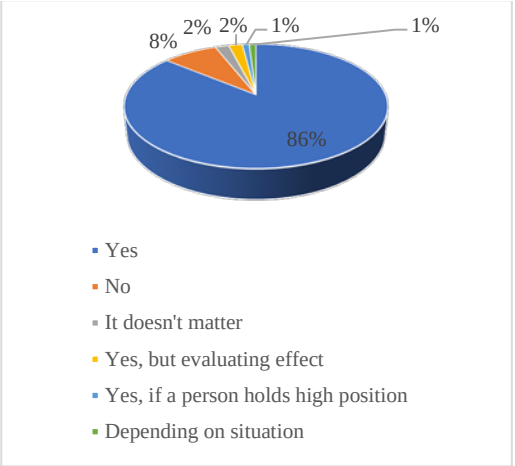

Fig. 2. Responsibility for sharing false information

Most of the respondents (86%) answered affirmatively, several with the remarks that it depended on the situation, or if a person held a high position, but only 8% answered no.

IV. CONCLUSIONS

During the survey the main sources of information of the respondents were identified and it was concluded that they are Internet news portals (44%), followed by social networks (36%), TV (13%), information from peers (5%) and other unidentified sources (2%). In addition, 59% of respondents have profiles on more than 3 social networks.

In the course of the survey it was found out that students, when evaluating their ability to distinguish false information from the true one, have assessed themselves relatively high - with the arithmetic mean 7.22.

Calculations of the correlation coefficient showed that respondents were most likely not able to assess their skills in recognizing false information, the more limited the students' information sources and the less they were able to recognize the world-class Latvian scientists, the higher was their self-evaluation. As well as those whose self-esteem was higher, trusted more the populistic personalities. But as the correlation appeared to be weak, the conclusion could not be fully applied to all respondents.

Summarizing all information obtained in the study, it can be concluded that students have problems with objective self-assessment of recognizing false information, and the majority, 60% of respondents, agree in part or in full with the statement that they share information on social networks without being convinced. Only 7% of respondents said they completely disagree with the statement that they always share news without being sure of its content. It is very important to understand that sharing false information (fake news) can bring about consequences. Therefore, the authors of the current research stress the necessity to develop socially responsible communication skills among students and general public.

Sharing fake news can have consequences. In the study, it was very important to understand the opinion of the respondents or to express or share false information, there should also be responsibility for it. Most of the respondents (86%) answered affirmatively, but several with the remarks that depending on the situation, or if a person holds a high position, but only 8% answered no. The authors of the current research believe that it would be necessary to work out the code of ethics (the voluntary code of behaviour) for the users of social media to reduce sharing of false and unverified information.

Research points at the need for critical thinking skills for both students and general public that would be basis of socially responsible communication.

REFERENCES

[1] R. L. Johannesen, K. S. Valde and V. E. Whedbee, Ethics in Human Communication. Long Grove, Il.: Waveland Press, Inc., 2008.

[2] Pearson 2013 results. [Online]. Available: https://www.pearson.com/news-and-research/announcements/2014/02/pearson-2013-results.html [Accessed: March 19, 2021].

[3] S. K. W. Chu and others, 21st Century Skills Development Through Inquiry-Based Learning. Singapore: Springer Science+Business Media, 2017.

[4] M. C. Gentile, Giving Voice to Values: How to Speak Your Mind When You Know What's Right. New Have and London: Yale University Press, 2010.

[5] D. L. Remund, The art of responsible communication. Leading with values every day. New Yourk: Business Expert Press, 2015.

[6] B. Dresp-Langley, "The Communication Contract and Its Ten Ground Clauses," Journal of Business Ethics, vol. 87, no. 3 2009, pp. 415–436.

[7] S. K. Bandyopadhyay and J. Szostek, „Thinking critically about critical thinking: Assessing critical thinking of business students using multiple measures," The Journal of Education for Business, vol. 94, no.4, 2018, pp. 1-12, DOI: 10.1080/08832323.2018.1524355

[8] D. F. Halpern, Halpern Critical Thinking Assessment manual. Vienna, Austria: Schuhfried GmbH, 2010.

[9] S. A. Nonis and G. I. Hudson, "Developing and assessing critical thinking skills in marketing students: The power of making explicit problem-solving processes," Journal of Education for Business, vol. 94, no. 3, 2019, pp. 195-203, https://doi.org/10.1080/08832323.2018.1504737

[10] R. Andrews, "Critical Thinking and/or Argumentation in Higher Education," in The Palgrave Handbook of Critical Thinking in Higher Education, New York: Palgrave Macmillan, 2015, pp. 49-62.

[11] R. Barnett, "A Curriculum for Critical Being," in The Palgrave Handbook of Critical Thinking in Higher Education, New York: Palgrave Macmillan, 2015, pp. 63-76.

[12] K. Thomas and B. Lok, "Teaching Critical Thinking: An Operational Framework," in The Palgrave Handbook of Critical Thinking in Higher Education, New York: Palgrave Macmillan, 2015, pp 93-106.

[13] A. S. Ünsar and E. Engin, "A case study to determine critical thinking skills of university students, " Procedia - Social and Behavioral Sciences, vol. 75, 2013, pp. 563 – 569, https://doi.org/10.1016/j.sbspro.2013.04.061

[14] M. Karakoc, "The Significance of Critical Thinking Ability in terms of Education, " International Journal of Humanities and Social Science, vol. 6, no. 7, July 2016, pp. 81-84.

[15] B. Critchley, "Critical Thinking in Business Education," Investigations in university teaching and learning, vol. 7, spring 2011, 5-15.

[16] A. Khalifa, "Rethinking the Current Dominant Approach to Business School Strategy," European Business Review, vol. 22, no. 6, 2009, pp. 591-607, https://doi.org/10.1108/09555341011082907

[17] T. Laurer, "Teaching Critical Thinking Skils Using Course Content Material: a reversal of roles," Journal of College Science Teaching, vol. 34, no. 6, 2005, pp. 34-37.

[18] The Foundation for Critical Thinking. [Online] Available: https://www.criticalthinking.org/pages/defining-critical-thinking/766 [Accessed 20 March, 2021].

[19] T. Bowell and G. Kemp, Critical thinking: A Concise Guide. London and New York: Routledge, 2015.

[20] R. Paul and L. Elder, Critical Thinking Tools for Taking Charge of Your Professional and Personal Life. Upper Saddle River, New Jersey, Pearson Education, Inc., 2014.

F. A. Yusuf and E. A. Adeoye, "Developing Critical Thinking and Communication Skills in Students: Implications for Practice in Education," African research review, vol. 6, no. 1, 2012, pp. 311-324, http://dx.doi.org/10.4314/afrrev.v6i1.26

[21] H. Hasanah and M. N. Malik, M. N., "Blended learning in improving students' critical thinking and communication skills at University," Cypriot Journal of Educational Science, vol. 15, no. 5, 2020, pp. 1295 - 1306, https://doi.org/10.18844/cjes.v15i5.5168

[22] I. Arhipova and S. Bāliņa, Statistics in Economy and Business [Statistika ekonomikā un biznesā]. Riga: Datorzinību centrs, 2006.

[23] S. L. Payne, The Art of Asking Questions. Princeton: Princeton University Press, 1978.

[24] P. L. Erdos, Professional Mail Surveys. Melburne, Fla.: Robert E.Krieger Publishing, 1983.

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Client Relationship Management in Latvian Retail Enterprises Under COVID-19 Circumstances

Iveta Linina
Turiba University, Latvia
Iveta.linina@turiba.lv

Rosita Zvirgzdina
Turiba University, Latvia
rosita@turiba.lv

Velga Vevere
EKA University College of Applied Sciences, Latvia
velga.vevere@gmail.com

Abstract **- Ensuring customer satisfaction is the key to a successful retail business. The process of attracting new customers always involves more money, time and energy. In order for a company to retain existing customers and build relationships with them, one of the basic tasks is to know the factors and levels that affect their satisfaction. In the current situation of COVI-19, this poses even greater obstacles and challenges. In order to identify the company's ability to ensure competitiveness in a crisis situation, the authors have set the goal of the research to study the factors influencing retail consumer behavior under COVID-19 circumstances.**

This study will provide retail businesses with an understanding of the need for consumer relationship management in a restricted situation. From the scientific point of view, the authors have analyzed the theoretical aspects and summarized the approach to the understanding of buyers' behavior in crisis conditions. As a result of the research, the authors conclude that even in crisis situations, companies can manage the relationship with consumers and shape the attitude of buyers, which can be one of the tools for ensuring competitiveness.

Keywords - consumer; consumer satisfaction; consumer relationship management; retail trade

I. INTODUCTION

The Covid 19 pandemic is also affecting retail businesses, forcing them to look for solutions to ensure and develop competitiveness. A retail company's focus on customer satisfaction and loyalty is one way to become competitive. This is especially true in the current context of the Covid 19 pandemic, when consumer dissatisfaction with government decisions and restrictions is growing. Building customer satisfaction and loyalty is based on purposeful relationship building. This goal must be based on creating a competitive and sustainable development of a trading company. Latvian retail companies do not have sufficient understanding of consumer relationship management and its benefits. The study examines the level of management development and use of Latvian retail companies' relationships with customers. Gaining an understanding of the target audience and developing marketing activities and communication based on this understanding increases customer satisfaction and builds loyalty, which in turn can ensure and increase competitiveness. In order to identify factors for building and ensuring customer relationship management in retail, the authors of the study have set the goal of the research to study the factors influencing retail consumer behavior under COVID-19 circumstances. In order to achieve the goal, the following tasks were set:

1. To analyze information on the principles of customer satisfaction and loyalty management.

2. To describe the Latvian retail sector and its operation in the conditions of the Covid 19 pandemic.

3. To determine the basic factors of building customer satisfaction and loyalty and their successful application in Latvian retail companies in the conditions of the Covid 19 pandemic.

In order to determine the basic factors of customer satisfaction and loyalty in Latvia in the conditions of the Covid 19 pandemic and their use in building and managing customer relationships in retail companies in Latvia, a customer survey was conducted. As a result of the research, proposals were made for building customer satisfaction and loyalty. The following limitations were set in the course of the study: the problem is studied mainly from the methodological aspects and the age and income level of the respondents to the survey were not taken into account. Research period: November 1, 2020 to March 1, 2021. The following research methods were used in the research: logical-constructive method - for comparison of theoretical material with empirical results; graphical - for display and analysis of visually collected information and consumer

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survey. The methodological basis of the research is foreign works and publications (P. DePelsmacker, J. Eskildsen, K. Kriestensen, M. Krauss, D. O` Reilijs, D. Gibass, etc.) process.

II. RESULTS AND DISCUSSION

Many specialists, researchers and managers today have come to the conclusion that in the conditions of fierce competition, one of the most important factors for the success of companies is consumer satisfaction with the offers and their loyalty to the product / brand / company. It is a favorable attitude and loyalty that is the basis for building a company's consumer capital. However, in order to achieve the desired level of consumer satisfaction and loyalty, the company must lead the process of relationship with consumers.

Analyzing several publications and other sources in the field of consumer relationship management (Reisheld, 2003; Evans, 2012; Butscger & Stephan, 2002; Kotler & Keller, 2006, 196–197; Toedt, 2015; Harker, 1999; etc.), the author is has come to the conclusion that four systems studied in theory and used in practice should be highlighted in retail:

1) Loyalty Program - LP;

2) Consumer Relationship Management - CRM;

3) Efficient Consumer Response - ECR;

4) Relationship Marketing Management - RMM.

Retail companies use different management systems in practice, but as they evolve, each new system incorporates both positive and proven elements from the previous system and new elements. This process is illustrated in 1.1. in the picture.

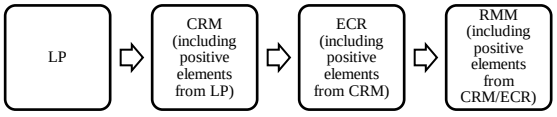

Fig. 1. Evolution of consumer relationship management systems in retail Linina, 2017).

The authors analyzed the literature on each of the management systems mentioned in Figure 1 and the experience of their practical use in order to draw conclusions about their differences, common elements, advantages and disadvantages.

Loyalty programs are used by many companies on all continents of the world.

F. Reisheld believes that the consumer loyalty program is aimed at increasing consumer activity through a systematic impact on consumer behavior (Reisheld, 2003).

M. Evans believes that the essence of the consumer loyalty program is the support and rewarding of the consumer for his constant cooperation with the company and making purchases (Evans, 2012). According to S. Butscher and A. Stephan, a company organizes a loyalty program with the aim of constant direct communication, creating an emotional connection with consumers and offering them a set of benefits with greater added value to increase the level of loyalty (Butscger & Stephan, 2002). A loyalty program can be defined as a set of marketing activities of a company that is carried out to influence consumer behavior for the purpose of ongoing cooperation and product / brand purchases through direct communication, incentives, rewards, and so on. Loyalty-building tools (Liniņa, 2016). When describing the advantages and disadvantages of loyalty programs, it is necessary to distinguish between objectively inherent content and subjective implementation, which does not always meet the requirements. For example, scientific publications in this area include descriptions of both positive and negative experiences (Kotler & Keller, 2006, 196–197; Toedt, 2015; Butcher & Stephan, 2002, etc.). In this case, it is a question of realizing the possibilities of subjective loyalty programs with objective shortcomings. To some extent, these shortcomings can be addressed through the use of CRM, which, on the one hand, incorporates the positive elements of a loyalty program, but, on the other hand, is the next step in building and managing a business relationship with consumers.

There are several explanations and definitions of CRM in the scientific literature. The author believes that this can be explained by two reasons. First, with the advent of new marketing tools and new technologies, the functions of CRM are also changing and new opportunities are emerging in the field of consumer research and relationship management. Secondly, the analysis of CRM development and use is performed from specialists in various fields - employees of marketing and sales departments, computer analysts, lawyers, etc. - a point of view which undoubtedly affects the understanding of the system.

The authors analyzed information on CRM theory and practice from a marketing perspective (Evans, 2012; Kotler & Keller, 2006, 196–197; Smith & Zook, 2011, 61–86; Harvey, 2015). For example, P. Kotler and K. L. Keller consider CRM to be “the use of detailed information about each consumer and the management of each consumer's contact with the product / brand / company” (Kotler & Keller, 2006, 196–197). PR Smith and Z. Zook emphasize that CRM is “a complex business operation that creates and maintains a database to help retain consumers through their needs, complaints, suggestions, and purchases” (Smith & Zook, 2011, 61–86). . According to Harvey, CRM combines two systems: internal (consumer research process) and external (building relationships with consumers), which are interconnected with the aim of attracting and retaining consumers by offering a product / brand that meets their needs (Harvey, 2015). . The authors of the paper agree with the opinion that “CRM is not just a technology and therefore it is not possible to increase the quality of relations with consumers only with the help of a computer program. CRM is a part of a company's interaction strategy with consumers” (Kraus, 2002). I. Liniņa offers the following definition of CRM: Consumer Relationship Management (CRM) is a company's strategy to attract, differentiate, serve and retain consumers through understanding and meeting their needs, developing long-

term cooperation based on creating and maintaining a consumer database (Liniņa, 2016).

The essence of CRM is already expressed in its name - the company's management's orientation towards building sustainable relationships with consumers. As a result, the company can get more satisfied and stable consumers, which will bring the company more income. CRM provides not only buying / selling, but also pre-purchase and post-purchase process management. Another important difference is related to the creation and use of a marketing database (MDB) based on new information technologies.

In summarizing publications on CRM, company reports, and reports on CRM conferences (Kotler & Keller, 2006, 196–197; Smith & Zook, 2011, 61–86; Tapp, 2011), the authors highlight the following key principles of CRM in consumer marketing databases (MDB), differentiation of consumers according to two criteria: needs and benefits for the business, personalized communication with consumers to obtain information on their needs, complaints, suggestions, on the one hand, and influence their actions on the other attracting new customers and retaining existing ones through incentives for repeat purchases and dialogue to increase loyal customers, building and managing long-term customer relationships to promote brand image and company reputation, which in turn affects consumer loyalty, relationship with consumers formation and management to ensure the average cost per consumer u Reducing and increasing profits by increasing the level of loyalty and optimizing the pre-purchase, sale / purchase and post-purchase process simultaneously from the consumer and business point of view. Of course, it is important not only to create an MDB and fill it with information, but also to use it rationally, because the effectiveness of CRM depends on its use. The purpose of using MDB is to link consumer needs, products / brands, price, product / brand distribution channels and communication in one system.

The authors join those researchers who first associate CRM with the company's marketing and management (Krauss, 2002; Reil & Gibass, 2000; De Pelsmacker, et.al. 2007, 397–407; Anderson, 2007, etc.), with five stages (see Figure 2).

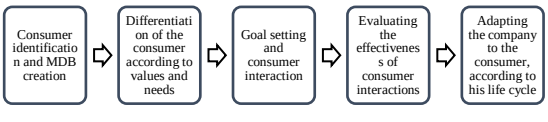

Fig. 2. Stages of consumer relationship management in the company (Liniņa, 2017).

In essence, the CRM scheme (see Figure 2) also meets the requirements of retail companies, of course, taking into account the specifics of the industry. Analyzing the publications on the use of CRM in retail (Anderson, et al., 2007; Griffin, 2002; Kim, et al., 2004), the authors have come to the conclusion that when developing a CRM system in retail, the following features should be taken into account: long-term system operation, it is necessary to ensure close functional cooperation of the company's marketing and sales departments / services, MDB creation, maintenance and improvement must be based on the customer card, the planning, creation and distribution of which must be reasonable and purposeful point-of-sale provision, the introduction and maintenance of MDBs in retail requires more investment in hardware, computer communications, software, staff training and education than in other sectors, and it must be borne in mind that not all individual consumers want to buy products at a point of sale is loyal and agrees to provide extensive information about himself, k also allow the company to use other databases for its personal data.

Consumer Relationship Management (CRM) systems are followed by ECR (Efficient Consumer Response), which we can translate as "effective response to consumer needs". As a result of the analysis of publications in the field of ECR (Dyer & Harbir, 1998, 660–679; Seifert, 2001; Hofstetter, 2006; Salmon, 1993; Teece, et al., 1997, 509–533, etc.), the author concluded that despite insignificant differences, all authors consider ECR to be "cooperation between trade and industry to meet consumer needs and to promote irrational cost avoidance in the producer-to-consumer supply chain".

ECR became popular in developed countries in the mid-1990s and was based on increasing competition in world markets, the rapid development of information technology, the emergence and development of international trade organizations, the need to optimize distribution channels and the growing consumer demand for valuable and high-quality products and high quality of service. Researchers have emphasized that it is mutual trust between all partners involved in the product delivery process that is a prerequisite for achieving positive ECR results (Dyer & Harbir, 1998, 660–679). ECR is a long-term relationship with relevant investments in the product delivery process, which aims to manage and resolve any disagreements in time to achieve an overall positive outcome (Teece, et al., 1997, 509-533).

However, agreeing with the statements of these researchers about the characteristics of ECR, the author considers that it is unreasonable to plan and implement this relationship management system in practice separately and independently of the implementation of CRM in retail. In essence, ECR is a modernized and supplemented CRM, as it serves the same purpose of managing customer relationships to meet their product needs and increase loyalty. It is clear that close cooperation between the manufacturer and the trader is needed in this area. Improved product quality will not matter if the retailer is unable to provide high quality customer service (a function of the CRM system) and loyalty rates will decline as a result. Summarizing the obtained information, it can be concluded that the basis for building a customer relationship system in retail companies is the effective use of CRM and ECR systems.

The development of the chain LP - CRM - ECR logically leads to Relationship marketing management (RMM) in companies (see Figure 1). A lot of research, publications and monographs have been devoted to this topic (Harvey, 2015; Krauss, 2002; Seifert, 2011). Analyzing the scientific literature in this field, it can be concluded that relationship marketing management is a process of creating, maintaining and developing cooperation with consumers and business partners in order to facilitate the long-term supply of consumers. It follows that this system requires all departments / services / employees of the company to work in the field of customer relationship management. If the implementation and maintenance of CRM and ECR can be done only by a separate structural unit of the company, then RMM is the strategic mission and vision of the whole company's activities. Relationships with consumers are formed on several levels - economic, social, technical, legal, thus ensuring consumer satisfaction and loyalty.

In order to describe the management of consumer relations in retail companies in Latvia, it is important to first describe the situation in this area of the economy. According to the data published by the Central Statistical Bureau, in the first month of 2021, compared to the corresponding period of the previous year, the total retail sales have decreased by 8.9%. A sharp decline in retail sales was already expected in January, as the retail sector operated under tight constraints throughout January. Thus, practically all non-food stores were not allowed to operate in person and the population could buy only a limited range of goods - food and those non-food items that are attributable to basic necessities. The restrictions also did not affect trade at service stations. Consequently, the retail trade of non-food products showed a sharper decline, excluding automotive fuel, which decreased by 23.4% year-on-year in January. Among non-food products, the strongest decline in January was recorded in retail trade of clothing and footwear, which was 64% lower than a year ago. The strongest negative contribution to the total results of non-food trade was made by a 28.9% decline in retail sales of metal products, paints and glass. Sales also decreased in several other categories of non-food products, including retail sale of information and communication technology equipment (-9.2% year-on-year), retail sale of cosmetics and toiletries (-27.9%), retail sale of cultural goods and leisure goods (29.2%) and others Meanwhile, sales growth continued in January in retail sale of household electrical goods (+ 21.2%) and after a break of several months, growth was again recorded in retail sale via mail order houses and online stores (+ 11.9%).

The latest data on consumer and business economic confidence compiled by the European Commission show that in February, Latvian retailers' sentiment deteriorated for the fourth month in a row, approaching the initial level of the Covid-19 pandemic, which was the lowest in ten years. The consumer sentiment indicator showed a slight improvement over the previous month in February, but is still well below the pre-pandemic average. Consumers' perception of higher purchases in the coming months has remained very low, driven not only by general uncertainty and caution, but also by government restrictions on the retail sector, which prevent the purchase of non-essential goods. At the same time, consumers' assessment of their household's financial situation, showing a significant deterioration in January, improved sharply in February, reaching an all-time high.

At the beginning of the year, household savings also continued to increase, as evidenced by both the results of consumer surveys on current and planned savings and the Bank of Latvia's data on deposits. In January of this year, compared to January 2020, household deposits attracted by Latvian commercial banks grew at an even faster pace than at the end of last year - by 14%, reaching 8.45 billion euros, which was determined by the increase in household funds at the end of the day. They increased by 27% over the year, while fixed-term household deposits and deposits redeemable at notice decreased by 28% and 33%, respectively. This indicates an increase in the funds available to the population, which will be directed to consumption at a time when, as the epidemiological situation in the country improves, restrictions will be significantly relaxed not only in the trade sector, but also in the provision of services.

Also in February, the restrictions related to the control of Covid-19 disease in the trade sector have remained relatively strict, taking into account that the statistics on the spread of the virus in Latvia are still alarming. Although grocery and hygiene stores were allowed to sell all goods and bookshops were opened to shoppers from 8 February this year, epidemiological safety rules were strengthened at the point of sale, and most non-food stores are still closed. Consequently, it is expected that in February the retail trade sector will also decrease (Ministry of Finance of Latvia).

In the framework of this study, in order to directly and indirectly find out the factors influencing the choice of buyers' place of sale and their assessment in the real situation, a traditional method was used - a survey was organized with the help of a questionnaire. Preparing to use this method involves six steps.

1. Determining the standardization and degree of openness of the questionnaire. Taking into account the purpose of the survey and the characteristics of the respondents, the authors of the paper chose a standardized open questionnaire. This means that all respondents were offered the same questions in the same order, which ensures an objective comparison of answers. The questions were selected with one answer variant according to the Likert scale in a 5-point system and other answer variants in the system.

2. Determining the survey method. (Arhipova & Bāliņa, 2006). The authors of the paper chose the following option - the survey was created on the website "Google Forms". The questionnaire was sent to the respondents via e-mails using the personal contacts of the author of the work, the questionnaires filled in by 398 respondents were recognized as valid for the research. All residents of Latvia were taken as a general group. At the 95% confidence level and the 5% margin of error, the minimum sample size was calculated - 387 respondents.

3. Determining the acquisition of the necessary information. Decision-making on this issue is to some extent facilitated by the focus group pilot studies already carried out on the factors influencing the choice of trading venue. In the light of the pilot study, questions were prepared to assess the factors influencing buyers' choice of outlet and their assessment. At the same time, it is very important to make sure that the respondents have the necessary information to answer the questions raised.

4. Question wording. To avoid such problems, the authors followed the recommendations of experts (Payne, 1978, 158-176):

- use simple words and sentences;
- avoid ambiguous words and questions;
- avoid prompting questions;
- avoid hidden alternatives;
- make sure the issue is specific.

5. Sequence of questions. The sequence of questions is also an important step, as it affects the respondent's interest in answering questions accurately. In order to avoid such mistakes, the authors of the paper followed special recommendations: general questions were asked at the beginning, but specific questions were followed; relatively difficult questions were placed on the second side of the questionnaire; questions on one topic were completed before moving on to the next topic.

6. Determining the form of the answer. In order to be able to provide a quantitative assessment and perform an appropriate analysis in the case of one possible answer, the authors used a Likert scale with a 5 (five) score, where 1 is a low grade and 5 is very high. But in order to assess the respondents' true skills, the degree of student's competence for a particular statement was chosen.

7. Statistical methods of processing and analysis of consumer survey evaluations. Extensive statistical analysis is possible for the questions given in the points. Using the SPSS computer program, the authors calculated the following indicators:

- the arithmetic mean ($\bar{X}$);
- the arithmetic mean standard error;
- median (Me);
- mode (Mo);
- amplitude of variation;
- standard deviation (Kristapsone, Kamerāde et al.. 2011: 199).

For questions with possible multiple choice answers, the percentage of answers in the total sum of answer options was calculated.

The responses were further processed and analyzed.

First, the issue of buyers' evaluation in the choice of a point of sale was addressed (see Table 1). In this question, buyers rated the factors that influence their choice for a particular point of sale on a 5-point scale, where 1 meant that this factor was insignificant and 5 - very important.

TABLE 1 EVALUATION OF FACTORS INFLUENCING BUYERS WHEN CHOOSING SPECIFIC OUTLETS

Factors influencing the choice of point of sale	Mean	Standard error of Mean	Median	Mode	Standard deviation	Skewness
Shop location, convenient parking, public transport and other amenities	4.52	0.04	4	4	0.82	4.00
Assortment of goods	4.15	0.05	5	5	1.07	4.00
Price level	3.55	0.05	3	4	0.99	3.00
Marketing activities: advertising, promotions, etc.	3.28	0.05	3	3	1.09	2.00
Quality of service	3.99	0.05	4	4	0.96	2.00
Socially responsible action in the Covid 19 pandemic	4.71	0.05	5	5	0.36	2.00

Analyzing the obtained results on the factors influencing the choice of a particular point of sale for buyers, it can be seen that the buyers have chosen the socially responsible operation of the trading company in the conditions of the Covid 19 pandemic as the most important. The buyer's safety is a factor that ensures his satisfaction with a particular point of sale, and the small amount of variation indicates the unanimity of views on this issue. Other factors are listed in the following order of importance - store location, convenient parking, public transport and other amenities, product range, price level, quality of service and finally marketing activities.

On the other hand, when it comes to assessing the real situation, the situation is different (see Table 2).

TABLE 2 BUYER RATING FOR THE POINT OF SALE

Point of sale evaluation factors	Mean	Standard error of Mean	Median	Mode	Standard devitation	Skewness
Shop location, convenient parking, public transport and other amenities	4.61	0.04	4	4	1.01	3
Assortment of goods	3.88	0.05	3	3	0.98	3
Price level	3.22	0.05	3	3	0.97	3
Marketing activities: advertising, promotions, etc.	2.88	0.05	2	3	1.02	2
Quality of service	4.08	0.05	4	4	0.96	4
Socially responsible action in the Covid 19 pandemic	3.41	0.05	2	3	0.98	3

The location of the store, convenient parking, public transport and other amenities are rated the highest, then the quality of service, product range and only then socially responsible activities in the conditions of the Covid 19 pandemic, but marketing activities are rated the lowest.

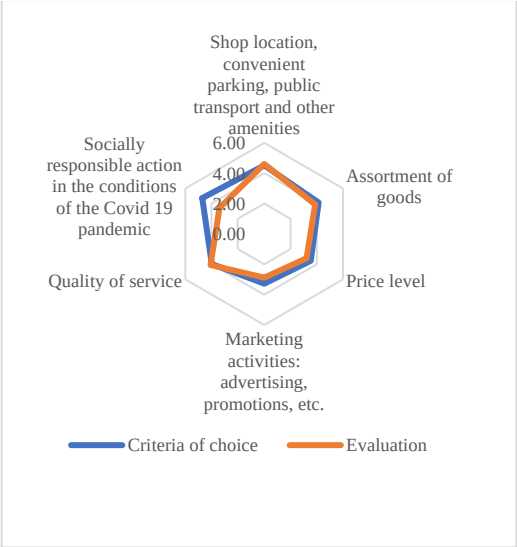

Fig. 3. Comparison of the arithmetic average of the factors influencing the choice of the buyer's point of sale with the arithmetic mean of the evaluation of the performance of the buyer's point of sale.

As shown in Figure 3, the location of the store, convenient parking, public transport and other amenities are rated on average 4.52 points, while the real rating is 4.61, which is even 0.09 points more. The assortment of goods by importance is on average 4.15, but the real assessment is 0.27 points less and makes 3.88 average points. In this case, retailers should find out what does not satisfy consumers in their product range in the context of the Covid 19 pandemic and address this issue as a matter of urgency in order to increase customer satisfaction. Also, the price level in terms of importance is assessed with an average of 3.55, but in reality it is assessed with an average of 3.22 points, which is 0.33 points less. This issue should also be considered as a basis for the development of customer satisfaction. In turn, the quality of service is rated by 3.99 on average, but in reality it is rated by 0.09 points high - 4.08. Marketing activities are evaluated on average in reality with the lowest with 2.88, but in terms of importance with 3.28, where the largest difference is observed - 0.40. This difference could be explained by the fact that in a Covid 19 pandemic situation, buyers expect a more responsible approach to providing a variety of information to buyers and retailers need to take this into account. The biggest difference is observed in the conditions of socially responsible activity in the conditions of the Covid 19 pandemic, with a difference of 1.3 points, because the average importance score of this factor was 4.71 in the respondents' assessment, but the assessment of the real situation is 3.41. Respondents' answers show that they do not really feel social responsibility on the part of retail companies, and this can be a problem in the long run for customer satisfaction and loyalty. It is crisis situations that point to weak links in companies' operations, which can reduce a company's competitiveness.

III. CONCLUSIONS

1. Customer satisfaction and the process of building loyalty is an important factor in the development and competitiveness of retail businesses. This means that in order to improve their performance in this area, companies need to focus on the opportunities offered by loyalty programs, CRM and ECR, based on the information collected and compiled in marketing databases and to guide the use of RMMs in the future.

2. Analyzing the obtained results on the factors influencing the buyers' choice of a particular point of sale, it can be seen that the buyers have chosen the socially responsible activity of the trading company in the conditions of the Covid 19 pandemic as the most important (4.71). The buyer's safety is a factor that ensures his satisfaction with a particular point of sale, and the small amount of variation indicates the unanimity of views on this issue. The buyer wants to shop in sales outlets that have a socially responsible approach to organizing their activities.

3. According to the respondents, the location of the store, convenient parking, available public transport and other amenities are rated on average by 4.52, but in reality with 4.61. In reality, this indicator is rated higher than the importance by 0.09 points. Similarly, the quality of service was assessed by importance on average with 3.99, but in reality it was assessed by 0.09 points high - 4.08

4. Buyers rated the assortment of goods in terms of importance with an average of 4.15 points, but in reality with 3.88 points. In reality, the assessment is less than 0.27 points, which indicates buyers' dissatisfaction with the range of available goods. In turn, the price level was rated on average with 3.55 points, but in reality with 3.22 points, where the difference between the arithmetic averages is 0.33 points. The biggest difference between the averages in the significance and real assessment is observed in the marketing activity 0.40 points (3.28 - 2.88). These indicators point to the need for retail companies to ensure customer satisfaction, to evaluate the available assortment and pricing policy more carefully, and to develop marketing activities in accordance with the current situation.

5. Retailers in the Covid 19 pandemic would be advised to conduct both customer monitoring and surveys to accurately identify current customer satisfaction factors. When creating a marketing complex, including marketing communication in these conditions, use the obtained data on customer satisfaction, which will promote the development of customer loyalty, which in turn will increase competitiveness.

REFERENCES

[1] Anderson, J. L., Jolly, L. D., Fairhurst, A. E. (2007). Customer relationship management in retailing: a content analysis of retail trade journals. Journal of Retailing and Consumer services, November, 14 (6), pp. 394-399.

[2] Arhipova, I., Bāliņa, S. (2006). Statistika ekonomikā un biznesā. Rīga: Datorzinību centrs.

[3] Butcher, S., Stephan, A. (2002). Customer Clubs on Loyality Programms. Abingdon, Oxsn, GBR: Gower Publishing Limited.

[4] Covid-19 ierobežojumi tirdzniecības jomā būtiski ietekmējuši nozares rezultātus janvārī, FM Preses relīze 26.02.2021. Iegūts 13.03.2021. https://lvportals.lv/dienaskartiba/325374-fm-covid-19-ierobezojumi-tirdzniecibas-joma-butiski-ietekmejusi-nozares-rezultatus-janvari-2021

[5] De Pelsmacker, P., Genens, M., Van den Bergh, J. (2007). Marketing Communication, 3rd ed., Prentice Hall, pp. 397–407, ISBN: 9780273721383.

[6] Dyer, J. H., Harbir, S. (1998). The Relational View: Cooperative Strategy and Sources of interorganizational Competitive Advantage. Academy of management Review, 23 (4), pp. 660–679.

[7] Hofstetter, J. (2006). Accessing the contribution ot ECR. ECR journal, vol. 6 issue 1, pp. 20–29.

[8] Evans, M. (2012). Consumer Behavior. Hoboken, NJ: Willey.

[9] Griffin, G. (2002). Customer Loyality. How to Earn it How To Keep it. San Francisco: Jossey Bass.

[10] Harvey, L. (2015). How to provide customer intelligence. [Online] no http://paperzz.com [Accessed 03/08.2015].

[11] Kim, J. W., Chi, J., Qualls, W., Park, J. (2004). The impact of CRM on firm and relationship lever perfomance in distribution networks. Communication of the Association for informations Systems. Vol. 14, pp. 632-652.

[12] Kotler, P., Keller, K. L. (2006). Marketing management. Hoboken, NJ: Prentice Hall.

[13] Krauss, M. (2002). At many firms, technology obscures CRM. Marketing News, 2002, 18 March.

[14] Kristapsone, S., Kamerāde, D.u.c. (2011). Ievads pētniecībā: stratēģijas, dizaini, metode. Rīga: RaKa.

[15] Liniņa, I. (2017). Customer Relationship Formation and Management in Retal Trade Enterprises in the Baltics Countries. Integrated and Sustanaible Regional Development Marketing and Sustainable Comsumption Book Series: Economic Science for Rural Development, Issue: 4, pp. 300-306.

[16] O`Reilijs, D., Gibass, D. (2000). Darījumu attiecības ar pircējiem.. Rīga, Biznesa augstskola Turība.

[17] Payne, S. L. (1978). The Art of Asking Questions. Princeton, N.I., Princeton University Press, pp.158–176.

[18] Reisheld, F. (2003). The One Number You Need to grow. Horvard Business Review, 81(12), pp. 46-54.

[19] Seifert, D. (2001). Efficient Consumer Response. Hampp, Mering.

[20] Smith, P. R., Zook, Z. (2011). Marketing Communication. New York: Kogan Page, pp. 61–86.

[21] Teece, D. J., Gary, P., Amy, S. (1997). Dynamic Capabilities and Strategic Management. Strategic Management Journal, 18(7), pp. 509–533.

[22] Toedt, M. (2015). The contribution of customer relationship management to sales perfomance in the hotel business. Summary of Doctoral Thesis, University of Latvia, Rīga.

[23] "A 'layman's' explanation of Ultra Narrow Band technology," Oct. 3, 2003. [Online]. Available: http://www.vmsk.org/Layman.pdf. [Accessed: Dec. 3, 2003].

[24] Thomson ISI, EndNote 7. [CD-ROM]. Berkeley, Ca.: ISI ResearchSoft, 2003.

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Modelling the Horizontal Velocity Field of the Nizhne-Kansk Massif According to GNSS Observations

Alexandr Manevich
Laboratory of Geodynamics
Geophysical Center RAS
Moscow, Russia
ai.manevich@yandex.ru

Vladimir Kaftan
Laboratory of Geodynamics
Geophysical Center RAS
Moscow, Russia
kaftan@geod.ru

Roman Shevchuk
Laboratory of Geodynamics
Geophysical Center RAS
Moscow, Russia
shevchuk.002@mail.ru

Danil Urmanov
Laboratory of Geodynamics
Geophysical Center RAS
Moscow, Russia
durmanov.dui@mail.ru

Abstract **- Within the boundaries of the Nizhne-Kansk granite-gneiss massif, which directly borders on the Atamanovskiy branch of the Yenisei Ridge, the building of an underground research laboratory for validating the safety of disposal of high-level radioactive waste began in 2019. In 2010, researchers of the Mining and Chemical Combine at Zheleznogorsk and the Geophysical Center, Russian Academy of Sciences, organized a satellite geodetic network within the boundaries of the Nizhne-Kansk massif; this network included 30 GNSS stations intended for observations of modern crustal movements.**

The purpose of this study is to determine vectors and simulate the field of horizontal modern crustal movements from measurements made in 2010 - 2019. The tasks included: creating a catalogue of displacement data; calculating and estimating horizontal velocities of modern crustal movements, modelling the horizontal velocity field using artificial neural networks, developing a kinematic model of the area and comparing it with geological survey data.

As a result, the resulting model was found to be in good agreement with the results of structural-geological and geodynamic studies in the area. The rate of convergence between the Siberian Platform and the West Siberian Plate in the interaction zone of the southern part of the Yenisei Ridge can be estimated as 2-4 mm/year. The movements of the selected area are due to sublatitudinal compression along an azimuth of 100-110 degrees. Within the selected tectonic blocks relatively low rates of modern horizontal movements of the earth's crust were obtained, which confirms the stable geodynamic regime of the structural block hosting the underground research laboratory. Thus, the results of the work demonstrate the possibility of disposal of high-level radioactive waste in the selected structural block.

Keywords - GNSS, modern crustal movements, horizontal velocity, modelling field, Nizhne-Kansk massif, Yenisei Ridge, radioactive waste

I. INTRODUCTION

At present, due to the development of nuclear power and nuclear technology, the problem of isolation of high-level radioactive waste is more urgent than ever in the world. Today, most researchers and international organizations agree that the best solution to this problem, taking into account the modern technological development of mankind, is to create special deep underground storage facilities in which long-lived high-level radioactive waste (RAW) will be reliably isolated for the entire period of its potential danger.

In 2019, the construction of the first and only deep disposal facility for radioactive waste in Russia began in Krasnoyarsk region. By 2025, the plan is to complete construction of the underground research laboratory and begin a ten-year research program on the selected site [1].

The operation of underground RAW containment facilities is impossible without a comprehensive and long-term study of the geological massif. One of the key aspects of long-term safety of RAW isolation in geological formations is the low risk of development of destructive

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geodynamic phenomena and processes, primarily such as earthquakes, faulting and modern crustal movements.

The development of hazard geodynamic processes and phenomena is determined by the laws of the stress and strain state of the studied subsurface area. Observations of modern crustal movements of the Earth's crust allow us to obtain the necessary data to study the geodynamic regime of the area and to assess the engineering criteria for the safe operation of the underground RAW isolation facility.

The organization of deformation monitoring is conditioned by the necessity to control modern movements and deformations of the Earth's crust. Currently, global navigation satellite systems (GNSS) are considered the most promising technology for these tasks, especially in combination with ground-based geological and geophysical methods and remote sensing. Particular importance is given to increasing the reliability and their analysis under conditions of insufficient instrumental data. The methodology of collection and high-precision processing of observations, as well as the program of observations of the modern crustal movements in the area of Nizhne-Kansk massif were developed at the laboratory of geodynamics of the Geophysical Center of the Russian Academy of Sciences [2-3].

The purpose of this work is to summarize the results obtained earlier, namely, the determination of vectors and modeling the field of modern horizontal movements of the Earth's crust based on the results of measurements carried out in 2012 - 2019 [3-4].

The insufficient amount of data for monitoring for modern crustal movements at the local geodynamic polygon, expressed in a small number of measurement points, geometric heterogeneity of geodetic networks, irregular in time data, as well as a drop in the quality of instrumental measurements, worsens the quality of information on the deformation of the earth's surface from remote places of the polygon. Either subsequent calculations based on the data obtained from the network can lead to a large loss of accuracy in determining displacements and deformation components, and hence to an increase in the unreliability of the resulting estimates and predictions [5-7]. To obtain regular, gridded data on earth surface deformations, it is necessary to use methods of mathematical modeling of displacement fields. Development of new methods and increasing the reliability of modeling displacement fields allows us to solve the problem of insufficient amount of deformation monitoring data.

II. Materials and Methods

In order to observe the modern movements of the Earth's crust in this area, geodetic points were laid out to make measurements using GNSS methods. The measuring network was laid in such a way as to cross all the main local tectonic disturbances, to cover the territory of the construction site and regional tectonic structures. After processing the results of geodetic measurements were used time series (fig. 1) displacements for 23 geodetic points. The figure (fig. 2) shows a scheme of points of the used points, for which the estimation of horizontal velocities in the work [4] was carried out.

In figure 2 the area of the contour of the used geodetic network (blue line) and the area on which the estimation of movements and deformations of the Earth crust (purple line) is necessary is allocated. Because of the complex local physical and geographical conditions about 2/3 of the entire area is outside the contour of the measurement network, and therefore for this area is impossible. obtain the values of movements and deformations of the earth's surface.

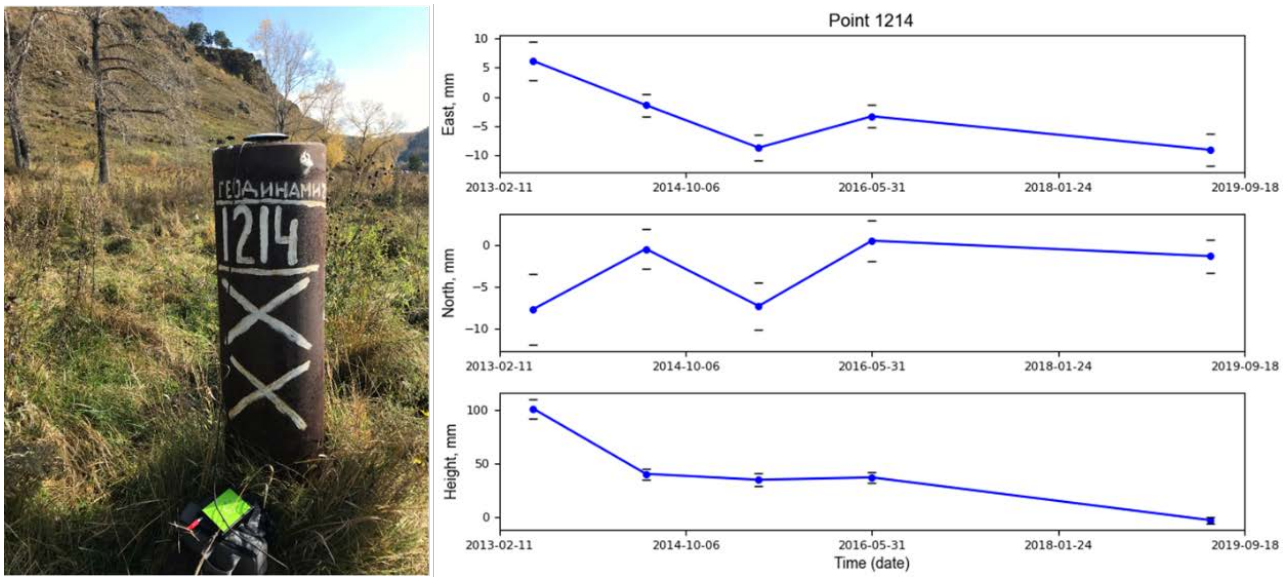

Fig. 1. Time series of displacement of point 1214.

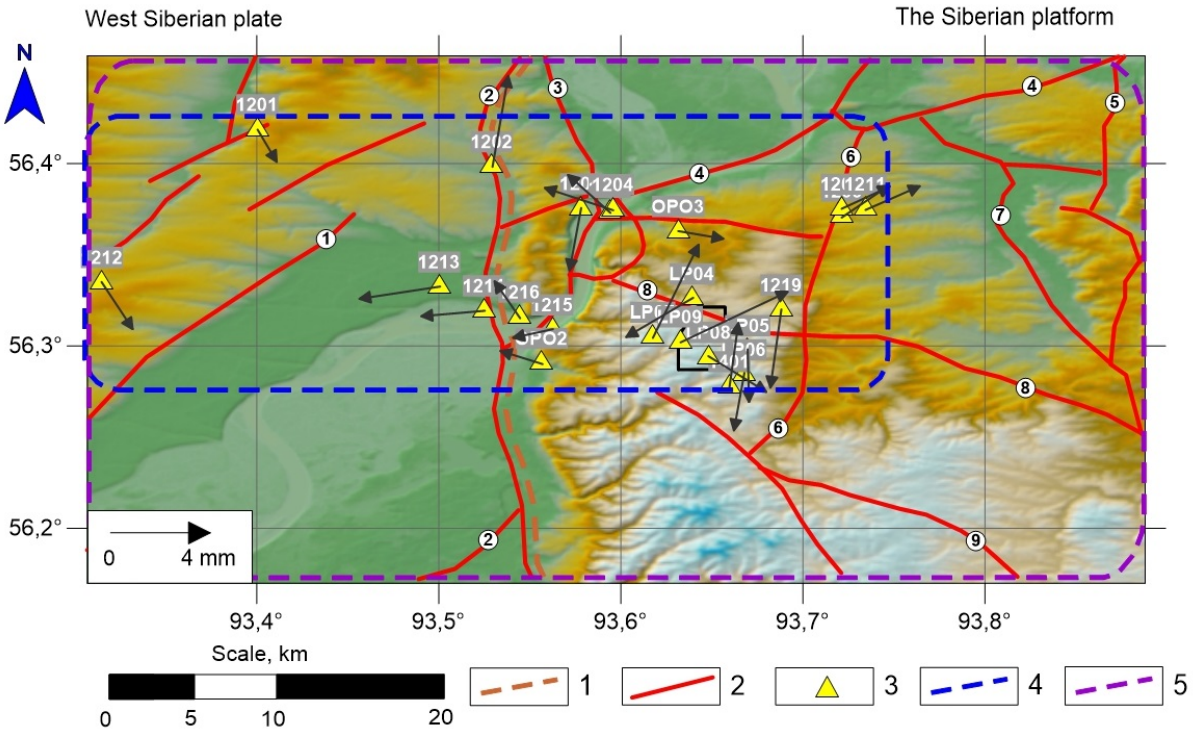

Fig. 2. The scheme of geodynamic polygon of Nizhne-Kansk massif. 1 - contact boundary of Siberian platform and West Siberian plate; 2 - tectonic faults; 3 - GNSS points; 4 - contour of geodetic network; 5 - area where forecast is required. The numbers in Figure 2 indicate major tectonic faults: 1 - First Krasnoyarskiy fault; 2 - Muratovskiy fault; 3 - Atamanovskiy fault; 4 - Kansko-Atamanovskiy fault; 5 - Malotel'skiy fault; 6 - Pravoberezhnyy fault; 7 - Bol'shetel'skiy fault; 8 - Shumikhinskiy fault; 9 – Baykal'skiy fault. The URL construction site is shown as a rectangle.

In this regard, it is necessary to obtain the values of velocities and displacements to the nodes of the regular network before the deformation analysis of the data. This requires extrapolating the raw data to obtain regular grid data.

Artificial neural networks were used for spatial extrapolation of the data. This algorithm is a layered system of connected and interacting simple processors (neurons). Each neuron of the network deals only with the signals it receives and the signals it sends to other neurons. When connected into a sufficiently large network, such individually simple neurons together are able to perform quite complex tasks. The network has interconnections between neurons, and the strength of these interconnections is expressed by certain weight coefficients. The full matrix of such weights and input and output signals of neurons, in fact, is the solving apparatus of this method.

In the example under consideration, the prediction of displacements and velocities of movements was spatial, carried out at a certain point in time. Incoming data (signals) were coordinates and terrain indicators. The structure of the neural network was chosen as follows - 5 neurons in the hidden layer (2 hidden layers), 1 neuron in the output layer (Fig. 3). Since the displacement can take both positive and negative values, the hyperbolic tangent was chosen as the activation function. The following metrics were chosen to assess the quality of the results of the algorithm's predictions:

Mean Absolute Error (MAE) shows the average absolute deviation of the predicted displacements from the true ones. The application of absolute deviation is due to the fact that the values of displacements can be both positive and negative. MAE is determined by formula 1:

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n}|U_i - a_i| \qquad (1)$$

where n is the number of points in the used sample (training, test, control);
U_i - value of the measured displacement;
a_i - value of the predicted displacement.

The Sum Absolute Error (SAE) shows the total absolute deviation of the predicted offsets from the true offsets. Gives an estimate of the integral cumulative prediction error for all measurement points. SAE is determined by formula 2:

$$\mathrm{SAE} = \sum_{i=1}^{n}|U_i - a_i| \qquad (2)$$

where U_i - value of the measured offset;
a_i - value of the predicted displacement.

In addition to quantifying shifts, it is crucial for the algorithm to accurately recognize the sign of the shift (negative or positive). To assess the quality of this aspect, accuracy metrics are used, defined by formula 3. This evaluation is based on the error matrices (Table 1).

$$\text{accuracy} = \frac{TP + FN}{TP + FP + FN + TN} \qquad (3)$$

TABLE 1 – ERRORS MATRIX

	a = 1	**a = 0**
$\hat{a} = \mathbf{1}$	True Positive (TP)	False Positive (FP)
$\hat{a} = \mathbf{0}$	False Negative (FN)	True Negative (TN)

Where a – the true offset sign label, $\hat{a}$ – the predicted value.

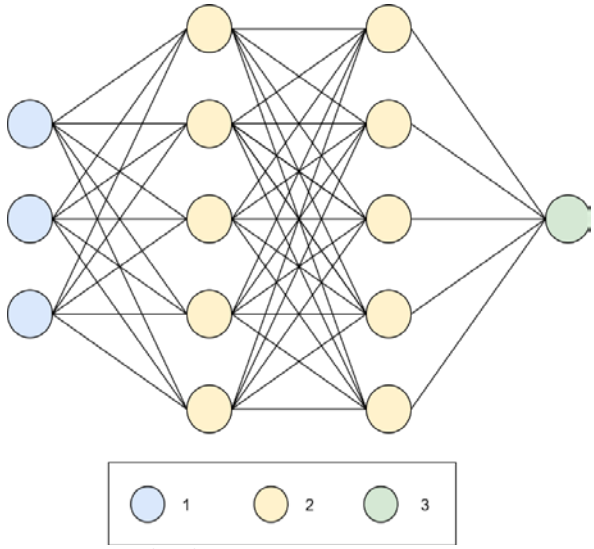

Fig. 3. Structure of artificial neural network. 1 - input layer neurons; 2 - hidden layer neurons; 3 - output layer neuron.

III. RESULTS AND DISCUSSION

Figure 4 shows an illustration of the interpolation and extrapolation of the initial data of the velocities of east horizontal movements. Interpolation was performed by the inverse distance method, extrapolation by the artificial neural network method. The figure clearly shows the difference in the amount of data obtained. Neural network extrapolation allows us to obtain data for the southern part of the study area, where a large number of local and large regional tectonic structures are located.

Figure 5 and table 2 shows the results of spatial prediction compared with kriging and inverse distance methods on an enlarged scale for the construction site area underground research laboratory (URL).

TABLE 2 – METRICS

Metrics	**Methods of spatial interpolation**		
	Inverse distance	***Artificial neural network***	***Kriging***
SAE, mm	65.02	13.36	59.58
MAE, mm	10.84	2.23	9.93
Accuracy	0.67	1	0.67

The quality metrics show that the neural network algorithm is the most optimal for modeling the displacement and velocity fields of modern crustal movements. The SAE metric is almost 5 times lower than the other methods with a MAE of about 2.23 mm per point, which corresponds to the RMS of determining displacements and therefore reduces the unreliability of the simulation. Also, the neural network algorithm correctly recognized all directions of movement, accuracy = 1, while the other methods have accuracy = 0.67, which is significantly lower.

As a result of the algorithm, the maps-distributions of velocities of modern horizontal movements were obtained for the territory of the Nizhne-Kansk massif (Figs. 6-7).

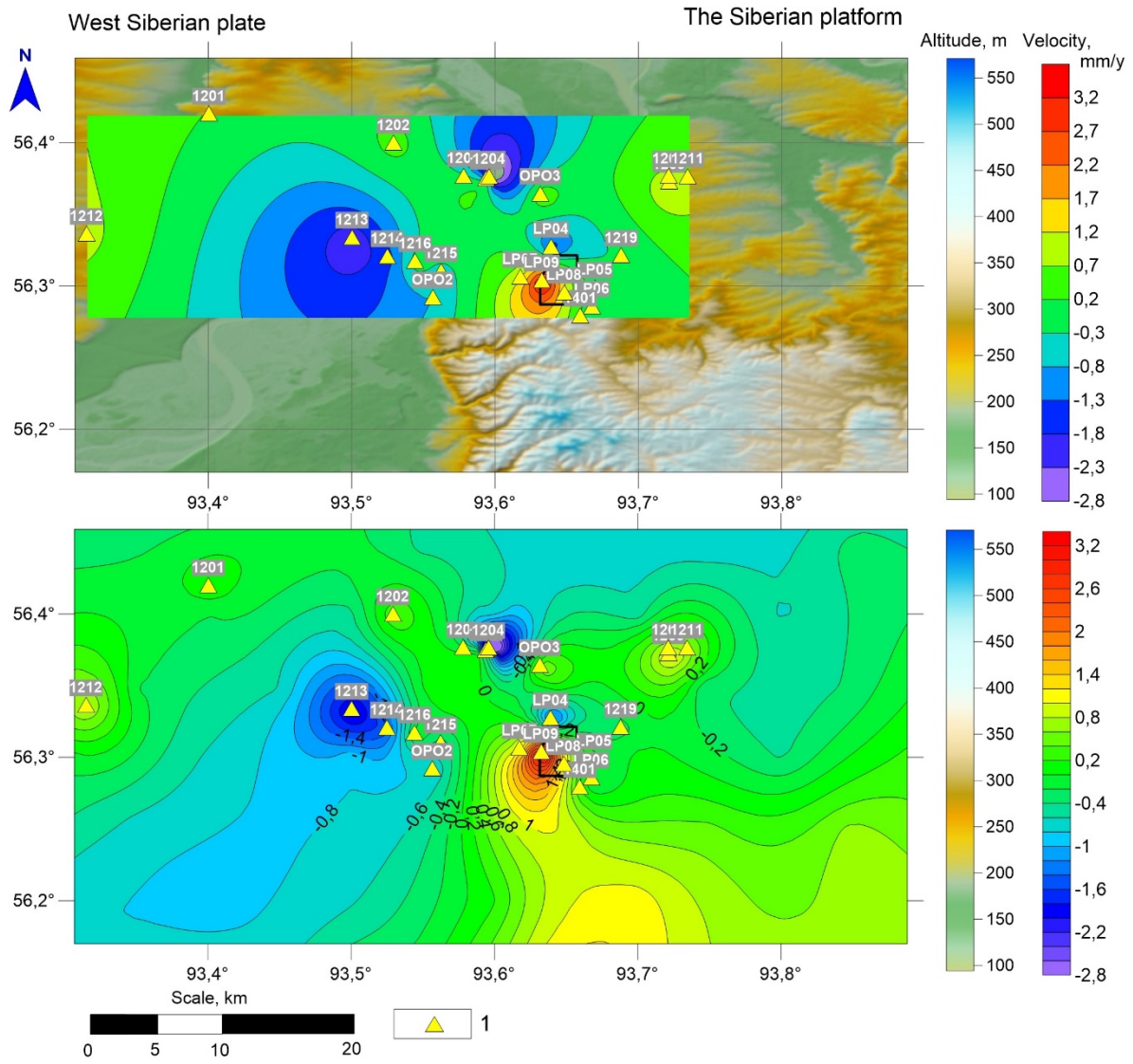

Fig. 4. Results of modelling the east velocities of modern horizontal movements of the Nizhne-Kansk massif by inverse distance and artificial neural network methods. 1 - GNSS points.

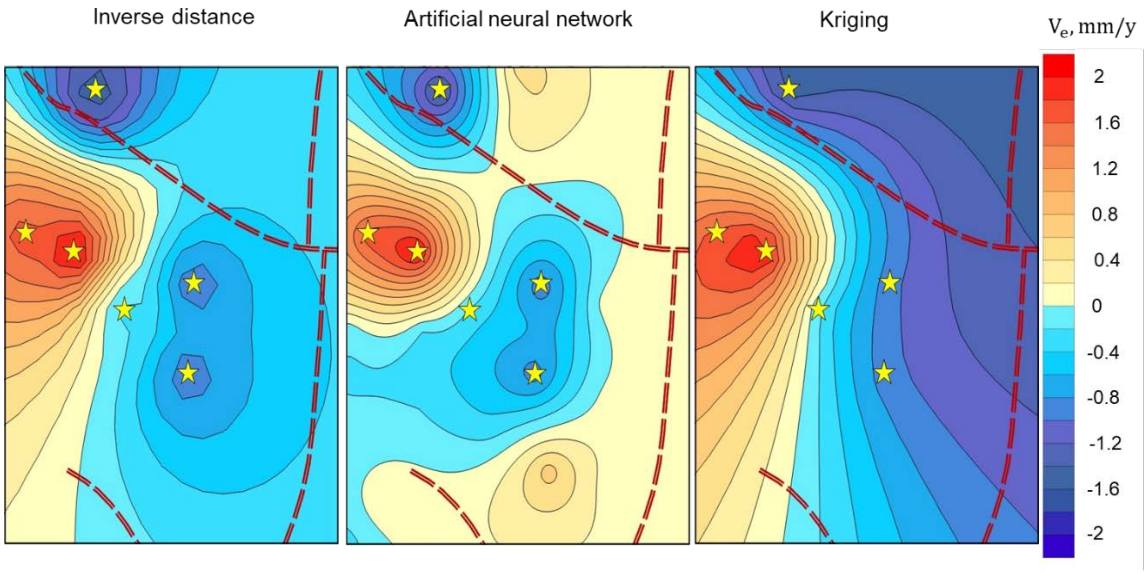

Fig. 5. Horizontal east velocity V_e maps for the URL construction site area modelled by methods: inverse distance, kriging and artificial neural network.

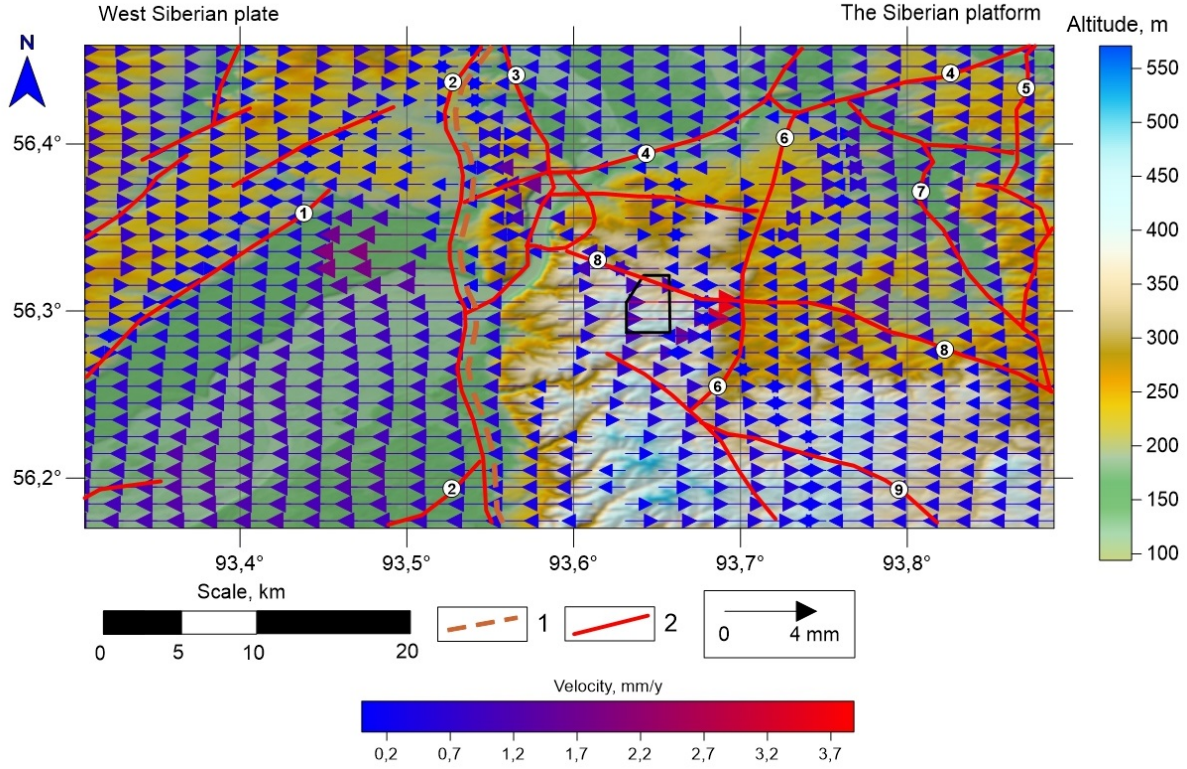

Fig. 6. The field of modern horizontal velocities of the Earth's crust in the east direction in the southern part of the Yenisei Ridge. 1 - contact boundary of Siberian platform and West Siberian plate; 2 - tectonic faults.

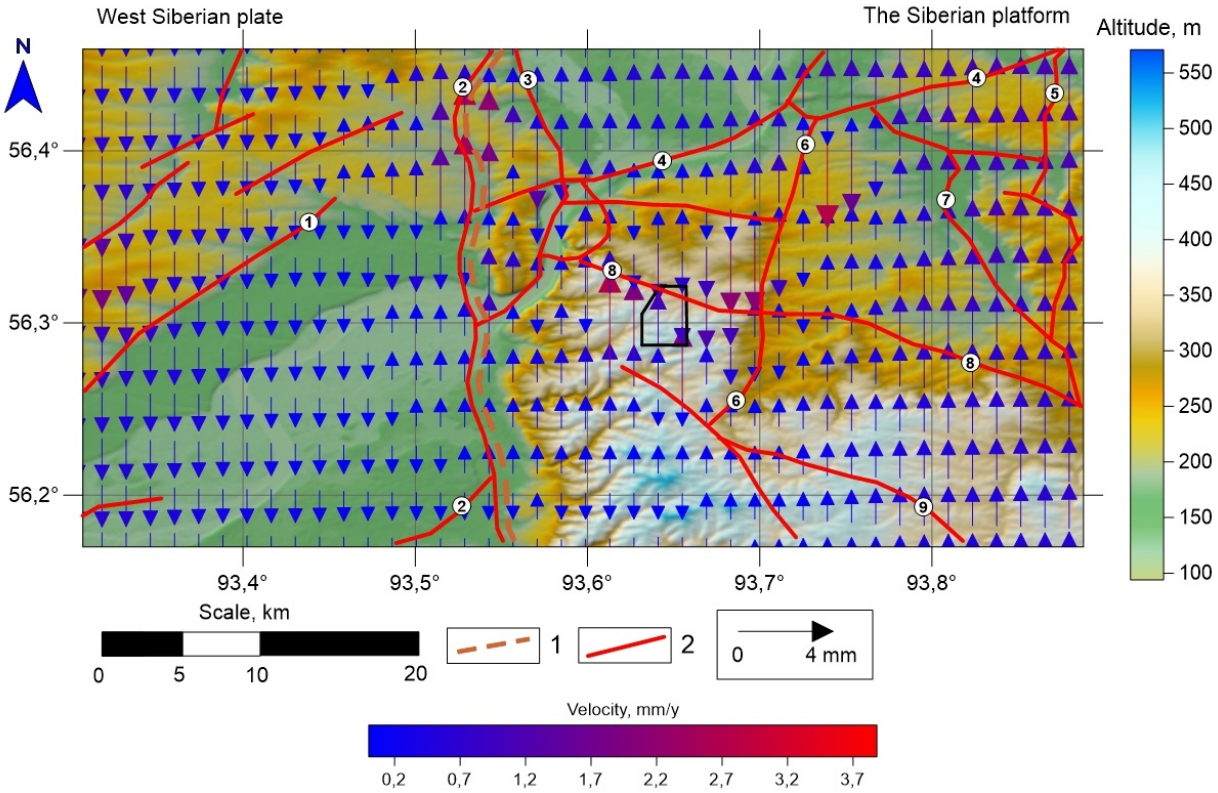

Fig. 7. The field of modern horizontal velocities of the Earth's crust in the north direction in the southern part of the Yenisei Ridge. 1 - contact boundary of Siberian platform and West Siberian plate; 2 - tectonic faults.

These are used to analyze the data. According to Figures 6 and 7, we can conclude that in the Central-Eastern part of the studied polygon, the most chaotic "picture" of the signs and magnitudes of movements was obtained.

CONCLUSIONS

As a result of modeling, new data were obtained, which were used to assess the geodynamic regime of the area. A more detailed analysis of the modeling results [4] showed good convergence with the results of geological studies [8-9]. The data obtained on the modern movements of the Earth's crust can be used for geodynamic zoning of the studied areas. It is possible to distinguish qualitative indicators - zones of tension and compression, calculate the tectonic component of stress in the rock massif, determine zones of high-gradient displacements, etc.

Spatial extrapolation based on the neural network approach allows us to cover the entire necessary area of the polygon and to investigate in more detail the current activity of local tectonic structures.

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REFERENCES

[1] Dorofeev A.N., Bolshov L. A., Linge I. I., Utkin S. S., Saveleva E. A. Strategic Master Plan for R&D Demonstrating the Safety of Construction, Operation and Closure of a Deep Geological Disposal Facility for Radioactive Waste // Radioactive Waste. 2017. № 1. p. 32-41. (In Russian).

[2] Kaftan V.I., Gvishiani A.D., Morozov V.N., Tatarinov V.N. Methods and results of determination of movements and deformations of the Earth's crust according to GNSS data at the Nizhne-Kansk geodynamic test network in the area of radioactive waste disposal // Sovremennye Problemy Distantsionnogo Zondirovaniya Zemli iz Kosmosa. 2019. №1. p. 83-94. DOI: 10.21046/2070-7401-2019-16-83-94.

[3] Tatarinov V.N., Morozov V.N., Kaftan V.I., Manevich A.I. Modern geodynamics of the southern of the Yenisei ridge derived from the results of satellite observations // Geophysical research. 2018. Vol.19. No.4. p. 65-79. DOI: 10.21455/gr2018.4-5.

[4] Gvishiani A.D., Tatarinov V.N., Kaftan V.I., Manevich A.I., Dzeboev B.A., Losev I.V. The velocities of modern horizontal movements of Earth crust in the South sector of Yenisei ridge according to GNSS observations // Doklady Earth Sciences. 2020. Vol. 493. №1. p. 73-77. DOI: 10.1134/S1028334X20070077.

[5] Wu J., Tang C., Chen Y. Effect of triangle shape factor on precision of crustal deformation calculated // Journal of Geodesy and Geodynamics. 2003. Vol. 23(3). p. 26-30. (in Chinese).

[6] Dokukin P.A., Kaftan V.I., Krasnoperov R.I. Influence of triangle shape in geodetic network on the results of definition of Earth surface deformations // Izvestiya vuzov. Geodeziya i aerofotosemka = Proceedings of universities. Geodesy and aerophotography. 2010. No. 5. p. 6–11.

[7] Markovich K.I. Influence of the configuration of final elements on the accuracy of determination of the components of deformation // Vestnik SSUGT (Siberian State University of Geosystems and

Technologies). 2019. Vol. 24. №3. p. 37-51. https://doi.org/10.33764/2411-1759-2019-24-3-37-51. [in Russian].

[8] Lobatskaya R.M. Neotectonic fault-block structure of junction of Siberian platform and West Siberian plate // Russian Geology and Geophysics. 2005. T.46. №2. p. 141-150.

[9] Kolmogorova P.P., Kolmogorov V.G. Modern vertical movements of the Earth's crust of the Yenisei ridge // Russian Geology and Geophysics. 2004. T.45. №4. p. 455-466.

Review of Characteristics of Alnus Glutinosa Stands Quality According to Forest Ttypes and Ages

Ziedonis Miklašēvičs
Rezekne Academy of Technologies
State Stock Company "Latvijas Valsts Meži" (Latvia's State Forests)
Rēzekne, Latvia
Email: (Ziedonis Miklašēvičs): z.miklasevics@lvm.lv

***Abstract* - Due to the interest in Alnus glutinosa as the plantation species has increasesed in Latvia during last years, a structural unit "LVM Sēklas un stādi" of State Stock Company "Latvijas Valsts Meži" (Latvia's State Forests) offers to the local market Alnus glutinosa bare root seedlings with an advanced root system obtained from Alnus glutinosa seeds growed in planting such selected seedlings in cutovers and for land reforestation theorectically will allow the land owner to increase the value of forest and the profit from its management. Practically, this prospects should be evaluated from the perspective of forest health.**

Therefore, the purpose of this study were to: (1) estimate the incidence of heart colouring and stem decay in Alnus glutinosa stands in different forest types and ages, (2) identify and measure heart colouring area /heartwood hard rot stage area diameter and soft rot stage area diameter/ cavity diameter of the stumps, (3) evaluate the relationships between stand species composition (forest types) and Alnus glutinosa stands age on heart colouring/heartwood hard rot stage and soft rot stage/cavity incidence, (4) by analysing the results to work out the recommendations to improve the forest managment in forest stands where Alnus glutinosa stands from plantations are growing.

Keywords* - *Alnus glutinosa, Dryopterioso-caricosa, Myrtillosa, Myrtillosaturf.mel, Dryopterioso-caricosa, Oxalidosa, Myrtilloso-sphagnosa, Oxalidosa turf.mel.

I. INTRODUCTION

Stands of black alder (*Alnus glutinosa (L.),Gaertn.)* comprise 5.1% of the total forest area of Latvia. *Alnus glutinosa* typicaly grows on wet petlands, usually comprising pure stands or stands mixed with *Alnus incana (L.) Moench., Bertula spp., Populus tremula L.* and *Picea abies (L.) Karst.* [1], [16]. Specific characteristics of this treee species are frost and waterlogging tolerance, a strong root system that penetrates both vertically and horizontally, adaption to various soil conditions and ability to fix nitrogen in symbioyic root nodules with bacteria in the genus *Frankia* [1], [3]. The root system is adapted to very wet soils. Many strong, vertically growing, sinker roots ancor the tree on riverbanks, and they are able to penetrate deeply into wet and anaerobic soils reaching almost 5m deep [9].

Three main site types where *Alnus glutinosa* grows can be identified [5], [6] in relation to the type of water supply are:

- Marshy sites that have waterlogged subsoil throughout the year. On these, *Alnus glutinosa* forms pure stands owing to its physiological adaptions that allow it to grow in anaerobic soils.
- Riverside sites in which the soil in the rooting zone is well aerated during the growing season. On these, *Alnus glutinosa* is often mixed with species that are adapted to alluvial sites (*Alno-Padion* community).
- Plateau sites which high soil moisture contents where the stand is dominated by other species that are more competitive (*Carpinion* community).

Alnus glutinosa is regarded a short living tree species, starting to die out naturally at about 60 years of age under Central European conditions [18]. However, depending on the region and growth conditions, the species might reach age of 100-160 years [5]. *Alnus glutinosa* is usually attacked by a heartwood rot at the age of 50-70 years [5]. Some authors noted that *Alnus glutinosa* wood quality declines after 60-70 years because of heartwood rot [4], [17]. According to investigations made in Bavaria [7] the beginning of the phenomenon at about age 50. According to the results of investigaton [1] made in Latvia, the

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frequency of stem decay and heart colouring of 51-84 year old *Alnus glutinosa* stands are sequental "Table 1".

TABLE 1 CHARACTERISTICS OF ALNUS GLUTINOSA STEM QUALITY

Age, years	Species composition (%)	Forest site type	Sampled trees, no.	Decayed stems (%)
51	100 *Alnus glutinosa*	*Mercurialiosa*	100	98
74	80 *Alnus glutinosa* +20 *Alnus incana*	*Filipendulosa*	100	82
76	60 *Alnus glutinosa* +30 *Alnus incana* +10 *Picea abies*	*Oxalidosa turf.*	150	53
84	80 *Alnus glutinosa* +20 *Alnus incana*	*Oxalidosa turf.*	100	78
			Average	75

According to investigations [10] the frequency of heartwood rot differs with site but diagnosis from external characteristics is unreliable.

Nowadays *Alnus glutinosa* is becoming increasly important as a plantation species. Aside from commeercial forestry, this tree species is important for riparian ecosystems and their biodiversity, providing habitants for specific wetland flora and fauna and stabilising riverbanks [1], [15].

If *Alnus glutinosa* is planted in a cutover where a heartwood rot has already been established [5], there will be no positive effect, as the young trees will become infected when their roots contact with the roots of the rotten stumps [13].

It is believed that deciduous tree in pure stands are generally resistant to *Heterobasidion* root rot. On the other hand, the results of studies performed in Lithuania show that *Bertula* stands planted in previously severely affected areas of *H. annosum* (*Pinus sylvestris*) is also infected with *H. annosum* [11]. However, it is possible that no suitable planting material has been selected in this case [8].

The vegetative method plays a very important role in the propagation of many deciduous tree species. *Alnus glutinosa* has great strain-healing abilities. A forest derived from seeds differs in many biological characteristics from a forest derived from coppice. In large forest stands, trees are often taller at the end of their lives compared to trees growed brom coppice. For example, oak forests continue to grow intensively until the age of 120-150 years, live 300-400 years and reach a height of 30-40 m. Oak shoots grow intensively for 70-80 years, live for 150-200 years and reach a height of 20-30 m.

II. STUDY GOAL

The goal of this study was to synthesize the existing experience and knowledge about the silviculture of *Alnus glutinosa* on suitable sites in relation to the production of high quality and valuable timber and to work out the recommendations to improve the forest managment in forest stands where *Alnus glutinosa* stands from plantations are growing.

The following objectives were set to achieve the study goal:

The third important difference between a large forest and a coppice is that the wood structure of a large forest is more even and correct than that of a coppice tree. Big forest trees differ much more radically from coppice trees in that the carcasses damage trees much less in stand stands than in coppice trees. In stands formed vegetatively, the stems and roots of the mother trees gradually die. Through the parts of the dying roots, the fungal filaments penetrate the coppice and develop freely in the new generation of forest.

Because of that foresters must ensure the regeneration of the forest with seeds, seedlings, not coppice [13].

The early stage of forestry is cruical for successful and sustainable forest managment. One third of the reforested forest in Latvia is regenerated by planting with different kinds of tree seedings. The success of forest regeneration by planting depends on correctly prepared soil and chouice of the right seeding material. Reforestation by *Alnus glutinosa* in Joint Stock Company "Latvia State Forests" (LVM) have been conducting by bare roots, containerized and with improved root system. The main aim in forestry is to achieve higher tree seeding establishment and promote their growth and improve fixation in soil. Practically, this procpects should be evaluated from the perspective of forest health.

In order to ensure and improve the ecological stability of forests, the ability to adapt to various pathogenic microorganisms and resistance to stress factors caused by anthropogenic effects, the territory of Latvia is divided into two regions for (*Alnus glutinosa Gaertn.)* reforestation. Seedlings obtained from clone seeds in West region "Fig. 2", "Table 4" can be planted only in West region of Latvia "Fig. 2". The same methodology applies to East and North regions.

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- To identify the origin of the clones in the West region of Latvia.
- To estimate the incidence of heart colouring and stem decay in *Alnus glutinosa* stands in different forest types and ages in all regions of Latvia.
- To identify and measure the diameter of heart colouring and stem decay area.
- To evaluate the relationships between stand species composition (forest types) and *Alnus glutinosa* stands age on heart colouring/heartwood rot incidence.

III. MATHERIALS AND METHODS

3.1. Field Measurements.

- Sampling stumps of *Alnus glutinosa* in different forest type and age class felling areas after commercial thinning and final felling for estimating the frequency of decay and heart colouring.
- Measuring the diameters of the stumps, the diameters of heart colouring areas, and diameters of heartwood rot areas according to the scheme "Fig. 1".

Fig.1. Dst- diameter of the stump; Dhr- Heart colouring area /Heartwood hard rot stage area diameter; Dc –Heartwood soft rot stage area diameter/ Cavity diameter

3.2. Statistical Analyses.

The sequental data were collected and analysed:

- Block area-Forest block-Forest compartment; Area (ha) ; Stock nr; Average tree (m^3); Stock (m^3); County; Coordinates X/Y; Forest type; Age class; Age decade; Species composition; Sampled stumps (pcs.); Decayed (Heartwood soft rot/ Cavity) stems(%); Stump diameter (mm)/ Average/Median/Stdev; Heart colouring area diameter/Heartwood hard rot stage diameter (mm); Average/Median/Stdev; Heartwood soft rot stage diameter/Cavity diameter(mm) Average/Median/Stdev

IV. RESULTS AND DISCUSIONS

In order to ensure and improve the ecological stability of forests, the ability to adapt to various pathogenic microorganisms and resistance to stress factors caused by anthropogenic effects, the territory of Latvia is divided into regions of origin of *Alnus glutinosa*, which must be observed in the processes of reforestation [12].

Fig.2. Regions of origin of *Alnus glutinosa* [12]

The Latvian State Forest Research Institute "Silava" has confirmed that the identification of 50 clones (*Alnus glutinosa Gaertn*.) of Platene (West region of Latvia) seed plantations and operations has been done with molecular passporting methods that ensure the acquisition of these plants in the forest reproductive material identification to be at the stage of production, trade or use. The results of the identification are given in "Table 2".

TABLE 2 MOLECULAR PASSPORT OF THE CLONES

Clone, no.	Sample, no.	Makers																	
		be 14		be1		be10		be12		be13		be5		be6		be8		be9	
1	43	189	189	335	340	247	247	116	116	233	233	242	246	151	157	230	247	190	190
2	10	189	193	344	348	247	247	116	120	225	233	242	256	157	157	247	247	132	134
3	21	0	0	337	344	247	247	116	118	225	236	246	246	151	187	226	247	0	0
4	28	0	0	318	346	247	247	116	118	225	233	248	248	157	157	0	0	0	0
5.-53.																			

Reforestation by *Alnus glutinosa* in LVM in West region "Fig. 2" have been conducting by bare roots, containerized and with improved root system. The scheme of manufacturing of seedings with improved root system is given "Fig. 3. "

Fig. 3. The scheme of manufacturing of seedings with improved root system

Reforestation by *Alnus glutinosa* in LVM in West, North and East region in 2021 will be conducted according to the plan of growing seedling "Table 3. "

TABLE 3 PLAN OF GROWING SEEDLING

Plantation	Region	Plan in 2020 (pcs.)	Sown in 2020 (pcs.)	Realization plan in 2021(pcs.)
Strenči	North	250000	479830	180000
Podiņi	East	693450	1729450	485415
Mazsili	West	328300	328300	229810

The origin of *Alnus glutinosa* clones for refrostation in West region were obtained in 2002. The characteristic of origin of the clones are given in "Table 4. "

TABLE 4 ORIGIN OF THE CLONES

Parameter	Data				
Block area-Forest block-Forest compartment	703-204-14	703-204-15	703-214-8	703-204-2	703-214-7
Area (ha)	2.39	4.27	8.8	2.96	2.94
County	Dundaga				
Age (Age decade) years	78 (8)	98 (10)	88 (9)	98 (10)	73 (8)
Species composition	9 *Alnus glutinosa 1 Bertula 78 +F.excelsior 78+P.Abies 71*	10 *Alnus glutinosa 98+ Bertula 98 +P.Abies 91*	8 *Alnus glutinosa* 2 *Bertula 88 + P.Abies 88*	10 *Alnus glutinosa* 98 *+Bertula 98*	10 *Alnus glutinosa* 73 *+Bertula 91+*
Specie	04-*Bertula*				
Age (years)	78		88		
Height (m)	26		27		
Diameter (cm)	27		29		
Basal area (m^2)	2		6		
Stock (m^3/ha)	23		72		
Specie	06-*Alnus glutinosa*				
Age (years)	78		88		
Height (m)	26		26		
Diameter (cm)	30		31		
Basal area (m^2)	25		26		
Stock (m^3/ha)	309		321		

In order to estimate the incidence of heart colouring and stem decay in *Alnus glutinosa* stands in different forest types and ages, to identify and measure the diameter of heart colouring and stem decay area and to evaluate the relationships between stand species composition (forest types) and *Alnus glutinosa* stands age on heart colouring/heartwood rot incidence, during 2020-2021, incidence of butt rot in *Alnus glutinosa* stands and the presence of fungi responsible for it were investigated

TABLE 5 CHARACTERISTICS OF INVESTIGATED FOREST SITE TYPES

Parameter	**Data**						
Block area-Forest block-Forest compartment	503-443-46-0 503-443-18-0	107-421-2	107-443-5	107-438-11	803-307-2	501-119-4	501-110-13
Area (ha)	0.77	0.8	1.99	1.75	4.03	0.85	0.8
Stock nr,	JD1071	AE1828_01	AE 1805_01	AE 1805_01	BS 1960_01 BS 1960_02	JN 0036	
Average tree (m^3)		0.45	0.4	0.4	0.4		
Stock (m^3)		163.11	372.56	372.56	372.56		
County	Pļaviņas		Alūksne		Madona	Ogre	
Parish	Aiviekste		Liepna		Vecumnieki	Jugla	
Coordinates X/Y		708934/366266	708846/366207			549831/302173	
Forest type	*Dryopterioso-caricosa Myrtillosa*	*Myrtillosa turf.mel.*	*Dryopterioso-caricosa*	*Dryopterioso-caricosa*		*Mercurialiosa mel.*	
Age class		Mature stand				Overmature stand	
Age decade	8 (1942.)	9	8	8	9 (1931)	10	
Species composition	8 *Alnus glutinosa* 1*P.abies* 1*Bertula* 78	8 *Bertula* 3 *Alnus glutinosa* 88+*Pinus sylvestris* *P.tremula* 88	7 *Alnus glutinosa* 3*Bertula* 73+*P.tremula* 71 *P.abies* 73	5 *Bertula* 4 *Alnus glutinosa* 1P.abies 78+Pinus sylvestris78 *P.tremula* 70	6 *P.abies* 2 *Alnus glutinosa* 1 *P.tremula* 89 +*P.abies* 67	5 *Bertula* 4 *Alnus glutinosa* 1 *P.tremula* 92+*P.Abies* 65	4 *Bertula* 3 *Alnus glutinosa* 2P.Abies 92+1*P.tremula* 50
Specie	04-*Bertula*		*Oxalidosa*		08-*P.tremula*	04-*Bertula*	
Age (years)	78				89	92	92
Height (m)	29				30	27	29
Diameter (cm)	25				36	29	31
Basal area (m^2)	2				9	11	11
Stock (m^3/ha)	23				128	132	142
Specie				06-*Alnus glutinosa*			
Age (years)	78					92	92
Height (m)	26					26	29
Diameter (cm)	25					30	30
Basal area (m^2)	20					8	7
Stock (m^3/ha)	247					99	97
Sampled stumps (pcs.)	85	48	92	68	53	55	38
Decayed soft rot/ cavity) stems (%)	75	88	48	55	82	88	87
Stump diameter (mm) Average/Median/Stdev	342/330/79	394/390/73	330/340/58	340/345/75	340/338/44	375/265/64	372/272/58
Heart colouring diameter*//Hard rot stage diameter (mm) Average/Median/Stdev	40/40/39* // 124/110/56	120/126/45	125/115/44	85/90/21	145/152/33	156/165/42	150/158/38
Soft rot stage diameter/Cavity diameter (mm)Average/Median/Stdev	126/100/73	185/185/46	150/146/46	110/110/57	173/167/28	186/190/43	192/188/45
Specie			03-*P.abies*			08-*P.tremula*	
Age (years)	78				89	92	50
Height (m)	27				31	29	29
Diameter (cm)	32				36	36	35
Basal area (m^2)	3				23	2	6
Stock (m^3/ha)	38				325	28	83

Parameter	Data					
Block area-Forest block-Forest compartment	803-305-23	807-71-4	202-454-8	202-453-29	313-42-25	312-228-18
Area (ha)	2	2.32	1.54	1.01	1.84	1.96
Stock nr,	AA2323	BS 1933	HT1840_01	HT1906_01	BT 2007_01	BT 2020_01
Average tree (m^3)	0.6	0.44	0.79	0.6	0.72	0.1
Stock (m^3)	795.57	292	512.4	262.5	367.8	91.14
County	Madona	Kārsava	Renda	Renda	Svente	Svente
Coordinates X/Y	661455/282037	697466/31613	396397/321503	398896/322313	668075/183534	658119/179698
Forest type	*Oxalidosa*	*Myrtilloso-sphagnosa*	*Oxalidosa*	*Myrtilloso-sphagnosa*	*Oxalidosa turf.me*	*Dryopterioso-caricosa*
Age class			Mature stand			Middle age stand
Age decade	8 (1946)	8	8	9	9	3
Species composition	8 *Alnus glutinosa* 1*P.tremula* 1 *Bertula 74 +P.Abies 56*	6 *Bertula* 1 *Alnus glutinosa 2 P.Sylvestris 1P.Abies 74 +P.Abies* 63	4 *Bertula* 4P.Abies 1 *P.Sylvestris* 1 *Alnus glutinosa*	4 *Bertula* 2 *Alnus glutinosa* 2 *P.Sylvestris* 1 *P.Abie* s 86 1 *Alnus glutinosa* 66 +*Bertula* 66	4 *Alnus glutinosa* 2 *Bertula* 2 *P.Abies* 1*P.tremula* 89	4Alnus glutinosa 3Bertula 28 +P.tremula28
Specie			04-*Bertula*			
Age (years)	74	74	71	86		28
Height (m)	25	23	25	23		16
Diameter (cm)	29	25	25	28		15
Basal area (m^2)	3	14	15	7		4
Stock (m^3/ha)	33	144	167	72		31
Specie			06-*Alnus glutinosa*			
Age (years)	74	74	71	86		28
Height (m)	26	21	21	23		16
Diameter (cm)	27	25	25	27		18
Basal area (m^2)	30	2	6	4		9
Stock (m^3/ha)	371	20	60	44	120	71
Sampled stumps (pcs.)	50	35	48	56	32	42
Decayed (soft rot/ cavity) stems(%)	88	83	79	67	92	4
Stump diameter (mm)/ Average/Median/Stdev	317/310/59	341/320/71	315/295/65	335/315/78	325/331/69	200/195/38
Heart colouring diameter/Hard rot stage diameter (mm) Average/Median/Stdev	152/160/30	133/140/39	115/135/42	142/155/42		
Soft rot stage diameter/Cavity diameter (mm)Average/Median/Stdev	167/160/27	138/145/37	108/120/40	145/150/40	152/149/48	
Specie	08-*P.tremula*	01-*P.sylvestris*	03-P.abies	01-*P.sylvestris*		
Age (years)	74	74	71	86		
Height (m)	26	26	24	26		
Diameter (cm)	44	27	28	32		
Basal area (m^2)	5	6	10	6		
Stock (m^3/ha)	62	71	114	71		
Specie				03-P.abies		
Age (years)				86		
Height (m)				23		
Diameter (cm)				27		
Basal area (m^2)				6		
Stock (m^3/ha)				66		
Specie				06-Alnus glutinosa		
Age (years)				66		
Height (m)				20		
Diameter (cm)				23		
Basal area (m^2)				2		
Stock (m^3/ha)				19		

Surveyed were altogether 13 felling areas in Vidusdaugava, Dienvidkurzeme, Zemgale, Ziemeļlatgale, Dienvidlatgale, Austrumvidzemes Forest Districts the results of the investigation are given in "Table 5". Characteristics data of investigated *Alnus glutinosa* stands are given in "Table 6. "

TABLE 6

CHARACTERISTICS OF INVESTIGATED ALNUS GLUTINOSA STANDS

Age (Age decade), years	Species composition (%)	Forest site type	Sampled stumps, no.	Decayed stems (%)	Stump diameter *Average* (mm)	Soft rot stage /Cavity diameter *Average* (mm)
28 (**3**)	4 *Alnus glutinosa* 3 *Bertula* 28 +*P.tremula* 28	*Dryopterioso-caricosa*	42	**4**	**200**	
74 (**8**)	8 *Alnus glutinosa* 1*P.tremula* 1 *Bertula 74* +*P.Abies 56*	*Oxalidosa*	50	88	317	167
74 (**8**)	6 *Bertula* 1 *Alnus glutinosa 2 P.Sylvestris 1P.Abies 74* +*P.Abies* 63	*Myrtilloso-sphagnosa*	35	83	341	138
79 (**8**)	4 *Bertula* 4*P.Abies* 1 *P.Sylvestris* 1 *Alnus glutinosa*	*Oxalidosa*	48	79	315	108
78 (**8**)	8 *Alnus glutinosa* 1*P.abies* 1*Bertula* 78	*Dryopterioso-caricosa Myrtillosa*	85	75	342	126
73 (**8**)	7 *Alnus glutinosa* 3*Bertula* 73+*P.tremula* 71 *P.abies* 73	*Dryopterioso-caricosa*	92	48	330	150
78 (**8**)	5 *Bertula* 4 *Alnus glutinosa* 1P.abies 78+Pinus sylvestris78 *P.tremula* 70	*Dryopterioso-caricosa*	68	55	340	110
			Average	**69**	**332**	**133**
86 (**9**)	4 *Bertula* 2 *Alnus glutinosa* 2 *P.Sylvestris* 1 *P.Abie*s 86 1 *Alnus glutinosa* 66 +*Bertula* 66	*Myrtilloso-sphagnosa*	56	67	335	145
89 (**9**)	4 *Alnus glutinosa* 2 *Bertula* 2 *P.Abies* 1*P.tremula* 89	*Oxalidosa turf.mel.*	32	92	325	152
88 (**9**)	8 *Bertula* 3 *Alnus glutinosa* 88+*Pinus sylvestris P.tremula* 88	*Myrtillosa turf.mel.*	48	88	394	185
89 (**9**)	6 *P.abies* 2 *Alnus glutinosa* 1 *P.tremula* 89 +*P.abies* 67	*Oxalidosa*	53	82	340	173
			Average	**81**	**345**	**164**
92 (**10**)	5 *Bertula* 4 *Alnus glutinosa* 1 *P.tremula* 92+*P.Abies* 65	*Mercurialiosa mel.*	55	88	375	186
92 (**10**)	4 *Bertula* 3 *Alnus glutinosa* 2*P.Abies* 92+1*P.tremula* 50		38	87	372	192
			Average	**88**	**373**	**188**

V. CONCLUSIONS AND RECOMENDATIONS

1. To ensure the quality of *Alnus glutinosa* wood, reforestation must be carried out with seeds, seedlings, not coppice.
2. In the processes of reforestation the regions of origin of *Alnus glutinosa* must be observed.
3. The main factor influencing the quality of wood is the age of the stems of *Alnus glutinosa*. The highest quality wood is up to 30-year-old stems.
4. When harvesting has been managed in stands older than 70 years, the proportion of decayed stems exceeds 69%, heartwood rot diameter reaches 133 mm at an average stump diameter of 332 mm.
5. When harvesting has been managed in stands older than 80 years, the proportion of decayed stems exceeds 81%, heartwood rot diameter reaches 164 mm at an average stump diameter of 345 mm.
6. When harvesting has been managed in stands older than 90 years, the proportion of decayed stems exceeds 88%, heartwood rot diameter reaches 188 mm at an average stump diameter of 373 mm.

VI. REFERENCES

[1] N. Arhipova, T. Gaitnieks, J. Donis, and J. Stenlid, "Heart rot and associated fungi in *Alnus glutinosa* stands in Latvia". Scandinavian Journal of Forest Research, 27 : 2012, pp. 327-336.

[2] N. Arhipova, J. Donis, T. Gaitnieks, and I. Liepa, "Root and butt rot causing fungi: the impact of broadleaved species admixture on the indicence of Heterobasidion spp. in spruce stands". Mežzinātne 22 (55): 2010, pp.70-87.

[3] G. M. Bond, W. Fletcher, and Ferguson, T, "The development and function of the root nodules of Alnus, Myrica and Hippophae." Plant Soil. 5, 1954, pp. 309-323.

[4] H.Claessens, L'aulne glutineux. Ses stations wet sa sylviculture. ASBL Fore Wallone, 2005, 189 p +2 annexes

[5] H. Claessens, A. Oosterbaan, and P. Savill, "A review of the characteristics of black alder (*Alnus glutinosa (L) Gaertn.)* and their implications for silvicultural practices". Forestry, 2010, Vol, 83, No. 2

[6] H. Claessens, "The alder populations of Europe". For. Comm. Bull. 126, 2003, pp. 5-14.

[7] T. Immler, T, "Waldbauliches Konzept zur Pflege der Schwarzerle. In Bayerische Landersanyalt fur Wald und Forstwirtschalf, Beitrage zur Schartzerle". LWF Wissen 42, 2004, pp. 27-30.

[8] K. Korhonen and O.Holdenrieder, "Neue Erkenntnisse uber den Wurzelschwann *(*Heterobasidion annosum s.l.)* ". Eine Literaturubersich. Forst and Holz 5: 2005, pp. 206-211.

[9] J.N. Koster, Die Wurzeln der Waldbaume. Paul Parey, Hamburg, Germany 1968,284p.

[10] K.W. Lockow, and S. Chizon, Diagnose des Roterlenkernfaule am stehenden Stamm. AFZ/Der Wald. 51, 1996, pp.1367-1371.

[11] V. Lygis, R. Vasiliauskas, J. Stenlid, and A.Vasiliauskas, "Silvicultural and pathological evaluation of Scots pine afforestations mixed with decidous trees to reduce the infection by *Heterobasidion annosum s.s.*" Forest Ecology and Management, 201. 2004, pp. 275-285.

[12]Meža enciklopēdija. (Forest encyclopedia) 1.sējums. R.; apgāds "Zelta grauds" 2003. 368 lpp.

[13]V. Ņesterovs, Vispārīgā mežkopība. (General forestry). Latvijas Valsts izdevniecība. 1954, 610 lpp.

[14]T. Piri, K. Korhonen, and A. Sairanen, "Occurrence of *Heterobasidion annosum* in pure and mixed stands in southern Finland". Scandinavian Journal of Forest Research 5: 1990, pp. 113-125.

[15]C.M. Popovska and D. Ivanovski, "Disturbed river corridors and protection measures". Balwois 27, 31 May Ohrid, Republic of Macedonia, 2008, pp. 1-7.

[16]N. Priedītis, "Black alder swamps on forested peatlands in Latvia." Folia Geobotanica &Phytotavonomica, 28, 1993, pp. 261-277.

[17]A.M. Thibaut and H. Claessens, Construction de tarifs de cubage d'arbres pour l'aulne glutineux (Alnus glutinosa L.Gaertn). 1998. Biotechnol. Agron. Soc. Environ. 2, 2003, 214 p.

[18]I. Vyhlidkova and D. Palovčikova, "Some aspects of alder decline along the Lužnice River". Journal of Forest Science, 51, 2005, pp. 381-391.

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Industry 4.0 – Advantages and Challenges in the Republic of Bulgaria

Nicholay Nenov
Department Management
Technical University of Gabrovo
Gabrovo, Bulgaria
e-mail:nenovtugabrovo@gmail.com

Abstract **- A retrospective review of the innovation process with its advantages, as well as the challenges in the conditions of Industry 4.0 in the Republic of Bulgaria. The emphasis is on digitalization and the strategy for its implementa-tion, as part of the national strategy for increasing the competitiveness of production and the economy.**

Keywords - digitalization, Industry 4.0, strategy.

I. INTRODUCTION

Undoubtedly, industrial production is the backbone of the national economy. There is no other way, because every manufacturing enterprise, in addition to being a source of profit, is a generator of national gross product, and therefore of economic prosperity. Industrial enterprises are one of the largest employers and importers of taxes in the state budget [2].

However, when we talk about industry, we must not forget that its development depends directly on scientific and technological progress, and in particular on advances in automation, mechanization and robotics.

The innovation process in enterprises is continuous. Sometimes innovation brings with it revolutionary changes that are difficult for people to accept at first. Industrial production today makes the most of the scientific and technical achievements of the 80s and 90s of the twentieth century - Internet, mechanization, advanced production lines, computing power, maximum flexibility and integrity of production systems. It is the accelerated automation and robotics that make experts believe that we are on the threshold of a fourth industrial revolution, and according to some others it has already occurred.

What's new in Industry 4.0 and Smart Factories?

- Brand new methods of interaction between humans and machines;
- New methods for receiving, storing, processing and moving information;
- Decentralized solutions (maximum possible autonomy of cyber systems controlling production machines);
- New types of industrial intranet networks.
- Industry 4.0 is a collective term that includes advances in digital technology, artificial intelligence, robotics, the Internet of Things, 3D printing, and more.

The fourth industrial revolution has the potential to fundamentally change the structure of the economy as a whole. The production process will rely mainly on automation, with high-tech robotic machines playing a leading role. This means that the need for qualified staff to adjust and maintain them will increase. The interaction between the education system and business will have to be strengthened. Cooperation between individual research centers and universities on the one hand, and entrepreneurs on the other, will become an integral part of the staffing of enterprises. The main requirement for the staff in the company will be digital competencies.

Company management and business management models will have to be reformatted and adapted to new technological realities. If we assume that people will still be needed to run the company, then a completely new entrepreneurial culture must be nurtured, coordinated and understanding the needs of the factories of the future.

The interaction between the individual units in the industrial enterprise will undergo a radical change due to the decreasing role of man in favor of machines. This is

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done with the help of re-engineering in management and processes.

Bulgaria must have a competitive digital economy and a high standard of citizens based on knowledge and smart growth. To have a modern and secure digital infrastructure, a high level of education and training, favourable conditions for the development and implementation of innovations based on advanced digital technologies in the economic and social sectors and accelerated digital transformation of the economy to generate high and sustainable economic growth [15].

This is not science fiction. This is the vision set in the new draft strategy for digital transformation for the period 2020 - 2030. The document was prepared by the Ministry of Transport, Information Technology and Communications and published for discussion on the site for public consultations.

II. EXPOSITION

What are the main benefits of Industry 4.0?

Undoubtedly, this is a drastic increase in productivity, and hence the economic profitability of the enterprise. Experts predict that the machines will initially "take over" the work associated with monotonous and repetitive movements, so characteristic of the production line. This does not mean that the work done by man will necessarily be unnecessary. People are still better at creating unique and innovative products. Human spirit, ingenuity and entrepreneurship should also play a major role in the industries of the future such as optical and laser technologies [5, 6].

It should be noted that for people, the work of the assembly line is associated with extreme mental stress and physical fatigue. The more we automate and robotize, the more the productivity of the enterprise will increase.

Man by nature always resists the process of change. In the 19th century, during the industrial era in Britain, textile workers protested against the growing role of machines. The Luditi movement appears. Seeing the danger of losing their jobs, they crept into factories and broke sewing machines. But that did not stop the industrial revolution.

The initial effect was really bad for some of the low-skilled workers. This was especially true for manual workers. In retrospect, however, the industrial revolution has improved productivity and optimized resource use.

Where will the higher efficiency of operational management come from?

Industry 4.0 will make the most of software advances in resource planning. This means better programs, better predictive algorithms that will make better analyses. This will allow the production process to be even more optimized, cost-effective and easy to manage, control and maintain. Thus, losses in production such as technological defects, defects in processes, etc. will be minimized, this example is present in optimizing of induction heating depending of the electromagnetic field [8].

The enterprises of the future will increasingly focus on management while machines perform monotonous and repetitive production activities. As a result, it is very likely that management science will acquire new significance and even greater importance, because human capital will be directed in this direction.

What will be the challenges for the labor market?

The fourth industrial revolution brought with it many unknowns as far as jobs were concerned. Since it is based on automation and robotics, the most vulnerable groups will understandably be the low-skilled workers. According to some estimates from the beginning of 2016, 47% of current occupations in the United States occupied by people are at risk of disappearing as a direct result of labor automation. Another report from the World Economic Forum predicts the loss of 5 million jobs over the next five years. We should ask ourselves, "What will these people do?"

It is clear that a problem with future technological unemployment will arise. What can be done are retraining and training programs for workers who have just lost their traditional jobs so that they can continue working. If, for example, the miller has just lost his job in favor of a robot, then the person should be trained to maintain and adjust the machine. Or to manage it, taking advantage of its greater precision in making and shaping the details. This activity can be carried out both on site and remotely - even from home.

Unfortunately, retraining workers does not mean a complete solution to the problem, because many employees will still be out of work and will not be able to be hired back in the company. Forecasting the effects of Industry 4.0 is characterized by strong uncertainty. There is no way to predict with maximum accuracy what will happen in the next 10-15 years, especially when the human factor is involved, with all its complexity and dynamics [10].

But it is certain that the role of education, in-house training and national programs for retraining people with professions falling into the so-called. "Risk group" are extremely important.

This requires the efforts of both business and the state, which must increase their investment in science - scientific developments with practical application, strategies, industrial innovations, etc.[4]

As a result of robotics, there is an option to make adjustments in working hours and work shifts. However, shortening the man-hours spent in work does not mean legitimizing laziness, but redirecting human efforts to another field of corporate activity.

Industry 4.0 will bring with it the need for new skills and abilities. Change will not be easy, but if we look back,

we will see that there have always been professions that have disappeared, precisely because of technological advances. An example of such a missing profession is the profession of "telephone operator". The first telephone exchanges appeared in the early 20th century. The task of the telephone operators working in them (mostly women) was to manually connect the individual subscribers. This was done by manually plugging in telephone jacks into various jacks located on a large switchboard.

A key moment in modern industry will be cybersecurity and artificial intelligence management. What if the machines become too independent and start making independent decisions? All important questions that will be answered.

From the point of view of the present, we cannot predict with 100% accuracy how the problems caused by the fourth industrial revolution will be answered. And like any radical change, the industry of the future comes with its benefits and negatives. Man must adapt as much as possible and realize his place in the new world, which in any case must remain leading [9, 16].

It can be summarized that Industry 4.0 will be more technological, more optimized, more knowledge-intensive. As far as people are concerned, the emphasis is on education and the acquisition of the widest possible range of competencies.

The digitalization of Bulgaria is a priority in a new strategy

Bulgaria still does not take full advantage of new digital technologies and innovative business models. The state of digitalisation of industry varies across sectors, especially between high-tech and traditional sectors, and much of the workforce lacks basic digital skills [1, 7].

The strategy sets the implementation of six main goals:

- deployment of secure digital infrastructure;
- providing access to adequate technological knowledge and digital skills;
- unlocking the potential of data;
- digitization in favor of circular;
- low carbon economy;
- increasing the efficiency of public administration and the quality of public services.

The priorities are:

- digital infrastructure;
- cybersecurity;
- research and innovation;
- education and training;
- adaptation of the labor market - education, training and social protection;
- digital economy;
- Agriculture;
- transport;
- environment and climate;
- healthcare;
- finance;
- culture;
- misinformation and media literacy;
- territorial development;
- digital control;
- security and citizen participation in the democratic process.

High speed connectivity

Efforts should focus on building an efficient cloud infrastructure, data exchange tools, architectures and mechanisms for managing thriving data sharing ecosystems and artificial intelligence.

By 2030, the Republic of Bulgaria must ensure gigabit connectivity of all major socio-economic engines such as schools, transport centers and major public service providers, as well as digitally intensive enterprises. Support for high-speed connectivity must be accompanied by measures to increase citizens' digital skills and stimulate the demand for Internet-based services from the public and businesses [11].

5G networks and optical networks will be among the most important building blocks of the digital economy and society over the next decade. 5G technology is seen as a tool for industrial transformation through the deployment of new networks that will provide gigabit data rates with low latency and significantly improved performance and reliability. In addition, high-quality connectivity will be provided to consumers and businesses, which will also support the development of the Internet of Things.

Future 5G networks will also be able to serve artificial intelligence-based systems through real-time data analysis and management. The 5G infrastructure is expected to serve not only individual users, but also a wide range of professional applications, enabling innovative business models in multiple sectors. 5G technology will also support the development of the Industry 4.0 model.

Research as a factor in achieving economic growth

Research centers of excellence and centers of excellence with the potential to connect to European networks through the modernization of research infrastructure and equipment will be built, the strategy states, for example Technical Parks and Zones, Business Incubators and clusters in Bulgaria at the Base of Industrial Competitiveness [13].

Additional funding will have to be provided for specific market-oriented applied research in the field of digital technologies on a competitive basis. Efforts will be made to create conditions for attracting young scientists and internationally renowned highly qualified scientists and, accordingly, to provide support for the transfer of scientific results to industry and the public sector. Work will be done to strengthen cooperation between academic institutions, enterprises, especially those in the information and

communication technology sector for joint participation in research and innovation projects within the programs of the National Research Fund and the National Innovation Fund, as well as specialized EU programs. It will be necessary to facilitate access to innovation for small businesses, start-ups and public organizations [12].

Digitization of education

An adequate and modern management vision presupposes a massive use of all new trends for technological renewal of educational institutions, which is able to qualitatively change the process of educational development. One of this is example - Educations – development innovation of program „Nano-microsystems and electronics technique"[3]. Another example present in "Higher Education in the Republic of Bulgaria at the Crossroad – Problems and Measures to Prevent Them" [14].

The priority areas in the field of education and training should be related to the provision and maintenance of high-speed and secure basic communication connectivity, as a basis for offering educational services, digital management and network interaction between the participants in the educational and scientific process. It is also necessary to create and maintain a cloud-based learning environment for services, including software as a service (SaaS), infrastructure as a service (IaaS) and platform as a service (PaaS).

For modern quality education, modern flexible platforms for distance learning and knowledge control and content management must be implemented and developed [14]. Providing modern quality education inevitably requires the development, adaptation, implementation of digital educational content, as well as the identification and validation of valuable digital educational resources, providing opportunities for blended learning, distance learning (both synchronous and asynchronous), use of augmented and virtual reality, as well as artificial intelligence for training purposes. This was done very quickly in a crisis caused by COVID 19. In just two weeks, the training of pupils and students in an electronic environment began. At the moment, the process is reported as successful on both sides - trainees and trainers. Society is rapidly adopting and using new technologies and education is one of the first to take advantage of them.

Labor market

Most jobs already require basic digital skills. In the future, this trend will increase and it can be argued that all participants in the labor market will need these skills to work. At the same time, much of the workforce does not even have basic digital skills. It will also be important to provide reliable, up-to-date information on future trends in labor supply and demand. Follow-up should be training to acquire new or improve existing key competences and professional qualifica-tions and to acquire new skills for specific new jobs.

Investments in skills development and retraining in the field of digital skills acquisition and in the modernization of the education system will have to be encouraged.

Other sectors

Digitization is also planned to cover sectors such as agriculture, transport, environment, health, finance. Automated and connected mobility will play the biggest role in transport. The environment sector must rely on technologies that accelerate the balancing of the energy system through the faster deployment of renewable energy sources and smart grids to manage energy consumption and traffic management.

As for the health sector, it is working towards the National Health Information System.

III. CONCLUSION

In conclusion we can consider that:

- The innovation process in enterprises is considered, as well as its innovations related to Industry 4.0 and "smart factories";
- The interrelations between the separate units in the industrial enterprise are determined;
- The main advantages of Industry 4.0 have been identified;
- It is indicated where the higher efficiency of the operational management will come from?
- Are the challenges facing the labor market in the Republic of Bulgaria and in general identified?
- The role of education, in-house training and national programs for retraining people with professions falling into the so-called. "Risk group" are extremely important.
- The 6 main goals in digitalization are defined: deployment of secure digital infrastructure; providing access to adequate technological knowledge and digital skills; unlocking data potential; digitization in favor of a circular low-carbon economy; increasing the efficiency of public administration and the quality of public services
- The priorities for digitalization of the economy are formulated: digital infrastructu-re; cybersecurity; research and innovation; education and training; adaptation of the labor market - education, training and social pro-tection; digital economy; Agriculture; transport; environment and climate; healthcare; finance; culture; misinformation and media literacy; territorial development; digital control; security and citizen partici-pation in the democratic process.
- High-speed connectivity is needed, and that research is a factor in achieving economic growth and competitiveness of the economy;
- The need to digitize education, the labor market and other sectors of the economy.

The presented theses, facts and analyzes clearly outline the advantages and challenges facing us for a knowledge-based economy in the Republic of Bulgaria.

REFERENCES

[1] Angelova, Y., Lazov, L., Mezinska, S., Innovative laser technology in textile industry: Marking and engraving, (2017) Vide. Tehnologija. Resursi - Environment, Technology, Resources, 3, pp. 15-21. DOI: 10.17770/etr2017vol3.2610

[2] Damianov, D., Modern alternatives to rapid innovative aging, Scientific Bulletins of NTS in Mechanical Engineering, Year XXVI, Vol. 3/224, ISSN 1310–3946, 27 ISTC "ADP 2018", June 2018, pp. 278-283.

[3] Kartunov S., D. Petrova, Educations – development innovation of program „Nano-microsystems and electronics technique", DANUBIA – ADRIA 26th September Symposium on Advances in Experimental Mechanics, September 23rd – 26th, 2009 Montanuniversität Leoben / Austria, ISBN: 978-3-902544-02-5, pp. 103-105.

[4] Lazov, L., H., Deneva, Teirumnieka, E., Study of auxiliary gas pressure on laser cutting technology, (2017) Vide. Tehnologija. Resursi - Environment, Technology, Resources, 3, pp. 159-162., DOI: 10.17770/etr2017vol3.2659

[5] Lazov, L., N., Angelov, Influence of some technological parameters on the contrast of laser marking on the fly, Laser Physics, (2012) Volume 22, 1755-1758, https://doi.org/10.1134/S1054660X12110084

[6] Lazov, L.K., Petrov, N.A., Investigation of the impact of the number of repetitions and the defocus on the contrast of laser marking for products made of tool steel (2012) Metallofizika i Noveishie Tekhnologii, 34 (7), pp. 1003-1011. https://www.scopus.com/inward/record.uri?eid=2-s2.084868115719&partnerID=40&md5=239b1b7e680d15bed534cb55fc9cbdb0

[7] Lazov, L., V Nikolić, S Jovic, M Milovančević, H Deneva, E Teirumenieka, Evaluation of laser cutting process with auxiliary gas pressure by soft computing approach, Infrared Physics & Technology, (2018), 91, 137-141, DOI: 10.1016/j.infrared.2018.04.007

[8] Mitev,I., Optimizing of induction heating depending of the electromagnetic field – part|II, 13th International conference RaDMI 2013, Kopaonik, Serbia, 12÷15 September, 2013, vol.2, p.888÷893.

[9] Nenov., N., P., Tomchev, R., Ivanova, Study of the Ion Radiation Influence on the Parameters of Unijunction Tran-sistors, 9th International Scientific and Practical Confe-rence "Environment. Technology. Resources". *Vol.1*, Latvia, Rēze-kne, 2013. Rēzekne: Rēzeknes Augstskola, RA izdevniecība, 2013, ISSN 1691-5402, ID in database – 16424, pp.137-139.

[10] Nikolova, Neli, Intellectual Capital Management used for Optimizing the Activities of Modern Small and Medium Enterprises/Companies. 4th International Conference Econo-mics and Management-Based on New Technologies, EMoNT 2014, 12-15 June 2014, Vrnjačka Banja, Serbia., pp.258-262, ISBN 978-86-6075-045-9.

[11] Petrova, D., Analysis of SMEs in Bulgaria – Assessment of Their Innovation Activities, Rezekne 2013, Latvia, Rezekne Higher Education Institution, Faculty of Engineering, Scientific Institute for Regional Studies, Environment. Technology. Resources, Proceedings of the 9th International Scientific and Practical Conference June 20-22, 2013, Volume 3, ISSN 1691-5402,pp 46-49. scopus

[12] Petrova, D., Intelligent, Innovative and Sustainable Industry in Bulgaria – Prospekts and Challenges, Environment. Technology. Recourses – Proceeding of the 12-th International Scientific and Practical Conference, Rezekne Academy of Technologies, Rezekne, Latvia, 2019, ISSN 1691-5402, p. 210-215.

[13] Petrova, D., Technical Parks and Zones, Business Incubators and clusters in Bulgaria at the Base of Industrial Competitiveness, International Scientific Journal "Innovations", Year VII, Issue 1/2019, Sofia: Sci. Techn. Union of Mech. Eng., Nat. Sci. Techn. Soc. Automation In Discrete Productions, ISSN 2603-3763 (print), ISSN 2603-3771 (online), pp. 18-20.

[14] Petrova, D., L., Lazov, Higher Education in the Republic of Bulgaria at the Crossroad – Problems and Measures to Prevent Them, "Society. Integration. Education" Proceedings of the International Scientific Conference, Volume II, Higher Education, May 22th-23th, 2020, Rezekne, Rezekne Academy of Technologies, 2020, ISSN 1691-5887, ISSN 2256-0629, pp. 214-226, http://dx.doi.org/10.17770/sie2020vol2.5158

[15] Petrova D., S. Dimitrova, Europe 2020 – The New Strategy for Smart, Susinable and Inclusive Growth and Bulgarian Industrial Competitiveness, Rezekne 2011, Latvia, Rezekne Higher Education Institution, Faculty of engineering, Latgale Sustainable Development Research Institute, scientific Institute for Regional Studies, Environment. Technology. Resources, Proceeding of the 8th International Scientific and Practical Conference June 20-22, 2011, Volume I, ISSN 1691-5402, pp. 333-339.

[16] Tomchev, P., N., Nenov, R., Ivanova, Instantaneous water heater with induction heater operating with grid frequency, „Research and Development in Mechanical Industry" RaDMI 2012, 13-17 September 2012, Vrnjačka Banja, Serbia, SaTCIP Ltd., Technical-Mechanical School in Trstenik, ISBN 978-86-6075-036-7, Volume II, pp. 1214-1218.

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Proceedings of the 13th International Scientific and Practical Conference. Volume 1, 183-190

Upcycling of Technogenic Mineral Waste – Challenges and Solutions

Gotfrids Noviks
Engineering faculty
Rezekne Academy of Technologies
Rezekne,Latvia
Gotfrids.Noviks@rta.lv

***Abstract* - Industrial mineral waste accounts for a significant proportion of all global waste. In the European Union it is more than 71% (2,5 Gt) of the total amount of non-hazardous waste - construction and demolition waste, ash and slag, tailings residues, unconditioned waste rocks, etc. In Latvia, the share of this waste is about 20%. Due to the fact that they are inert, non-biodegradable materials and cannot be used for energy production and cannot be reduced by incineration, their stocks are increasing every year. Their utilization volumes are low and focused mainly on use as backfill when carrying out various earthworks.**
At the same time, mineral waste, both in terms of composition and structure, physical and chemical properties, is a serious mineral resource, the processing of which can result in high-quality useful products, thus implementing the waste upcycling principle - the newly acquired product has higher added value than the original.
The paper evaluates the physical and technical possibilities and perspectives for the production of eco-innovative materials from mineral waste - geopolymers, glass ceramics, porous ceramics and mineral-organic composite materials.

Keywords - technogenic mineral waste, upcycling principle, geopolymers, composites

I. INTRODUCTION

The amount of any mineral resource in nature is objectively limited and gradually diminishes.
The stable supply of mineral resources to the industrial sector is one of the most important problems for the sustainable development of humankind.
There are different ways of possible solutions to this problem - they can be both extensive and intensive.
Among the extensive ones can be noted the following:
1. Discovery of new mineral deposits - expansion of geological exploration in hitherto little-explored areas and depths.
2. Discovering and / or intensifying the use of new mineral resources (not from the depths of the Earth - e.g. minerals from seawater, magma, space objects).
The intensive directions are:
1. Development of extraction methods for very low concentrations of the useful component in minerals, thus involving the use of ores listed so far as waste rocks, or the waste rock dumps of already developed deposits, where the content of the useful component is lower than possible for extraction at the moment.
2. Replacement of the critical mineral resource required for production with other minerals, the amount of which is much larger or even unlimited - finding alternatives to them. As we know, the Earth's crust consists mainly of silicates - the use of silicon and its compounds and the substitution of other substances with them in the sphere of production and consumption could become a radical solution to the problem of depletion of mineral resources.
3. Reuse of used mineral resources as technological resources - secondary raw materials in the sphere of production and consumption.
The extraction, processing and exploitation of mineral resources generate a lot of residue and waste, the volumes of which increase over time.
Analyzing the composition, structure and properties of this waste, it can be seen that they are essentially the same mineral formations as natural minerals and rocks. Mineral waste can be considered as a transformed primary mineral resource into another category of secondary (technogenic) mineral resources.
Many mineral wastes have retained virtually unchanged the components from which the original product was formed, as well as partially the original structure and physical properties, and can therefore potentially be used either directly or after processing to serve as a raw material

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for new products - thereby reducing the intensity of the depletion of non-renewable resources and the amount of waste going to landfill.

Over the last 40 years, the world's consumption of mineral resources has increased 25 times, but the amount of industrial waste generated is 10-100 times higher. Therefore, saving resources and reducing pollution is in fact one and the same integral problem and must be tackled in a complex way.

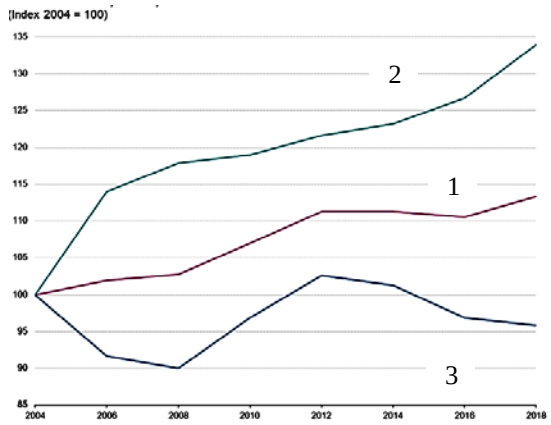

Fig.1. Changes in the amount of waste produced (1), recovered (2) and deposited(3) since 2004in the 28 countries of the European Union *(Eurostat (online data code: env_wasgen)*

At the same time, although the level of mineral waste processing has been increasing over the last 15 years (Fig. 1), its use is not related to the production of new high-quality products. Statistics show that the treatment of waste currently produced in the European Union is mainly related to its disposal (46%). Waste recycling (which actually can be considered as their using as technogenic resources) are subjected to 873 Mt of waste, which constitutes 38% of the processed waste.

II. MATERIALS AND METHODS.

In this work, based on our previous research from the 1990s on the complex and rational use and processing of mineral and technogenic resources [1],[2],[3],[,[4],[5] as well as on the analysis, compilation and calculation of literature data provides a methodology for evaluating and substantiating the prospects for the processing of technogenic mineral materials. The main thesis on which this methodology is based is the concept of up cycling. Waste recycling should focus on the development of recycling technologies that use end products with a quality not lower than the quality of the original product - the principle of “up-cycling” is now a predominant practice instead of the principle of “down-cycling”, where each subsequent recycling phase produces product of a quality lower than the previous [6],[7].The development of an eco-innovative product from secondary resources (waste) with better (at least not inferior) properties than the properties of the former product requires detailed and comprehensive investigation of physical, chemical, structural properties of these raw materials and processes in different physical fields.

Life cycle analysis of the global extraction and production of seven metals (iron, aluminum, copper, zinc, lead, nickel and manganese) shows a strong impact of these processes on the quality of the environment. It is expected that the impact of the use of these seven metals on the environment in 2060 will increase from two to four times compared to 2011.

The extraction and production of cement raw materials, sand and gravel have a much lower specific impact (per kilogram of production) on the environment, but their use is so large that the total impact also increases. Together, seven metals and two building materials account for almost a quarter of all greenhouse gas (GHG) emissions and one sixth of total energy demand.

Although the recycling and use of secondary materials cannot be without an impact on the environment, it is generally ten times lower than the impact of primary production processes.

III.RESULTS AND DISCUSSION

The European Commission (EC) approved the European Waste Catalog (EWC) by Decision 2000/532 / EC [8]. The EWC is a hierarchical list in which all waste is divided into twenty main sections, each assigned a two-digit code from 01 to 20. Most sections are based on industry, but some are based on materials and processes. Each waste is assigned a six-digit code in each compartment.

We propose a waste classification based on the European Waste Catalog but more appropriate for the research and analysis of treatment processes of technogenic materials (Fig. 2).

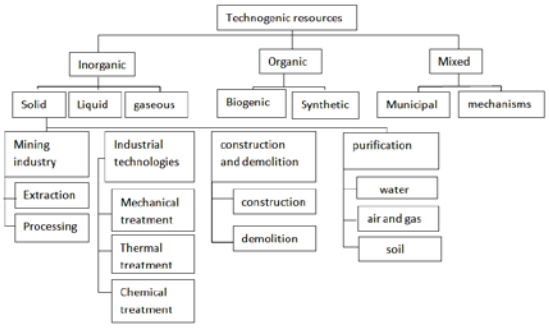

Fig 2. Classification of technogenic waste sources . Detailed group of inorganic solid technogenic resources

The recycling of mineral waste is in fact a process in which the physical and chemical properties of a technogenic resource are transformed into the properties of the intended end product. Therefore, it is logical to divide all properties into three groups according to the analyzed process:

• properties that characterize the raw material;

•characteristics that characterize the final product;

•properties that describe the ability of the raw material to transform into the final product - physical and chemical activity of the raw material.

It is known that the physicochemical activity (reactivity) of a thermodynamic system is characterized by the speed and depth of the process. The direction and depth of the process are determined by thermodynamic laws, but the speed of the process - by the kinetics.

The change of the Gibbs energy G of system can be taken as the main thermodynamic parameter what regulate efficiency of raw materials transformations.

$$\Delta G=\Delta H-T\Delta S \quad (1)$$

The process rate constant K_V can be taken as a kinetic parameter of the system.

$$K_V= d\xi/dt[V_1^{a1}\cdot V_2^{a2}\cdot\cdot V_n^{an}]^{-1} \quad (2)$$

where dξ - the degree of perfection of the process during the period dt, $V_{(1,2,3,...)}$ - relative volumes of the components included in the interaction, $a_{(1,2,3,...)}$ - empirical indicators of the nature of the interaction process.

It is known, that the higher the negative value of ΔG and the higher the positive value of K_V, the more active the process will be. Therefore, the process activity parameter can be evaluated by the complex parameter α, which is the product of these two indicators.

$$\alpha=-\Delta G\cdot K_V \quad (3)$$

In turn, the Arrhenius equation determines the dependence of K_V on the activation energy E_a

$$K_V=A\cdot exp(-E_a/RT) \quad (4)$$

Hence

$$\alpha= (T\Delta S-\Delta H)\, A\cdot e^{(-Ea/RT)} \quad (5)$$

In the case of chemical reactions, these parameters are within the following values: A = 1010-1014 s^{-1}, E_a = 50-300 kJ / mol, ΔS = 10-500 J / mol, ΔH = 300-5000 kJ / mol.

Using these regularities, it is possible to perform a comparative analysis of any chosen type of interaction of mineral components and, consequently, to substantiate the usefulness and efficiency of its implementation from the physicochemical point of view.

Analyzing the results of research on the dependence of mineral properties on the effects of external fields, the following can be concluded:

1. In the general case, changes in the physical parameters of a mineral occur in a non-monotonic manner. This manifests in the extremes of correlation curves, changes in the speed of processes at different levels of exposure. Thus, the strength of a number of rocks (marble, gabbros, labradorite, etc.) decreases with increasing temperature, while for others the strength increases (urtite), but quartzite, granite have a maximum strength in the respective temperature range. The parameters of elasticity also change analogously. In addition, it is important which physical fields cause the temperature to increase in the mineral. Heating of iron quartzite with a high-frequency electromagnetic field gives a minimum of strength. These facts show that changes in physical parameters occur in the process of realization of several mechanisms of interaction between matter and field, the effects of which are different and sometimes even opposite.

2. Different modes of exposure cause different changes in physical parameters. In addition, depending on the composition and structure of the substance, the same mode of action may cause different changes in the physical parameters of the mineral.

3. Changes in the physical parameters of the minerals as a result of exposure to external fields after removal of the acting field may be permanent, may increase, or may relax over time completely or partially (Fig.3). These changes are the means by which it is possible to transform a mineral into a useful product, to change its properties in the desired direction. Thus, previously exposed minerals containing quartz up to 500^0C are much easier to grind in crushers and mills , grinding energy intensity is reduced by 30-40%. On the other hand, rocks characterized by an increase in plasticity with temperature (e.g. gabbros) after heating increase the energy intensity of crushing. Preheating of materials containing metallic minerals in a high-frequency electromagnetic field cause cracking in the grain contact areas, resulting in crushing to give a crushed material from which the metal-containing fractions can be efficiently separated.

On the other hand, in the fields of ionizing flows the processing results gradually relax and disappear. The same happens with mechanical activation in high-intensity dynamic fields. This means that the time of use of the induced changes in minerals is limited, which must be considered in the implementation of technological processes.

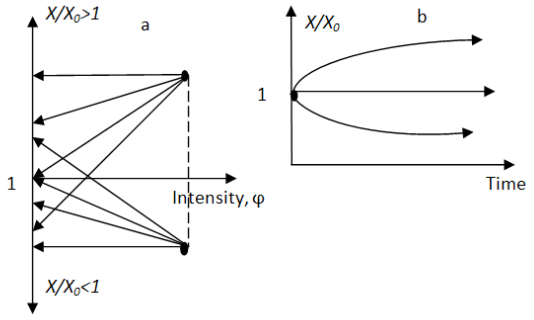

Fig.3. Possible changes in the effect after the exposure to the physical field depending on the field strength (a) and the time after exposure (b). X / X_0 - the ratio of the value of the current physical parameter X to the initial mineral parameter X_0 (a- before exposure, b-obtained as a result of exposure).

4. The result of exposure of physical fields to minerals depends on the time, intensity of the field exposure and the rate of its change, cyclicality and other parameters characterizing the physical treatment regimes.

Compliance with the upcycling principle for the conversion of mineral waste into high quality products can be assessed according to the following criteria:

1. The product is obtained from low-value raw materials which are currently not used at all or little and only as an auxiliary material.

2. The parameters of the obtained product, which characterize the quality of its use, are at the level of the existing product or exceed it - the new product can be used as an alternative.

3. The fields of application and range of the new product become wider compared to the traditional product.

4. The technology of manufacturing the new product does not generate or generate much less waste (especially hazardous), does not cause pollution, does not increase the negative burden on the ecological environment.

5. The production of the new product from mineral waste is economically advantageous - at least does not exceed or insignificantly exceeds (in the first stage of

implementation) the economic costs of production of the traditional product.

These criteria can be normalized and quantified by taking the relevant parameters of the traditional product as a basis and applying them to the parameters of the alternative product.

Thus, coefficients can be obtained:

Raw material value factor V

$$V = \frac{\text{mineral waste price}}{\text{traditional raw material price.}}$$

Quality factor of the manufactured product Q

$$Q = \frac{\text{quality of the alternative product}}{\text{quality of the traditional product}}$$

Ecological impact factor D

$$D = \frac{\text{impact of the production of the alternative product}}{\text{impact of the production of the traditional product.}}$$

Area of use factor J

$$J = \frac{\text{uses of the alternative product}}{\text{uses of the traditional product.}}$$

Economic expenditure ratio E

$$E = \frac{\text{production cost of the alternative product}}{\text{production cost of the traditional product.}}$$

Based on these factors, the level of upcycling can be quantified by the complex indicator UC

$$UC = \frac{Q.J}{V.E.D} \qquad (6)$$

The ideal option is when Q, J> 1, but V, E, D <1. When comparing the possible processing options, the one with the highest parameter UC is preferred.

The analysis shows that these criteria for obtaining quality products from mineral waste at the moment are most met by such promising directions of construction and building materials production as the development of binders, porous and glass ceramics, geopolymers and composite materials (including organominerals).

The main physical processes used in the development of these technologies are machining-disintegration (crushing and grinding), integration (consolidation, dynamic and static pressure); heat treatment - integration (sintering, melting, solid phase reactions), disintegration (chemical reagent environment, biogeochemical processes).

The use of additional physical effects - mechanical, thermal, chemical activation of substances, acoustic (especially in the ultrasonic range) and electromagnetic (especially, high frequency range) fields, phase and polymorphic effects - has a perspective for the intensification of basic processes in technology.

Thus, the areas of research and information base of mineral properties and their changes are specified: composition - both mineral and chemical;structure - macro and crystalline scale; properties - mechanical, thermal, physico-chemical - their changes, stability and critical (extreme) values under the influence of physical fields.

HIgher level of mineral waste processing technologies are associated with their physico-chemical, chemical and physico-biological disintegration. Research in these areas for mineral waste is currently limited, but mining industry uses hydrometallurgy, geobiotechnology, oxidation and reduction reactions to extract useful chemical elements or compounds from unconditioned ores and residues.

All types of mineral waste processing, except when the mineral waste is used directly or with little mechanical pre-treatment can be grouped in two opposite directions - disintegration and integration. Under the term "disintegration" we combine a wide group of physical, physic-chemical and chemical processes in which a mineral is broken down into components of various scales - from mineral aggregates to individual chemical elements (Fig. 4). The efficiency of physical field-substance interaction processes highly depends on the free surface area of the exposed mineral, surface energy, crystal lattice defects, their types and concentration, structural distortions, diffusion and reactivity. All these parameters increase strongly after crushing the mineral, in proportion to the degree of crushing. Therefore, all processing activities start from the crushing and grinding of the material. Disintegration, by its nature and types of processes, is sharply divided into three directions - mechanical, physicochemical and microbiological.

The goals of disintegration are:

• crushing of mineral material to the stage necessary for its further use in a direct way or for activation of further processing (including the implementation of the next disintegration and also for the provision of consolidation processes);

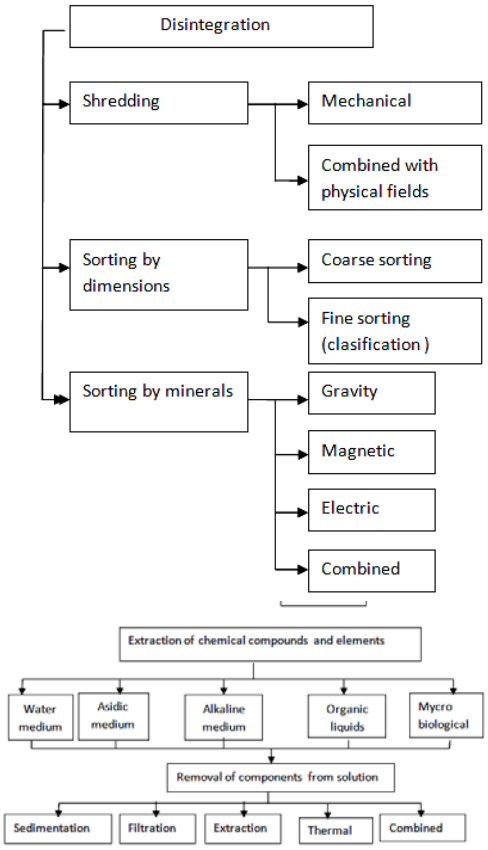

Fig.4. Classification of disintegration methods.

•sizing of crushed mineral material (sifting, classification);

•division by composition (mineral individuals);

•extraction of the single compounds or chemical elements

As shredding is energy-intensive - in many cases exceeding 40% of the total energy consumed in recycling - it becomes very important to maximize the recycling of mineral waste already shredded in the basic technology or generated at the relevant stages of this technology - ash,

treatment plant dust, enrichment plant tails, since in this case the crushing stage becomes redundant. In other cases, it is necessary.

By "integration" we mean the direct compaction of a loose aggregate - consolidation to form a solid monolith, as well as the combination of individual components through binders, thermal and other field effects or chemical reactions, resulting in a compact new substance with new properties. The task of integration (consolidation) is to create strong mechanical bonds between individual grains, crystals or their elements of a mineral or a mixture thereof. The integration of minerals is performed with crushed, often highly dispersed materials, except in cases when large pieces of raw material (slabs, blocks) are combined in a cohesive macrostructure. So, the first stage of integration (consolidation, monolithization) technology also starts from disintegration. The choice of the next processing stage is related to the production of the planned final product and the properties that need to be created in the obtained product. There are two options - to move the crushed mineral for further direct processing without any additives or to add additional components and create a batch of the respective composition.

In the basic processing process, the crushed material or their respective mixture is exposed to physical or substance fields (solutions).Considering the currently most feasible and effective types of exposure to minerals, we distinguish four types of exposure - the effects of mechanical, thermal, chemical reagents on the environment and complex (combined) fields (Fig. 5). Each of these routes of exposure is subdivided according to the physic-chemical process that makes up the structure and composition of the final material.

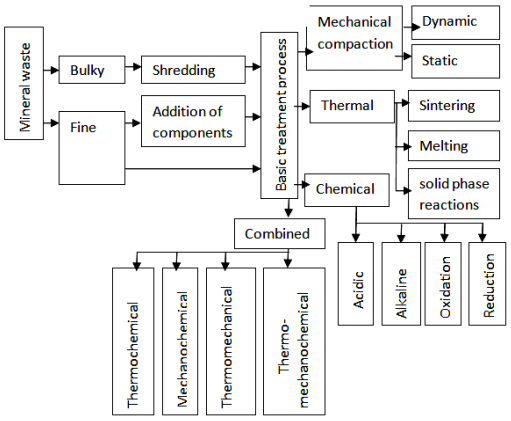

Fig.5. Classification of integration methods.

Depending on the types of fields acting, their intensities, duration of action and modes, new different types of energy bonds between the particles of the material change or are formed, both interatomic (covalent, ionic) and intermolecular (electrostatic, donor-acceptor, hydrogen).

In the sintering process of materials at temperatures of 1000^0C and more, traditional ceramics are formed - crystalline inorganic, non-metallic material, consisting mainly of oxides, nitrides or carbides. A mixture of low-melting clay minerals with quartz sand is used as a raw material in traditional brick production technology.

Glass is the result of the melting of minerals and forms a separate group of amorphous solids.

In the appropriate technological process, an intermediate product can be obtained - glass ceramics, which is used for the production of tiles and other construction materials. Many technogenic mineral wastes can be included in the production of glass ceramics. This issue has received a great deal of attention recently [9], [10]. Glass-ceramic technology includes a two-stage heat treatment process - nucleation (sludge formation) and crystallization stages. The glass-ceramic structure is characterized by fine, chaotically oriented crystals embedded in a matrix of partially amorphous material, without pores, micro cracks and voids.

A study [11] has shown that basalt and residues from the ceramics industry can be used in the production of glass ceramics. The chemical composition of the used raw materials is quite close to most of the technogenic minerals, including the composition of construction debris (clay and silicate bricks, concrete residues).

The obtained glass-ceramics showed high mechanical properties - hardness from 9.6 to 10 GPa, bending strength in the range from 92 to 135 MPa (Fig. 6), water adsorption at zero level. As a result of sintering, four mineral phases were formed - grown, anortitis, olivine and magnetite. Typically, the addition of ceramic waste to basalt increased the mechanical properties of glass ceramics by up to 40% compared to ceramics made from basalt alone. This leads to the conclusion that the use of this waste in the production of glass-ceramics can prove to be quite efficient.

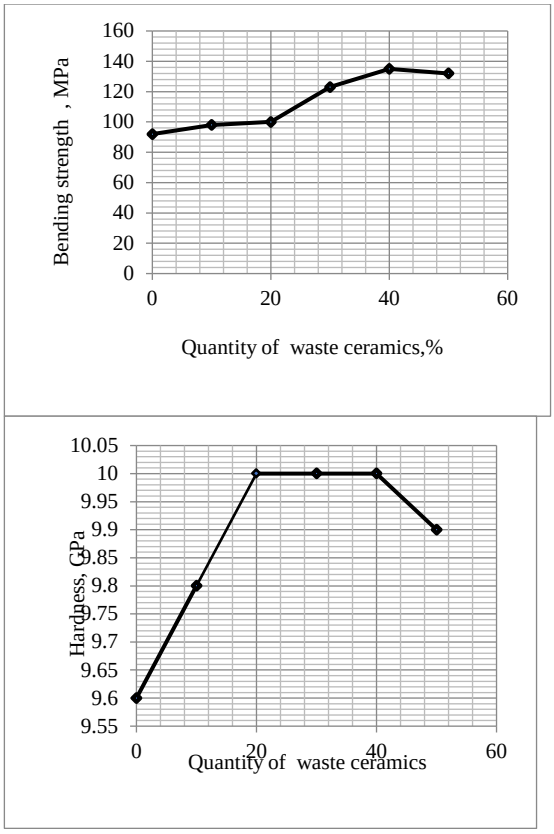

Fig.6. Changes in glass ceramic mechanical properties with addition ceramic waste.

In [12], fly ash and tails of a rare metal ore from the Baijan Obo enrichment plant in China were studied as a raw material for the production of glass ceramics.

The mineral waste from the enrichment plant was added to the ash in various proportions from 10 to 50% by weight. The results showed that the density of the obtained glass-ceramics is about 3 g/cm^3, bending strength about 193 MPa, hardness (according to Vickers method) 1.3 GPa, thermal expansion coefficient - $8.3.10^{-4}K^{-1}$.

Another study [13] examined the use of enrichment plant residues for the production of porous glass ceramics. The mixture was formed from operational waste from boron mineral deposits, basalt, ordinary soda-lime glass production residues, silicon sand and limestone.

The prospect of inorganic waste recycling is the use of inorganic polymer technologies. As is known, inorganic polymers are, for the most part, products of the synthesis of chemical elements of groups III-VI.

Artificially synthesized inorganic polymers are currently widely used. French chemist J.Davidovits [14] discovered that the reaction of metakaolin and soluble alkali silicate formed a binder capable to replace cement. Subsequent studies have shown that there are two possible directions of polymerization: in alkaline media (Na +, K +, Li +, Ca ++, Cs + and others) and in acidic media (phosphoric acid, organic carboxylic acids). The alkali method is currently being further studied. J.Davidovits called such materials geopolymers (other names - alkali-activated cement, alkali-activated binder, alkaline cement, and alkaline binder.

Geopolymer, - inorganic binder (aluminosilicon gel) with low calcium content, consisting of tetrahedral SiO_4 and AlO_4 stages, polycondensed in the spatial structure as a result of reaction between aluminosilicates and alkaline activators [15]. Alkali activation usually occurs by mixing powdered aluminosilicate with liquid activator sodium or potassium hydroxide at most temperatures up to 100 ° C. The main products of the interaction between aluminosilicate and alkali are of two types. One of them is an aluminum silicate gel consisting of alkali and alkaline earth hydroalosinosilicates (R-A-S-H). The second type is low basic hydro silicates, calcium hydro aluminates (C-S-H, C-A-H). The hardening of the gel results in water-resistant hydrates - hard artificial stone with high mechanical properties and chemical stability. The composition of geopolymers is characterized by a formula Mn [- (Si-O) zAl-O] n · wH_2O, wherein M is K, Na or Ca, n is the degree of polycondensation, z is 1, 2, 3 or more. The Si: Al ratio is crucial in shaping the properties of the geopolymer - as the Si-Al ratio increases, the heat resistance and mechanical strength of the geopolymer increase. Geopolymers have good chemical and thermal stability, high compressive strength and low permeability. In addition, the production of geopolymers is cheaper and less energy-intensive and more environmentally friendly (emitting 80% less CO_2) compared to the production of Portland cement. Metakaolin is the most widely used raw material in the production of geopolymers because of its high reactivity and ability to form homogeneous reaction products. Studies have shown that a variety of natural and technogenic mineral raw materials in the composition of which are aluminum silicates can be used in the production of geopolymers. The main criterion for the suitability of raw materials is the degree of disordered structure of the aluminosilicate substance. Many silica- and alumina-rich minerals (ash , slag, granite waste, clay minerals in the original and calcined state, effluent rocks with a high degree of vitrification, construction debris, etc.) may be used in geopolymers production.

The report [16] informs about experiments where geopolymer was produced of unconditioned kaolin residues containing about 59% SiO_2, 33% Al_2O_3, 3% Fe_2O_3, 2% TiO_2.

Mineral wastes such as fly ash and glass fragments are also subject to geopolymerization. In [17] it was shown that the polymerization of inorganic materials can be used not for the final product, but for the production of an intermediate-gel, which is further subjected to heat treatment - ceramication. The mixture of fly ash and glass waste was activated in weakly alkaline solutions, resulting in a polymerized gel suspension which is mechanically foamed by the addition of surfactants, dried and sintered without foam structure collapse at temperatures below 1000 ^{0}C to form a highly porous, chemically stable, mechanically durable glass ceramics.

The report [18] analyzes two possibilities of chemically bound ceramics extraction by processing mine waste: by alkali activation (geopolymerization) and acid activation (chemically bound phosphate ceramics). It was found that the activation of alkali has been studied for 28 silicate minerals, and results have been obtained confirming the efficiency of this method in the production of ceramics.

Alkali activation is a promising technology for the recycling of inorganic waste and industrial residues in construction materials. This process makes it possible to regulate the properties of the final product according to the chemical composition of the raw materials. At the same time, it is less sensitive to various non-essential impurities. Studies have been carried out at the Kazan State University of Architecture and Construction in which finely dispersed mineral materials have been subjected to alkali treatment: quartz sand, processed foundry sand,, ash, ceramic brick and Portland cement concrete fragments, synthetic zeolite waste. As a result of slag use studies, it has been found that the highest mechanical properties are achieved after grinding the batch to a degree of fineness that gives a mixture with a degree of dispersion (specific surface area) of 600-700 m^2/kg. The inclusion of 30% crushed ceramic bricks in the mixture increases the stone strength of the geopolymer by 30% (for example, a geopolymer made of neutral slag with silicate coating increases the strength from 116 MPa to 140 MPa, but with soda ash increases from 61 to 80 MPa). 25-30% ash additive for slag with a dispersion of 500-800 m^2 / kg increases the strength of geopolymer stone up to 60% during heat treatment. Micro silicon with a specific surface area of 15,000 m^2/kg additive in the amount of 5-7% gives maximum strength values.

When the mineral waste is intended to use for production materials, which are the replacement of an existing traditionally used product, its component or as an intermediate product, the research program should consist of the following stages (Fig.7):

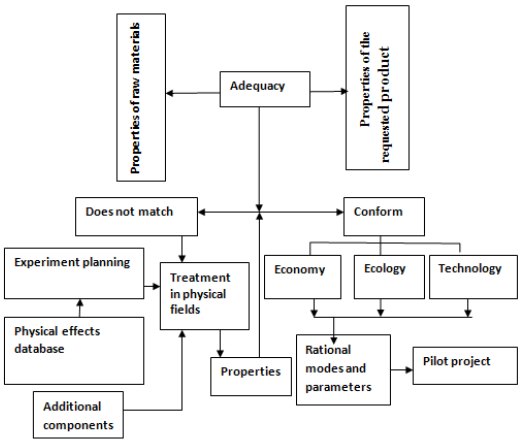

Fig.7. Algorithm for selection of research on the substantiation of mineral waste processing technologies

> the basic requirements and properties (P) that the product must meet are precisely defined the final product;
> mineral properties are studied (M);
> the correspondence of these properties is determined (M ~ P);
> in the event of non-compliance, specify the exact parameters of the non-compliance and, on the basis of a database of physical effects, assess the possible courses of action that could lead to the required property;
> organizes the planning of experiments and performs experiments;
> investigates the properties M 'of the material obtained during the experiments and their compliance with the requirements (M '~ P);
> if necessary, continue experiments with other physical fields.

IV. CONCLUSIONS

Development of high-quality up cycled products from mineral waste is one of the perspective directions, which on the one hand ensures saving of natural mineral resources and on the other hand reduction of environmental pollution by implementing the principles of circular economy.

There may be important economic and environmental benefits of using inorganic mineral waste for producing new up cycled products. For example , Australian researches Ross P.Williams and others [19]estimated , that producing geopolimers from waste raw materials it is possible to achieve 44-64% improvement in greenhouse gas emissions over ordinary Portland cement production , while the financial cost of geopolymers are 7% lower to 39% higher compared with OPC.

In recent years, many studies [20],[21],[22],23],[24],[25],[26],[27] have been carried out in the world which have proven that the processing of mineral waste in accordance with the current economic and environmental conditions is the most reliable in the production of building materials such as cement, various classes of ceramics (light bricks, water permeable bricks, tiles, glass ceramics), geopolymers, mineral-organic composites.

The successful development of these recycling technologies requires the acquisition of much broader and deeper information on the properties, composition, structure and ability of mineral waste to change them in the required direction as a result of exposure to external physical and chemical fields.

An appropriate classification of technogenic mineral resources for processing in this direction has been developed, thermodynamic parameters characterizing the efficiency of impact on the mineral environment have been determined, criteria for evaluation of processing technology in accordance with the upcycling principle have been proposed.

The classification of mineral waste disintegration and integration processes is given. An optimal algorithm for evaluation and research of possible physical processes of mineral waste processing is proposed.

REFERENCIES

[1] Г.Я.Новик, С.В.Ржевская. ”Физико-техническое обеспечение горного производства”, М.Недра, 1995 , 258с.
[2] Г.Я.Новик, М.Г.Зильберштмидт.“ Управление свойствами горных пород в процессах горногопроизводства”, М. Изд.ЛКИ, 2010, 224с.
[3] G.Noviks. “The development of complex analysis system of ecotechnology paramaters“, Rēzeknes augstskolas zinātniskie raksti”, 2003, pp.97-110
[4] G.Noviks.”Basis of optimal mineral inorganic waste processing methods”, Environment. Technology. Resources. Proceedings of the 6-th International Scientific and Practical Conference, 2007, Rezekne, pp.87-101
[5] G.Noviks. “Physico-technical approach to design of composites from mineral and polymer technogenic resources”, Environment. Technology. Resources. Proceedings of the 10-th International Scientific and Practical Conference, 2015, pp162-169,
[6] Sung, K.; Cooper, T.; Kettley, S. “Individual Upcycling Practice: Exploring the Possible Determinants of Upcycling Based on a Literature Review”, Sustainable Innovation Conference, Copenhagen,2014.
[7] G.Noviks,”Eco-innovative solutions for the processing of technogenic mineral resources Environment. Technology. Resources. Proceedings of the12-th International Scientific and Practical Conference, 2019, Rezekne, pp. 204-209
[8] European Waste Classification for Statistics, version 4 Commission Regulation (EU) No 849/2010 of 27 September 2010 amending Regulation (EC) No 2150/2002 of the European Parliament and of the Council on waste statistics
[9] F.L.da Silva, F.G.S.Araújo, M.P.Teixeira, R.C.Gomes, F.L.vonKrüger, ”Study of the recovery and recycling of tailings from the concentration of iron ore for the production of ceramic”, Ceramics International 40,2014,pp.16085–16089
[10] A.Jonker, J.H. Potgieter, “An evaluation of selected waste resources fertilization in ceramic materials application”, Journal of the European Ceramic Society 25 , 2005,pp.3145–3149.
[11] G.A. Khater, A. Abdel-Motelib , A.W. El Manawi , M.O. Abu Safiah”Glass-ceramics materials from basaltic rocks and some industrial waste”,Journal of Non-Crystalline Solids, 358 , 2012, pp. 1128–1134
[12] LiBaowei, Deng Leibo, Zhang Xuefeng, Jia Xiaolin, “Structure and performance of glass–ceramics obtained by Bayan Obo tailing and fly ash” Journal of Non-Crystalline Solids, 380, 2013, pp. 103–108
[13] Mauro Marangoni, Enrico Bernardo, Suna Cetin, ”Lightweight glass–ceramic tiles from the sintering of mining tailings”, Ceramics International, 41, 2015, pp.5294–5300
[14] Davidovits, J. Geopolymers. Journal of Thermal Analysis 37, 1991, pp.1633–1656

[15] PaivoKinnunen, Arnold, Ismailov, Soili Solismaa, Harisankar Sreenivasan, Marja- Liisa Raisanen, Erkki Levanen, ,Mirja Illikainen, ”Recycling mine tailings in chemically bonded ceramics. A review”, Journal of Cleaner Production, 174, 2018, pp.634-649

[16] Marlon A. Longhi , Erich D. Rodríguez , Susan A. Bernal , John L. Provis ,Ana Paula Kirchheim,” Valorisation of a kaolin mining waste for the production of geopolymers”, Journal of Cleaner Production, 115 ,2016, pp.265-272

[17] Acacio Rincón Romero, Daniele Desideri, Aldo R. Boccaccini, Enrico Bernardo,“Up-Cycling of Iron-Rich Inorganic Waste in Functional Glass-Ceramics”, Minerals 2020, 10, 959; doi:10.3390/min10110959

[18] Paivo Kinnunen, Arnold Ismailov, ,,Soili Solismaa , Harisankar Sreenivasan, MarjaLiisa Raisanen, Erkki Levanen, Mirja Illikainen, “Recycling mine tailings in chemically bonded cerami cs.A review”, Journal of Cleaner Production, Vol. 174, 2018,pp. 634-649

[19] Ross P.Williams, JanineLay, Arievan Riessen, Glen D.Corder.“Costs and carbon emissions for geopolymer pastes in comparison to ordinary portland cement”, Journal of Cleaner Production,Vol.19, Iss. 9–10, 2011, pp. 1080-1090

[20] Natalia Babak1.Emperor Alexander, “Structure of Atoms of the Main Phase of Industrial Wastes Predict Properties of Building Materials in Transport Construction in Cold Regions”, St. Petersburg State Transport University, Proceedings of TRANSOILCOLD, Transportation Soil Engineering in Cold Regions, Volume 2.2019.

[21] Hailing Kong, Zhanqing Chen, Luzhen Wang, Haide Shen “Experimental study on permeability of crushed gangues during compaction,” International Journal of Mineral Processing 124 , 2013, pp. 95–101

[22] Qianxing Huang, Taoyong Liu , Jiashuo Zhang, Xi He, Jianlei Liu, ZhiweiLuo, AnxianLu,“Properties and pore-forming mechanism of silica sand tailing-steel slag-coal gangue based permeable ceramics”,School of Materials Science and Engineering, Central South University, Changsha 410083, China. Construction and Building Materials 253, 2020, 118870.

[23] Sung-Hoon Kang, Yeonung Jeong, Kiang HweeTan, Juhyuk Moon, “The use of limestone to replace physical filler of quartz powder in UHPFRC” Cement and Concrete Composites 94 , 2018, pp. 238–247

[24] Nancy A. Soliman, Arezki Tagnit- Hamou, ”Using glass sand as analternative for quartz sand in UHPC” Construction and Building Materials 145 ,2017,pp.243–252

[25] BoWei, Yimin Zhang, Shenxu Bao “Preparation of geopolymers from vanadium tailings by mechanical activation” Construction and Building Materials 145, 2017, pp 236–242

[26] MengguangZhu, Hao Wang, Li Li Liu, RuJi, Xidong Wang, ”Preparation and characterization of permeable bricks from gangue and tailings” Construction and Building Materials 148 , 2017, pp. 484–491

[27] Diana Bajare, Girts Bumanis, Genadij Shakhmenko, Janis Justs“Obtaining composition of geopolymers (alkali activated binders) from local industrial wastes” 3 rd International conference Civil engineering`11. proceedings, building, 2011

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Influence of Temperature on Methane Output from Bog Sludge and Crushed Reed Raw Materials

Sergejs Osipovs
Department of Applied Chemistry
Daugavpils University
Daugavpils, Latvia
sergejs.osipovs@du.lv

Aleksandrs Pučkins
Department of Applied Chemistry
Daugavpils University
Daugavpils, Latvia
aleksandrs.puckins@du.lv

Mihails Pupiņš
Department of Ecology
Daugavpils University
Daugavpils, Latvia
mihails.pupins@du.lv

Jeļena Kirilova
Department of Applied Chemistry
Daugavpils University
Daugavpils, Latvia
jelena.kirilova@du.lv

Juris Soms
Department of Environmental
Science and Chemistry
Daugavpils University
Daugavpils, Latvia
juris.soms@du.lv

***Abstract* - The research summarizes information on biochemical processes of biogas production and the parameters that affect the results of its production. The research examines the result of obtaining biogas from bog sludge and a mixture of crushed reed. Particular attention is given to temperature, as a parameter that affects the results of methane and biogas production.**

The yield of biogas and methane during the bioprocess depends on the effect of temperature. During the experiment, 2.78 L of biogas with an average methane content of 38.7% was obtained from a mixture of bog sludge and crushed reeds. If the content of organic compounds in the sludge was higher, the biogas yield would increase during the process. It is more advantageous to use the raw material mixture for biogas production.

Keywords* - *Anaerobic fermentation, biogas, influence of temperature.

I. Introduction

Biogas is a gaseous energy resource that can be obtained by anaerobic fermentation (AF) using biomass. The main component of biogas is methane (CH_4) and carbon dioxide (CO_2), which also includes other gases with certain physical properties. Biogas is a renewable energy resource that does not pollute the environment and the air. Biogas production reduces landfill growth and reduces water and soil pollution. The trend of biogas technologies is improving every time, thus the supply for biogas production is increasing. Capital investment in biogas plants requires relatively low costs. Their use reduces the greenhouse effect, as decomposing products emit CH_4 and CO_2 gases, which trap infrared (thermal) radiation reflected from the earth's surface [1].

Unlike fossil fuels, biogas is a fully renewable resource because it is produced from biomass. Biogas will not only improve the country's energy balance, but will also make a major contribution to conserving natural resources and improving the environment.

Another major environmental challenge for modern society is the growing amount of waste. Controlled landfilling or incineration of organic waste is not best practice.

According to the Multiannual Strategic Guidelines for Aquaculture 2014-2020, it is known that the biggest problems for aquaculture are the large amount of waste from fish life processes, as well as the large amount of energy required for economic activity [2].

The production of biogas by anaerobic fermentation is considered to be the optimal solution for the recycling of various types of organic waste, converting this waste into renewable energy and organic fertilizers.

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Latvia has experience in biogas production in landfills and wastewater treatment plants, as well as attempts to produce biogas on farms. In turn, the production of biogas from aquaculture residues has not been studied and is currently not used in Latvia.

The uses of biogas are different, they provide electricity and heat production. Compared to other renewable energy sources, biogas is a permanent, regular source, so energy can be obtained all year round. Purified biogas is used as a vehicle fuel and can be fed into the common natural gas supply network. Combustion of biogas can produce carbon dioxide for use in greenhouses [3]. Biomethane, or enriched biogas, is used as a fuel because the calorific value of biomethane is relatively higher than that of other hydrocarbons [4]. By purifying biogas from CO_2, its calorific value increases.

The AF process takes place in thermophilic (55-70°C) or mesophilic (32-45°C) temperature mode. It is important to maintain a constant temperature in the bioreactor, as methanogens, especially thermophilic methanogens, are very sensitive to temperature fluctuations. This is due to the fact that there are fewer thermophilic methanogenic microorganisms than mesophilic methanogens [5]. The thermophilic process has several advantages: it is characterized by a high metabolic rate, the destruction and elimination of the pathogen, and a high biogas yield. The disadvantages of the thermophilic process are the increase in volatile fatty acids, which results in an unstable yield of methane [6]. Hu, Kobayashi and co-authors [7] found in the study that methane yields are temperature dependent. Under mesophilic conditions, the yield of methane was higher than in thermophilic conditions.

Microorganisms need a certain amount of time to process the appropriate substrates. It is therefore important to determine, specify and select the appropriate exposure time (HRT) for each biochemical process in the AF phase. When HRT is not at optimal levels, metabolic adverse conditions occur. If the holding time is too long, the microorganisms die due to lack of nutrients. Conversely, if the HRT is too fast, the amount of volatile fatty acids increases and the yield of methane decreases.

Organic Loading Rate (OLR) is an operating parameter that shows how much organic solids can be fed to the bioreactor per m^3 of volume and per unit time. If too much OLR is fed into the bioreactor, inhibitory substrates such as volatile fatty acids may accumulate. This situation reduces the outcome of CH_4, because the acidic pH has a negative impact on the activity of microorganisms [8].

II. Materials and Methods

A. Biomass

In order to perform the work and obtain biogas, bog sludge from Viļaka region, and bog reeds from Daugavpils Esplanāde park were used in, which were dried and divided into components: stems, leaves, flowers.

In order for anaerobic fermentation processes to be possible, digestate from the biogas plant ”Skaista“, Daugava region, Skrudalienas parish was used.

B. Laboratory scale bioreactor

Bioreactor EDF-5.4_2 (manufactured by *Biotehniskais centrs*, Latvia) has a compact, ergonomic and robust design. Glass cylinder vessel is mounted between the upper lid and the metallic jacketed bottom. The design of the bioreactor is easy to maintain and apply basic operations and preparatory process, in particular, washing and autoclaving.

Gas mixing measurement was done using mass flow controllers *Hamilton* ARC pH and DO sensors. These sensors send 4-20 mA signals directly to process control system (PCS) and ensure at the same time information management via Bluetooth in smartphones or PC installed programs. This program generates a report about all calibration procedures, sterilization numbers, predicted service life. Connection of sensors: off-gas analysis O_2, CO_2, CH_4.

On-line/off-line data analysis and advanced process control possibilities was carried out using PC implemented program (Matlab, Python) algorithms communicating to process control system (PCS and SCADA).

C. Determination of sludge and reed moisture

The sludge substance was mixed in a container with a metal spatula so that the moisture in the substrate was evenly distributed. Pieces of roots and other plant remains were removed from sludge by tweezers. A 10 g sample of substrate was weighed. The sample was placed in a humidity analyzer *Mettler Toledo* HB43-S with a drying temperature 105±2°C [9]. The moisture content of the substrate was determined and a dry residue was obtained. The moisture of 3 samples was determined for the accuracy of one study. The resulting dry residue was further used to determine the organic matter content. Similar procedures were done by the reed.

D. Determination of sludge and reed organic matter content

The empty crucibles were placed in a muffle furnace where they were heated to 550±10°C for at least 60 minutes. Then the crucibles were removed from furnace and placed on a heat-resistant surface for 5-10 minutes, subsequently after a while the crucibles were left to cool in a desiccator. The cooled crucible was weighed to the nearest 0.1 mg on an analytical balance and weigh 1 to 2 g of the test sample was put into the crucible. The test sample was heated in a muffle furnace for two hours at 800±10°C; after that placed in a cool desiccator. This procedure of heating and weighing was repeated to constant weight. The organic matter content was calculated as a percentage of the dry residue [10]. Similar procedures were done by the reed.

E. Preparation of the mixture for biogas production

To the prepared 1,200 g of bog sludge was added 50 g of crushed reed powder and mixed thoroughly. The prepared mixture was thoroughly immersed in the reactor vessel and 300 mL of bog water was added, mixed thoroughly with a metal spatula. 1,000 g of digestat was added and was tightly sealed with a bioreactor lid. The appropriate temperature mode and agitator rotation speed are selected and connected to the bioprocess controller.

F. Selected parameters of the bioprocess controller

The following parameters were used in the bioprocess controller to perform the work:

- 38°C, 40°C, and 42°C temperature mode;
- Agitator rotation speed interval 50 rpm;
- Foam level sensors.

A computer with SCADA (Supervisory control and data acquisition) software was connected to the bioreactor, which recorded the volume and composition analysis of the released biogas.

III. RESULTS AND DISCUSSION

A. Determination of sludge and reed moisture and organic matter content

The obtained moisture results of sludge samples are valid for biogas production, as the dry residue in substrate samples is about 15% (see Tab. 1). The results are in line with the type of wet fermentation, which is similar to the other potential biogas technology [11].

TABLE 1 SLUDGE AND REED MOISTURE AND ORGANIC MATTER CONTENT

Biomass	Moisture, %	Organic matter content (from dry matter), %
Sludge	84.96±0.46	27.31±0.42
Reed	1.26±0.22	96.61±0.74

The amount of organic matter obtained from sludge samples is about 27%, which indicates a high content of inorganic substances in the substrate. In order to obtain more biogas yield in the study, a relatively larger amount of bog sludge must be fed into the bioreactor, with the addition of another type of substrate in which the percentage of organic matter is about 90% or more.

The amount of organic matter obtained from reed samples is about 97%, which indicates a high content of organic matter, so it is advantageous to add it to the bog sludge in a certain ratio. The improved mixture can then be used for biogas production.

B. Biogas production

During each experiment, the released volume of biogas and the gas composition in the obtained biogas were studied with the research software SCADA.

The Fig. 1 shows the trend in biogas volume release over 60 days at 38°C, 40°C, and 42°C.

Of the total biogas produced during the fermentation period (60 days), 95% was produced from the 10th to the 55th day at all temperatures tested (see Fig. 1). The optimal retention time is about 35 days at temperature 40°C, 38 days at 38°C, and 33 days for at 42°C. The mixing mode of the feed during the experiment prevents the formation of dry and inactive flotation layers and can influence the optimal retention time. In this study, more than 95% of biogas can be produced in less than two months.

The average concentration of methane in biogas resulting from AF at a temperature of 40°C is 38.7%, carbon dioxide – 60.4%, other gases – 0.9%; from AF at a temperature of 38°C concentration of methane is 39.9%, carbon dioxide is 59.3%, other gases are 0.8%; and from AF at a temperature of 42°C concentration of methane is 36.1%, carbon dioxide – 63.1%, other gases – 0.8%.

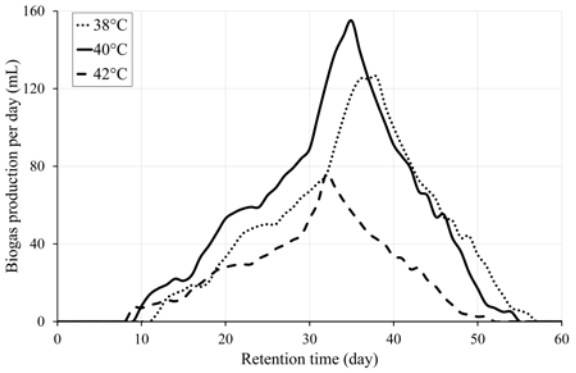

Fig. 1. Trend in biogas volume release over 60 days at different temperatures.

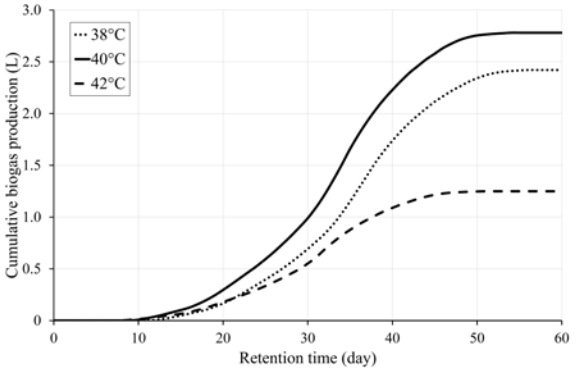

Fig. 2. Trend in cumulative biogas production over 60 days at different temperatures.

For the three temperature, the average cumulative biogas production in mL was measured and recorded daily as shown in Fig. 2.

IV. Conclusions

The biogas yield during the bioprocess depends on the effect of temperature, the best results in our study were obtained at a temperature of 40°C.

During the experiment, 2.78 liters of biogas with an average methane content of 38.7% were obtained from a mixture of bog sludge and crushed reed at a temperature of 40°C. If the organic matter content in sludge were higher, the biogas yield would increase during the process.

The proportion of methane in biogas was the best at a temperature of 38°C – 39.9%, but at this temperature regime the total volume of biogas turned out to be about 15% less.

The worst results were obtained at a temperature of 42°C – both in terms of the volume of biogas and the proportion of methane in it.

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REFERENCES

[1] S. Bhardwaj and P. Das, "A Review: Advantages and Disadvantages of Biogas" *International Research Journal of Engineering and Technology*, vol. 4 (10), pp. 890-893, October 2017. Available: IRJET, https://www.irjet.net/archives/V4/i10/IRJET-V4I10155.pdf [Accessed: March 31, 2021].

[2] "Akvakultūras daudzgadu stratēģiskās pamatnostādnes 2014.–2020. gadam", 2013. [Online]. Available: https://www.zm.gov.lv/public/files/CMS_Static_Page_Doc/00/00/00/35/82/akvakultura_2014.pdf [Accessed: March 31, 2021].

[3] A. Kalniņš, "Biogāzes iespējas un tās kā transportlīdzekļu degvielas izmantošana", 2007. [Online]. Available: http://petijumi.mk.gov.lv/sites/default/files/file/EM_Biogazes_iespejas_un_tas_ka_transportlidz_degv_izmantos_2007.pdf [Accessed: March 31, 2021].

[4] Z. Bagi, N. Ács, T. Böjti, B. Kakuk, G. Rákhely, O. Strang, M. Szuhaj, R. Wirth and K. L. Kovács, "Biomethane: The energy storage, platform chemical and greenhouse gas mitigation target" *Anaerobe*, vol. 46, pp 13-22, August 2017. Available: ScienceDirect, https://www.sciencedirect.com/ [Accessed: March 31, 2021], https://doi.org/10.1016/j.anaerobe.2017.03.001

[5] S. Mirmohamadsadeghi, K. Karimi, M. Tabatabaei and M. Aghbashlo, "Biogas production from food wastes: A review on recent developments and future perspectives" *Bioresource Technology Reports*, vol. 7, 100202, September 2019. Available: ScienceDirect, https://www.sciencedirect.com/ [Accessed: March 31, 2021], https://doi.org/10.1016/j.biteb.2019.100202

[6] P. Wang, H. Wang, Y. Qiu, L. Ren and B. Jiang, "Microbial characteristics in anaerobic digestion process of food waste for methane production–A review" *Bioresource Technology*, vol. 248 (Part A), pp. 29-36, January 2018. Available: ScienceDirect, https://www.sciencedirect.com/ [Accessed: March 31, 2021], https://doi.org/10.1016/j.biortech.2017.06.152

[7] Y. Hu, T. Kobayashi, W. Qi, H. Oshibe and K. Xu, "Effect of temperature and organic loading rate on siphon-driven self-agitated anaerobic digestion performance for food waste treatment" *Waste Management*, vol. 74, pp. 150-157, April 2018. Available: ScienceDirect, https://www.sciencedirect.com/ [Accessed: March 31, 2021], https://doi.org/10.1016/j.wasman.2017.12.016

[8] S. K. Pramanik, F. B. Suja, S.M. Zain and B.K. Pramanik, "The anaerobic digestion process of biogas production from food waste: Prospects and constraints" *Bioresource Technology Reports*, vol. 8, 100310, December 2019. Available: ScienceDirect, https://www.sciencedirect.com/ [Accessed: March 31, 2021], https://doi.org/10.1016/j.biteb.2019.100310

[9] S. Achinas and G. J. W. Euverink, "Theoretical analysis of biogas potential prediction from agricultural waste" *Resource-Efficient Technologies*, vol. 2, pp. 143-147, September 2016. Available: ScienceDirect, https://www.sciencedirect.com/ [Accessed: March 31, 2021], https://doi.org/10.1016/j.reffit.2016.08.001

[10] J. Kainthola, A. S. Kalamdhad and V. V. Goud, "A review on enhanced biogas production from anaerobic digestion of lignocellulosic biomass by different enhancement techniques" *Process Biochemistry*, vol. 84, pp. 81-90, September 2019. Available: ScienceDirect, https://www.sciencedirect.com/ [Accessed: March 31, 2021], https://doi.org/10.1016/j.procbio.2019.05.023

[11] T. Getahun, M. Gebrehiwot, A. Ambelu, T. Van Gerven and B. Van Der Bruggen, B, "The potential of biogas production from municipal solid waste in a tropical climate" *Environmental Monitoring and Assessment*, vol.186 (7), pp. 4637-4646, July 2014. Available: SpringerLink, https://link.springer.com/ [Accessed: March 31, 2021], https://doi.org/10.1007/s10661-014-3727-4

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Biogas Production Possibility from Aquaculture Waste

Sergejs Osipovs
Department of Applied Chemistry
Daugavpils University
Daugavpils, Latvia
sergejs.osipovs@du.lv

Aleksandrs Pučkins
Department of Applied Chemistry
Daugavpils University
Daugavpils, Latvia
aleksandrs.puckins@du.lv

Mihails Pupiņš
Department of Ecology
Daugavpils University
Daugavpils, Latvia
mihails.pupins@du.lv

Jeļena Kirilova
Department of Applied Chemistry
Daugavpils University
Daugavpils, Latvia
jelena.kirilova@du.lv

Juris Soms
Department of Environmental
Science and Chemistry
Daugavpils University
Daugavpils, Latvia
juris.soms@du.lv

***Abstract* – The research explores the possibilities of biogas extraction from aquaculture waste. Samples of fish-farming pool sludge were taken from a fish farm, which is located in the Krāslava district, Kalnieši rural municipality. Prior to experimental fermentation and extraction of biogas, samples were analyzed in order to determine their moisture and organic matter content (OMC). For purpose of increasing OMC available for fermentation, sludge was mixed with crushed reeds. Biogas was obtained from the samples at various ratios of sludge and reed residues. During the experiments, 3.81 liters of biogas were obtained from a mixture of fish-farming pool sludge and crushed reed at reed mass 100 g. The results of experimental research indicate that aquaculture residues can be used to produce biogas.**

Keywords – biogas, aquaculture, waste

I. Introduction

The current global energy supply depends on fossil fuels (oil, coal, natural gas). Fossil fuels are a non-renewable resource and their reserves are declining very rapidly. In contrary to fossil fuels, biogas is a fully renewable resource because it is produced from biomass. The advantages of biogas also are obvious - (a) improving the country's energy balance, (b) making a major contribution to conserving natural resources and (c) improving the environmental situation and mitigation of global warming [1].

Another major environmental challenge for modern society is the growing amount of waste, including organic one. Controlled landfilling or deposition of organic waste is not a best practice, as environmental standards have now become much stricter [2].

Aquaculture is one of the fastest growing food industries in the world today. Growing global demand for food is driving the rapid development of aquaculture: from only 3.2% of total fisheries production in 1950, it has now reached 50%, in response to limited natural resources and the rapid growth of the world's population [3].

As mentioned in Article 224 of the “Latvian Sustainable Development Strategy until 2030” on the use of biogas resources, “One of the potential resources for biogas production is biological waste. By developing biogas production, it can be used in the public transport sector, agriculture, as well as heat production” [4]. In 2016, the production volume of the aquaculture sector was 788 tons. One of the largest aquaculture companies at present is the joint-stock company "Nagļi". Currently, Nagļi Fisheries is the largest fish farm not only in Latvia but in the entire Baltics. It is a full-cycle aquaculture farm, which has its own carp and pike breeding material, where fish spawn is incubated, fry are farmed, and then fish production is being sent to market. The aquaculture facilities cover an area of about 2000 ha, which includes

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ponds, dams, land under the hatchery and workshops, and the Malta River reservoir, from which all fishing ponds are filled [5].

Potentially, Nagļi Fisheries can produce up to 1,500 tons of aquaculture production per year. At the same time the amount of waste produced in the course of fish life cycle in this case will also be 1,500 tons per year. On the one hand, it is a very big problem – to dispose such amount of waste, but on the other hand – waste from fish breeding processes is a good raw material for biogas plants. For example, a biogas plant with an electrical capacity of 100 KW_{el} requires about 6 tons of raw materials per day. This means that the "Nagļi" aquaculture farm can practically provide a raw material biogas plant with an electrical capacity of 100 KW_{el}, thus solving the problem of waste utilization and providing itself with electrical and thermal energy [6].

Fish processing companies also face waste disposal problems and energy shortages. In 2016, the number of fishery product processing companies was more than 100, producing almost 100 tons of fish products. Waste from fish processing plants is also a good raw material for biogas plants [7].

Any organic substance can be used as a raw material for biogas production. It is useful to use existing and available biomass – manure, homogeneous by-products of food production, forest and wood processing waste, sewage sludge, municipal organic waste, straw, etc. The amount of biogas that can be obtained from different sources varies and is not a constant [8].

Substrates used for biogas production can be classified according to their origin, dry matter composition, methane yield and other criteria [9].

Substrates with a dry matter content of less than 20% are used for purposes of wet fermentation. This category includes animal slurry, sewage sludge, manure, as well as wet organic waste from the food industry (e.g. whey from milk products processing). Dry fermentation is used if the dry matter content of the substrates is at least 35% and it is typical for energy crops and silage [10]. Energy crops are represented by herbaceous plants (grass, maize, oilseed rape, etc.) grown directly for energy/biogas production and trees (willow, poplar, oak), although the trees require special pre-treatment for delignification [11].

Strict separation of wet and dry fermentation technologies is biologically misleading, as the microorganisms involved in the fermentation process need a liquid medium for growth and multiplication [12]. The classification of technologies depends not on the dry matter content of the individual substrates used, but on the dry matter content of the bioreactor. In wet fermentation technology, the dry matter content of the reactor is about 12% and the reactor content can usually be pumped by means of pumps because it is liquid. If the dry matter content of the reactor is increased to 15-16%, the reactor content can no longer be pumped and this technology is called dry fermentation [13].

II. Materials and Methods

A. Biomass

Aquaculture residues (sludge) from a fish farm located in the Krāslava district, Kalniešu rural municipality were selected as raw material for biogas production and research. Samples were taken from the farm's wastewater collectors. The reeds from Daugavpils Esplanāde park were used for increasing of OMC. The reeds were dried and divided into components: stems, leaves, flowers.

In order to successfully provide anaerobic fermentation processes, digestate from the biogas plant "Skaista", Daugava region, Skrudalienas parish was used.

B. Laboratory scale bioreactor

For the implementation of experimental research bioreactor EDF-5.4_2 manufactured by *Biotehniskais centrs*, Latvia was used. The aforementioned bioreactor has a compact, ergonomic and robust design fully customized for experimental research on biomethane production. Glass cylinder vessel is mounted between the upper lid and the metallic jacketed bottom. The design of the bioreactor is easy to maintain and apply basic operations and preparatory process, in particular, washing and autoclaving.

Gas mixing has been done using mass flow controllers *Hamilton* ARC pH and DO sensors. These sensors send 4-20 mA signals directly to process control system (PCS) and ensure at the same time information management via Bluetooth in smartphones or PC installed programs. This program generates a report about all calibration procedures, sterilization numbers, predicted service life. The sensors for identification and volumetric estimation of O_2, CO_2, CH_4 .are connected to PCS for off-gas analysis.

On-line/off-line data analysis and advanced process control possibilities were performed using PC implemented program (Matlab, Python) algorithms communicating to process control system (PCS and SCADA).

C. Determination of sludge and reed moisture

The sludge substance was mixed in a container with a metal spatula so that the moisture in the substrate was evenly distributed. Pieces of roots and other plant remains were removed from sludge by tweezers. A 10 g sample of substrate was weighed. The sample was placed in a humidity analyzer HB43-S with a drying temperature 105±2°C [14]. The moisture content of the substrate was determined and a dry residue was obtained. The moisture of 3 samples was determined for the accuracy of one study. The resulting dry residue was further used to determine the OMC. Similar procedures were done by the reed.

D. Determination of sludge and reed organic matter content

The empty crucibles were placed in a muffle furnace where they were heated to 550±10°C for at least 60 minutes. Then the crucibles were removed from furnace and placed on a heat-resistant surface for 5-10 minutes, subsequently after a while the crucibles were left to cool in a desiccator. The cooled crucible was weighed to the nearest 0.1 mg on an analytical balance and weigh 1 to 2 g of the test sample was put into the crucible. The test sample was heated in a muffle furnace for two hours at 800±10°C; after that placed in a cool desiccator. This procedure of heating and weighing was repeated to constant weight. The organic matter content was calculated as a percentage of the dry residue [15]. Similar procedures were done by the reed.

E. Preparation of the mixture for biogas production

The experiment was repeated three times. To the prepared 1,200 g of aquaculture sludge was added 50 g, 100 g, and 150 g of crushed reed powder and mixed thoroughly. The prepared mixture was thoroughly immersed in the reactor vessel and 300 mL of bog water was added, mixed thoroughly with a metal spatula. 1,000 g of digestat was added and then firmly sealed with a bioreactor lid. The appropriate temperature mode and agitator rotation speed are selected and connected to the bioprocess controller.

F. Selected parametrs of the bioprocess controller

The following were used in the bioprocess controller to perform the work:

- 40°C temperature mode;
- Agitator rotation speed interval 50 rpm;
- Foam level sensors.

A computer with SCADA software was connected to the bioreactor, which recorded the volume and composition analysis of the released biogas.

III. RESULTS AND DISCUSSION

A. Determination of sludge and reed moisture and organic matter content

The obtained moisture results of sludge samples are valid for biogas production, as the dry residue in substrate samples is about 15% (see Tab. 1). The results are in line with the type of wet fermentation, which is similar to the other potential biogas technology [16].

TABLE 1 SLUDGE AND REED MOISTURE AND ORGANIC MATTER CONTENT

Biomass	Moisture, %	Organic matter content (from dry matter), %
Sludge	85.63±0.32	29.49±0.92
Reed	0.99±0.17	95.88±1.16

The amount of organic matter obtained from sludge samples is about 29%, which indicates a high content of inorganic substances in the substrate. In order to obtain more biogas yield in the study, a relatively larger amount of aquaculture sludge must be placed into the bioreactor, with the addition of another type of substrate in which the percentage of organic matter is about 90% or more.

The amount of organic matter obtained from reed samples is about 96%, which indicates a high content of organic matter, so it is advantageous to add it to the fish-farming pool sludge in a certain ratio. For experimental research the three mixtures were used to produce biogas.

B. Biogas production

During each experiment, the released volume of biogas and the gas composition in the obtained biogas were studied with the research software SCADA (Supervisory control and data acquisition).

The Fig. 1, Fig. 2, and Fig. 3 shows the trend in biogas volume release over 60 days at added reed 50 g, 100 g, and 150 g respectively.

Of the total biogas produced during the fermentation period (60 days), 95% was produced within the period from the 10th to the 55th day. This regularity was observed for all three types of sludge and reed proportions (see Fig. 1-3). The optimal retention time is about 33 and 35 days at added reed 50 g, 36 days at added reed 100 g, and 35-36 days for at added reed 150 g.

The total volume of biogas, produced during the fermentation period, is about 2.84 liters from sample with added reed 50 g, 3.81 liters from sample with added reed 100 g, and 3.28 liters from sample with added reed 150 g (see Fig. 1-3).

The Fig. 1, Fig. 2, and Fig. 3 shows the trend in biogas volume release over 60 days at added reed 50 g, 100 g, and 150 g respectively.

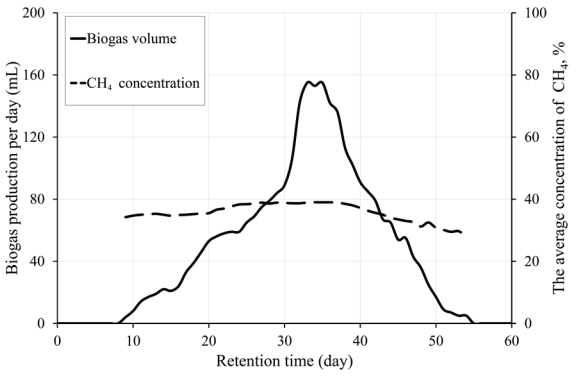

Fig. 1. Trend in biogas volume and proportion of methane in biogas release over 60 days at added reed 50 g.

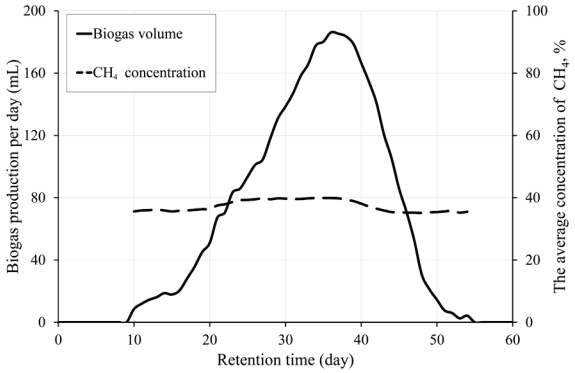

Fig. 2. Trend in biogas volume and proportion of methane in biogas release over 60 days at added reed 100 g.

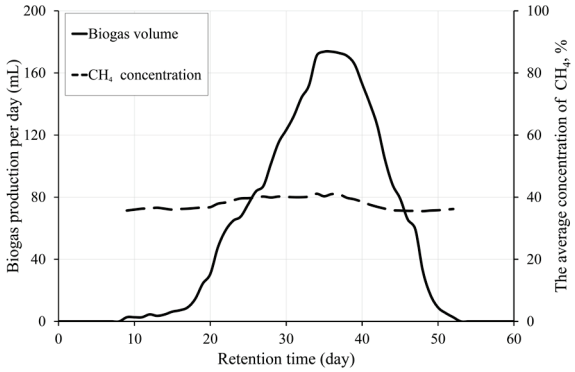

Fig. 3. Trend in biogas volume and proportion of methane in biogas release over 60 days at added reed 150 g.

The average concentration of methane in biogas is 35.6%, carbon dioxide is 63.3%, other gases are 1.1% from the sample with added 50 g of reed, methane is 37.3%, carbon dioxide is 61.8%, other gases are 0.9% from the sample with added 100 g of reed, and methane 37.8%, carbon dioxide – 61.0%, other gases 1.2% from the sample with added 150 g of reed (see Fig. 1-3).

IV. Conclusions

The studies of biogas yield during the bio-fermentation process depending on the effect of the proportion of biomass components – sludge and reed indicate that the result was not so unambiguous.

During the experiments, 2.84 liters of biogas were obtained from a mixture of aquaculture sludge and crushed reed at added reed 50 g, 3.81 liters at added reed 100 g, and 3.28 liters at added reed 150 g. From this, we cannot conclude that if the organic matter content in sludge is higher, the biogas yield would increase during the process.

However, the proportion of methane in biogas increased during the fermentation process, if the organic matter content in sludge were higher.

Accordingly, it is difficult to decide which ratio of sludge and reed in biomass is optimal – on the one hand adding 100 g of reed to the aquaculture sludge resulted in a larger volume of biogas, on another hand – adding 150 g of reed to the aquaculture sludge resulted in the highest percentage of methane in biogas. Hence it highlights the necessity of further research.

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REFERENCES

[1] S. Achinas, V. Achinas and G. J. W. Euverink, "A Technological Overview of Biogas Production from Biowaste" *Engineering*, vol. 79, pp. 299-307, June 2017. Available: ScienceDirect, https://www.sciencedirect.com/ [Accessed March 30, 2021], https://doi.org/10.1016/J.ENG.2017.03.002

[2] K. Paritosh, S. K. Kushwaha, M. Yadav, N. Pareek, A. Chawade and V. Vivekanand, "Food Waste to Energy: An Overview of Sustainable Approaches for Food Waste Management and Nutrient Recycling" *BioMed Research International*, vol. 2017, pp. 1-19, February 2017. Available: Hindawi, https://www.hindawi.com/ [Accessed March 30, 2021], https://doi.org/10.1155/2017/2370927

[3] A. Ahmad, S. R. S. Abdullah, H. A. Hasan, A. R. Othman and N. I. Ismail, "Aquaculture industry: Supply and demand, best practices, effluent and its current issues and treatment technology" *Journal of Environmental Management*, vol. 287, 112271, June 2021. Available: ScienceDirect, https://www.sciencedirect.com/ [Accessed March 30, 2021], https://doi.org/10.1016/j.jenvman.2021.112271

[4] "Latvijas ilgtspējīgas attīstības stratēģija līdz 2030. gadam", 2010. [Online]. Available: https://www.pkc.gov.lv/sites/default/files/inline-files/Latvija_2030_6.pdf [Accessed: March 30, 2021].

[5] D. Blumberga, L. Balode, K. Bumbiere, Z. Indzere, E.Kudurs, K. Spalviņš, A. Vēciņa and A. Tamane, "Zivju apstrādes efektivitātes ceļvedis". Rīga: RTU Izdevniecība, 2021.

[6] "Biogāzes ražošanas attīstības iespējas Cēsu, Daugavpils, Jēkabpils, Madonas, Gulbenes un Valkas rajonos: atskaites ziņojums", 2008. [Online]. Available: http://petijumi.mk.gov.lv/sites/default/files/file/RAPLM_Biogazes_razosanas_iespejas.doc [Accessed: March 30, 2021].

[7] C. E. Manyi-Loh, S. N. Mamphweli, E. L. Meyer, A. I. Okoh, G. Makaka and M. Simon, "Microbial Anaerobic Digestion (Bio-Digesters) as an Approach to the Decontamination of Animal Wastes in Pollution Control and the Generation of Renewable Energy" *International journal of environmental research and public health*, vol. 10, pp. 4390-4417, September 2013. Available: MDPI, https://www.mdpi.com/ [Accessed March 30, 2021], https://doi.org/10.3390/ijerph10094390

[8] C. Zhang, H. Su, J. Baeyens and T. Tan, "Reviewing the anaerobic digestion of food waste for biogas production" *Renewable and Sustainable Energy* Reviews, vol. 38, pp. 383-392, October 2014. Available: ScienceDirect, https://www.sciencedirect.com/ [Accessed March 30, 2021], https://doi.org/10.1016/j.rser.2014.05.038

[9] K. Zhou, S. Chaemchuen and F. Verpoort, "Alternative materials in technologies for Biogas upgrading via CO_2 capture" *Renewable and Sustainable Energy Reviews*, vol. 79, pp. 1414-1441, November 2017. Available: ScienceDirect, https://www.sciencedirect.com/ [Accessed March 30, 2021], https://doi.org/10.1016/j.rser.2017.05.198

[10] K. Hagos, J. Zong, D. Li, C. Liu and X. Lu, "Anaerobic co-digestion process for biogas production: Progress, challenges and perspectives" *Renewable and Sustainable Energy Reviews*, vol. 76, pp. 1485-1496, September 2017. Available: ScienceDirect, https://www.sciencedirect.com/ [Accessed March 30, 2021], https://doi.org/10.1016/j.rser.2016.11.184

[11] M. Zhou, B. Yan, J. W. C. Wong and Y. Zhang, "Enhanced volatile fatty acids production from anaerobic fermentation of food waste:

A mini-review focusing on acidogenic metabolic pathways" *Bioresource Technology*, vol. 248 (Part A), pp. 68-78, January 2018. Available: ScienceDirect, https://www.sciencedirect.com/ [Accessed March 30, 2021], https://doi.org/10.1016/j.biortech.2017.06.121

[12] M. Westerholm, S. Isaksson, O. K. Lindsjö and A. Schnürer, "Microbial community adaptability to altered temperature conditions determines the potential for process optimisation in biogas production" *Applied Energy*, vol. 226, pp. 838-848, September 2018. Available: ScienceDirect, https://www.sciencedirect.com/ [Accessed March 30, 2021], https://doi.org/10.1016/j.apenergy.2018.06.045

[13] J. N. Meegoda, B. Li, K. Patel and L. B. Wang, "A Review of the Processes, Parameters, and Optimization of Anaerobic Digestion" *International journal of environmental research and public health*, vol. 15, 2224, October 2018. Available: MDPI, https://www.mdpi.com/ [Accessed March 30, 2021], https://doi.org/10.3390/ijerph15102224

[14] S. K. Pramanik, F. B. Suja, S.M. Zain and B.K. Pramanik, "The anaerobic digestion process of biogas production from food waste: Prospects and constraints" *Bioresource Technology Reports*, vol. 8, 100310, December 2019. Available: ScienceDirect, https://www.sciencedirect.com/ [Accessed: March 30, 2021], https://doi.org/10.1016/j.biteb.2019.100310

[15] S. Achinas and G. J. W. Euverink, "Theoretical analysis of biogas potential prediction from agricultural waste" *Resource-Efficient Technologies*, vol. 2, pp. 143-147, September 2016. Available: ScienceDirect, https://www.sciencedirect.com/ [Accessed: March 30, 2021], https://doi.org/10.1016/j.reffit.2016.08.001

[16] J. Kainthola, A. S. Kalamdhad and V. V. Goud, "A review on enhanced biogas production from anaerobic digestion of lignocellulosic biomass by different enhancement techniques" *Process Biochemistry*, vol. 84, pp. 81-90, September 2019. Available: ScienceDirect, https://www.sciencedirect.com/ [Accessed: March 30, 2021], https://doi.org/10.1016/j.procbio.2019.05.023

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Number of fine Particles' and their Mass Concentration: Comparison of Emission of New Printing Technology Versus Traditional Laser Technology

Linda Paegle
Rīga Stradiņš University
Institute of Occupational Safety and Environmental Health
Riga, Latvia
Linda.Paegle@rsu.lv

Žanna Martinsone
Rīga Stradiņš University
Institute of Occupational Safety and Environmental Health
Riga, Latvia
Zanna.Martinsone@rsu.lv

Ivars Vanadziņš
Rīga Stradiņš University
Institute of Occupational Safety and Environmental Health
Riga, Latvia
Ivars.Vanadzins@rsu.lv

Ilona Pavlovska
Rīga Stradiņš University
Institute of Occupational Safety and Environmental Health
Riga, Latvia
Ilona.Pavlovska@rsu.lv

Lāsma Akūlova
Rīga Stradiņš University
Institute of Occupational Safety and Environmental Health
Riga, Latvia
Lasma.Akulova@rsu.lv

***Abstract* - For many years the printers have been essential part of our offices and exposures from various printing technologies have been widely researched. The main objective of this study was to compare emitted number and mass of fine particles from laser printers and new Micro Piezo technology ink jet printers during the printing process and one hour afterwards as these emissions have potential for negative health effects.**

Air samples were taken with the particle size spectrometer for real-time ELPI+, Dekati (air flow rate 10 l/min). Measurements were taken ~0.5 m from the printers: one hour before the test, during printing and one hour afterwards. Similar class black&white (b/w) and colour printer of each technology were tested. Each printer performed a 10-page and a 100-page test according to ECMA 328-1 Standard [1].

During laser printer tests from 8324 to 19943 pt/cm^3 fine particles were determined on printing phase from b/w and colour printers. Ink jet (Micro Piezo) printers produced less: from 3239 to 5247 pt/cm^3. One hour after the printing phase for both types of laser printers' there were 54722 to 152351 pt/cm^3 particles in air and 4270 to 9579 pt/cm^3 particles for ink jet printers. Detected particle mass differences was insignificant: in range of 0.002 to 0.012 mg/m^3 for laser printers and 0.002 to 0.019 mg/m^3 for ink jet printers. Micro Piezo technology printers emitted mass particles were with bigger median size µm.

The highest number of particles was observed one hour after the printing for both tested printer technologies. Laser printers' emitted 2.5 to 3.8 times more particles in printing phase and 12.8 to 15.9 times more after printing phase. Particle mass in mg/m^3 was detected in the size range 6nm - 2.5 µm with no significant mass differences.

Keywords* - *emission, exposure, indoor air quality, laser printer, ink printer, Micro Piezo, particulate matter.

I. INTRODUCTION

Nowadays large proportion of people spend their daily lives, whether at home, in an educational establishment or at work, indoors [2]. In some countries, up to even 90% of everyday life is spent indoors [3]. Since 1991, indoor air quality has deteriorated rapidly, leading to increased rates of illness and death [2].

Indoor air quality is also inseparable from the ambient air and environment: traffic and industrial pollution are often noticed to enter indoor areas through ventilation systems [4], [5], [6]. Indoor air quality is related to a number of indoor environmental factors, such as exposures from construction and furniture materials, as well as emissions during various processes that people do indoors (e.g. cooking, heating of houses etc.) [6], [7], [8].

Employees' complaints about poor air quality in offices are growing year by year due various reasons.

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First, traditional office spaces and other premises are no longer imaginable without various types of office equipment, printers being one of most wide spread source of pollution with various particles and chemicals [8], [9]. After first generation of dot matrix printers replaced largely by ink printers, laser printers are currently the most common type of printers due to their speed, low noise and fast printing capabilities [10].

The fact that laser printers emit various pollutants during their operation was discovered already more than 20 years ago [11]. The most common printer emissions are volatile organic compounds (VOCs) and ozone, but printers also emit large number of ultra fine particles [10]. Gradually, new technologies are being developed for consumers, among these namely, new generation of inkjet printers claiming to be considered as low-emission printers compared to similar speed laser printers. However, so far this technology is better known for printing on various materials and textiles and not so much as a competition to laser technology [12]. Last generation of these inkjet printers claim to be as fast and more economic than laser printers but little is know on their emissions.

This study compared the emitted particulate matter (PM) from laser and Micro Piezo ink jet black and white (b/w) and color printers.

II. MATERIALS AND METHODS

A. Test environment

The comparative testing of printers was chosen to be performed in a real work environment with real work tasks, but with partial control of external influencing parameters. The room in which the printers were located, as well as the room in which one of the measuring devices was located, was demarcated with the closed door with sealing. The presence of a person in printers room during the print tests was avoided and allowed only for technical assistance with the print test, such as restacking of paper, removing of paper jam and similar tasks. If technical problems took more than 5-10 minutes to resolve (such as running out of printer cartridge) the test was stopped and repeated the next day (including a full repetition of the test process and room preparation). Supply ventilation was left in the test room, monitoring before and after each measurement was made to ensure determination of the supply flow rate and measure possible background dust particles.

The total area of the test room was 23.5 m^3. Before each test, the walls, floor and horizontal surfaces of the room were cleaned and fresh air exchange was made the day before. There were two tables and one closed cupboard (approximately 5 years old) made from special laboratory grade laminate in the room during the test. Reflective window blinds were used for the windows to avoid changes in the room temperature. Measurements were performed in the period from June to July 2020, development of the research model and compilation of results from May to October 2020. The air temperature during the measurement period was: 23–26°C; relative humidity: 50-66%; atmospheric pressure: 746-760 mm Hg.

B. Test description

There were two types of tests performed on each printer model: a 10-page test and a 100-page print test. The printing process was started manually by supervising staff from a personal computer prepared and equipped for printing. Printers used standard print speed according to the program settings. Depending on the type of test (10 or 100 pages), there was a 1 minute break after the last page was printed. A total of 460-470 pages were printed during the 10-page test, and 1100-1200 pages during the 100-page test. The duration of one measurement was on average 60 - 90 minutes. The duration of the test were different, because according to the chosen methodology, the test was concluded when one of the conditions was met - the limit of 1200 pages was reached or 90 minutes had elapsed. The one side of the A4 sheet attached to the ECMA standard Annex A.2 file was printed. For both b/w and color printing, a sample of this standard with 20% coverage was used. Black and white printer tests required 20% page coverage for black color, but color printer - 5% page coverage for each of the 4 basic colors - black, magenta, cyan, yellow. For all tests, the manufacturer's Stora Enso paper Multicopy 80 g/m^3 A4 paper (Made in Sweden, labelled with "Totally Chlorine Free", Nordic Ecolabel" (3044 0044), "EU Ecolabet" (SE/011/01) and "Forest Stewardship Council" (FSC CO15932) was used.

C. Sample collection and analyze

Air samples were taken with the particle size spectrometer for real-time ELPI +, Dekati. The Elpi+ impactor classified particles on the so-called stages into 14 fractions by size in the range from 6 nm to 10 µm with a 9.87 lpm sample flow rate using an outlet/inlet pressure, 40 mbar, and 1 013.3 mbar, respectively. The data were saved every second. All ELPI+ measurement files were transferred to Excel spreadsheets for further calculations. The maximum uncertainty for this measuring device is 20% [13].

Measurements were performed at a distance of ~ 0.5 m from the printer under test and at a height of ~ 1 m from the floor. ELPI +, Dekati was placed in the adjacent room, inserting the sampling tube into the room through a specially created opening in the wall (see Fig.1).

Fig.1. Air sample collection.

Each test consisted of several stages:

- Room background particle pollution measurement. Only the air sample were taken, no people entered the room, the printer did not worked. Duration of the stage 60 minutes;
- Printing test. Printing of 10 or 100 pages was performed according to the already mentioned methodology. The supervisor entered the room only in case of extreme need (for example, the need to supplement the white pages or for the clearing of a paper jam). At the end of this test phase, there were an hour break when the room is closed, but no air sampling, printing or human entry is performed. Duration of the stage 60 - 90 minutes;
- One hour after the end of the print test. No printing is performed in the room, but an air sample is collected. Duration of the stage 60 minutes.

D. Tested printers

Four printers were selected by availability for testing. Two of them were b/w and two - colour. One pair (b/w and colour) belonged to the laser printer group according to the specification, and the other – represented new technology - ink printing (Micro Piezo). The selected printer models represented three manufacturers. Original cartridges from the manufacturers and their refills were used for printing. Printers were matched for their average print speed (see Table 1).

TABLE 1. TESTED PRINTERS PARAMETERS

Printer type	**Parameters**		
	Dimensions Width x Depth x Height), mm	***Weight, kg***	***Printing speed for A4, ppm***
B/w laser printer	400 x 376 x 263	11.2	33
B/w ink printer	375 x 347 x 302	6.4	20
Colour laser printer	825 x 915 x 948	40.8	31
Colour ink printer	425 x 535 x 357	18.7	24

III. RESULTS AND DISCUSSION

When testing particles emitted from printers, either a special camera is used, or the test is performed in a particularly unaffected office environment. Each method has its strengths and limitations. In-chamber experiments are usually performed in a well-controlled environment, reducing the background concentration of particles; however, the size, material, air exchange rate, and other characteristics of the chamber differ from the actual work environment. On the other hand,
measurements in, for example, office cover the concentration of particles in the real world, but face the challenge that other indoor pollutants or factors may also have an impact on the measurement results. At present, determination of the values of nanoparticles emitted from office equipment and assessing the impact on health is especially important as there is growing evidence of effects from poor indoor air to health [14].

The effects on human health are different depending from different sizes of particles. Particles larger than 100 μm can cause eye and nasal mucosal irritation. Dust particles smaller than 100 μm form so called fraction of respirable (inhalable) dust; they enter the upper respiratory tract. Particles smaller than 20 μm are part of the thoracic dust fraction, while particles smaller than 10 μm enter deep airways and often precipitate there. Respirable dusts with a particle size of less than 5 μm are the most dangerous to human health, as most of them reach the alveoli as well as the gastrointestinal tract. Ultramicroscopic dust particles can be exhaled again if they do not dissolve and are not rapidly absorbed. Nanoparticles (less than 0.1 μm (or 100 nm)) are able to pass through cell membranes [15].

The number of particles released, their mass, as well as their composition and even diameter, surface area and shape are important and might affect health of workers. The typical size range of particles emitted from printers is 2 - 30 μm, they are influenced by the design, technical parameters and technology of the printer, as well as the paper used for printing [14].

A. B/w printer test comparison

Comparing the tested b/w laser and ink jet (Micro Piezo) printers of different models, it can be seen that the number of detected particles pt /cm^3 (detection range: 6 nm - 10µm) is significantly lower for ink jet printers. Here and in the other results the tendency for the number of particles to be higher not during the printing test, but after it was observed. It could be caused by the condensation processes of the aerosol particles, as well as the fact that the test was performed indoors instead of in a test chamber where emitted particles are perceived faster [14], [16]. Comparing the 10-page test for both types of b/w printer models, laser printer detected four times more particles during the print test and more than 16 times after the test. Similar results were observed during the 100-page test: during the test, the number of particles emitted by the b/w laser printer was 2 times higher, but one hour after the test - even 35 times higher than from b/w ink printer (see Table 2). The detected particles were up to 2.5 µm in size. No particles in the size range of 2.5-10 µm was detected during the tests.

TABLE 2. B/W PRINTER COMPARISON

		B/w laser printer 10 page test, pt/cm^3		**B/w laser printer 100 page test, pt/cm^3**		**B/w ink printer 10 page test, pt/cm^3**		**B/w ink printer 100 page test, pt/cm^3**	
Chanel	**Diameter / size**	**Printing test**	**1 hour after**	**Printing test**	**1 hour after**	**Printing test**	**1 hour after**	**Printing test**	**1 hour after**
1	0,01	9413	83659	5772	105582	0	4507	2860	3238
2	0,02	934	17685	946	17523	1481	749	456	205
3	0,04	1286	10379	870	17259	721	741	442	344
4	0,07	870	3537	926	8128	531	669	254	247
5	0,12	778	1458	531	3171	266	267	119	129
6	0,20	234	312	161	688	145	110	64	73
7	0,31	102	41	69	0	95	52	49	28
8	0,48	12	0	18	0	41	16	2	4
9	0,76	0	0	1	0	0	1	0	2
10	1,25	0	0	0	0	3	0	1	0
11	2,02	0	0	0	0	1	0	0	0
12	3,02	0	0	0	0	0	0	0	0
13	4,45	0	0	0	0	0	0	0	0
14	7,31	0	0	0	0	0	0	0	0
Total number		**13630**	**117071**	**9294**	**152351**	**3285**	**7112**	**4250**	**4270**

B. Color printer test comparison

Color printer technology comparison tests show the same trends - the highest peak of the results was observed one hour after the end of the printing process. The color laser printer detected a higher number of particles during the printing process: 6 times more in the 10-sheet and almost 2 times more in the 100-sheet compared to the color ink jet (Micro Piezo) printer during the printing process. The measurement also shows a higher number of detected particles one hour after printing for the color laser printer manufacturer's model, reaching almost 6 times the specified number of particles during the 10-page test and 14 times the 100-page one hour after test. Particles detected by the color printers are up to 2.5 µm in size (see Table 3).

TABLE 3. COLOUR PRINTER COMPARISON

		Colour laser printer 10 page test, pt/cm³		**Colour laser printer 100 page test, pt/cm³**		**Colour ink printer 10 page test, pt/cm³**		**Colour ink printer 100 page test, pt/cm³**	
Chanel	**Diameter / size**	**Printing test**	**1 hour after**	**Printing test**	**1 hour after**	**Printing test**	**1 hour after**	**Printing test**	**1 hour after**
1	0,01	10867	25793	6554	36152	1281	5994	1953	5904
2	0,02	4940	16364	0	33917	795	947	1454	1099
3	0,04	1681	8780	883	32616	487	1332	836	581
4	0,07	749	2369	345	14033	253	649	503	504
5	0,12	875	789	281	5042	223	400	308	224
6	0,20	425	365	170	840	120	184	121	108
7	0,31	301	199	66	245	68	65	59	39
8	0,48	103	63	26	49	9	7	12	7
9	0,76	2	0	1	0	0	0	0	0
10	1,25	0	0	0	0	1	0	1	0
11	2,02	0	0	0	0	2	1	0	0
12	3,02	0	0	0	0	0	0	0	0
13	4,45	0	0	0	0	0	0	0	0
14	7,31	0	0	0	0	0	0	0	0
Total number		**19943**	**54722**	**8324**	**122895**	**3239**	**9579**	**5247**	**8465**

C.. Detected mass comparison

Analyzing the mass of the detected particles (mg/m³) in the 10 and 100 page tests at different periods (during the test and one hour after the test), it can be seen that the data obtained did not show important differences and significant concentrations. Detected particle mass from laser printers was from 0.005 to 0.019 mg/m³, but ink jet - 0.002 to 0.012 mg/m³. A more important indicator of this type of comparative test for the assessment of human health effects is the number of particles already described above and particle median size (see Table 4). Median size of particles emitted by laser printers was from 0.116 to 0.539 µm but for ink jet – 0.990 to 5.267 µm. The mass values set for both types of printers were similar, the particles produced by the ink jet were larger in size, which has less of impact on human health.

TABLE 4. EMITTED MASS COMPARISON

	10 page test		**After 10 page test**		**100 page test**		**After 100 page test**	
Printer type	**Mass, mg/m³**	**Median size, µm**	**Mass, mg/m³**	**Median size, µm**	**Mass, mg/m³**	**Median size, µm**	**Mass, mg/m³**	**Median size, µm**
B/w laser printer	0,005	0.280	0,005	0.130	0,006	0,529	0,008	0,116
B/w ink printer	0,012	2,240	0,003	0,990	0,003	1,754	0,002	5,267
Colour laser printer	0,014	0,340	0,010	0,270	0,005	0,539	0,019	0,171
Colour ink printer	0,011	1,250	0,007	1,111	0,004	1,425	0,002	4,710

IV. CONCLUSIONS

In general, the comparative tests for printers between the b/w printers of different manufacturers, showed that lower number of particles in pt/cm^3 (range of detection: 6 nm - 10 µm but not more than 2,5 µm) was emitted from ink jet (Micro Piezo) printer. According to the data found in the scientific literature, a large part of research and printer tests have been performed in special test chambers with controlled and constant environmental conditions [17].

In a semi-controlled office space test in Australia, the average particle number achieved during printing was 18,060 pt/cm^3 (but no post-printing measures were made). Also in a comparative test of different models of printers in Germany, the median number of particles per cm^3 was around 18,000 (with a peak value of 190,000 pt/cm^3). According to other researchers, the number of captured particles during printing ranges from 12,000 pt/cm^3 (with a peak value of 99,000 pt/cm^3) to 26,000 pt/cm^3. Particle measurements after printing and pt/cm^3 of the number of particles detected during printing are not emphasized [17].

The results obtained and summarized are indicative and applicable to the environmental parameters of the day and only to the printer of the tested model that were used for testing. Generalization of results requires longer tests with multiple iterations and comparisons between single-series printer models. However, this study shows clear tendency that modern inkjet technologies (e.g. Micro Piezo) shows potential for lover exposures to particles in office air.

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REFERENCES

[1] ECMA Inernational "Determination of chemical emission rates from electronic equipment - Part 1 (using-consumables)," 9th edition (December 2018) - Part 1 (using-consumables).

[2] H. Ritchie and M. Roser "Indoor Air Pollution," revised 2019 [online] Available: https://ourworldindata.org/indoor-air-pollution#annual-deaths-from-indoor-air-pollution-have-declined-globally-by-more-than-1-million-since-1990

[3] J. Sundell "On the history of indoor air quality and health," Indoor Air, 14 (7), pp. 51–58, 2004.

[4] M. Ścibor, B. Balcerzak, A. Galbarczy, T. Targosz and G. Jasienska. "Are we safe inside? Indoor air quality in relation to outdoor concentration of PM10 and PM2.5 and to characteristics of homes," Sustainable Cities and Society, 48, 2019. https://doi.org/10.1016/j.scs.2019.101537

[5] Q. Y. Meng, B. J. Turpin, L. Korn, C. P. Weisel, M. Morandi et all "Influence of ambient (outdoor) sources on residential indoor and personal PM2.5 concentrations: Analyses of RIOPA data," Journal of Exposure Science & Environmental Epidemiology, 15, pp. 17-28, 2005.

[6] A. Cincinelli and T. Martellini "Indoor Air Quality and Health," International Journal of Environmental Research and Public Health, 14, 2017. https://doi:10.3390/ijerph14111286

[7] A. P. Jones "Indoor air quality and health," Atmospheric Environment, 33(28), pp. 4535-4564, 1999. https://doi.org/10.1016/S1352-2310(99)00272-1

[8] The WHO European Centre for Environment and Health, "WHO guidelines for indoor air quality: selected pollutants," 2010.

[9] C. He, L. Morawska and L. Taplin "Particle Emission Characteristics of Office Printers," Environmental Science & Technology, 41(17), pp. 6039–6045, 2007. https://doi.org/10.1021/es063049z

[10] Z. M. Wang, J. Wagner and S. Wall "Characterization of Laser Printer Nanoparticle and VOC Emissions, Formation Mechanisms, and Strategies to Reduce Airborne Exposures," Aerosol Science and Technology, 45(9), 2011. https://doi.org/10.1080/02786826.2011.580799

[11] C. He, L. Morawska, H. Wang, R. Jayaratne, P. McGarry et all. "Quantification of the relationship between fuser roller temperature and laser printer emissions," Journal of Aerosol Science, 41(6), 2010. https://doi.org/10.1016/j.jaerosci.2010.02.015

[12] O. Motonori and T. Tomoaki "Novel Micro Piezo Technology for Ink Jet Printhead," International Conference on Digital Printing Technologies, pp. 314-318, 2007.

[13] I. Pavlovska, Ž. Martinsone, I. Vanadziņš, I. Mārtiņsone, A. Seile and P. Sudmalis "Occupational exposure parameters for characterization of nanoparticulate matter toxicity: Metal versus wood processing," Process Safety and Environmental Protection, 102, pp.230-237, 2016. https://doi.org/10.1016/j.psep.2016.03.018

[14] J. G. Jianwei, S. Karrasch, T. Salthammer "Review of the characteristics and possible health effects of particles emitted from laser printing devices," Indoor Air, 30, pp. 396 – 421, 2020. https://doi.org/10.1111/ina.12646

[15] M. Eglīte "Occupational Medicine," Riga: Rīga Stradiņš University, 2012.

[16] E.Uhde, C. He, M. Wensing "Characterization of Ultra-fine Particle Emissions from a Laser Printer," Proceedings of Healthy Buildings, 2006.

[17] T. Tang, J. Hurraß, R. Gminski and V. Mersch-Sundermann "Fine and ultrafine particles emitted from laser printers as indoor air contaminants in German offices," Environmental Science and Pollution Research, 19(9), 2012. doi:10.1007/s11356-011-0647-5

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Productivity of Different Soybean Cultivars Depending on Meteorological Conditions and Growing Manner in Latgale 2018–2020

Kintija Pekša
Institute of Agricultural Resources and Economics
Viļāni, Latvija
kintija.peksa@arei.lv

Sanita Zute
Institute of Agricultural Resources and Economics
Stende, Latvija
sanita.zute@arei.lv

Aldis Stramkalis
Institute of Agricultural Resources and Economics
Agriculture Science Centre of Latgale
Viļāni, Latvija
aldis.stramkalis@arei.lv

Veneranda Stramkale
Institute of Agricultural Resources and Economics
Agriculture Science Centre of Latgale
Viļāni, Latvija
veneranda.stramkale@arei.lv

Arnis Justs
Institute of Agricultural Resources and Economics
Agriculture Science Centre of Latgale
Viļāni, Latvija
arnis.justs@arei.lv

***Abstract* - In recent decades in Latvia and other European countries increased interest about growing protein-rich crops and especially soybeans (*Glycine max*). Although soybean cultivation experiments in Latvia have been carried out for some time, there is still insufficient knowledge about cultivating these plants in the country's climatic conditions. A field trials was carried out in 2018, 2019 and 2020 in the Latgale Agricultural Science Centre. The effect of three factors (A: soybean cultivar (A1 — 'Lajma', A2 — 'Laulema', A3 — 'Merlin', A4 — 'Tiguan', A5 — 'Paradis', A6 — 'Touttis'); B: sowing rate (B1 — 40, B2 — 50, B3 — 60 germinable seeds per 1 m^2); C: row spacing (C1 — 12.5 cm, C2 — 25 cm) on the development and yield formation of soybean was examined. The experiment was carried out in the framework of the project 'New technologies and economically viable solutions for the production of local feed for pig production: cultivation of not genetically modified soybean and new feed barley varieties in Latvia'. The soybean seed yield was significantly affected by the cultivar ($p < 0.001$) and the sowing rate ($p < 0.01$) in all study years, as well as the meteorological conditions in the specific year affected the yield significantly ($p = 0.012$). In 2018 and 2020, more productive was the cultivar 'Merlin' (3.77 t ha^{-1} and 3.18 t ha^{-1} respectively), but in 2019 the most productive cultivar was 'Paradis' (2.55 t ha^{-1}). Although meteorological conditions during the growing season have a greater impact on the formation of the soybean yield, if it is cool and humid, the soybean vegetation period can be significantly extended, which hinders its ripening and makes harvesting more difficult. Therefore, it is very important to look for earlier cultivars to avoid farming risks.**
Keywords - growing conditions, varieties, Latvia, yield.

INTRODUCTION

Soybean (*Glycine max*) is an important crop, and interest in its importance in a healthy diet is growing every year. Currently, the largest soybean growers are in the United States, South America and China [2]. Attempts to grow soybean in Latvia had already been implemented in the 20th century. The first serious research aimed at supplementing the range of protein-rich plants in Latvia was carried out in the 1980s. [8] Soybeans are considered a warm climate crop, but due to climate change, it could become a valuable crop due to its high protein content. Soybean is one of the most valuable crops in the world as multipurpose crop, as it is also an important source of protein, fibre and fat as well as a feedstock for biofuels [7] Soybean growing areas in the world from 2010 to 2018 have increased from 102.7 million ha, up to 124.9 million ha [4] The area of soybean sowings in Latvia in 2015 was 93.18 ha, but in 2017 it already was 200 ha, but in 2020 it was already 286 ha [1]

Due to climate change and purposeful selection of early, cold-resistant soybean cultivars, soybean cultivation may also become a perspective in the Baltic region [11] The

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growing season of the earlier soybean cultivars lasts 130–140 days, and the rate of soybean development depends to a large extent on air temperature. Soybean is a thermophilic plant, and for its successful cultivation during the growing season the sum of the effective temperature (temperature above +10 °C) must be at least 2000 °C [6] The earliest cultivars are also suitable for cultivation in regions with a lower amount of effective temperatures, and could be perspective for Latvia's conditions. The suitability of cultivars for soybean yield in a particular region depends on their plasticity with changing temperature, as well as reactions to the length of the day at different stages of plant development.

research was carried out in the framework of the project 'New technologies and economically viable solutions for the production of local feed for pig production: cultivation of not genetically modified soybean and new feed barley cultivars in Latvia'.

MATERIALS AND METHODS

A field trials was set up in 2018, 2019 and 2020 in the Latgale Agricultural Science Centre. The effect of three factors (A: soybean cultivar (A1 — 'Lajma', A2 — 'Laulema', A3 — 'Merlin', A4 — 'Tiguan', A5 — 'Paradis', A6 — 'Touttis'); B: sowing rate (B1 — 40, B2 — 50, B3 — 60 germinable seeds per 1 m^2); C: row spacing (C1 — 12.5 cm, C2 — 25 cm) on the development and yield formation of soybean was examined. The experiment was carried out in the framework of the project 'New technologies and economically viable solutions for the production of local feed for pig production: cultivation of not genetically modified soybean and new feed barley cultivars in Latvia'. There was sod podzolized loam (Sm) soil. According to the results of soil analyses performed by State Plant Protection Service of Latvia the soil reaction in 2018 pH KCl was 6.6, organic matter content — 4.1 %, easy K_2O content for plants — 112 mg kg^{-1}, P_2O_5 — 83 mg kg^{-1}, Ca — 223.8 mg kg^{-1}, Mg — 673 mg kg^{-1} and S — < 0.79 mg kg^{-1} and soil reaction in 2019 pH KCl was 6.5, content of organic matter — 2.6%, content of easily usable K_2O for plants — 104 mg kg^{-1}, P_2O_5 — 56 mg kg^{-1}, Ca — 1539 mg kg^{-1}, Mg — 523 mg kg^{-1} and S — <5.9 mg kg^{-1}. Soil reaction in 2020 pH KCl was 6.1, content of organic matter — 3.5%, content of easily usable K_2O for plants — 94 mg kg^{-1}, P_2O_5 — 51 mg kg^{-1}, Ca — 2113 mg kg^{-1}, Mg — 315 mg kg^{-1}.

Meteorological conditions in the 2018 (Fig. 1, 2)**.** In Viļāni, vegetation resumed in the second decade of April. Spring started rapidly in April, the average daily air temperature was 4.3 °C (and the total precipitation was 27.5 mm. The average air temperature in June was 15.6 °C, which is 0.8 °C higher than the norm, but the precipitation in June was 42.3 mm, which was 56.4% of the norm. The average air temperature in July was 19.2 °C, which is 2.3 °C higher than normal. The hottest time was in the 2nd and 3rd decades of July, but the amount of precipitation in July was 35.4 mm, In Viļāni, the average air temperature in August was 18.0 °C, which is 2.5 °C higher than normal. The hottest weather was in the 1st decade of August. Precipitation in August was 93.0 mm, which was 131.0 % of the norm. Precipitation in September was 29.4 mm, which was 47.4% of the norm. The dry weather was favourable for the harvest.

Meteorological conditions of the 2019 (Fig. 1, 2). In Viļāni, vegetation resumed in the first decade of April. From 9 to 16 April, when the daily average temperatures dropped below 5 °C, the active vegetation stopped and resumed on 17 April. The total amount of precipitation in Latvia in the spring was 100.5 mm, which is 18 % below the seasonal norm (122.7 mm). In Viļāni, the amount of precipitation in March was 31.1 mm, but in April there was no precipitation at all. On average in Latvia, the meteorological spring of 2019 lasted 98 days. June 2019, with an average air temperature of 18.6 °C became the warmest June in the history of observations. In August, the average air temperature was 17.0 °C. In Viļāni, the average air temperature in June was 18.9 °C July was cool, 1.6 ° C below normal, but August 0.3 °C warmer than normal.

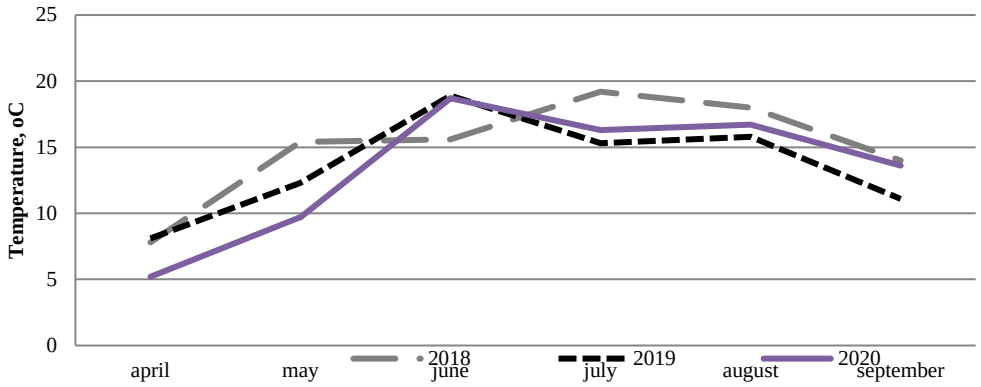

Figure 1 Temperature curves in all years of the study

Meteorogical conditions of the 2020 (Fig. 1, 2). In Viļāni, vegetation resumed in the first decade of April. The precipitation in April was lower than usually, but in may it was significantly higher than usually (84.7 mm), but in other vegetation period it was lower than usually. In April and may temperature a little lower than norm, in June it was significantly higher (18.7 °C) than norm, but in august and September temperature was little higher than norm.

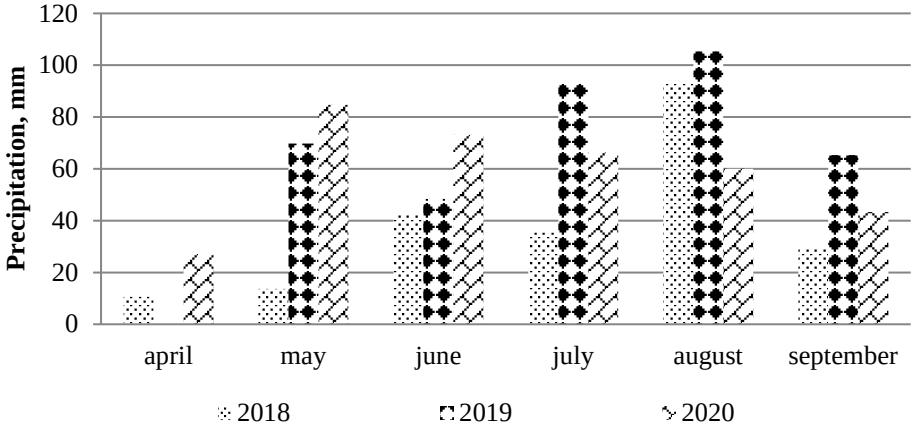

Figure 2 Precipitation in all years of the study

RESULTS

The most productive soybean cultivars was 'Merlin' in 2018 (3.68 t $ha^{-1}$and 2.80 t ha^{-1} accordingly) and 'Paradis' (1.68 t ha^{-1}). Pod formation, which is important for soybean productivity, took place in August and September. Significant impact on soybean seed yield in 2018 was for cultivar ($p < 0.001$) and sowing rate ($p < 0.001$), but the effect of row spacing was not significant in any of the experimental years. At a sowing rate of 60 germinating seeds per m^2, the yield was significantly higher in all trial years (Table 1). There was a tendency — the more plants per 1 m^2, the higher the yield.

There was no significant effect of row spacing, but still slightly higher seed-yield was available in variants with row spacing of 12.5 cm. In 2018, more productive was the cultivar 'Merlin' — 3.77 t ha^{-1}, but in 2019, the situation was different and the most productive cultivar was 'Paradis' 2.55 t ha^{-1}, in 2020, like in 2018, the most productive cultivar was 'Merlin' (Table 1).

TABLE 1 SOYBEAN YIELD IN 2018–2020 DEPENDING ON CULTIVAR, ROW SPACING AND SOWING RATE

Factors	**Soybean yield, t ha^{-1}**		
	2018	2019	2020
Cultivar			
p-value	< 0.001	< 0.001	< 0.001
'Lajma'	2.79	1.18	1.94
'Laulema'	2.03	1.93	2.44
'Merlin'	3.68	0.66	2.80
'Tiguan'	2.98	1.10	2.36
'Paradis'	2.76	1.59	2.48
'Touttis'	3.11	0.65	2.18
Row spacing, cm			
p-value	0.179	0.726	0.114
12.5	2.44	1.56	2.35
25	2.38	1.54	2.02
Sowing rate germinable seeds per 1 m^2			
p-value	< 0.001	< 0.002	< 0.001
40	2.22	1.52	1.74
50	2.29	1.49	2.17
60	2.72	1.65	2.66

Plant density (number of plants per 1 m^2) was determined when most soybean plants were at least 5 cm long — 15 AE (development phase). With the row space 12.5 cm — for the cultivar 'Lajma' the plant density was

from 27 plants per 1 m^2 at sowing rate 40 germinating seeds per 1 m^2 up to 36 plants per 1 m^2 at sowing rate 60 germinating seeds per 1 m^2. The plant density of the cultivar 'Laulema' was 26 plants 1 m^2 at sowing rate 40 germinating seeds per 1 m^2 up to 31 plants 1 m^2 at sowing rate 60 germinating seeds per 1 m^2 (see Table 2). With row spacing 25 cm — for the cultivar 'Lajma' the plant density was from 38 plants per 1 m^2 at the sowing rate of 40 germinating seeds per 1 m^2 to 47 plants per 1 m^2 at the sowing rate of 60 germinating seeds per 1 m^2. The results for both cultivars in all years shows that plant density was higher in the row space — 25 cm and when the highest sowing rates were used.

TABLE 2 NUMBER OF PLANSTS AND FIELD GERMINATION DEPENDING ON ROW SPACING ANDSOWING RATE IN 2018–2020

Cultivar	Row spacing, cm	Sowing rate germinable seeds per 1 m^2	Field germination, %	Number of plants per 1 m^2	Field germination, %	Number of plants per 1 m^2	Field germination, %	Number of plants per 1 m^2
Year			**2018**		**2019**		**2020**	
'Lajma'	12.5	40	66	27	97	39	70	28
		50	63	32	98	49	56	28
		60	59	36	92	55	47	38
	25	40	93	38	79	32	70	37
		50	89	45	73	37	56	39
		60	77	47	68	41	47	51
'Laulema'	12.5	40	65	26	95	38	70	38
		50	59	30	92	46	56	43
		60	51	31	95	57	47	53
	25	40	78	32	89	36	70	40
		50	86	43	83	42	56	51
		60	87	53	87	52	47	52

With row space 12.5 cm, the cultivars of the cultivar 'Lajma' had from 59% at the sowing rate of 60 germinating seeds per 1 m^2 to 66% at the sowing rate of 40 germinating seeds per 1 m^2 (Table 2). For the 'Laulema' cultivar, the yield is 51% at a sowing rate of 60 germinating seeds per m^2 to 65% at a sowing rate of 40 germinating seeds per 1 m^2. Overall, the yield was low. This could be due to the low moisture content of the soil during germination. For both cultivars, the field yield was higher at a larger row spacing — on average 83%.

Precipitation in May was 13.6 mm, which was 26.1% of the norm. Reduced soil moisture affected plant germination and development. Field germination in 2020 was similar in both row spacings for cultivar 'Lajma', there was no significant difference, but number of plants was higher with row spacing 25 cm. For the cultivar 'Laulema' row spacing did not affect the field germination and number for plants per 1 m^2 significantly. Compared to 2018, with row space 12.5 cm number of plants was higher was 30–40% higher. The field germination of the cultivar 'Laulema' was similar to that of 2018, but 10–15% lower for the cultivar 'Lajma', although the moisture supply during germination was sufficient — 69.8 mm in May.

TABLE 3 NUMBER OF PODS AND 1000 SEED WEIGHT OF SOYBEAN DEPENDING ON CULTIVAR, ROW SPACING AND SOWING RATE GERMINABLE SEEDS PER 1 m^2

Factors	Number of pods	1000 seed weight, g	Number of pods	1000 seed weight, g	Number of pods	1000 seed weight, g
Year	**2018**		**2019**		**2020**	
Cultivar						
p-value	< 0.001	< 0.001	0.007	0.081	0,0002	0.01
'Lajma'	37.5	175.13	23.8	159.44	42.5	165.68
'Laulema'	23.3	165.46	21.0	164.08	28.0	162.26
Row spacing, cm						
p-value	0.057	0.637	0.833	0.022	0.0001	0.001
12	29.1	169.79	22.5	158.68	45.00	160.45
25	31.7	170.79	22.2	164.85	37,67	166.58
Sowing rate germinable seeds per 1 m^2						
p-value	< 0.001	0.837	< 0.001	0.013	0,001	0.0002
40	33.8	170.94	25.6	161.14	32,3	159.87
50	30.9	170.50	21.3	167.01	33,5	162.36

60	26.5	169.44	20.3	161.76	44,3	161.25

Cultivar ($p = 0.007$) and sowing rate ($p < 0.001$) had a significant effect on the number of pods, but the effect on row spacing was not significant ($p = 0.833$). There were significantly more pods for the cultivar 'Lajma' — on average 23.8 pods for the plant, and for the cultivar 'Laulema' — on average 21.0 pods for the plant (Table 3). Among the sowing rate variants, significantly more pods were formed for plants at sowing rate 40 germinating seeds per 1 m^2 on average 25.6 pods, against sowing rate variants 50 and 60 germinating seeds per 1 m^2, which had on average 21.3 and 20.3 pods per plant, respectively. There were no significant differences between the row spacing variants — in the conventional row sowing variants only 0.3 pods per plant were formed on average than in the broad row sowing variants.

Spacing between rows ($p = 0.022$) and sowing rate ($p = 0.013$) had a significant effect on 1000 seed weight, but there was no significant effect on cultivar ($p = 0.081$). The coarser seeds were in the broad-row variants — on average 164.85 g, but in the conventional row-seed variants the weight of 1000 seeds were on average 158.68 g, or 6.17 g less. There was no significant difference between sowing variants 40 and 60 germinating seeds per 1 m^2 — on average 161.14 and 161.76 g, respectively, but for the sowing norm variant 50 germinating seeds per 1 m^2, the weight of 1000 seeds was 167.01 g. Compared to cultivars, the weight of 1000 seeds was higher for the cultivar 'Laulema' — on average 164.08 g, but for the cultivar 'Lajma' — 159.44 g (Table 3).

Cultivar ($p < 0.001$) and sowing rate ($p < 0.001$) had a significant effect on the number of pods, but the effect on row spacing was not significant ($p = 0.057$). As in 2018, there were significantly more pods for the cultivar 'Lajma' — on average 37.5 pods for the plant, and for the cultivar 'Laulema' — on average 23.3 pods for the plant (Table 3). Depending on the variant of the sowing rate, the same tendency was observed as in 2018 — there were more pods per plant in the variant of the lowest sowing norm — on average 33.8 pieces. In the sowing norm variant 50 germinating seeds per 1 m^2 there were on average 30.9 pods per plant, but in the sowing norm variant 60 germinating seeds per 1 m^2 — significantly less - on average 26.5 pods per plant. There were no significant differences in the number of pods for the plant between the usual row and broad-row variants - on average 29.1 pods for the plant in the conventional row-seed variants and on average 31.7 pods for the plant in the broad-row variants.

Cultivar had a significant effect on 1000 seed weight ($p < 0.001$), but row spacing ($p = 0.637$) and sowing rate had no significant effect ($p = 0.837$). The weight of 1000 seeds were significantly higher for the cultivar 'Lajma' — on average 175.13 g, compared to the average of 165.46 g for the cultivar 'Laulema'. In 2018, the weight of 1000 seeds were only 1.38 g less for the cultivar 'Laulema' and 15.69 g less for the cultivar 'Lajma'. The TSW (thousand grain weight) differed by only 1 g on average between the line spacing variants, which is not significant. There were also no significant differences between the variants of sowing norms. TSW averaged from 169.44 g at a sowing rate of 60 germinating seeds per 1 m^2 to an average of 170.94 g at a sowing rate of 40 germinating seeds per 1 m^2.

TABLE 4 SOYBEAN YIELD AND YIELD COMPONENTS DEPENDING ON YEAR'S METEOROLOGICAL CONDITIONS

Year	**Yield, t ha^{-1}**	**Number of pods**	**Number of pods on first productive knot**	**Number of seeds in firsts knot pods**	**1000 seed weight, g**
2018	2.41	22.3	3.65	1.49	161.76
2019	1.55	30.4	6.00	1.54	170.33
2020	2.20	30,68	3,3	1,01	162.56
p-value	0.012	0.006	< 0.001	0.237	< 0.001

The seed yield in 2018 was on average 2.41 t ha^{-1}, but in 2019 on average 1.55 t ha^{-1} — by 0.86 t ha^{-1} less, but in 2020 was 2.20 t ha^{-1}. The number of pods per plant was significantly higher in 2019 and 2020 — 30 pieces. against 22 pods per plant in 2018. The average number of pods at the first productive knot also increased in 2019 — 6.0 against 3.7 pods in 2018 and 3.3 pods in 2020. The mass of 1000 seeds were significantly higher in 2019 — on average 170.33 grams against 161.76 grams in 2018 and 162.56 grams in 2020 (Table 4). The highest values of the structural elements of the harvest could be explained by the fact that in the vegetation season of 2019 the plants had a more even moisture supply and there was no drought stress, which allowed to form more green masses — grow in length and form more productive branches, pods. But the first productive knot and pods formed lower, which made it difficult to harvest. However, the average yield in 2019 was significantly lower due to the large yield losses of the cultivar 'Lajma' at harvest, as the first node with pods was located only 3.8 cm from the soil surface. The only stable indicator over the years was the number of seeds in the pods of the first node - it differed between the years only by an average of 0.05 seeds.

DISCUSSION

Soybean is a short-day plant [5] Weather conditions at this time have a significant impact on soybean yield and harvesting potential. Consequently, in Latvia's conditions, pod formation, which is important for soybean productivity, takes place in August and September. Different meteorological conditions each year make it difficult to predict the ripening time of soybeans. When evaluating soybean cultivars, which are recommended as very early in other European countries, the results of the research in Latvia show that the vegetation time of the particular cultivars in Latvia's conditions does not always correspond to the early age group assigned by breeders [12]

In Brazil it has been found that a higher seed sowing rate (60 germinating seeds per 1 m^2) increase yield, especially in late sowing, as the total plant biomass per unit area, plant length, lower productive node height, number of pods and number of seeds per unit area increase. However, higher seeding rates reduce the shoot biomass, leaf area, number of pods and number of seeds per plant [10]

We concluded, however, that meteorological conditions during the growing season have a greater impact on the formation of the soybean yield than other factors. If it is cool and humid, the soybean vegetation period can be significantly extended, which hinders its ripening and makes harvesting more difficult (as it was in 2019 and 2020). Therefore, it is very important to choose earlier cultivars to avoid this risk.

Also, in Russia, it has been established that yield is significantly affected by the sowing rate [16] Study in USA indicate that soybean planted in narrow rows of 19 cm have higher yield potential when compared to soybean planted in wider rows [9]

The lower crop yield with 12 cm row spacing can be explained by the fact that the plants in the row have more competition for moisture and nutrients than in the conventional sowing[15]The same competitive tendency can be observed depending on the sowing norm — at the sowing norm of 60 germinating seeds per 1 m^2 the competition between germinating plants is higher than at the sowing norm of 40 germinating seeds per 1 m^2, which could affect field germination.

As Иванов, Мордвинцев (2014) demonstrate, increasing the sowing rate significantly reduced the number of pods per plant. At the sowing rate of 350,000 seeds per 1 ha per soybean plant there were on average 23.1 pods, but at the sowing rate of 550,000 seeds per 1 ha — 20.6 pods[14]Several authors (Грибанов, 2004; Иванов, Мордвинцев, 2014) have drawn the same conclusions about the productivity of soybean plants - there is an increase in plant productivity density (sowing rate), the lower the number of seeds in one pod, the number of pods, the mass of 1000 seeds, the number of productive branches. Some studies show that that soybean is more susceptible to water stress at the full seed beginning of pod, and beginning of seed reproductive stages and water stress also have impact on 1000 seed weight [3]

CONCLUSIONS

Experiments with soybean cultivars took place during significantly different vegetation seasons, which showed well the different reactions of cultivars to variations in meteorological conditions. Soybean seed yield was significantly influenced by cultivar choice, sowing rate and meteorological conditions of the year. It is important to choose cultivars with the shortest possible vegetation period so that the crop can be harvested until the autumn frosts. In 2018, more productive was the cultivar 'Merlin' — 3.77 t ha^{-1}, but in 2019, the situation was different and the most productive cultivar was 'Paradis' — 2.55 t ha^{-1}, in 2020, like in 2018, the most productive cultivar was 'Merlin' — 3.18 t ha^{-1}. The sowing rate of 60 germinable seeds per 1 m^2 ensured a significantly higher seed yield in both years. The quality of the yield varied from year to year as a result of meteorological conditions.

REFERENCES

[1] Apstiprinātās platības par kultūrām un atbalsta veidiem 2020. gadā (2021). [viewed: 20 February 2021]. Avalaible: https://www.lad.gov.lv/lv/statistika/platibu-maksajumi/periods-2004-2016/statistikas-dati-par-2020-gadu/

[2] Colletti A., Attrovio A., Boffa L., Mantegna S., Cravotto G. (2020). Valorisation of By-Products from Soybean (*Glycine max* (L.) Merr.) Processing. *Molecules*, Vol. 25, article 2129; https://doi.org/10.3390/molecules25092129

[3] Dogan E., Kirnak H., Copur O. (2007). Deficit irrigations during soybean reproductive stages andCROPGRO-soybean simulations under semi-arid climatic conditions. *Field Crops Research* 103 pp. 154–159

[4] EUROstat: Agricultural production – crops. [viewed: 20 February 2021]. Avalaible:https://ec.europa.eu/eurostat/statisticsexplained/index.php?title=Agricultural_production_-_crops#Oilseeds.

[5] Holdsworth M. (1964). The leaf movementsof soybean, a short-day plant. Journal of Experimental Botany, Volume 15, No. 44, pp. 391-398.

[6] Lewandowska S. (2016). Perspectives of soybean cultivation in Poland. [Online] [viewed: 16 February 2021]. Avalaible: https://www.researchgate.net/publication/304898171_Perspectives_of_soybean_cultivation_in_Poland.

[7] Masudaa T., Goldsmith P.D. (2009). World Soybean Production: Area Harvested, Yield, and Long-Term Projections. *International Food and Agribusiness Management Review*, Vol. 12, Issue 4, p. 143–162

[8] Sarja L., Malceniece I. (1990) Introducētās sojas šķirnes un formas. Tautaismniecībā derīgo augu bioķīmija un bioloģija. Zināta, Rīga, pp. 28–37.

[9] Schutte M., Nleya, T. (2019). Row Spacing and Seeding Rate Effects on Soybean Seed Yield. Soybean - Biomass,Yield and Productivity. . [viewed: 28 February 2021]. Avalaible:https://www.semanticscholar.org/paper/Row-Spacing-and-Seeding-Rate-Effects-on-Soybean-Schutte-Nleya/2df35bc6d98ac70af4d3a7c80b45690e19d90e13

[10] Umburanas R.C., Yokoyama A.H., Balena L., Dourado-Neto D. (2019). Soybean yield in different sowing dates and seeding rates in a subtropical environment. *International Journal of Plant Production*, Vol. 13, Issue 2, pp. 117–128.

[11] Wienda-Piesik A., Kasek M. (2016). Productivity of early maturing cultivars of soybeans (Glycine maxL.Merr) in North-Western Poland. In: Conference Paper of 14th ESA Congress, Edinburgh, Scotland, 5–9 September, 2016, pp. 25–26.

[12] Zute S,. Damškalne M., Jansone I., Morozova I., Justs A. (2020). Sojas šķirņu ražība Latvijas agroklimatiskajos apstākļos 2018. un 2019. gadā. Zinātniski praktiskā konference "LĪDZSVAROTA LAUKSAIMNIECĪBA". LLU:Jelgava, 40–45lpp.

[13] Грибанов А.Н. (2004). *Нормы высева и способы посева разных по скороспелости сортов сои в северной лесостепи ЦЧР*: Диссертация кандидата сельскохозяйственных наук. Мичуринск, 182 с.

[14] Иванов В.М. Мордвинцев Н.В. (2014). Реакция сортов сои на норму высева и глубину основной обработки почвы на черноземах Волгоградской области. *Фундаментальные исследования*, № 6 (часть 3), с. 526–530.

[15] Огурцов Е.Н., Гайовой А.Г., Белинский Ю.В. (2014). Урожайнось сои в зависимости от способов посева в восточной части левобережной лесостепи Украины. ***В кн.:*** *Инновационные технологии и технические средства для АПК: Материалы Международной. научно-практической конференции молодых ученых и специалистов* 27–28 марта 2014 г. Воронежский государственный унивеоситет им. Императора Петра I. –Воронеж, Ч. I, с. 185–190.

[16] Пигорев И.Я., Данилова Л.В. (2009). Влияние нормы высева на урожайность и качество семян сои на серых лесных почвах Центрального Черноземья. *Вестник Курской государственной сельскохозяйственной академии,* Nr. 3, с. 57–59.

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Mechanical Properties of Wood Plastic Composites with the Activated Wood Filler

Galia Shulga
Latvian State Institute of Wood Chemistry
Riga, Latvia
shulga@junik.lv

Brigita Neiberte
Latvian State Institute of Wood Chemistry
Riga, Latvia
bricis46@inbox.lv

Sanita Vitolina
Latvian State Institute of Wood Chemistry
Riga, Latvia
sanita.vitolina@gmail.com

Anrijs Verovkins
Latvian State Institute of Wood Chemistry
Riga, Latvia
anrivero@inbox.lv

Julia Brovkina
Latvian State Institute of Wood Chemistry
Riga, Latvia
yuli@inbox.lv

Talrits Betkers
Latvian State Institute of Wood Chemistry
Riga, Latvia
betalrits@gmail.com

***Abstract* - The aim of the research was a study of the effect of activation of birch sawdust microparticles with a dilute solution of sodium hydroxide at a low temperature on mechanical properties and water sorption of the obtained wood plastic composite (WPC) samples obtained from a by-product of a domestic wood mechanical processing and a recycled polymer municipal waste. It was found that the mechanical (tensile, bending) properties of the WPC samples filled with the activated birch sawdust microparticles were higher than those of the samples filled with the initial sawdust. The sorption and swelling degree of the WPC samples with the activated filler were lower than those for the samples with the initial sawdust. However, the difference in the values of the water sorption and the swelling degree for the samples filled with the activated and initial wood microparticles were relatively low in comparison with the observed essential difference in their mechanical properties. This fact was explained by the enhanced content of carbonyl groups in the activated sawdust microparticles that are able to absorb water.**

Keywords - mechanical properties, recycled polypropylene, wood-plastic composite, wood surface activation

I. INTRODUCTION

The increasing focus on eco-friendliness, such as the European Union's directives, has led to greater challenge for the development of commercially viable biodegradable composites. Due to the renewability, easy availability, low cost and biodegradability of lignocellulose, its usage as a filler in wood-plastic composites (WPCs) containing two main components – a lignocellulosic filler and a thermoplastic polymer is very promising and perspective [1-2]. WPCs are a young generation of composites with rapidly growing usage within the plastics industry. Such type of composite materials responds to (semi)bio-composites, because a content of a wood filler in them can achieve 70-80 wt%. Their global market is increasing at a very rapid pace, and is predicted to exceed 10 billion dollars by 2026. WPCs find wide application for producing of decking and decorative materials for building engineering, in auto industry, for production of domestic and technical items, etc. It is known that reducing the concentration of atmospheric carbon dioxide is a fundamental challenge for the twenty-first century. In this connection, EU sets out ambitious targets towards to recycling and recovery of polymer wastes, preventing their leakage into the environment as well accelerating their usage efficiency [3]. Evidently that the practice for development of WPCs based on recycled polymers in a more extent is gained by the growing awareness of environmental problems and the importance of energy conservation.

The main problem for all WPCs is a low interfacial adhesion between a polymer matrix and a wood filler that negatively affects the WPC performance properties [4-5]. A strong adhesion at the polymer/wood interface is

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needed for an effective transfer of stress and load distribution throughout the interface as well as for the prevention of fibre-fibre interaction leading to agglomeration of wood particles. This is a challenge for the development of effective functionalization methods for a wood particles surface. There are many various physical (corona, plasma) and chemical methods (mercerisation, acetylation, benzylation, amination, graft copolymerisation, treatment with acids, peroxide, various anhydrides, permanganate, silane, etc.) for wood functionalisation as a filler, which are able increasing the interfacial adhesion in WPCs via strengthening physicochemical interaction between a polymer matrix and a wood surface [6-9].

Alkaline treatment is one of the most commonly used chemical treatments of lignocellulosic fibres for improving compatibility at the polymer/filler interface in WPCs [10-11]. During alkali treatment, the destruction of hydrogen bonding in the lignocellulosic matrix network occurs. This leads to the increase in an amorphous cellulose content and surface roughness of lignocellulosic fibres as well as causes the disintegration of bundles of the fibres, reducing their sizes. Additionally, extracts and wax are removed from the cell wall too. In such a manner, the alkali treatment increases the availability of a wood surface for interfacial interaction with a polymer matrix during their thermal processing.

It is known that the alkaline treatment is carried out using the enhanced concentrations of alkali solutions at high temperatures. However, very scarce information is available about the effect of wood fibres treated with a low concentration alkali solution at a moderate temperature on the WPCs properties.

In this research the effect of the activation of birch wood sawdust with a low concentrated alkali solution at a low temperature on the mechanical and water sorption properties of recycled polymer-based wood-plastic composite was investigated.

II. MATERIALS AND METHODS

A. Materials

All the initial materials for fabricating a new WPC are represented the Latvian origin wastes. The birch wood sawdust was a by-product of the Latvian wood processing company. The main part of its fractional composition consisted of wood particles with a size between 250 and 500 μm. The sawdust was characterized by elemental analysis (ElementarAnalysensysteme GmbH, Germany) and wood polymers composition according to Klason and Kürschner chemical procedures for lignin (TAPPI 2002-2003) [12] and cellulose (TAPPI 1999) [13], respectively, as well as hemicelluloses (TAPPI 1997) [14].

Recycled polypropylene (rPP) (0.9 t/m^3, 5.2 g/10 min at 230 °C, and 2.16 kg) was produced from municipal polypropylene wastes at a Latvian polymer recycling plant (Nordic Plast Ltd., Latvia) and used as a thermoplastic polymer matrix.

B. Methods

Milling. For obtaining a fraction less than 100 μm, both the initial and activated birch sanding dust were milled and sieved. Milling was carried out with a planetary ball mill (Retsch, Germany) at 300 min-1 during 15 min. The fractionation was performed by using Pulverizette 0 (Fritsch, Germany) during 30 min.

Conductometric titration. The conductometric titration was used for determination of a total content of acidic groups in the sawdust samples. The curves of water suspensions of the initial and alkaline sawdust microparticles were obtained using InoLab level 3 Multiparameter Meter (WTW, Germany) at their constant stirring at 25°C. 0.1 mol/dm^3 HCl solution was used for the adjustment of pH values.

Water sorption and swelling. The water sorption and swelling of the composite samples were determined after their full immersion in distilled water for 16 days at room temperature according to ASTM D 570-98. Water adsorption (WA) amount as calculated using the following formula:

$$WA\ (\%) = (m_o - m_t)/m_o \times 100,$$

where m_o and m_t were the initial oven-dry weight and weight after time t, respectively.

By recording the changes in the thickness (T) of the samples over a given period of time (t) and applying it to the thickness of the dry sample, the degree of swelling (SW) was calculated.

$$SW\ (\%) = (T_t - T_o)/ T_o \times 100,$$

where T_o and T_t were the initial thickness and thickness after time t, respectively.

Mechanical tests. Mechanical properties were determined with a universal machine "Zwick" (Zwick/Roell, Germany) with a load capacity of 0.5 kN at a rate of 50 mm/min and 2 mm/min for tensile and bending tests, respectively, according to ASTM D638 (ASTM 2007) and EN ISO 178 (EN ISO 2003) with the help of the software program TestXpert. Before testing, the samples were conditioned at 60°C during 24 h. Five replicates were made for each mechanical testing, and the standard deviation for each index was found.

Transmission electron microscopy (TEM). The shape of the dust particles was measured by transmission electron microscopy (Leo 912 AB Omega microscope, Germany).

Scanning electron microscopy (SEM). The morphology of the obtained WPC samples was examined using a scanning electron microscope (Tesla, Czech Republic).

Differentialthermal analysis (DTA). Thermal stability was determined using a thermal analyser "PerkinElmer" at a heating rate of 5o C under a nitrogen atmosphere.

Alkaline treatment. To activate birch wood sawdust, alkaline treatment was carried out by using a 5-L three-neck flask equipped with a return condenser, a thermometer and a stirrer under the following conditions: NaOH concentration of 0.025 g/dl, temperature 60°C and duration 5 h at a hydromodulus (sawdust/water mass ratio) of 1/20. After the treatment, the activated sawdust was washed, dried and milled for obtaining microparticles

less than 100 µm. For comparison of the activation effect, the initial sawdust was also milled, and its fraction less than 100 µm was used.

Preparation of WPC samples. Before obtaining the WPC samples, the powdered rPP and the sawdust microparticles were mixed for 3 min at room temperature, using an electrical mechanical grinder. The samples for tensile and bending tests were prepared by the extrusion and moulding method using HAAKE MiniLab II and MiniJet II (Thermo Fisher Scientific, Germany) at a temperature of 175°C, a circulation time in the two-screw extruder of 5 min, and a moulding pressure of 45 MPa at a temperature of 120 °C. The content of the sawdust microparticles in the WPC samples varied from 10 wt% to 50 wt%.

III. RESULTS AND DISCUSSION

A. Characteristic of activated sawdust microparticles

The initial birch sawdust had the following elemental composition: 48.1% C, 5.93% H, 45.7% O and 0.26% N. The alkaline treatment resulted in a slight decrease in the carbon content (47.7%) and a slight increase in the oxygen content (46.3%). A content of the main wood components of sawdust particles before and after their alkaline treatment is presented in Table 1. According to the chemical analysis, the activated sawdust contains a little more cellulose (Cel), but a slightly less lignin (Lig) and hemicellulose (HC). The treatment with the dilute sodium hydroxide solution leads to the remarkable increase in the amount of acidic groups (phenolic hydroxyl, carboxyl) (OH_{tit}) and carbonyl (CO) groups (almost two times) and to the slight decrease in the content of methoxyl groups (OCH_3) that indicated the activation of the surface of the wood sawdust microparticles.

TABLE 1. CHEMICAL COMPOSITION OF INITIAL AND ACTIVATED BIRCH SAWDUST

Sample	Wood components, %			Functional composition, %		
	Cel	***Lig***	***HC***	***OCH_3***	***OH_{tit}***	***CO***
initial	50.2	21.8	23.5	5.7	10.4	2.1
activated	51.7	20.3	22.4	5.5	13.3	3.9

Scanning electron microscope images of the initial and activated milled sawdust are shown in Fig. 1. The images clearly indicate the distinction in fibres dimensions of these sawdust samples.

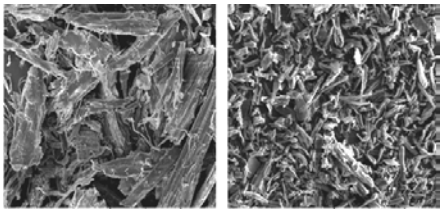

Fig. 1. Fig.1. SEM images of initial and activated milled sawdust (x 500)

The TEM micrographs of the activated sawdust microparticles (< 100 µm) (Fig. 2) shown the presence of two shapes of the microparticles. The oval particles has an average diameter of 2-3 µm, but the extended ones have a length of 4-6 µm and a width of 0.5-1.5 µm, respectively. Their low length and low aspect ratio between the width and the length indicated a short fibre nature of the activated microparticles.

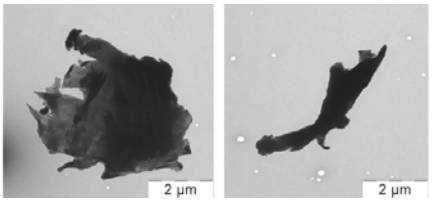

Fig. 2. TEM micrographs of the activated sawdust microparticles

Since the fabricating of WPC samples occurs at high temperatures, it was interest to study a thermal stability of the activated wood. Fig. 3 shows the thermogravimetric (TGA), differential gravimetric analysis (DTG), and differential thermal analysis (DTA) curves for the activated sawdust microparticles. According to the obtained curves, the mass losses of the activated sawdust at a temperature of 170°C-180°C, which is the processing temperature of WPC samples in the extruder and moulding machine, do not exceed 8 ± 2% by weight (for the initial sawdust - 7 ± 2%), and are mainly related to the residual moisture content in the activated sawdust. This means that the alkaline activation of the birch sawdust does not reduce its thermal stability.

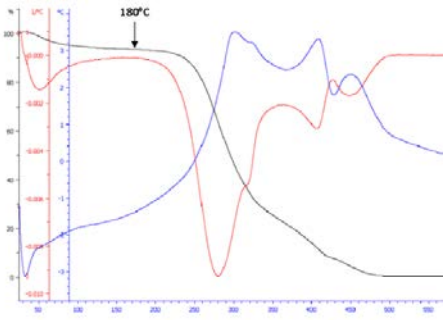

Fig. 3. TGA, DTG un DTA curves of the activated wood sawdust

B. Properties of WPC samples

The composite raw blends were prepared by mixing rPP powder with the initial and activated birch sawdust microparticles less than 100 µm using an electrical mechanical grinder. The mechanical properties of rPP and the rPP-based composite samples filled with the initial and activated birch wood microparticles with a filling from 10 wt% to 50 wt% are shown in Fig. 4-7. It can be seen that the mechanical properties of the obtained WPC samples filled with the activated microparticles are much higher than those of the samples filled with the initial sawdust microparticles and the recycled polymer.

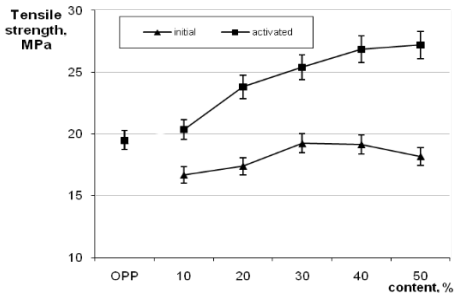

Fig. 4. Tensile strength of WPC samples filled with the activated and initial sawdust

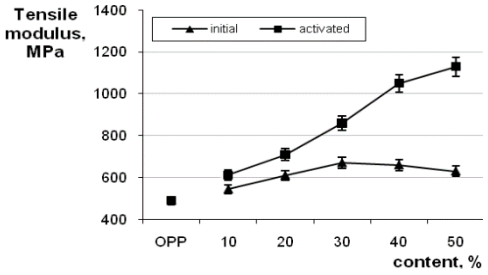

Fig. 5. Young's modulus of WPC samples filled with the activated and initial sawdust

As shown Fig. 4 and Fig. 5, the values of ultimate tensile strength and Young's modulus for the samples with the activated wood microparticles ranged from 20.4 MPa to 27.2 MPa and 613 MPa to 1300 MPa, respectively, with increasing a content of the filler from 10 wt% to 50 wt%. The given results indicate a pronounced improvement of the mechanical parameters of the WPC samples filled with the activated microparticles, compared with the case of recycled PP. The ultimate tensile strength and Young's modulus of the samples incorporating the activated microparticles increases almost 1.3 and 2 times, respectively, at 50% filling. At the same time, the samples containing the initial sawdust were characterised by lower values of the ultimate tensile strength in comparison with rPP.

The dependences of bending strength and bending modulus on the content of the initial and activated wood particles are shown in Fig. 6 and Fig. 7. It can be seen that, with increasing the content of both initial and activated microparticles, the bending strength and bending modulus grow and are higher than those of the rPP values. The values of bending strength and bending modulus for the samples with the activated wood microparticles ranged from 22.5 MPa to 29.1 MPa and 1256 MPa to 2707 MPa, respectively, but for the samples with the initial sawdust varied from 21.8 MPa to 25.3 MPa and 1054 MPa to 2105 MPa with increasing a content of the particles from 10 wt% to 50 wt%. The bending strength and the bending modulus of the samples incorporating the activated and initial microparticles increase almost 3.0 and 2.3 times, respectively, at 50% filling. Simultaneously, the deformability of these composites essentially decreases, namely, elongation at break dropped 5 and 2 times, but deflection ability diminished more than 4 and 2 times for the samples with the initial and activated sawdust, respectively, in comparison with the case of the initial recycled polymer. This may indicate the enhanced stiffness of the obtained WPC samples.

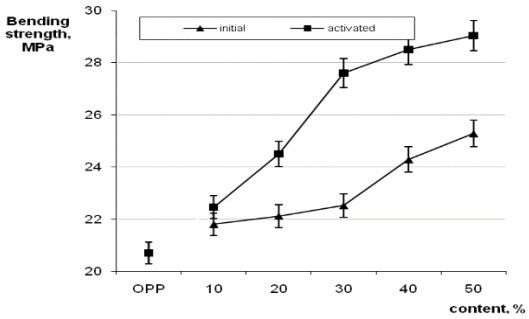

Fig. 6. Bending strength of WPC samples filled with the activated and initial sawdust

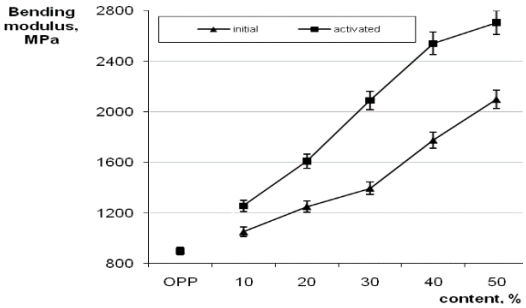

Fig. 7. Bending modulus of WPC samples filled with the activated and initial sawdust

Evidently, the appearance of the added amount of the acidic groups such as phenolic at the wood particles' surface by its treatment with the dilute alkaline solution promotes the interaction at the polymer matrix/wood filler interface due to the possible formation of a hydrogen linkages network between the oxygen-containing groups at the filler surface and the hydroxyl groups of the recycled PP in the composite processing, which can lead to the partial structuring of the interfacial layers. These factors favour the compatibility between the polymer matrix and the filler in the complex system. Lower indicators of the mechanical properties for the samples with the initial sawdust microparticles were attributed to the insufficient interface adhesion between the phases.

It is known that the ability of WPCs to uptake water vapours during exploitation can negatively affect their mechanical strength, dimensional stability, and resistance against biological decay [15, 16]. Fig. 8 and Fig. 9 demonstrate the results of a study of the water sorption and swelling degree of the composites, which were obtained for 4, 8, 12 and 16 days. For this purpose, the samples were totally immersed in distilled water at room temperature. It can be seen that the sorption and swelling degree of the composites with the activated filler are lower than those for the sample with the initial sawdust.

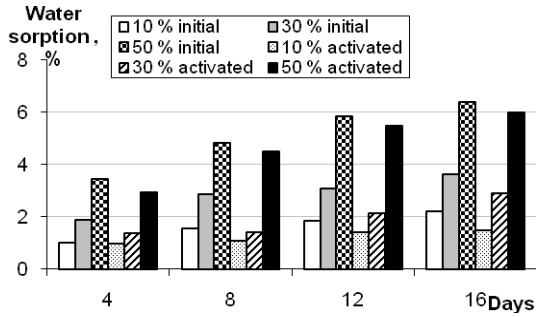

Fig. 8. Water sorption of WPC samples filled with the activated and initial sawdust

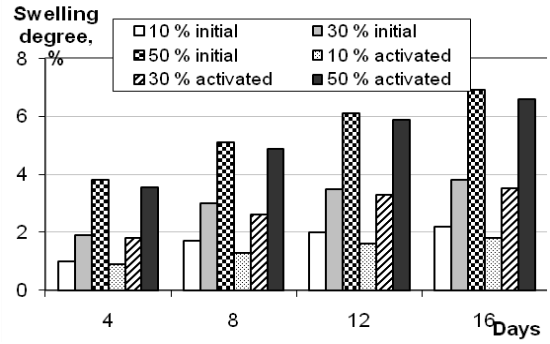

Fig. 9. Swelling degree of WPC samples filled with the activated and initial sawdust

With increasing the time of the test, the water uptake grows achieving 6.4 wt% и 6.0 wt% for the WPC samples containing the 50% initial and 50% activated sawdust microparticles, respectively, after 16 days of their immersion in water. The values of the swelling degree for these samples after the end of the test are 6.9% and 6.6 %, respectively. The highest gain in the weight and the thickness is characteristic for the samples containing the maximum amount of the sawdust microparticles, while at a filling of 30 wt%, the values of the water uptake and the swelling degree after 16 days do not exceed 2.9 wt% and 3.5%, respectively, for the samples with the activated sawdust, and 3.5 wt% and 3.8%, respectively, for the samples with the initial microparticles. The relatively low difference in the values of the water sorption and the swelling degree for the samples filled with the activated and initial wood microparticles in comparison with the observed essential difference in their mechanical properties may be explained by the enhanced content of the carbonyl groups in the activated sawdust, which were able to absorb water. No other hand, this may indicate the fact that the same method of functionalization of the wood surface does not always has the same effect on both mechanical and wetting properties of the WPC samples.

IV. CONCLUSIONS

Thus, using the by-product of a domestic wood mechanical processing and the recycled municipal polymer waste, the new wood-plastic composite has been obtained. It was characterised by the enhanced mechanical properties and stiffness in comparison with the properties of the composite filled with initial sawdust. The insufficient water resistance of the obtained WPC filled with the activated sawdust particles was explained by the enhanced content of carbonyl groups in the activated sawdust.

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REFERENCES

[1] K. L. Pickering, M. A. Efendy, T. M. Le, A review of recent developments in natural fibre composites and their mechanical performance, *Compos. Part A- Appl. S.*, 2016, 83, pp. 98-112.

[2] O. Faruk, A. K. Bledzki, H.-P. Fink, M. Sain, Biocomposites reinforced with natural fibers: 2000-2010, *Prog. Polym. Sci.*, 2012, 201237(11), pp. 1552-1596.

[3] J. Korhonen, A. Honkasalo, J. Seppälä, Circular economy: The concept and its limitations, *Ecol. Econ.* 2018, 143, 37-46.

[4] M. Farsi, Effect of surface modification on thermo-mechanical behaviour of wood-polymer composite, *Asian J. Chem.*, 2012), 24(6), pp. 2775-2779.

[5] K. L. Pickering, M. A. Efendy, T. M. Le, A review of recent developments in natural fibre composites and their mechanical performance, *Compos. Part A- Appl. S.*, 2016, 83, pp. 98-112.

[6] M. J. John, R. D. Anandjiwala, Recent developments in chemical modification and characterization of natural fibre-reinforced composites, *Polymer Composites*, 2008, 29(2), pp. 187-194.

[7] K.G. Satyanarayana, G.G.C. Arizaga, F. Wypych, Biodegradable composites based on lignocellulosic fibers, An overview, *Progress in Polymer Science*, 2009, 34, pp. 982 -998.

[8] G. Shulga, B. Neiberte, A. Verovkins, S. Vitolina, J. Jaunslavietis, J. Ozolins, Short fibre filler from wood residue for polymeric composite materials, *Mater. Sci. (Medžiagotyra),* 2016, 22(3), pp. 370-375.

[9] X. Li, L.G. Tabil, S. Panigrahi, Chemical treatments of natural fiber for use in natural fiber–reinforced composites, *Journal of Polymers and the Environment*, 2007, 15, pp. 25-28.

[10] J. Lin, Z. Yang, X. Hu, G. Hong, S. Zhang, Wei Song, The Effect of Alkali Treatment on Properties of Dopamine Modification of Bamboo Fiber/Polylactic Acid Composites, *Polymers*, 2018, 10, pp.1-12.

[11] G. Rajesh, AVR. Prasad, Effect of fibre loading and successive alkali treatments on Tensile properties of short jute fibre reinforced polypropylene composites. *Advanced Materials Manufacturing and Characterization*, 2013, 3, pp. 528-535.

[12] TAPPI T203 cm-99 (1999). "Alpha-, beta- and gamma-cellulose in pulp," TAPPI Press, Atlanta, GA, USA.

[13] TAPPI T222 om-02 (2002). "Acid-insoluble lignin in wood and pulp," TAPPI Press, Atlanta, A, USA.

[14] TAPPI T264 om-97 (1997). "Preparation of wood for chemical analysis," TAPPI Press, Atlanta, GA, USA.

[15] R. M. Taib, Z. A. M. Ishak , H. D. Rozman, W. G., Glasser, Effect of moisture absorption on the tensile properties of steam-exploded Acacia mangium fiber-polypropylene composites, *J. Thermoplast. Compos. Mater*., 2006, 19(5), pp. 475-489.

[16] A. Fortini, V. Mazzanti, Combined effect of water uptake and temperature on wood polymer composites: Research Article. *J. of Applied Polymer Science*, 2018, 135(5): 46674, pp. 1-9.

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Alternative UV Light Sources for Surface Disinfection

Atis Skudra
Institute of Atomic Physics and Spectroscopy
University of Latvia
Riga, Latvia
askudra@latnet.lv

Linda Mežule
Water Research and Environmental Biotechnology Laboratory
Riga Technical University
Riga, Latvia
linda.mezule@rtu.lv

Karīna Spunde
Latvian Biomedical Research and Study Centre,
Riga, Latvia
spunde.carina@gmail.com

Gita Rēvalde
Institute of Technical Physics
Riga Technical University
Riga, Latvia
gita.revalde@rtu.lv

Anna Zajakina
Latvian Biomedical Research and Study Centre
Riga, Latvia
anna@biomed.lu.lv

Madara Ziņģe
Institute of Atomic Physics and Spectroscopy
University of Latvia
Riga, Latvia
madara.zinge@lu.lv

Tālis Juhna
Water Research and Environmental Biotechnology Laboratory
Riga Technical University
Riga, Latvia
talis.juhna@rtu.lv

***Abstract* - Mercury UV-C light sources are long known to be efficient for microbial inactivation and have been widely used. At the same time, the radiation, if used in inappropriate doses and spectral regimes, can also cause harmful effects to human tissue. The aim of the study was to evaluate the applicability of the novel UV light sources from thallium – antimony at different UV-C. For the research specially made light sources were produced. The influence of UV-C radiation in the range of 200 - 280 nm was tested on Gramnegative bacterium *Escherichia coli*, both with mercury and thallium. More than 99.99 % inactivation of *E. coli* cells was obtained after 10 min contact time for thallium – antimony UV-C light source, demonstrating the potential of the produced lamps.**

Keywords - disinfection, UV thallium lamp, UV mercury lamp, UV-C, antiviral, antibacterial

I. INTRODUCTION

Ultraviolet radiation in the range of 200 – 280 nm (UV-C) has long been known to have the abilities to cause damage to the cellular material of bacteria or viruses, including their DNA or RNA. The inactivation occurs when the absorption of a photon forms pyrimidine dimers between adjacent thymine bases and renders the microorganism incapable of replicating [1]. As reported [2], at appropriate doses UV-C can selectively inactivate microorganisms while preserving viability of mammalian cells and, moreover, promote wound healing.

The wide application of UV-C for disinfection purposes has been linked with multiple advantages over liquid disinfectants and heat sterilization. It can be performed to disinfect surfaces, liquids, air and rooms, and it is also very energy-efficient [3]. All these factors are of high importance not only in routine disinfection but also during local and global pandemics, e.g., SARS-CoV-2, swine flu, MERS-CoV.

The spectral region used for disinfection is mainly the UV- C radiation in the spectral range of 200 – 280 nm. To produce radiation in the UV-C region, in almost all disinfection experiments mercury low-pressure lamps have been used with a strong emission line at 254 nm what is close to the RNA absorption peak [3]. There are very few experiments applying other wavelengths. Only individual

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experiments with a peak wavelength at 222 nm, and 365 nm (UV-A) [3] or 207 nm [4] have been reported. One of the reasons for the predominant use of Hg 254 nm light is the widespread ability of Hg light sources due to simple manufacturing process and lack of other appropriate UV-C light sources. This has so far been a limitation for exploitation of other UV- C wavelengths.

Thus, the aim of this study was to evaluate the applicability of the novel UV light sources filled with thallium and antimony for their potential to be used in disinfection. Thallium and antimony filling would give more working spectral lines in the same region. These wavelengths of the UV-C spectral region will be compared with mercury resonance line to demonstrate the efficiency.

Institute of Atomic Physics and Spectroscopy, University of Latvia has experience in development and manufacturing of special design high-frequency low pressure metal vapour light sources. Such light sources are widely used as bright radiators of intense spectral lines in different types of scientific devices, for instance, in atomic absorption spectrometers [5,6].

The high –frequency light sources are excited by the electromagnetic field, using electrodes outside the lamp. As the result, the inductive coupled discharge is initiated. It has been proven that such kind of discharge plasma is characterised by both, higher electron temperature and concentration, giving more intense spectral lines in comparison to other type of low pressure discharges.

Multiple high-frequency light sources, radiating in UV region filled with such elements like lead, phosphor, selenium, arsenic, thallium, antimony and mercury have been manufactured [7]. At the moment, these light sources have to be optimized for each particular use, and it is of great importance to use reliable methods for these investigations and further on for improvement of the light sources.

Within this work, we report the results of disinfection experiments with the thallium – antimony light sources in comparison with mercury lamps for neutralisation of *Escherichia coli* as representative Gramnegative bacterium.

MATERIALS AND METHODS

A. UV-ligh sources

For the experiment, special type high-frequency electrodeless light sources were manufactured at the Institute of Atomic Physics and Spectroscopy, University of Latvia. The light sources were made of SiO_2 glass with a diameter of 10 mm, filled with a metal vapour and a buffer gas at low pressure (Fig. 1).

Fig. 1. Typical design of the high-frequency light source.

In this case, thallium and antimony mixture was used for filling to excite more spectral lines in the UV-C spectral region. As a buffer gas, argon was used at the pressure of 3 torr. An outer electromagnetic field of about 100 MHz frequency was applied to initiate a discharge inside the lamp.

Spectra of the manufactured metal vapour light sources were recorded by the high – resolution Jobin Yvon 1000 M spectrometer.

B. Bacterial culture and growth conditions

Escherichia coli ATCC®10536 was used as the test bacterium. Overnight culture in Tryptone soya agar (Oxoid Ltd, UK) were thrice washed with sterile peptone water (0.1%) by centrifugation (6000 rpm for 2 minutes, Minispin, Eppendorf). The final bacterial pellet was re-suspended in sterile peptone water (0.1%) to obtain a stock solution of approximately 10^7 colony forming units (CFU) mL^{-1}. For cell enumeration 0.002 mL of the stock suspensions were filtered through a 25–mm-diameter 0.2–µm-pore–size filter (Polycarbonate Track- Etch Membrane, Sartorius, Germany) and fixed with 3–4% formaldehyde for 10 minutes, washed with sterile distilled water and stained with 10 µg mL^{-1} DAPI (4',6-diamidino-2-phenylindole, Merck, Germany) for 5–10 minutes. Cell concentrations were determined with epifluorescence microscopy (Ex: 340/380; Em: > 425, dichromatic mirror 565 nm, Leica DM6000B, Germany) by counting of 20 random fields of view.

C. Disinfection experiments

To test the inactivation efficiency, 3 mL of *E. coli* stock was inserted in sterile 30 mm borosilicate Petri dish and placed under the lamp at the distance of 11 cm. The SiO_2 lens was used to create parallel light rays. The measurements were performed in several series, changing the irradiation time form 1 min to 10 min.

Fig. 2. Experimental set-up for irradiation tests.

Immediately after irradiation, the sample was removed from the light source and decimal dilutions of the sample were inoculated onto Tryptone soya agar (Oxoid Ltd, UK) plates and incubated for 24 hours at 37°C. The result (reduction in cultivable *E. coli*) is expressed as negative log reduction of colony forming units after treatment divided by colony forming units before treatment.

II. RESULTS AND DISCUSSION

A design of a high – frequency thallium – antimony light source is shown in Fig.3.

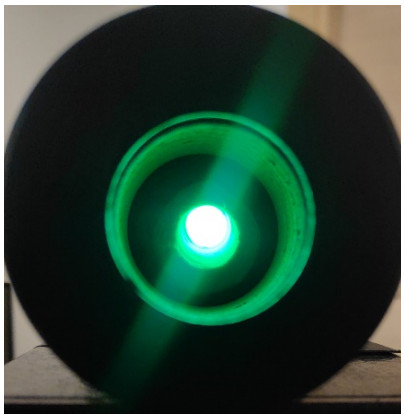

Fig. 3. Design of a high-frequency thallium - antimony metal vapour light source

UV- C spectra of thallium-antimony and mercury light sources are shown in Fig.4 and Fig. 5, respectively. As can be seen, the mercury UV- C spectrum contains only one strong emission line, however thallium – antimony spectrum have many spectral lines, giving a possibility to irradiate broader region of the RNA absorption band [4].

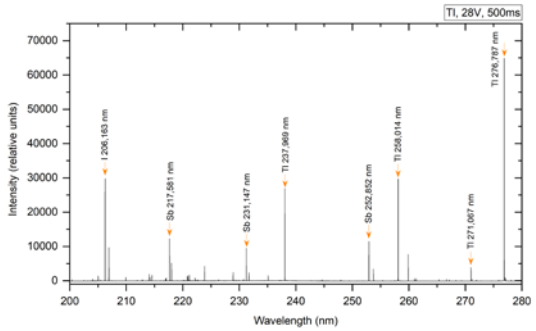

Fig.4. Spectrum example of thallium - antimony light source in the region of 200 – 280 nm.

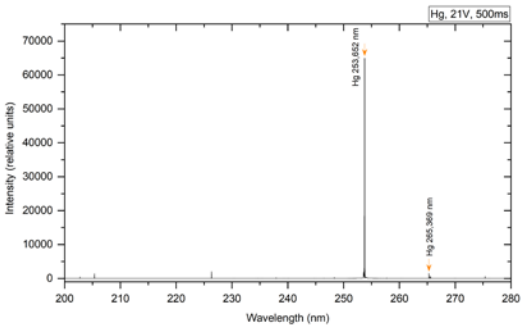

Fig. 5. Spectrum example of mercury light source in the region of 200 - 280 nm.

To evaluate and compare the performance of both UV-C light sources, bacterial inactivation tests with Gramnegative bacterium – *E. coli* have been performed to mimic faecal and surface contamination. In general, higher inactivation efficiency was observed with mercury light source, yielding 99 % reduction within 2.26 min of irradiation (Fig. 6, Fig. 7).

At the same time thallium - antimony produced 99 % reduction within 6 minutes and followed a linear reduction pattern all through the irradiation tests (Fig. 7, Fig. 8).

Till some extent this can be explained by different spectral compositions of both light sources. As a result thallium demonstrated comparable efficiency for reduction of cultivable *E. coli* to mercury UV-C.

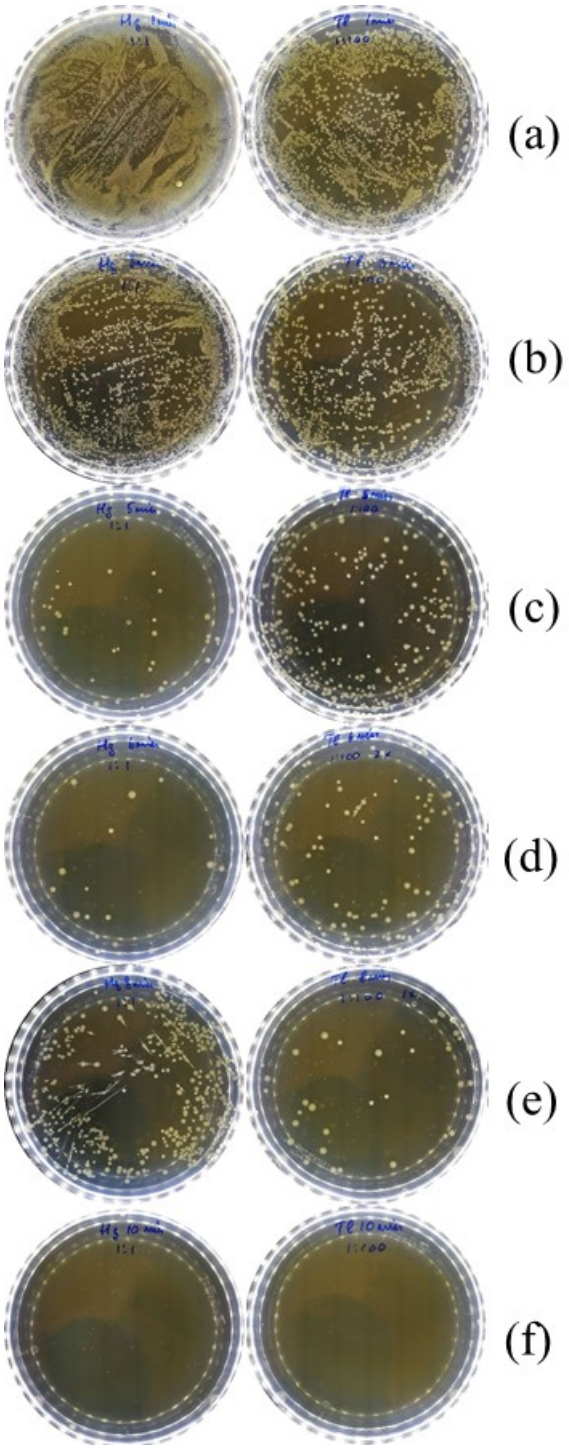

Fig. 6. Decrease in cultivable *E. coli* (CFU per plate) at various treatment times with mercury (left, no sample dilution) and thallium – antimony (right, 10^2 dilution) UV-C light source.(1 min (a), 3 min (b), 5 min (c), 6 min (d), 8 min (e) and 10 min (f))

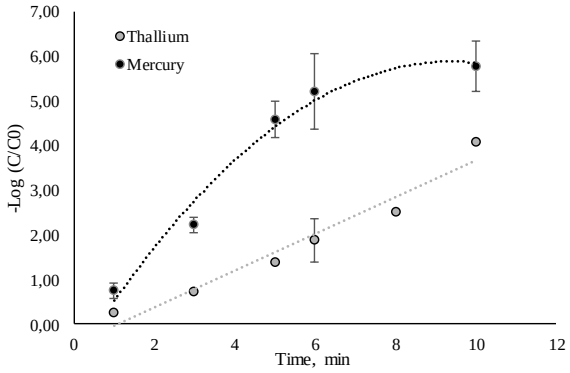

Fig.7. Log-reduction of *Escherichia coli* CFU as a function of exposure time for thallium – antimony and mercury light sources by equal irradiation conditions.

To date, mercury 254 nm spectral line irradiation has been demonstrated as efficient source to inactivate both microbial cells and viruses [8, 9]. Within this study even low irradiation doses of thallium - antimony UV-C at spectral region of 200 – 280 nm containing many spectral lines showed to be efficient to obtain 99 % reduction of *E. coli* within 6 minutes of contact time. The obtained results demonstrate the potential application of thallium as alternative UV-C light source for microbial and viral contaminant inactivation on surfaces.

III. CONCLUSIONS

Mercury UV light source at 254 nm spectral line demonstrated 99,99 % reduction in less than 5 minutes. The thallium – antimony light source demonstrated lower but still comparable efficiency in tests with *Escherichia coli*. Thus, UV-C irradiation with non-mercury light sources can be a promising tool for surface and room disinfection.

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REFERENCES

[1] N.G. Reed, "The history of ultraviolet germicidal irradiation for air disinfection," Public health rep., vol 125(1), pp. 15-27, Jan-Feb. 2010.

[2] T. Dai, M.S. Vrahas, C. K. Murray, M.R. Hamblin, "Ultraviolet C irradiation: an alternative antimicrobial approach to localized infections?", Expert Rev Anti Infect Ther, vol. 10(2), pp. 185-195, Feb. 2012.

[3] M. Heßling, K. Hönes, P. Vatter, C. Lingenfelder, „Ultraviolet irradiation doses for coronavirus inactivation – review and analysis

of coronavirus photoinactivation studies", GMS Hyg. Infect. Control, vol.15, 2020, pp. 1-8.

[4] M. Buonanno, G. Randers-Pehrson, A.W. Bigelow, S. Trivedi, F.D. Lowy, H.M. Spotnitz, S.M. Hammer, D.J. Brenner, "207-nm UV light - A promising tool for safe low-cost reduction of surgical site infections. I: In vitro studies", PLoS One, vol. 8(10), Oct. 2013.

[5] Z. Gavare, A. Svagere, M. Zinge, G. Revalde, V. Fyodorov, Determination of gas temperature of high-frequency low-temperature electrodeless plasma using molecular spectra of hydrogen and hydroxyl-radical. Journal of Quantitative Spectroscopy & Radiative Transfer 113 1676–1682 , 2012

[6] G. Revalde et.all, Use of radiaton sources with mercury isotopes for real-time highly sensitive and selectibve benzene determination in air and natural gas by direct differential absorbtion spectrometry with the direct Zeeman effect, *Analytica Chimica Acta 887*, 172-178, 2015.

[7] A.A.Ganeev, Z. Gavare, V.I.Khutorshikov , S.V.Khutorshikov, G. Revalde, A.Skudra G.M.Smirnova, N.R.Stankov, High-frequency electrodeless discharge lamps for atomic absorption, Spectrochemica Acta B, Vol. 58, Issue 5, p. 879-889 (2003).

[8] A. H. Malayeri, M. Mohseni, B. Cairns, J. R. Bolton, „Fluence (UV dose) required to achieve incremental log inactivation of bacteria, protozoa, viruses and algae", IUVA Newa, 2016.

[9] M. Raeiszadeh, B. Adeli, "A critical review on ultraviolet disinfection systems against COVID-19 outbreak: applicability, validation, and safety considerations", ASC Photonics, Oct. 2020.

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Application of Low-Cost Optical PM Sensor for Monitoring of Particulate Matter Air Pollution in the Urban Environment: a Case Study in Esplanāde Housing Estate, Daugavpils City

Juris Soms
Dept. of Environmental Science and Chemistry
Daugavpils University
Daugavpils, Latvia
juris.soms@du.lv

Haralds Soms
Daugavpils secondary school No. 12
Daugavpils, Latvia
haralds.soms@gmail.com

Abstract **- The harmful health effects of airborne particulate matter (PM) pollutants are well-known. However, the spatial coverage of automated air quality observation stations of Latvian Environment, Geology and Meteorology Centre (LEGMC) is sparse. Therefore the capability for PM concentration detection was examined by using the low-cost optical PM sensor to improve the spatial resolution of environmental data. The aim of the study was to perform 24h/7d measurements of PM2.5 and PM10 concentrations during a period of one year and to identify air quality in Esplanāde housing estate, Daugavpils city. For data obtaining on the concentration of PM2.5 and PM10 particles measurements have been performed by optical sensor Nova SDS011; meteorological data were obtained using the database of LEGMC; for processing, analysis and visualization of obtained data statistical methods were applied. Evaluation of PM2.5 and PM10 daily average concentration variability in 2020 indicates that air quality in the urban environment could be assessed as good. A well-expressed statistical correlation between meteorological factors (t°C, relative humidity) and the average concentration of PM particles was not found. It highlights the necessity of further research.**

Keywords - air pollution, environmental quality, particulate matter sensor, PM2.5, PM10.

I. INTRODUCTION

Air pollution is a complex process that brings various physical, chemical, organic and other pollutants into the atmosphere that in result negatively affect living organisms including humans, and the natural environment [1]. Among these pollutants fine particulate matter (PM) entails harm to human health even at relatively low concentrations; hence the concerns on issues dealing with public health are straightforward. According to definitions, airborne PM consists of a heterogeneous mixture of solid and liquid particles suspended in the air that varies continuously in size and chemical composition in space and time [2]. The PM itself can be classified in several ways. However, the aerodynamic diameter of a fine particle usually is the generally accepted criteria to describe its transferring ability in the atmosphere and ability to penetrate and deposit in the respiratory tract [3]. Usually, particles have been divided into two size categories as either (1) coarse particulate matter (PM10) with an aerodynamic diameter of 10 μm or (2) fine particulate matter (PM2.5) with an aerodynamic diameter of 2.5 μm [3]. Because of their small size, PM remains suspended in the air for a long time due to turbulence of the atmosphere and, as a result of a transfer by wind, can be transported far from their original sources – for hundreds or even thousands of km [4].

Air pollution by fine particulate matter (PM) is common in urban environments and currently is ranked among important environmental concerns [5]. This type of air pollution can be released into the atmosphere by various activities or processes from both anthropogenic and natural sources [6]. Anthropogenic sources and human activities associated with PM emissions are highly variable and include agricultural and industrial production, combustion of fuel in transportation, energy sectors, construction and quarrying works, wearing of the road pavement by traffic and re-suspension of road dust, mechanical abrasion of vehicle tires and brakes etc. [7]-[11]. In comparison, those PM emissions occurring naturally can be accounted for by such sources as forest fires, windblown dust, volcano

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eruptions, spores and pollen from living vegetation, sea sprays etc. [12]-[13].

Considering that PM pollution can remain in the suspended state over long periods and can be transported over long distances, its harmful effect can cause a wide range of diseases. The researchers have been identified that exposure to high PM concentrations can cause numerous negative health effects including disorders in lung functions and lung cancer, asthma, exacerbation of chronic respiratory and cardiovascular diseases, premature mortality etc. [11], [13], [14]-[16]. Hence for the purposes of air quality monitoring and public health data analysis, PM10 and PM2.5 concentrations are being measured in very many countries. In Latvia the measurements of PM concentrations are carried out by automated air quality observation stations of Latvian Environment, Geology and Meteorology Centre (LEGMC). However, the spatial coverage of these stations is sparse, i.e. only in seven locations – two of these monitoring points are located in Riga, other five in Liepāja, Rucava, Rēzekne, Ventspils and Zosēni. At the same time, there is no monitoring of air quality in the second largest city in Latvia – Daugavpils. Considering that, the capability for PM concentration detection in a practical application was examined by using the low-cost optical PM sensor to monitor air quality in the urban environment and to improve the spatial resolution of environmental data.

II. Materials and methods

The aim of the present study was to perform continuous 24h/7d measurements of PM2.5 and PM10 concentrations during a period of one year and to identify air quality in Esplanāde housing estate, Daugavpils city. For the obtaining of data on the PM2.5 and PM10 concentrations, measurements have been performed by optical sensor Nova SDS011. This sensor corresponds to a category of DIY (*Do It Yourself*) measuring instruments because it can be easily assembled from module components. Besides, thousands of Nova SDS011 sensors are connected into the global network which is maintained by public platform openSenseMap at the Institute for Geoinformatics in Münster for storing and visualising open environmental sensor data [17]. The sensor was mounted in outdoor environment beside the premises of the Daugavpils University. The air intake nozzle of the sensor was put into a downward-orientated U-shaped plastic tube ensuring that the precipitation or small windblown physical objects cannot get into the sensor. The characteristics of the sensor are given in Table 1. The main advantages of such sensors are the low-cost pollution monitoring; easy operation; low energy consumption; high frequency of data recording (Table 1). Therefore such sensors are well suited for developing of widely dispersed sensor networks [18], [19].

TABLE 1 CHARACTERISTIC OF PM SENSOR USED IN THE RESEARCH

Parameter	**Characteristic**
Sensor model	SDS011
Manufacturer	Nova Fitness
Approximate price (EUR)	68
Dimensions (mm)	71 × 70 × 23
Approximate weight (g)	50
Power supply voltage (V)	5
Working current (mA)	220
Detectable size range (μm)	0.3–10
Size bins	Not available
Estimated PMx concentration	PM2.5; PM10
Concentration range (μg/m^3)	0–999.9
Measurement frequency	once per minute
Data logging	To cloud server via WiFi

The sensor was pre-calibrated by the manufacturer, and, in addition, studies of scientific literature reveal that low-cost optical PM sensors generally well record the trend of PM concentration changes in the air and errors associated with overestimates or underestimates are within the range up to 7% [20]. Hence the results of this study can be utilised for the monitoring of air pollution by particulate matter. The measurements of both PM2.5 and PM10 concentrations (unit - μg/m^3) were performed every minute continuously 24h/7d during the 2020 monitoring year. All data on concentrations were transferred via WiFi and stored in the cloud server of the Institute for Geoinformatics in Münster [17].

In order to identify the correlation between weather conditions (air t°C; relative humidity) and PM concentrations, selection and aggregation of meteorological data for station Daugavpils were done using the public database of LEGMC [21]. In that way, hourly values of meteorological data were downloaded for the whole period of monitoring and subsequently modified by Microsoft Excel into tables with columns containing the date, time and record of the parameter.

The data on measured PM concentrations were downloaded from the cloud server [17] as *.csv format files for each month of the monitoring period, obtaining four separate data rows – PM2.5 hourly max. concentrations, PM2.5 hourly average concentrations, PM10 hourly max. concentrations and PM10 hourly average concentrations, respectively. The *.csv data rows cannot be directly used for correlation and frequency analysis, therefore the Microsoft Excel functions TEXT TO COLUMNS, TRANSPOSE, MID, SUBSTITUE and CONCATENATE were applied to convert initial raw data into the tables with columns containing the date, time and record of the relevant concentration value.

To assess the level of air pollution by fine PM2.5 and PM10 particles and elucidate air quality in the urban environment of Esplanāde housing estate, the recorded concentrations were examined in respect to exceeding the thresholds specified by official regulations in Latvia (Table 2).

TABLE 2 INDEX OF AIR QUALITY AND CORRESPONDING THRESHOLD VALUES OF PM2.5 AND PM10 CONCENTRATION IN THE AIR [22]

Index of air quality	**PM2.5 threshold value (μg/m^3)**	**PM10 threshold value (μg/m^3)**
Very good	< 10	< 20
Good	10 – 20	20 – 40

Moderate	20 – 25	40 – 50
Poor	25 – 50	50 – 100
Very poor	50 – 75	100 – 150
Particularly poor	> 75	> 150

The correlation and regression analysis of the recorded data was performed following the standard procedures of environmental statistics and data analysis [23], [24].

Finally, interpretation of data obtained by low-cost optical PM sensor in the course of one year period monitoring of particulate matter air pollution in the urban environment was done.

III. Results and Discussion

A. Monthly and intra-annual variability of PM2.5 and PM10 concentrations

The measurements of PM2.5 and PM10 concentrations by the sensor Nova SDS011 have been performed for one full year, obtaining 527 040 records. After the processing of these data, the line charts as graphic representations of the variability of PM2.5 hourly max. and average concentrations, and PM10 hourly max. and average concentrations were analysed and compared on a monthly scale.

The results indicate that for both PM2.5 and PM10 hourly max. concentrations air quality threshold limits were quite often exceeded. In some months, e.g. in June, PM2.5 hourly max. concentrations for a short time exceed value 425 µg/m3. However, max. concentration reflect only the short-period temporarily peak values which do not characterize the overall situation of air quality. Therefore hourly average concentrations were analysed too as it is proposed by World Health Organization report on air pollution [2]. From this point of view, the quality of the environment in Esplanāde housing estate can be considered good - PM concentrations only temporarily exceeded air quality limit values during each month. The thresholds 25 µg/m^3 and 50 µg/m^3 for PM2.5 and PM10 concentrations, respectively, were most often exceeded in March. The most feasible explanation of this effect is the impact of old grass burning in the spring and releasing particulate matter by smoke. The results of the research also reveal that PM concentrations can fluctuate greatly at a short temporal scale as either from one day to the next or even hourly. This is consistent with data given in the literature on issues of PM pollution [25].

To better estimate the quality of the environment, as well as to get a more complete understanding on the aspects of annual and inter-seasonal variability of the PM2.5 and PM10 concentrations, all hourly values of 2020 was aggregated into daily ones and plotted as a line chart. (Fig. 1). Daily average values allow us to assess air quality even better because they provide the information on the number of days when exceedance of threshold limits occurred, hence permitting to identify potential negative effects of the PM pollution associated with longer exposure to high PM concentrations [2]. Within the period of PM2.5 monitoring, the 24-hour threshold limit for the protection of human health (25 µg/m^3) for this type of particulate matter pollution concentration in the air was exceeded 7 times (Fig. 1). Thus citizens were not exposed to the negative influence of PM2.5 particles for long period. As for PM10 particulates, the 24-hour threshold limit value for the protection of human health (50 µg/m^3) was exceeded 14 times during the measurement period, particularly in autumn (Fig. 1). The EC Ambient Air Quality Directive [26] and World Health Organization [2] stipulate that the PM10 limit value should not be exceeded more than 35 times in a calendar year. Hence the results point out that air quality in the urban environment of Daugavpils could be assessed as good.

As for PM2.5 and PM10 particulates, the exceeding of limit values of average daily particulates concentrations mostly occurred in September and October (Fig. 1). This fact can be explained by the transboundary transferring of PM aerosols to Latvia by the wind from southern regions of the Russian Federation and eastern Ukraine, where extensive forest fires occurred in the autumn of 2020.

In general, during the warm period of the year from April till October concentrations of PM particulates are lower in comparison to the cold period (Fig. 1). This could be explained by the decrease in solid fuel combustion at residential dwellings during the warm season.

In order to find out the relationship between two components of the air PM pollution, the regression analysis of obtained data on average daily PM10 concentration values versus average daily PM2.5 concentration values has been performed. The results plotted in the bivariate scatter diagram (Fig. 2) show that with an increase of the average daily PM10 concentration values, the average daily PM2.5 concentration values also increase. Furthermore, this regularity is confirmed by the statistical analysis, which indicates that there is a statistically significant strong positive linear correlation between average daily PM10 concentration and average daily PM2.5 concentration in the air (Pearson's correlation coefficient $r = 0.89$ at $p<0.01$). Such a close relationship can be explained by the fact that the group of PM10 particulates actually includes aerosols with an aerodynamic diameter < 10 µm including also finer PM2.5 particles. However, due to differences in their formative processes, sources of provenance and composition, correlation is not perfect. From chart also follows that the distribution of points in the relationship diagram is uneven (Fig. 2).

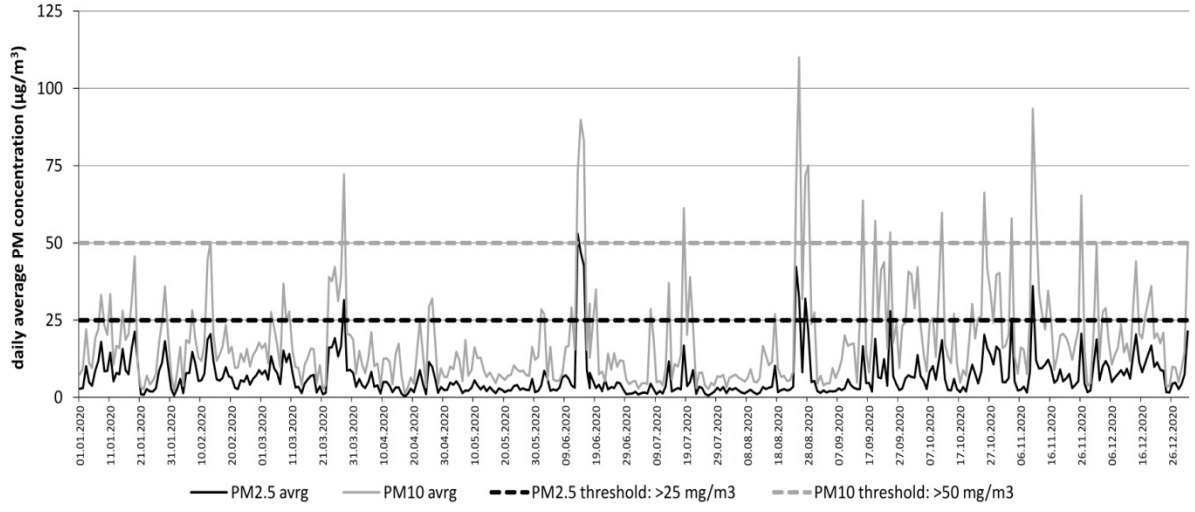

Fig. 1. Variability of daily average PM2.5 and PM10 concentrations in the air of Esplanāde housing estate in 2020 and the 24 hour threshold limits defined by LEGMC for air pollution by particulate matter.

Many points form a compact group at low concentrations – up to 20 µg/m^3 and 10 µg/m^3 for PM10 and PM2.5 particulates, respectively. Hence it indicates that the majority of recorded PM2.5 and PM10 daily concentrations in the air are low, under the limit value for the protection of human health.

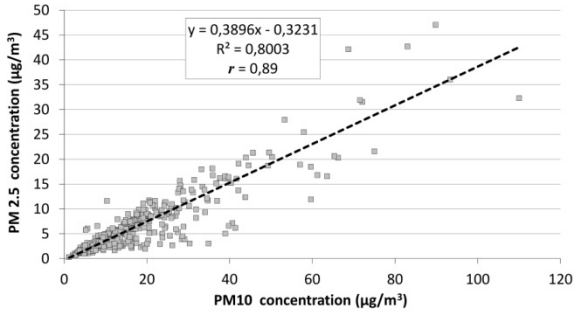

Fig. 2. Relationship between average daily PM10 concentration and average daily PM2.5 concentration in the air of Esplanāde housing estate (Daugavpils) in 2020.

B. Variability in hourly concentrations of PM10 and PM2.5 particulates at a daily temporal scale

In the next stage data recorded by the PM sensor were analysed in order to find out the dynamics of changes in hourly concentrations of PM10 and PM2.5 particulates at a daily temporal scale for each month. For that statistical processing of data and distribution frequency analysis have been done. It allowed to identify when exceedance of limits specified for air quality indices [22] occurred at certain hours of the day. The PM10 and PM2.5 concentration daily distribution frequencies of each month subsequently were compared and inter-seasonal variability of ones was estimated (Fig. 3).

The distribution frequency histogram reveals that in the winter season there is a tendency of PM concentrations increasing at evening hours. This increasing is most pronounced from 17:00 till 20:00 (Fig. 3a; 3b). During these hours, air quality threshold values 25 µg/m^3 for PM2.5 and 50 µg/m^3 for PM10 are also most often exceeded. During the night time, PM concentrations decrease. However, limited pollution by fine particulates persists throughout the day (Fig. 3a; 3b).

The established regularity can be explained by the impact of many private residential houses in Grīva housing estate located just on the opposite bank of the River Daugava. In winter time residents of the aforementioned dwelling area burn up wood or other types of solid fuel in stoves and boilers, hence smoke and associate PM pollution plumes are transported across the river towards Esplanāde housing estate. This finding indicates that in winter time the main source of air pollution by PM particulates in the study area is the combustion of solid fuel at residential dwellings.

At the spring and autumn seasons distribution frequency patterns are similar to winter ones (Fig. 3c; 3d; 3g and 3h), i.e. there is a tendency of PM concentration increasing at evening hours. Notwithstanding, in the spring increasing is shifted to late evening hours due to longer daytime. In the autumn of 2020 more frequent exceedance of limits specified for air quality indices is associated with transboundary transferring of PM aerosols to Latvia by the wind from countries, where extensive forest fires occurred.

The distribution frequency pattern at the summer season indicates that there is no explicit regularity of the PM2.5 and PM10 concentration variability at a daily scale (Fig. 3e; 3f). The exceedance of limits specified for PM2.5 concentrations in the afternoon can be explained by the suspension of dust particles by the wind when the ground surface dries up. Besides, summer time is the period when the flowering of many plant species occurs, thus a significant amount of pollens enters in the atmosphere. The fact that pollen is a direct source of PM aerosols, particularly PM10 particulates, has been revealed in scientific studies on PM pollution sources [4]; [11]. In comparison to other seasons, however, air quality is much better.

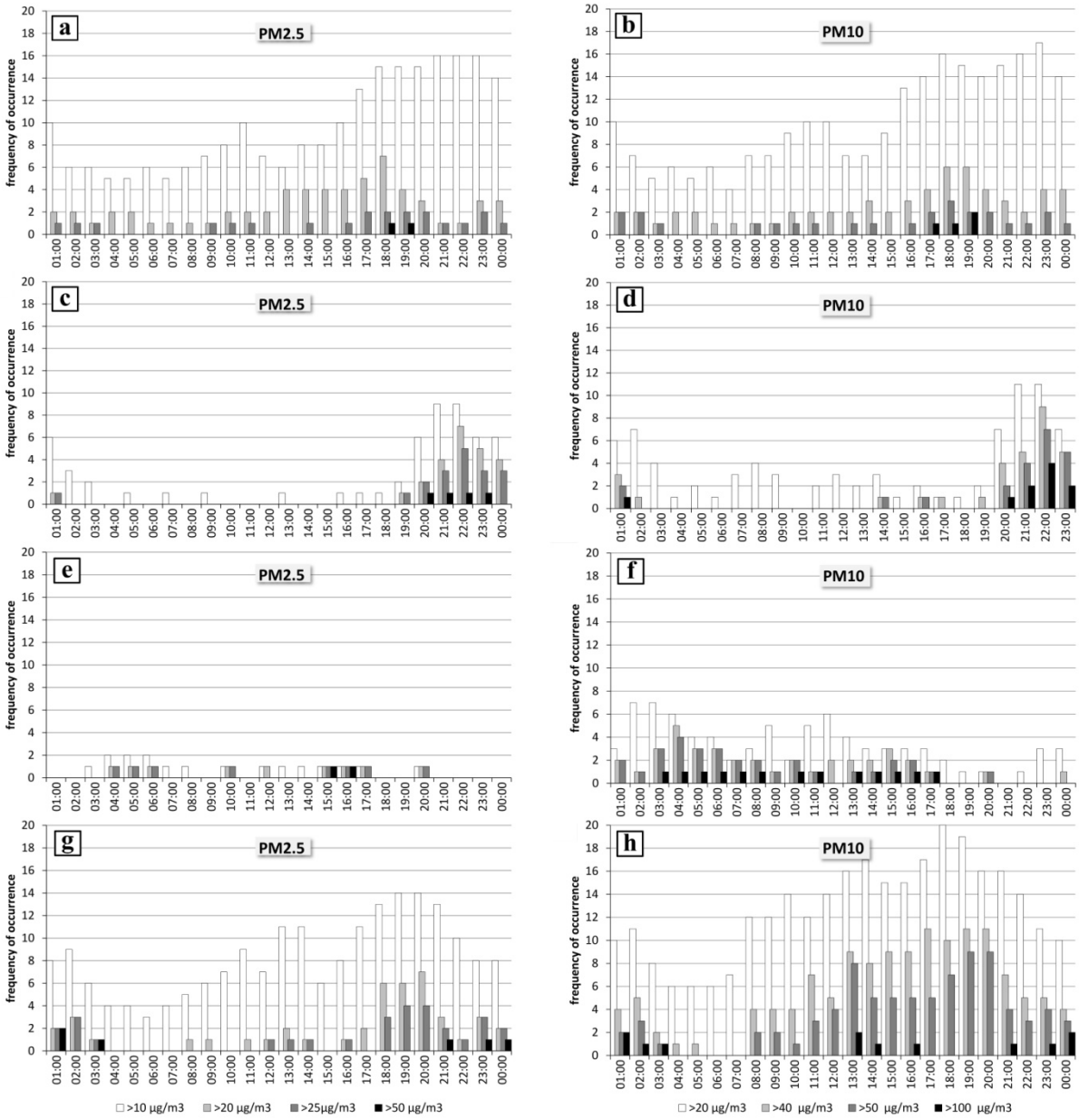

Fig. 3. The frequency histograms showing inter-seasonal variability of the PM2.5 and PM10 concentration distribution at a daily temporal scale (hours of the day when exceedance of corresponding limits specified for air quality indices occurred): examples of the PM concentration distribution for the winter season (**a** and **b**; January as an example), the spring season (**c** and **d**; April as an example), the summer season (**e** and **f**; July as an example) and the autumn season (**g** and **h**; October as an example).

C. Impact of meteorological factors on PM2.5 concentrations

The regression analysis of obtained data on average daily PM2.5 concentration values versus values of meteorological factors (air t°C; relative humidity) have been performed in order to elucidate possible relationships. In this case PM10 concentrations were not analysed due to fact that PM2.5 particulates have more harmful health effects then PM10 [11].

Theoretically, lower temperatures in the winter season should correlate with higher concentration of PM2.5 due to increase in fuel combustion as well as formation of stagnant atmospheric conditions [13], [27]. On the other hand, higher temperatures in the summer season should correlate with higher concentration of PM2.5 due to remobilization of dust by wind from dried soils and roads, as well as and enhancing secondary photochemical reactions in the atmosphere, which in turn increase the concentration of fine particles [13], [28]. Despite that, no consistent, well-expressed pattern has been found between air temperature and PM2.5 concentrations neither in the winter (Fig. 4a) nor in the summer (Fig. 4b). Thus statistical analysis of data for the winter season and scatter plot (Fig. 4a) indicate that there is statistically significant, but a very weak negative linear correlation between air temperature and PM2.5 concentration (Pearson's correlation coefficient $r = -0.24$ at $p < 0.05$).

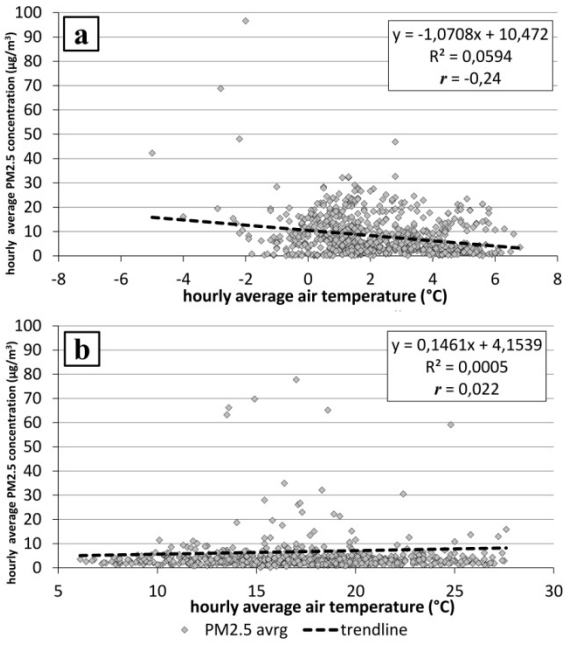

Fig. 4. Relationship between air temperature and PM2.5 concentration in the air of Esplanāde housing estate (Daugavpils) in the winter season (a) and the summer season (b) of 2020.

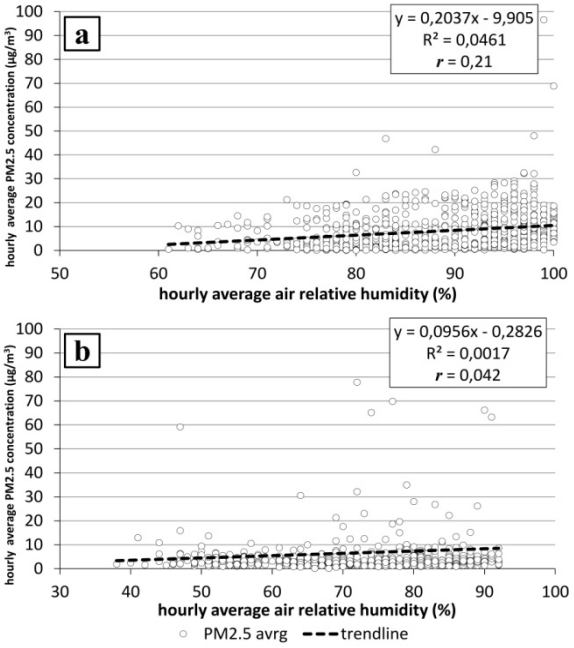

Fig. 5. Relationship between air relative humidity and PM2.5 concentration in the air of Esplanāde housing estate (Daugavpils) in the winter season (a) and the summer season (b) of 2020.

It is obvious that the highest PM2.5 concentration values correspond to lower temperatures, however, we have to take into account that winter of 2020 was unusually warm and it could have an effect on the results. Therefore the correlation has to be examined additionally in further research. Besides, the relationship in the summer period is not confirmed by the statistical analysis and scatter plot (Fig. 4b), which indicate that there is no statistically significant linear correlation between air temperature and PM2.5 concentration (r= 0.022 at p=0.55).

Similarly, the obtained results show that relative humidity also has no consistent correlation with PM2.5 concentrations neither in the winter nor in the summer (Fig. 5). As it follows from statistical analysis of data for the winter season and scatter plot (Fig. 5a), there is statistically significant, but a very weak positive linear correlation between relative humidity and PM2.5 concentration (r = 0.22 at $p < 0.05$).

However, the relationship in the summer period is not confirmed by the statistical analysis (Fig. 5b), i.e. there is no statistically significant linear correlation between air temperature and PM2.5 concentration (r = 0.042 at p = 0.27). Literature review reveals that some components of PM2.5 aerosols like organic compounds and dust particles decrease with higher humidity levels, while the concentration of others like sulphates in contrary increases [13], [28]. Furthermore, the higher humidity level can have a twofold impact: on the one hand, it can lead to the formation of microdroplets in the air causing the increase of aerosols concentration; on the other hand, it can lead to further condensation and to precipitation, which decreases overall PM2.5 particulates level [13], [29].

IV. Conclusions

The obtained results indicate the possibility to apply a low-cost optical PM sensor for monitoring of particulate matter air pollution in the urban environment, hence the main goal of the study has been achieved.

Within the period of PM particulates monitoring, the limit values for the protection of human health were exceeded less than 35 times which is specified in regulations. Thus citizens were not exposed to the negative influence of PM pollution for a long period and air quality in the urban environment could be assessed as good.

The main source of air pollution by PM particles is the burning of solid fuel at residential dwellings in Grīva housing estate, from where pollution plumes are transported towards Esplanāde housing estate.

In general, the decrease in solid fuel combustion at residential dwellings during the warm period of the year results in lower PM concentrations in comparison to the cold period.

There is a tendency of PM concentrations increasing at evening hours in the autumn, spring.

The decreasing of air quality can be caused by the transboundary transferring of PM aerosols to Latvia by the wind from other countries or regions.

A well-expressed statistical correlation between meteorological factors (air temperature, relative humidity) and the hourly average concentration of PM particles was not found. It highlights the necessity of further research.

REFERENCES

[1] K-H. Kim, S.A. Jahan, E. Kabir, "A review on human health perspective of air pollution with respect to allergies and asthma. Environment International, vol. 59, pp. 41–52, Sept. 2013. https://doi.org/10.1016/j.envint.2013.05.007

[2] World Health Organization: Review of evidence on health aspects of air pollution –REVIHAAP project: Technical Report Copenhagen, Denmark: WHO Regional Office for Europe, 2013. [Online]. Available: http://www.euro.who.int/__data/assets/pdf_file/0004/193108/REVIHAAPFinal-technical-report.pdf [Accesed: Feb. 12, 2020]

[3] R. Esworthy, "Air quality: EPA's 2013 changes to the particulate matter (PM) standard," Congressional Research Service 7-5700, No. R42934, p. 6, 2013

[4] K. Cheung, N. Daher, W. Kam, M.M. Shafer, Z. Ning, J.J. Schauer, C. Sioutasa, "Spatial and temporal variation of chemical composition and mass closure of ambient coarse particulate matter (PM10–2.5) in the Los Angeles area," Atmospheric Environment, vol. 45 (16), pp. 2651–2662, May 2011. https://doi.org/10.1016/j.atmosenv.2011.02.066

[5] P.L. Kinney, "Climate change, air quality, and human health," Am J Prev Med, vol. 35 (5), pp. 459–567, Nov. 2008, https://doi.org/10.1016/j.amepre.2008.08.025

[6] R.W. Atkinson, G.W. Fuller, H.R. Anderson, R.M. Harrison, B. Armstrong, "Urban ambient particle metrics and health. A time series analysis," Epidemiology, vol. 21, pp. 501–511, Jul. 2010. https://doi.org/10.1097/EDE.0b013e3181debc88

[7] A. Charron, R. Harrison, "Fine and coarse particulate matter on a heavily trafficked London highway: sources and processes," Environ Sci Technol, vol. 39 (20), pp. 7768-7776. Oct. 2005, https://doi.org/10.1021/es050462i

[8] T. M.C.M. de Kok, H. A.L. Driece, J.G.F. Hogervorst, J. J. Briedé, "Toxicological assessment of ambient and traffic-related particulate matter: A review of recent studies," Mutation Research, vol. 613, (2–3), pp. 103-122, Nov.–Dec. 2006, https://doi.org/10.1016/j.mrrev.2006.07.001

[9] B. Srimuruganandam, S. Nagendra, "Source characterization of PM10 and PM2.5 mass using a chemical mass balance model at urban roadside,"Sci Total Environ, vol. 433, pp. 8–19. Sept. 2012, https://doi.org/10.1016/j.scitotenv.2012.05.082

[10] P. Kassomenos, S. Vardoulakis, A. Chaloulakou, G. Grivas, R. Borge, J. Lumbreras, "Levels, sources and seasonality of coarse particles (PM10-PM2.5) in three European capitals - Implications for particulate pollution control," Atmospheric Environment, vol. 54, pp. 337-347, Jul. 2012, https://doi.org/10.1016/j.atmosenv.2012.02.051

[11] K-H. Kim, E. Kabir, S. Kabir, "A review on the human health impact of airborne particulate matter," Environment International, vol. 74, pp. 136–143. Jan. 2015, http://dx.doi.org/10.1016/j.envint.2014.10.005

[12] C. Misra, M.D. Geller, P. Shah, C. Sioutas, P.A., Solomon, "Development and evaluation of a continuous coarse (PM10–PM2.5) particle monitor," J Air Waste Manage Assoc, vol. 51, pp. 1309–1317, Dec. 2001. https://doi.org/10.1080/10473289.2001.10464360

[13] N. R. Martins, G. C. da Graça, "Impact of PM2.5 in indoor urban environments: A review," Sustainable Cities and Society, vol. 42, pp. 259-275. Oct. 2018 https://doi.org/10.1016/j.scs.2018.07.011

[14] E, Samoli, R. Peng, T. Ramsay, M. Pipikou, G. Touloumi, F. Dominici, R. Burnett, A. Cohen, D. Krewski, J. Samet, K. Katsouyanni, "Acute effects of ambient particulate matter on mortality in Europe and North America: results from the APHENA Study," Env Health Persp, vol. 116 (11), pp. 1480–1486, Nov. 2008. https://doi.org/10.1289/ehp.11345

[15] K. Katsouyanni, J.M. Samet, H.R. Anderson, R. Atkinson, A. Le Tertre, S. Medina, E. Samoli, G. Touloumi, R.T. Burnett, D. Krewski, T. Ramsay, F. Dominici, R.D. Peng, J. Schwartz, A. Zanobetti, "HEI Health Review Committee, 2009. Air pollution and health: a European and North American approach (APHENA). Research Report Health Effects Institute, vol. 142, pp. 5-90.

[16] H. Ather, S. Z. Ilyas, S. Agathopoulos, S. M. Hussain, A. Jalil, S. Ahmed, Y. Baqir, "Evaluation of adverse effects of particulate matter on human life," Heliyon, vol. 7 (2), e05968, Febr. 2021. https://doi.org/10.1016/j.heliyon.2021.e05968

[17] openSenseMap, openSenseMap platform for open sensor data, 2020. [Online]. Available: https://opensensemap.org/about [Accesed: Jan. 01, 2020]

[18] N. Zikova, M. Masiol, D. Chalupa, D. Rich, A. Ferro, P. Hopke, "Estimating hourly concentrations of PM2.5 across a metropolitan area using low-cost particle monitors," Sensors, vol. 17(8), p. 1922, Aug. 2017. https://doi.org/10.3390/s17081922

[19] J. Hua, Y. Zhang, B. de Foy, X. Mei, J. Shang,Y. Zhang, I. D. Sulaymon, D. Zhou, "Improved PM2.5 concentration estimates from low-cost sensors using calibration models categorized by relative humidity," Aer Sc & Techn, Feb. 2021, https://doi.org/10.1080/02786826.2021.1873911

[20] M. Badura, P. Batog, A. Drzeniecka-Osiadacz, P. Modzel, "Evaluation of Low-Cost Sensors for Ambient PM2.5 Monitoring," Journal of Sensors, vol. 2018, pp. 1-16, Oct. 2018. https://doi.org/10.1155/2018/5096540

[21] Meteorological network, Latvian Environment, Geology and Meteorology Centre (LEGMC) data base of meteorological data records, 2020. [Online]. Available: https://www.meteo.lv/meteorologija-datu-meklesana/?nid=461 [Accesed: Dec. 31, 2020]

[22] Index of the air quality, Latvian Environment, Geology and Meteorology Centre (LEGMC), 2020. [Online]. Available: https://videscentrs.lvgmc.lv/lapas/gaisa_kvalitates_indekss [Accesed: Nov. 14, 2020]

[23] W. R. Ott, Environmental Statistics and Data Analysis, London: CRC Press, 1994, pp. 336

[24] Essential Environmental Science: Methods and Techniques,. Watts S. and Halliwel L. (eds.), London: Routledge, 1996, 544 pp.

[25] C. Johansson, M. Norman, L. Gidhagen, "Spatial and temporal variations of PM10 and particle number concentrations in urban air," Environ Monit Assess, vol. 127 (1–3), pp.477–87, Sept. 2007, https://doi.org/10.1007/s10661-006-9296-4

[26] Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe, Official Journal of the European Union, vol. L 152, 11.6.2008, pp. 1–44 http://data.europa.eu/eli/dir/2008/50/oj

[27] R. Toro A., R. G. E. Morales S., M. Canales, C. Gonzalez-Rojas, M. A. Leiva G., "Inhaled and inspired particulates in Metropolitan Santiago Chile exceed air quality standards," Building and Environment, vol. 79, pp. 115–123, Sept. 2014. https://doi.org/10.1016/j.buildenv.2014.05.004

[28] B. M. Kim, J. Seo, J. Y. Kim, J. Y. Lee, Y. Kim, "Transported vs. Local contributions from secondary and biomass burning sources to PM2.5, "Atmospheric Environment, vol. 144, pp. 24–36, Nov. 2016. https://doi.org/10.1016/j.atmosenv.2016.08.072

[29] J. Luo, P. Du, A. Samat, J. Xia, M. Che, Z. Xue, "Spatiotemporal pattern of PM2.5 concentrations in Mainland China and analysis of its influencing factors using geographically weighted regression," Scientific Reports, vol. 7, No. 40607, pp. 1-14, Jan. 2017. https://doi.org/10.1038/srep40607

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Using of Airborne LiDAR Altimetry and Semi-Automated GIS Tools for Identification and Mapping of Fluvial Terraces in the Augšdaugava Spillway Valley

Juris Soms
Dept. of Environmental Science and Chemistry
Daugavpils University
Daugavpils, Latvia
juris.soms@du.lv

Valdis Vorslavs
Faculty of Natural Sciences and Mathematics
Daugavpils University
Daugavpils, Latvia
valdis.vorslavs@inbox.lv

Abstract **- River terraces are one of the typical and widespread Quaternary fluvial landforms in Latvia. Until recently, distinguishing and mapping of these features have required extensive field surveys. However, the availability of high resolution digital elevation models (DEM) derived from airborne laser altimetry and application of modern geographic information systems (GIS) provides sufficient background to resolve these tasks. In this study, we apply an integrated methodology based on using of remote sensing, i.e. laser scanning or Light Detection and Ranging (LiDAR) data and combining of semi-automated TerEx tools for the detection of fluvial terraces in DEM. The empirical tests performed using the tools in the study area reveal that the application of TerEx gives the reliable results. However, presence of minor landforms which increase the topographical roughness of the surface directly influence the quality of extracted data, thus leading to the necessity of additional manual editing. The obtained data indicate that the terrace sequence in the Augšdaugava spillway valley consists of eight different terrace levels – T1 to T8. Only terraces T1 and T2 are easily recognizable in the study area, whereas the upper terraces do not have explicit edges.**

Keywords - Augšdaugava spillway valley, DEM, fluvial terraces, GIS, LiDAR.

I. INTRODUCTION

Fluvial terraces are rather common landscape elements of many watercourses located in different regions across the entire planet. These relief features associated with river valleys are typical and widespread Quaternary fluvial landforms in Latvia too [1].

In general, stream terraces can be characterized as geomorphological units of river valleys that developed through the fluvial morphogenesis, i.e. downcutting of water stream into a previously formed floodplain [2]. This process leads to the formation of a distinctive step-like topographic cross profile, where terraces are situated at a higher elevation above the current floodplain. Terraces as features of fluvial origin typically have a relatively flat, sub-horizontal surface, which is separated from the adjacent elements of the valley below or above by a steep slope or scarp [3]. As with other landforms, fluvial terraces are described by the material of which they are formed, in this case – alluvial deposits. Considering the thickness of these deposits, as well as the morphology of terraces, two main types of alluvial terraces can be distinguished – strath or erosional terraces and fill or aggradational terraces [4]. The first ones can be formed in valleys of actively incising rivers and are characterized by thin layers of alluvium covering a bedrock surface. In contrary, fill terraces typically are developed in valleys as a response to stabilization or rise in base level and are characterized by thick deposits of alluvial material covering terrace surfaces [4], [5].

Fluvial terraces are considerably complex since they have been developed in the course of the interplay of many geological processes - incision, accumulation, lateral erosion and mass wasting This fact can be attributed to fluvial terraces in south-eastern Latvia (Fig. 1a), where the terraced Augšdaugava spillway valley (WGS84 55°53'44" North and 26°52'26" East) (Fig. 1b) represent the evidence of past fluvial activity as driving force of landscape evolution during the transition from glacial to periglacial

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and later to post-glacial conditions in this region [1], [6]. Therefore terraces are substantial 'archives' of paleoenvironmental and geomorphological data, as they could provide key information for a better understanding of the morphogenesis of the spillway valley and to untangle its evolutionary history. In addition, the data obtained from the research of terraces would be also useful to provide the framework for the management and use of natural resources, e.g. identification and assessment of sand and gravel deposits associated with river terraces. Thus it indicates the need for precise identification and mapping of terraces.

However, these geomorphological units as fluvial landforms of complex origin commonly are not well expressed and preserved in the Augšdaugava spillway valley. It is a result of Daugava meandering, topography smoothed by mass wasting and active water erosion processes, making their identification difficult. Until recently, distinguishing and mapping of these features has required extensive field surveys and has been extremely time consuming [7]. However, over the several last years in Latvia, the availability of high resolution DEM derived from airborne laser altimetry and application of modern GIS techniques provides sufficient background to resolve these problems. Hence the main goal of the study presented in this article was to apply an integrated methodology based on using of remote sensing (LiDAR) data and combining of different semi-automated GIS analysis tools for the detection, delineation and mapping of fluvial terraces in DEM.

II. Materials and methods

The general aim of this research was to verify a high-precision and high-resolution relief data analysis methodology applying GIS and geospatial analysis for the detection and mapping of fluvial landforms. To reach this aim, a methodology elaborated by Demoulin et al. [8] and further developed by other authors [7]-[9] was applied. In a broader context, this study was carried out to promote and facilitate the understanding of the geological processes and controlling factors involved in the geomorphological evolution of the Augšdaugava spillway valley, terraces of which never before have been studied with this methodology. For this purpose, this study suggests the novelty of using high-resolution (pixel 0,5 m) DEM for processing data on elevation with GIS tools to identify and delineate geomorphological features. Besides, the reliability of the methodology is assessed by comparing and validating the results of GIS analysis with field survey.

In this research, LiDAR data available in the Digital Height Data open data infrastructure [10] of the Latvian Geospatial Information Agency (LGIA) was used to generate a high resolution DEM. In the Augšdaugava spillway valley, the airborne laser scanning coverage provided by LGIA consists of 317 data folders in *.LAS format, each one of 1 km^2 extent.

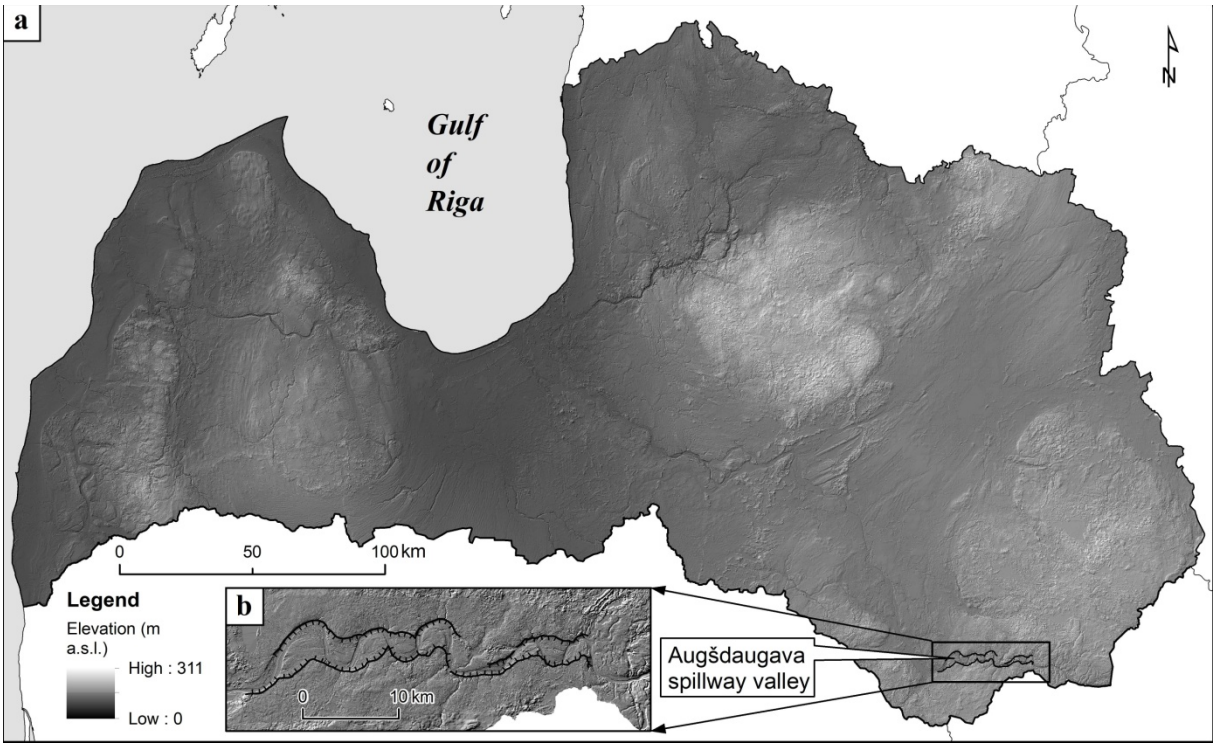

Fig. 1. Location of study area – the Augšdaugava spillway valley in Latvia (A), and relief of the study area and adjacent territories (B) by a shaded DEM in the background.

The data density of points characterizing the Earth's topographic surface is not less than 4 p/m² in open areas, and in areas under forest vegetation – not less than 1.5 p/m². LiDAR data is linked to the LKS-92 TM coordinate system and LAS-2000.5 for the Latvian standard altitude system. The vertical accuracy of data is up to 0.12 m (2 σ with 95% confidence level) against the State Geodetic Network, the horizontal accuracy of data is up to 0.36 m (2 σ with 95% confidence level) against the State Geodetic Network.

For optimization of DEM constructing process, firstly all 317 LiDAR archives of the *.LAS data points have been merged into *.LAS dataset covering the whole spillway valley. Then LiDAR point cloud was filtered with ArcGIS 10.8.1 software by classification code 'ground' and using the automated tool [11], thus extracting from *.LAS dataset only points representing the bare earth and excluding points other than relief surface. Subsequently, ESRI regular grid raster format DEM with spatial resolution 0.5 m was created from pre-processed data by ArcGIS tool 'LAS Dataset to Raster' following the standard procedure of the Inverse-Distance Weighting (IDW) interpolation [12]. The IDW is a deterministic method of georeferenced point data interpolation and it is one of the most popular methods adopted in geosciences [13]. The obtained regular grid raster file additionally was processed with the Hydrology Fill tool to get a smoothed DEM with filled sinks and corrected pixels of elevation errors. Vectorised Daugava channel shapefile, river tributaries shapefiles and other additional geospatial data were also prepared for further analysis.

After the construction of DEM, the TerEx toolbox [7] integrated into the ArcGIS environment was used for extraction and delineation of terrace surfaces. Considering physical attributes of real terraces and floodplains, several adjustable parameters have to be set as rules for extraction of terraces in TerEx toolbox: (i) local difference in relief of the flattened surface of terrace cannot exceed a user-defined value (unit - m) within a user-defined area of moving window (unit - m^2); (ii) the user-defined minimum area of the potential terrace surface (unit - m^2); (iii) the user-defined width (unit - m) of the spillway valley within which the potential surface of the terrace must be located; and (iv) smoothing parameter (unitless). Following these rules, the semi-automated GIS tools of TerEx perform the identification and delineation of fluvial terraces in two steps. In the first step, the TerEx analyzes DEM and successively performs the following operations: (i) selecting raster cells from DEM which correspond to surfaces of potential terraces; (ii) removing non-selected raster cells that are not surfaces of terraces; (iii) generalizing the shape of the selected surfaces; and (iv) finally producing a shapefile consisting of potential fluvial terrace surfaces. At the end of the first step, the preliminary delineated terraces surfaces should be edited by a user, because these fluvial landforms may be inappropriately identified in cases if the scarp between adjacent flattened surfaces is gentle or modified by erosion, or if the terrace is dissected by gullies or roads, or by other minor landforms.

In the second step, the TerEx uses the Daugava river channel centreline shapefile and splits the stream at a specified interval (100 m) into equal sections. Then the average elevation of each stream section is automatically extracted from the DEM. After that, the attribute table of terraces is joined with the stream section attribute table, and the average elevation of the terrace surface is calculated. Hence after applying DEM analysis by TerEx tool, a shapefile showing the distribution of terraces and containing data on elevation of terraces is obtained. However, presence of minor landforms which increase the topographical roughness of the surface, e.g. gullies or glaciokarst kettles directly influence the quality of extracted data, thus leading to the necessity of additional manual editing.

In order to provide visual identification of other geomorphological features associated with the surfaces of fluvial terraces, e.g. landforms of aeolian origin, as well as for precise delineation of fluvial relief elements like foothills and edges of terraces, hill-shaded relief model was derived from DEM, and slope and profile curvature GIS tools were applied. In the process of visual interpretation, combining different raster layers, landforms or their elements were manually digitised as polygon or polyline features. Overlaying fluvial terrace surface shapefiles with the latter ones digital geomorphological map of the Augšdaugava spillway valley was developed. After the completion of GIS works, the reliability of the obtained data on the location of fluvial terraces and their elements was assessed during field geomorphological reconnaissance supported by GPS survey. During field expeditions also geological survey was carried out and the spatial distribution of terraces forming Quaternary sediment cover was ascertained. For this purpose mainly conventional geologic survey georeferenced by GPS, i.e., hand-dug pits and near-surface augering by AMS Mud Auger or Eijkelkamp equipment were used to investigate the lithofacies of sediments, as well as their spatial distribution. These data were compiled with the geomorphological map of terraces identified from DEM; hence the detailed framework for further studies was established.

III. Results and discussion

Fluvial terraces represent evidence of incision by fluvial activity in the Augšdaugava spillway valley, and as it was mentioned before, are substantial 'geo-archives' of paleoenvironmental and geomorphological data. Therefore it is necessary to identify precisely the number, elevation and distribution of terraces along the present-day profile of the river within the Augšdaugava spillway valley, which is one of the largest and at the same time oldest of such landforms in Latvia [14]. Notwithstanding that studies on the development and geomorphology of the terraced spillway valley have been carried out in Latvia since the 1930s [15], these issues are still under debate. According to different scientific publications, the number

of terraces distinguished by independent authors in the spillway valley varies. Thus, Majore [16] described the sequence of five terraces, whereas Eberhards [1], [14] identified eight terraces. Furthermore, G. Eberhards (*ibid*.) identified the upper terraces T7 and T8 only as fragments in some parts of the spillway valley. Despite the differences in the number of distinguished terraces, there is a consensus among scientists that the development of these fluvial landforms has started during the retreat of glacier of the last Weichselian glaciation [6].

In order to obtain scientifically reliable data on the distribution of flattened surfaces of terraces in the study area as well as on their elevation, series of geospatial data in shapefile format was acquired during the semi-automated extraction from DEM by TerEx tools. In the course of performed many empirical tests and comparison of shapefile series with terrace surfaces visually distinguishable in the DEM, authors found that the TerEx tools provide the best results when adjustable parameters – specified change in elevation, minimum terrace area, focal window and smoothing parameter were set as 0.5 m; 10,000 m^2; 3 pixels and 45 units, respectively. To ensure that the surfaces of terraces extracted from DEM are accurate, field geomorphological observations were carried out *in situ* along the transect lines from the spillway valley margin to the top of the meander bend.

After applying the GIS based semi-automated methodology to extract potential fluvial terraces in the Augšdaugava spillway valley from airborne LiDAR-derived high resolution DEM, a detailed map of terrace surfaces and their elevation is obtained in this research, finally answering the question about the exact number of terraces in sequence typical for the study area. To be specific, DEM analysis allowed to identify the terrace sequence in the Augšdaugava spillway valley consisting of eight different terrace levels – T1 to T8 where the number indicates terrace elevation in the sequence from the lowest to the highest, respectively (Fig. 2a).

From the applied methodology, authors were able to delineate surfaces of fluvial terraces in those parts of the study area, where in the course of previous research [14] terraces were interpreted incorrectly or even not identified at all. The results of DEM analysis indicate, that fluvial terrace sequences in the Augšdaugava spillway valley are located asymmetrically, i.e. making step-like landscape on the inside of meander bends, whilst on the outside of bends only T1 or T2 usually are presented and the spillway valley margin is delimited by steep slopes (Fig. 2b). The terraces (except terrace T1) which are found at certain elevations typically are not matched with ones at the same elevations across the spillway valley, indicating that these fluvial landforms identified in the study area refer to unpaired terraces.

Such geomorphological finding on the asymmetrical distribution of unpaired terraces indicates that the River Daugava during its paleogeographic development has phases of down cutting (due to change of base-level) alternate with phases of stabilization and accumulation. Simultaneously lateral migration and meandering of the river channel took place, thus creating step-like terrace sequences inside of meander bends and eroding the terrace surfaces adjoining to the outside of bends. This is consistent with an erosional scenario of the spillway valley development and geomorphology [14].

The GIS analysis of individual elements of the terrace sequence in the Augšdaugava spillway valley reveals that only terrace T1 can only be unambiguously identified along the present-day profile of the river and throughout the entire spillway valley. The terrace T2 also is easily recognizable, however, it encounters only in shorter stretches in comparison to T1. Both T1 and T2 terraces have pronounced edge between their flattened tread and steep slope, and their both are bounded by the riser of the lowermost surface of floodplain or terrace. Contrary to the rest of the terraces in the sequence, the surface of T1 usually matches with one at the same elevation across the river. Hence T1 refers to paired terraces.

The results of the geological survey indicate that T1, which also is the youngest terrace in this stretch of the Daugava, is an aggradational or fill terrace, consisting of typical alluvial sand deposits. On the surface of terrace T1 in several hand-dug pits and drillings, the buried soils with small pieces of charcoal were found at a depth from 0.9 m to 0.3 m. The radiocarbon dating of the charcoal performed in other research [17] shows that the age of this material is 255 ± 30 cal yr BP or AD 1620–1675 (sample No. Poz-76256, Poznan Radiocarbon Laboratory). Despite our preliminary assumptions that dates would indicate the beginning of settlement history and slash-and-burn agriculture activities related to the Iron Age in this area or, the development of terrace T1 in the Atlantic period, the results display that deposited material is younger. The texture and granulometric properties of the layer covering charcoal point to an aeolian origin of sand. This fact in combination with results of the ^{14}C dating in turn indicates that in Medieval Times, i.e. during the Little Ice age (as indicate the dates), high-magnitude wind-driven geomorphic processes took place in the Augšdaugava spillway valley, leading to intensive deposition of aeolian sediments and burring of soils and organic material.

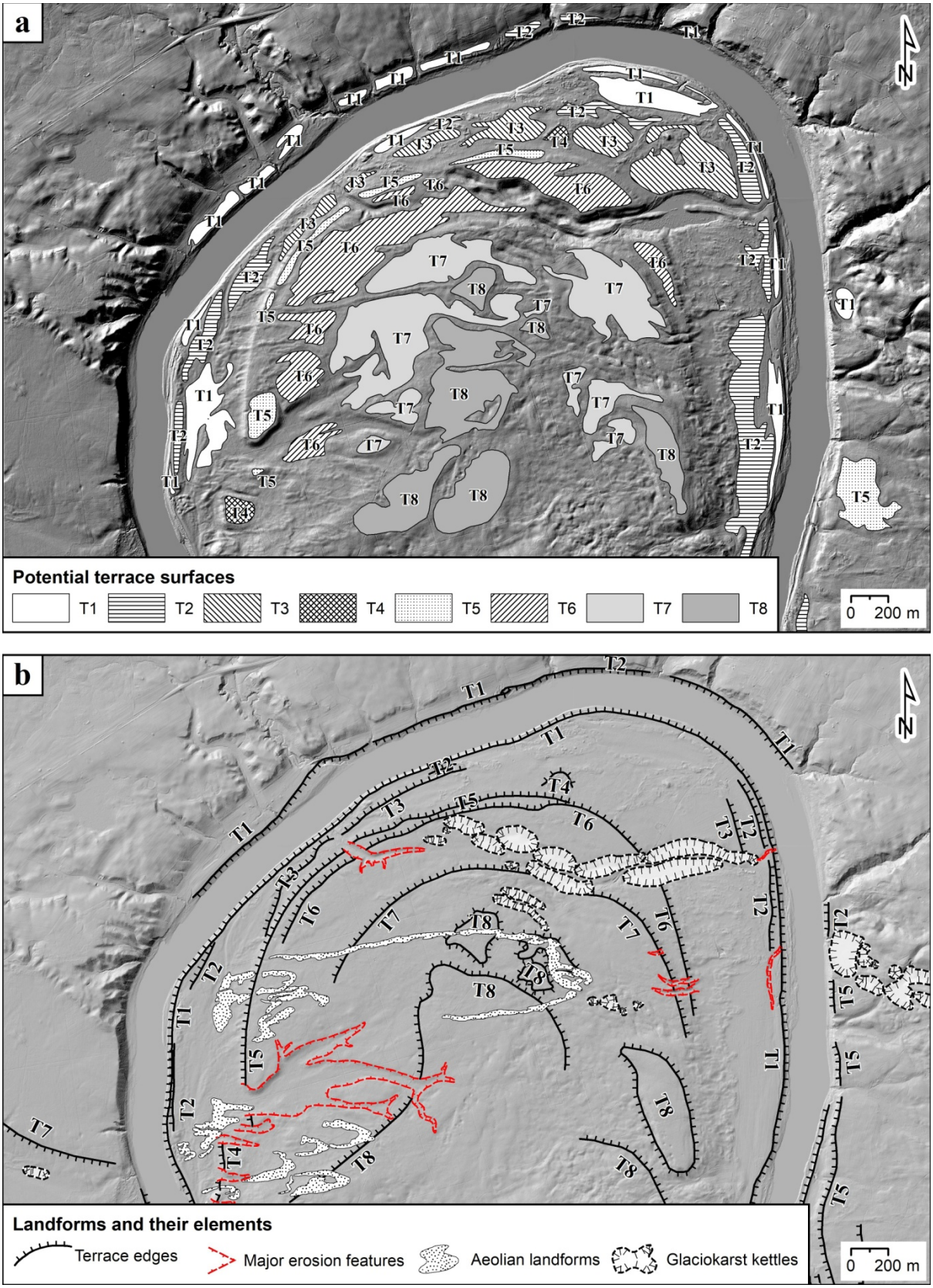

Fig. 2. Distribution of fluvial terraces in the Augšdaugava spillway valley – an example from the Daugavsargu meander: (a) eight levels of potential terrace surfaces extracted and mapped by TerEx tools – map over LiDAR data based shaded DEM; (b) geomorphological map with identified landforms. Terrace edges delineated only for those segments which have explicit break detectable in DEM or by the field survey.

Hence the findings of this research will stimulate to carry out additional and new studies, because geomorphic events of the Little Ice age remain poorly documented in this part of Latvia, thus the extent to which environmental conditions and controlling factors of processes during this time are currently studied is insufficient.

The evidence of presumable past aeolian activity is represented also by linear or parabolic dunes the length of which in some bends exceeds 0.5 km (Fig. 2b).These linear landforms have an orientation from W to E, with elongated crests sub-parallel to the margins of the spillway valley. Such orientation of dune linear axis possible can be explained by the formation of tunnel effect during air mass transfer through the depression of the spillway valley by prevailing westward winds. The groups of dunes stretch across the surface of terraces situated at different elevations and this fact directly indicates the later origin of aeolian features in comparison to fluvial terraces. The finding of inland dunes in the study area is the geomorphological novelty directly related to capabilities of identification small relief features in the high resolution DEM.

Summarizing the results for terraces T2 to T8 it is necessary to note, that, unlike T1, other terraces situated at higher levels do not form a continuous spectrum along the longitudinal profile of the river and are encountered only in some stretches of the spillway valley. The treads of these terraces occur fragmentary as flat-topped erosional remnants of different size (Fig. 2b), and the edges of these terraces are smoothed or modified by exogenic geological processes. Particularly dissected and fragmented are terraces T3 and T4, which throughout the entire studied valley can be identified neither in DEM nor in nature as typical fluvial terraces with flattened surface and topographically well-expressed edge.

The GIS analysis of DEM and subsequent geomorphological field survey also allowed to identify many glaciokarst kettles on the surfaces of terraces T3 – T8 (Fig. 2b). These kettles occur as slightly elongated, semi-circular in planar view closed depressions, which form groups over inside of meander bends in several meanders.

Finally, the results of DEM analysis, geomorphological reconnaissance and geological field survey indicate that morphogenesis of the uppermost terraces T7 and T8 is still an open question. The edges of these terraces are very smoothed, but surfaces are complicated by dispersed microforms like old gullies (presumably of the Late Pleistocene time), other erosional features and depressions of different size and shape. The terraces constitute of poorly-sorted deposits with texture and granulometric properties characteristic for glacioaquatic sediments. Moreover, the surfaces of T7 and T8 are sub-horizontal or even incline slightly to the east, i.e. in the direction of the former Polotsk ice-dammed lake. The previous assertion [1], [14] has specified that the terraces T7 and T8 were erosional, formed by streams of glacial meltwater flowing westward from Lake Polotsk into the Nīcgale ice-dammed lake at the initial phase of development of the Augšdaugava spillway valley. Eberhards [14] attempted to explain the upstream inclination of the levels of both above mentioned terrace treads, opposite to the direction of paleo-stream flow, in terms of glacial isostatic adjustment. Without completely rejecting the idea of changing the terrace treads inclination caused by Late Glacial glacio-isostatic uplift, the results of recent research lead to a different assumption and reveal that terraces T7 and T8 are not fluvial erosional terraces but kame terraces. However, to verify this assumption, it is necessary to perform optically stimulated luminescence (OSL) dating of T7 and T8 forming sediments. Hence it's obvious the need for more detailed and complex further studies.

IV. Conclusions

The main goal of the applied methodology to detect and delineate potential fluvial terrace areas from remote sensing (LiDAR) data using semi-automated GIS analysis tools has been achieved. The high resolution digital elevation models derived from airborne laser altimetry can be used GIS environment to extract fluvial landforms, their elements and minor geomorphological features in river valleys, where an extensive amount of time and workload would spend to obtain the same data by conventional field survey and geomorphological reconnaissance. The main advantages of using semi-automated GIS tools are avoiding the subjectivity related to the manual identification of the landforms, and rapidity of data processing and obtaining of results, thus allowing to process and elaborate digital geomorphological maps of relatively large areas readily and consistently. Additionally, the advantage also is the analysis and classification of the relief at finer scales due to higher resolution elevation data. Hence the obtained results provide much more information than those previously obtained from analysis of topographic maps and manual digitizing of contour lines, particularly in terms of interpretation of local morphology of fluvial terraces. However, the required input parameters for TerEx tools have to be adjusted empirically to optimize automated extraction and delineation of fluvial terraces, and subsequent ground-truthing should be performed to validate the results of GIS analysis.

New and scientifically more reliable data have been obtained on the exact number of terraces in sequence typical for the Augšdaugava spillway valley, consisting of eight different terrace levels – T1 to T8. In the Augšdaugava spillway valley, however, it is not common to observe well-preserved terraces at levels higher than T2. Furthermore, morphogenesis of the uppermost terraces T7 and T8 is an issue which is still under debate.

Also, the results of the geological field survey lead to the conclusion that during the Little Ice age, high-magnitude wind-driven geomorphic processes took place in the study area. Hence the findings of this research will stimulate to carry out more detailed and complex further studies in the Augšdaugava spillway valley.

REFERENCES

[1] G. Eberhards, Upju ieleju veidošanās un mūsdienu gultnes procesi Dienvidaustrumu Baltijā (Development of river valleys and channel processes in Southeatern Baltic), in Latvian. Rīga: Latvijas Universitāte, 2013, pp. 211.

[2] R. Charlton, Fundamentals of fluvial geomorphology, London: Routledge, 2009, pp. 163.

[3] M. A. Summerfield, Global geomorphology, Harlow: Longman, 1999, pp. 224-225.

[4] F.J. Pazzaglia, "Fluvial terraces (chapt. 9.22.)," In Treatise on Geomorphology, F.S. John, Ed. San Diego: Academic Press, 2013, pp. 379–412.

[5] G.S. Hancock, R.S. Anderson, "Numerical modeling of fluvial strath terrace formation in response to oscillating climate," GSA Bulletin, vol. 114 (9), pp. 1131–1142, Sept. 2002. https://doi.org/10.1130/0016-7606(2002)114<1131:NMOFST>2.0.CO;2

[6] V. Zelčs, A. Markots, M. Nartišs, T. Saks, "Pleistocene Glaciations in Latvia," In Developments in Quaternary Science, vol. 15, J. Ehlers, P.L. Gibbard, P.D. Hughes (Eds.). Amsterdam: Elsevier, 2011, pp. 221–229.

[7] J. C. Stout, P. Belmont, "TerEx Toolbox for semi-automated selection of fluvial terrace and floodplain features from LiDAR," Earth Surface Processes and Landforms, vol. 39 (50), pp. 569–580, Apr. 2014. https://doi.org/10.1002/esp.3464

[8] A. Demoulin, B. Bovy, G. Rixhon, Y. Cornet, "An automated method to extract fluvial terraces from digital elevation models: The Vesdre valley, a case study in eastern Belgium," Geomorphology, vol. 91 (1–2), pp. 51–64, Oct. 2007. https://doi.org/10.1016/j.geomorph.2007.01.020

[9] M. del Val, E. Iriarte, M. Arriolabengoa, A. Aranburu, "An automated method to extract fluvial terraces from LIDAR based high resolution Digital Elevation Models: The Oiartzun valley, a case study in the Cantabrian Margin," Quaternary International, vol. 364, pp. 35-43, Apr. 2015. https://doi.org/10.1016/j.quaint.2014.10.030

[10] Latvian Geospatial Information Agency, "Digital Height Model Basic data," LGIA, Open data, 2021. [Online]. Available: https://www.lgia.gov.lv/lv/Digit%C4%81lais%20virsmas%20modelis [Accesed: Jan. 17, 2021]

[11] G. Sithole, G. Vosselman, "Experimental comparison of filter algorithms for bare-Earth extraction from airborne laser scanning point clouds," ISPRS J. Photogramm. Remote Sens., vol. 59 (1–2), pp. 85–101, Aug. 2004. https://doi.org/10.1016/j.isprsjprs.2004.05.004

[12] N. Polat, M. Uysal, A. S. Toprak, "An investigation of DEM generation process based on LiDAR data filtering, decimation, and interpolation methods for an urban area," Measurement, vol. 75, pp. 50–56, Nov. 2015. http://dx.doi.org/10.1016/j.measurement.2015.08.008

[13] G.Y. Lu, D.W. Wong, "An adaptive inverse-distance weighting spatial interpolation technique," Comput. Geosci., vol. 34, pp. 1044–1055, Sept. 2008. https://doi.org/10.1016/j.cageo.2007.07.010

[14] G. Eberhards, Stroyeniye i razvitiye dolin basseyna reki Daugava (Structure and development of valleys of the Daugava river catchment), in Russian. Rīga: Zinātne, 1972, pp.131.

[15] I. Sleinis, K. Ašmanis, N. Delle, J. Siliņš, V. Lamsters, Daugava (The River Daugava), in Latvian. Rīga: Valters un Rapa, 1933, pp. 107.

[16] M. Majore, Daugavas ielejas attīstība (Development of the Daugava river valley), in Latvian. Rīga: Latvijas valsts izdevniecība, 1962, pp. 77.

[17] E. Muižniece, J. Soms, "A geomorphological approach for enhancing environmental management and conservation of landforms as protected nature objects in the Upper Daugava spillway valley," In Proceedings of the 10th International Scientific and Practical Conference "Environment. Technology. Resources". Rēzekne, Latvia, 20 – 22 June, 2015. vol.2., pp.225-231. http://dx.doi.org/10.17770/etr2015vol2.252

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Effect of Vermicompost Doses on Canabis Sativa Photosynthesis-Related Parameters, Growth and Yield

Veneranda Stramkale
Institute of Agricultural Resources and Economics
Struktoru iela 14, Rīga, Latvia
veneranda.stramkale@arei.lv

Gederts Ievinsh
Faculty of Biology
University of Latvia
Jelgavas iela 1, Rīga, Latvia

Māra Vikmane
Faculty of Biology
University of Latvia
Jelgavas iela 1, Rīga, Latvia

Agnese Ķirse
Faculty of Biology
University of Latvia
Jelgavas iela 1, Rīga, Latvia

Ieva Kroica
Institute of Agricultural Resources and Economics
Struktoru iela 14, Rīga, Latvia

Abstract **- Hemp, *Cannabis sativa* is certainly a multifunctional as well as a niche crop, due to great potential for innovative use of its different products. Aspects of hemp mineral nutrition are very important in the cultivation of these plants, in particular to make cultivation environmentally friendly by replacing synthetic fertilizers with organic ones. Among organic fertilizers, vermicompost has gained particular attention within the last decades. Explaining the role of vermicompost, this study evaluated the effects of different doses of this fertilizer on hemps in two separate field studies. In a small-scale field experiment, the effect of two doses of vermicompost and adequate concentrations of mineral elements fertilizers the growth, physiological condition, as well as yield of hemp was compared. The effect of increasing doses of vermicompost on the physiological condition and yield of hemp was analysed in a broader field experiment. The experiments were performed at the Viļāni Scientific Centre of the Agricultural Resources and Economics, in 2017 and 2018, using the Latvian hemp cultivar 'Pūriņi'. For the experiments, certified vermicompost produced by 'Eko Zeme' (Latvia) was used, which was produced from composted cow manure by adding grass biomass. In field experiment, the positive effect of vermicompost on hemp growth was greater than the effect of equivalent mineral fertilizer concentrations. When using vermicompost in increasing doses, better hemp growth (40–60 %) was observed at 5 and 10 t ha^{-1}, stem yield increased on average by 40 % due vermicompost, seed yield ranging from 1.00 t ha^{-1} in control plants, to 1.56 t ha^{-1} in 20 t ha^{-1} in plants treated with 20 t ha^{-1} vermicompost plants. The weight of 1000 seeds per plant in all variants (from 13.54 to 13.85 g) was relatively close to the indicated maximum level (14.59 g). A statistically significant increase in chlorophyll concentration in plant leaves was observed under the influence of vermicompost. The increase in the Performance Index of the chlorophyll *a* fluorescence measurement was only for plants in individual experimental variants; regardless of how significant the increase in stem and seed yield was due to the respective doses of vermicompost. In general, the results characterize the growth of hemp in local agroclimatic conditions and allow to expect a stable increase in yield under the influence of vermicompost.**

Keywords - chlorophyll a fluorescence, bio-humus, plant growth, stem and seed yield.

I. Introduction

Cultivars of *Cannabis sativa* L., grown for both fiber and seed, are known as hemp, and have been traditionally cultivated since early years of agriculture [31]. Currently hemp is characterized as a multipurpose or even a niche crop due to large potential in different innovative applications. Biology, and uses and cultivation techniques of hemp have been thoroughly reviewed recently [3], [4]. More recent reviews on other important aspects of hemp cultivation emphasize large scientific and practical interest on this crop [17], [21].

Modern trends in agrobiological studies of hemp show that aspects of mineral nutrition still prevail [20], [28] followed by comparison of suitability of different hemp

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genotypes over different cultivation conditions [1], [7], [22], [29] and resistance to environmental constraints, like temperature [28] and soil salinity [12]. A recent meta-analysis of yield-determining factors of *C. sativa* provided further evidence that complex of abiotic factors (most importantly, light and fertilization) together with genotype and performed agronomic techniques (most importantly, plant density) jointly affect plant yield [6].

In respect to mineral nutrition of hemp, mainly effect of nitrogen has been studied so far [17], [18], [20], [26], [28], supporting the nitrophilous status of the crop [25]. However, due to growing concerns for environment protection and increased agricultural sustainability, more environment-friendly means of fertilization needs to be proposed and approved also for hemp production. As a reasonable alternative to application of soluble inorganic nutrients, balanced use of organic fertilizers not only results in remarkable plant production with less environmental contamination but also provides significant increase in soil sustainability [30].

Among organic fertilizers, vermicompost has gained particular attention within the last decade. Vermicompost is produced by a coordinated action of earthworms and their symbiotic organisms from organic waste, resulting in production of stabilized peat-like material with fine structure and high porosity [11]. In general, vermicompost application results in increased physiological performance and growth of cultivated plants (reviewed by [13]). One of beneficial effects of vermicompost application on plants is associated with increased supply of plant-available mineral nutrients in soil [16]. Another positive benefit of vermicompost application is due to additional effect of biologically active, plant hormone-like substances produced by microorganisms [10]. It has been found that both mechanisms are responsible for positive effects on plant growth and yield in vermicompost-amended soils [16], [14]. In the context of the present study, vermicompost extract has been shown to stimulate germination of hemp seeds due to summed activity of humic and fulvic acids, while linear growth stimulation of a plant hypocotyls was induced by some unidentified soluble compounds, but increase in fresh mass of the hypocotyls resulted from effect of mineral nutrients [15]. Consequently, there is a good reason to consider that hemp plants can benefit from application of vermicompost in field conditions as a result of stimulation at the level of both increased physiological performance and growth.

The aim of the present study was to evaluate effect of different vermicompost doses on hemp plants. Two separate experiments with vermicompost in natural conditions were performed, including small-scale field study and field study. The goal of the small-scale field experiment was to compare the effect of two doses of vermicompost with that of respective doses of mineral nutrients on growth, physiological status and yield of hemp plants. The goal of the field experiment was to analyse the effect of increasing doses of vermicompost on physiological status and yield of hemp.

II. Materials and Methods

Plant material and organic fertilizer

Seeds of local hemp cultivar 'Pūriņi' were obtained directly from growers and used in the present study. The same plant material has been successfully used in local agroclimatic conditions in the previous studies [18], [26].

Vermicompost (bio-humus, earthworm compost) used in both experiments was produced by 'Eko Zeme' (Latvia) from composted cow manure with addition of grass biomass, and was certified for organic farming according to the EU Council Regulation No. 889/2008. NPK ratio in vermicompost was 1.0-2.9-7.6, indicating high predominance of K and dominance of P; with reasonable amount of other macro- and micronutrients except Mo (Table 1).

Field experiment was performed at Viļāni Scientific Centre of Institute of Agricultural Resources and Economics in 2017 and 2018.

TABLE 1 CHARACTERISTICS OF SOIL USED IN SMALL-SCALE FIELD EXPERIMENT AND VERMICOMPOST USED IN BOTH EXPERIMENTS IN COMPARISON TO OPTIMUM LEVEL OF MINERALS FOR CULTIVATED PLANTS [19]. CONCENTRATION (mg L^{-1} DRY SUBSTRATE) OF PLANT-AVAILABLE ELEMENTS WAS MEASURED IN 1 M HCl EXTRACT. EC—ELECTRICAL CONDUCTIVITY

Element	Soil	Vermicompost	Optimum for cultivated plants
N	90	670	120
P	218	1924	60
K	300	5100	150
Ca	840	12750	800
Mg	195	3250	50
S	11	213	50
Fe	815	185	30
Mn	165	120	1.5
Zn	5.0	65	1
Cu	2.7	7.0	0.5
Mo	0.04	0.02	0.02
B	0.1	2.9	0.2
Na	0.003	0.17	—
pH_{KCl}	5.34	7.74	—
EC (mS cm^{-1})	0.49	18.4	—

Small-scale experiment in field conditions

Due to legal restrictions to grow hemp indoor introduced in Latvia, experiments with hemp plants in controlled conditions, like vegetation pot study in greenhouse, are not possible. Therefore, initial screening of vermicompost effects in comparison to that of identical dose of mineral nutrient addition was performed as a small-scale experiment in soil in field conditions in 2017.

Analysis of plant-available mineral nutrient concentration in the soil and vermicompost was performed in a certified agrochemical laboratory using 1 M HCl as an extractant. The soil was loamy sand (2 % organic matter content), slightly acidic, well balanced in respect to mineral nutrients, but with some shortage of N, S and B (Table 1; [19]).

Seeds were sown by hand in 1 m^2 plots, 100 seeds per plot. Two doses of vermicompost (0.5 and 1.0 kg m^{-2}) were used, equivalent to 5 and 10 t ha^{-1}. Mineral nutrients in amounts equivalent to these in respective vermicompost treatments were used for two mineral fertilizer treatments. As a non-treated control, soil with no added fertilizers was used. Four plots per treatment were used. Replicates were randomly distributed on site.

Plant height was measured four times during the vegetation period (2, 15, 29 July and 12 August) separately for female and male plants. Leaf chlorophyll content was measured by a chlorophyll meter SPAD-507 (Konica-Minolta, Japan). Ten plants per replicate were randomly selected, with three readings per plant on the major photosynthetically active leaves.

Experiment was terminated on 31 August for male plants and on 17 September for female plants. All plants in each plot were cut manually and seeds were separated. To measure dry mass weight, plant material was dried in a ventilated place to a constant air-dry mass.

Field study

Field experiment was performed at in 2018. Soil was humi-podzolic gley, with 8.1 % organic matter content, pH 7.1, P_2O_5 201 mg kg^{-1}, K_2O 139 mg kg^{-1}. The pre-crop was spring wheat, fertilized by Yara Mila NPK(S) 18-8-16(8), 300 kg ha^{-1}, and additional fertilization by NH_4NO_3 330 kg ha^{-1}. Soil tillage was performed in autumn followed by cultivation at the end of April.

Plot size was 2.0 × 2.5 m, with four replicates per treatment. Treatments were organized by a randomized block method. Seeds were sown on 11 May by means of sowing machine SN-16, with sowing rate 50 kg ha^{-1}.

Non-destructive physiological measurements were performed three times during the vegetation season, on 26 June, 23 July and 17 September. Ten plants per replicate were randomly selected and analysed, using the largest leaf from top of the individual plant. Leaf chlorophyll concentration was measured by a chlorophyll meter CCM-300 (Opti-Sciences, USA). Chlorophyll a fluorescence was measured in dark-adapted, physiologically most active leaves by Handy PEA fluorometer (Hansatech Instruments, UK). Chlorophyll a fluorescence parameter total Performance Index was used for characterization of photochemical activity, combining three function-related (trapping of absorbed exciton, electron transport between the photosystems, reduction of end-electron acceptors) and one structure-related (antenna chlorophyll per reaction centre chlorophyll) parameters [27].

Climate variables (temperature and precipitation) were measured by an on-farm meteorological station Adcon connected to a computer program Dacom Plant Plus. According to the obtained data (Fig. 1A), average temperature values were relatively close to long-term values in 2017, with significantly warmer first decade of April, followed by somehow cooler temperatures through the rest of April and May. Precipitation level in May was only 29 % from long-term average, but heavy rain occurred on the third decade of August (Fig. 1B). May and July in 2018 was relatively warm, with average temperature exceeding long-term values by 4.2 and 2.3 °C (Fig. 1A). In contrast, precipitation level in May, beginning of June and July was lower than long-term average, but abundant rain was occurring at the end of June and in mid-August (Fig. 1B).

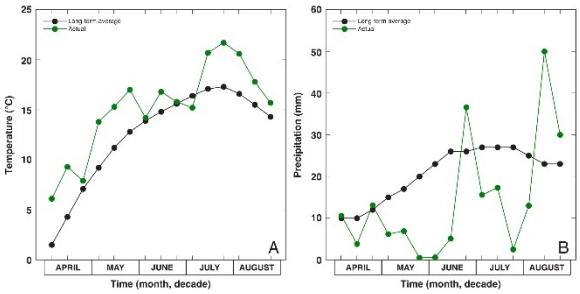

Fig. 1. Seasonal variation in local temperature (A) and summary precipitation (B) during the field study in 2018 as compared to long-term local average values.

Experiment was terminated on 19 September. All plants in 1 m^2 area in the centre of each plot were cut manually. Seeds were separated and dried in an oven at 60 °C. Harvested stems were dried in a ventilated place to determine the fibre content.

Statistical analysis

Data analysis was performed using KaleidaGraph (v. 4.1, Synergy Software). Student t-test was used to estimate statistically significant differences for morphological data between individual treatments ($p < 0.5$).

III. Results

Small-scale experiment in field conditions

Both vermicompost and mineral fertilizer treatments resulted in significant stimulation of stem growth of hemp plants at both doses used (Fig. 2). Effect of vermicompost application on stem growth was significantly more pronounced than that of equivalent mineral dose. Relative intensity of stem growth stimulation in comparison to control plants became less pronounced later in the season.

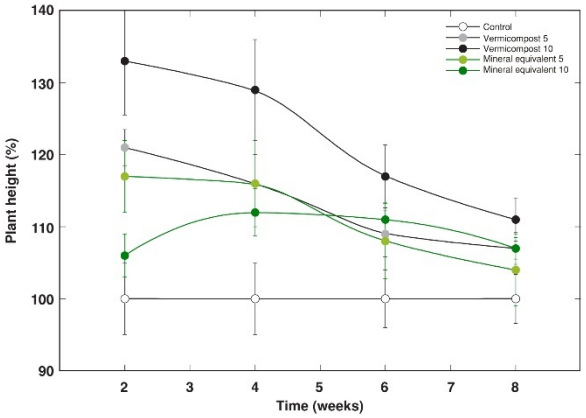

Fig. 2. Effect of increasing vermicompost rate or equivalent mineral nutrient application on changes in relative height of hemp plants in conditions of the small-scale field experiment. Results are means ± SE from four replicates with ten individual measurements each.

Dry mass of vegetative above-ground parts of female hemp plants significantly increased in all fertilizer applications (Fig. 3A). There was a tendency that vermicompost treatment resulted in higher mass increase in comparison to that by equivalent mineral fertilizer, but the effect was not statistically significantly different. Also, there was no significant difference between the two doses of either vermicompost or mineral fertilizer. Dry mass accumulation in vegetative aboveground parts of male hemp plants was also significantly stimulated by both doses of vermicompost application, but to a lesser extent than that for female plants (Fig. 3B). Application of mineral fertilizer at 5 t ha^{-1} equivalent dose had no significant effect on dry mass of male plants, but there was a statistically significant mass increase at 10 t ha^{-1} equivalent mineral fertilizer dose, which was even higher than that of respective vermicompost treatment. Similarly, seed mass per plant significantly increased in hemp plants under both vermicompost doses, with significantly more pronounced effect at 5 t ha^{-1} (Fig. 3C). Equivalent mineral nutrient dose had significant effect on seed mass only for 10 t ha^{-1} treatment.

Leaves of female plants had significantly higher chlorophyll concentration in comparison to that in male plants (Fig. 4). No significant differences in chlorophyll concentration were caused by any of the treatments.

Field study

In field conditions, vermicompost application resulted in significantly increased stem yield (Fig. 5A) as well as seed yield (Fig. 5B) of hemp plants at all doses. However, while seed yield significantly increased with increasing vermicompost dose, stem yield increase with vermicompost concentration was significant only up to 10 t ha^{-1} and further increase was not significant. Mass of 1000 seeds was rather constant up to 10 t ha^{-1} vermicompost applications, and significantly increased only at 20 t ha^{-1} (Fig. 5C). In contrast, relative fibre content tended to decrease in vermicompost-treated plants (both female and male) in comparison to control plants, but the effect was not statistically significant (Fig. 5D).

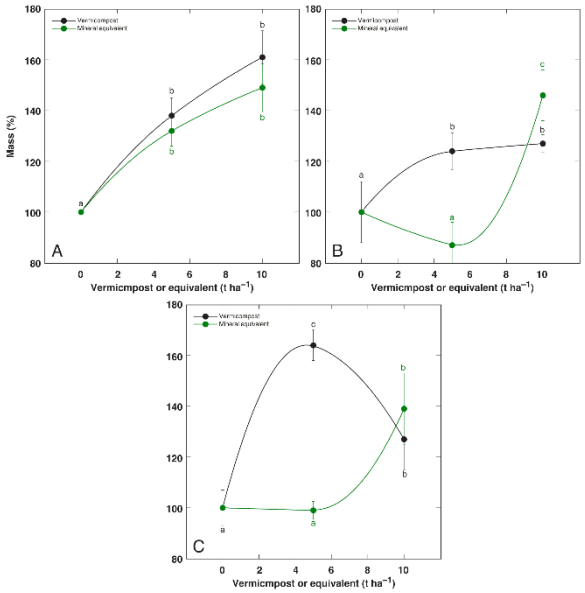

Fig. 3. Effect of increasing vermicompost rate or equivalent mineral nutrient application on relative dry mass of vegetative parts of female plants (A), male plants (B) and seed mass per plant (C) during the small-scale field experiment. Results are means ± SE from four replicates. Values indicated by the same letters do not show statistically significant differences ($p < 0.05$).

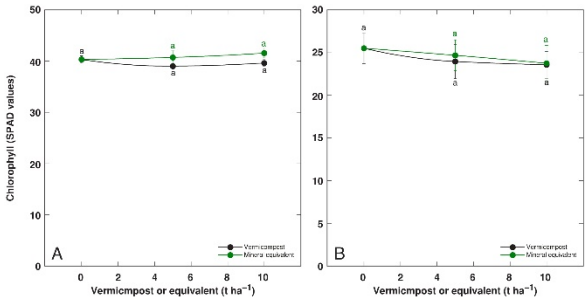

Fig. 4. Effect of increasing vermicompost rate or equivalent mineral nutrient application on leaf chlorophyll concentration of female (A) and male (B) hemp plants in conditions of the small-scale field experiment. Results are means ± SE from four replicates with ten individual measurements each. Values indicated by the same letters do not show statistically significant differences ($p < 0.05$).

Both leaf chlorophyll concentration and chlorophyll a fluorescence parameter Performance Index showed similar significant variations during vegetation season (Fig. 6). Both parameters increased from 26 June to 23 July, and decreased further to 17 September. Statistically significant increase of chlorophyll concentration in hemp plants was evident only for 5 t ha^{-1} treatment on 26 June and for 10 t ha^{-1} treatment on 17 September (Fig. 6A). Statistically significant increase of Performance Index in hemp plants occurred only on 26 June for all vermicompost treatments independently on the applied concentration (Fig. 6B).

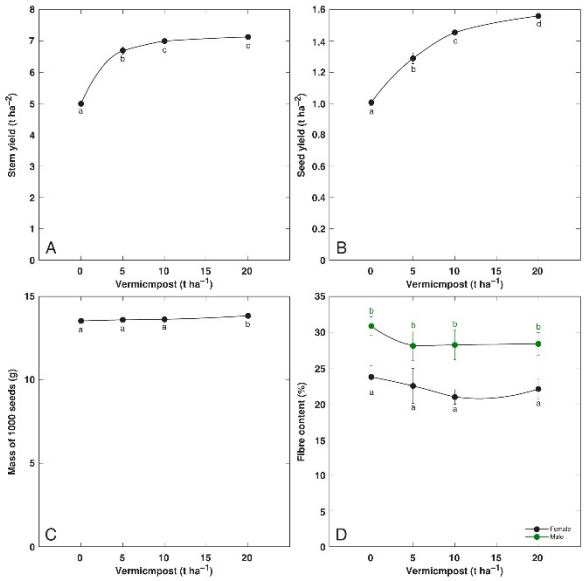

Fig. 5. Effect of increasing vermicompost application rate on stem yield (A), seed yield (B), mass of 1000 seeds (C) and fiber content (D) of hemp plants in conditions of the field experiment. Results are means ± SE from four replicates. Values indicated by the same letters do not show statistically significant differences ($p < 0.05$).

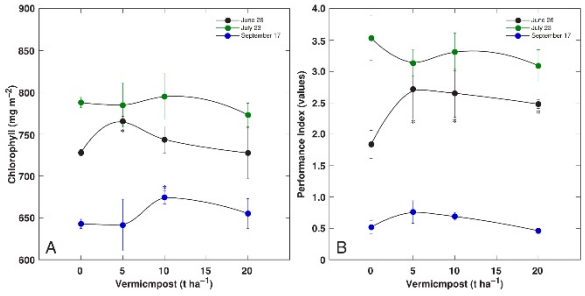

Fig. 6. Effect of increasing vermicompost application rate on leaf chlorophyll concentration (A), and chlorophyll *a* fluorescence parameter Performance Index (B) of hemp plants in conditions of the field experiment. Results are means ± SE from four replicates with ten independent measurements each. Values indicated by asterisks are statistically significantly different from the respective control value ($p < 0.05$).

IV. Discussion

As far as mineral nutrition of hemp plants is considered, mainly nitrogen fertilization effects have been studied so far [1], [17], [18] [20], [28]. In contrast, vermicompost as a form of organic fertilizer contains significantly higher proportion of plant-available P and K (Table 1). In a conditions of a small-scale field experiment, positive effect of vermicompost amendment on growth of hemp plants was significantly higher than that of equivalent mineral nutrient dose (Fig. 2 and 3), indicating that other constituents of vermicompost in addition to plant-available mineral nutrients were responsible for the effect. Plant physiology-related benefits of vermicompost application have been recently reviewed in detail [14], and it was concluded that most likely ingredients of vermicompost with putative growth-promoting effect could be soluble humic substances and microorganism-derived plant hormone-like compounds. We have shown previously that stimulation of hemp seed germination by vermicompost extract was due to summed activity of humic and fulvic acids, linear growth of hypocotyl and radicle was promoted by hormone-like substances, but mass accumulation in seedlings was promoted by plant-available minerals [15].

When comparing both performed experiments, it is evident that increase in plant dry mass due to vermicompost amendment was by 60 % in the small-scale field experiment (Fig. 3A), but only by 40 % in the field experiment (Fig. 5A). One of the reasons for this discrepancy could be differences in soil characteristics between the two sites. In a soil with relatively high organic matter content, similar to conditions of the field experiment performed in the present study, humic substances in vermicompost amendment would probably have a small effect in stimulating hemp plant growth. One can also need to consider differences in climatic conditions for the respective site of particular experiment and the year, but particular climatic conditions were not registered during the small-scale experiment. However, as it was evident from climate data recorded in the Viļāni station, season of 2017 was significantly cooler than that of 2018, especially, in June and July. Relatively small amount of precipitation during early seedling growth in May in both years evidently negatively affected hemp plant germination and initial development, but general positive effect of vermicompost in 2018 could be related to further periods of low precipitation. It has been shown previously that vermicompost amendment can protect plants and increase their yield in conditions of water shortage [2].

In respect to other yield components, stem yield under field conditions increased on average by 40 % due to vermicompost, seed yield in the present study varied from 1.00 t ha^{-1} in control plants up to 1.56 t ha^{-1} in plants treated with 20 t ha^{-1} vermicompost (Fig. 5B), which is within the four-year annual seed yield range of this cultivar in the local conditions when no additional nitrogen fertilizer is supplied (0.83 to 1.60 t ha^{-1}—[26]). Mass of 1000 seeds (13.54 to 13.85 g) was relatively close to maximum level reported (14.59 g) for the particular cultivar even with additional nitrogen fertilizer [26]. Consequently, results of the present study adequately reflect typical performance of hemp plants in local agroclimatic conditions, and stable increase of yield parameters by vermicompost amendment can be predicted.

Increased physiological performance is an extremely important aspect of plant growth stimulation. It is evident that in order to sustain increased biosynthetic and energetic needs of a plant individual during enhanced growth, an adequate level of photosynthetic activity needs to be maintained. Therefore, photosynthesis-related parameters such as leaf chlorophyll concentration and chlorophyll *a* fluorescence indices, which reflect energy flow during photochemical reactions, have been widely used for characterization of physiological status of plants both in respect to environmental variables as well as agro-climatic factors [5], [15]. In particular, in experiments with nitrogen

fertilization of hemp plants, it was shown that different aspects of photosynthesis are differentially affected by increased nitrogen availability [18]. While it is usually thought that increased leaf chlorophyll concentration always reflects nitrogen concentration [9], [23], in hemp leaves this parameter was only approximate indication of their nitrogen content. However, activity of photochemical reactions of photosynthesis increased in a concentration-dependent manner due to increased nitrogen availability [18]. For example, stimulation of photosynthetic performance of hemp plants by increased doses of nitrogen without growth stimulation is thought to be due to redistribution of nitrogen to synthesis of ribulose 1,5-biphosphate carboxylase protein, resulting in increased photosynthetic performance [24]. Similarly, in the case of vermicompost application, improvement of metabolism in vermicompost-treated plants was partially independent on growth-related effects [13].

Factors, stimulating plant growth, not always show metabolic stimulation and increased physiological performance of plants and vice versa. Increase of chlorophyll concentration in cotyledons of germinated seedlings of hemp as a result of vermicompost treatment has been shown to be a direct general response, mainly associated with effect of humic acid [15]. In field conditions, this effect can be greatly masked by fluctuations in different soil- and climate-related factors, as shown also in the present study in the experiment in small-scale field conditions, where there were no changes in leaf chlorophyll concentration (Fig. 4) of vermicompost-treated hemp plants despite significant stimulation of their growth (Fig. 2 and 3). In field conditions, vermicompost-related statistically significant increase in leaf chlorophyll concentration (Fig. 6A) and chlorophyll a fluorescence parameter Performance Index (Fig. 6B) was evident only in plants for separate treatments and/or dates irrespective of significant stimulation of stem (Fig. 5A) and seed yield (Fig. 5B) by all applied vermicompost doses.

It can be concluded that soil amendment with vermicompost is a promising technique to increase both hemp seed and fibre yield when using dual purpose hemp cultivars, similar to cultivar ‘Pūriņi’ used in this study, in conditions of temperate agriculture. Further studies are clearly necessary to promote integration of vermicompost use with other agrotechnical measures as well as to understand different aspects of yield quality as affected by organic amendments of this multipurpose crop.

V. Conclusions

1) Vermicompost ‘Eko Zeme’ application 5 and 10 t ha^{-1} resulted in better hemp plant ‘Pūriņi’ growth, in comparison to that of equivalent mineral nutrient dose.

2) Under the influence of vermicompost the dry weight of plants increased (40–60 %), stem and seed yield, 1000 seed weight.

3) There was a statistically significant increase in the concentration of chlorophyll in hemp leaves associated with vermicompost. However, the parameters characterizing photosynthesis under field conditions were relatively weak.

4) On the basis of our experiments soil amendment with vermicompost may be a promising technique to increase both hemp seed and fibre yield, when cultivating multi-purpose hemp

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REFERENCES

[1] A. Adamovičs, S. Ivanovs and V. Stramkale, "Investigations about the impact of norms of the fertilisers and cultivars upon the crop capacity biomass of industrial hemp", Agron. Res., vol. 14, pp. 641-649, 2016. https://doi.org/10.15159/ar.17.002

[2] D. Akhzari and M. Pessarakli, "Effects of vermicompost and urea fertilizers on qualitative and quantitative characteristics of *Vetiveria zizanioides* Stapf. grown under drought stress conditions", J. Plant Nutr., vol. 40, pp. 2063-2075, 2017. https://doi.org/10.1080/01904167.2017.1346126

[3] S. Amaducci, M. Colauzzi, G. Bellochi, S. L. Cosentino, K. Pahkala, T. J. Stomph, W. Westerhuis, A. Zatta and G. Venturi, "Evaluation of a phenological model for strategic decisions for hemp (*Cannabis sativa* L.) biomass production across European sites", Industr. Crops Prod., vol. 37, pp. 100-110, 2012. https://doi.org/10.1016/j.indcrop.2011.11.012

[4] S. Amaducci, D. Scordia, F. H. Liu, Q. Zhang, H. Guo, G. Testa and S. L. Cosentino, "Key cultivation techniques for hemp in Europe and China", Industr. Crops Prod., vol. 68, 2-16, 2015. https://doi.org/10.1016/j.indcrop.2014.06.041

[5] U. Andersone, I. Druva-Lūsīte, B. Ieviņa, A. Karlsons, J. Ņečajeva, I. Samsone and G. Ievinsh, "The use of nondestructive methods to assess a physiological status and conservation perspectives of Eryngium maritimum L.", J. Coastal Conserv., vol. 15, pp. 509-522, 2011. https://doi.org/10.1007/s11852-010-0139-7

[6] R. Backer, T. Schwinghamer, P. Rosenbaum, V. McCarty, S. E. Bilodeau, D. Lyu, M. B. Ahmed, G. Robinson, M. Lefsrud, O. Wilkins and D. L. Smith, "Closing the yield gap for *Cannabis*: a meta-analysis of factors determining *Cannabis* yield", Front. Plant Sci., vol. 10, article 496, 2019. https://doi.org/10.3389/fpls.2019.00495

[7] M. Baldini, C. Ferfuia, F. Zuliani and F. Danuso, "Suitability assessment of different hemp (Cannabis sativa L.) varieties to the cultivation environment", Industr. Crops Prod., vol. 143, article 111860, 2020. https://doi.org/10.1016/j.indcrop.2019.111860

[8] J. C. Callaway, "Hempseed as a nutritional resource: an onerview", Euphytica, vol. 140, pp. 65-72, 2004. https://doi.org/10.1007/s10681-004-4811-6

[9] R. H. Fox and C. L. Walthall, "Crop monitoring technologies to assess nitrogen status" in Nitrogen in Agricultural Systems, J. S. Schepers and W. R. Raun, Eds. Madison: ASA-CSSA-SSSA, 2008, pp. 647-674. https://doi.org/10.2134/agronmonogr49.c16

[10] L. Grantina-Ievina, U. Andersone, D. Berkolde-Pīre, V. Nikolajeva and G. Ievinsh, "Critical tests for determination of microbiological quality and biological activity in commercial vermicompost samples of different origins", Appl. Microbiol. Biotechnol., vol. 97, pp. 10541-10554, 2013. https://doi.org/10.1007/s00253-013-4825-x

[11] K. Huang, F. Li, Y. Wei, X. Fu and X. Chen, "Effects of earthworms on physicochemical properties and microbial profiles during vermicomposting of fresh fruit and vegetable wastes", Bioresour. Technol., vol. 170, pp. 45-52, 2014. https://doi.org/10.1016/j.biortech.2014.07.058

[12] H. Huaran, L. Hao and L. Feihu, "Seed germination of hemp (*Cannabis sativa* L.) cultivars responds differently to the stress of

salt type and concentration", Industr. Crops Prod., vol. 123, pp. 254-261, 2018. https://doi.org/10.1016/j.indcrop.2018.06.089

[13] G. Ievinsh, "Review on physiological effects of vermicomposts on plants" in Biology of composts, M. K. Meghvansi and A. Varma, Eds. Cham (Switzerland): Springer Nature Switzerland, 2020, pp. 63-86. https://doi.org/10.1007/978-3-030-39173-7

[14] G. Ievinsh, U. Andersone-Ozola and S. Zeipiņa, "Comparison of the effects of compost and vermicompost soil amendments in organic production of four herb species", Biol. Agric. Hortic., vol. 36, pp. 267-282, 2020. https://doi.org/10.1080/01448765.2020.1812116

[15] G. Ievinsh, M. Vikmane, A. Ķirse and A. Karlsons, "Effect of vermicompost extract and vermicompost-derived humic acids on seed germination and growth of industrial hemp", Proc. Latv. Acad. Sci., Sect. B, vol. 71, pp. 286-292, 2017.

[16] A. Karlsons, A. Osvalde, U. Andersone-Ozola and G. Ievinsh, "Vermicompost from municipal sewage sludge affects growth and mineral nutrition of winter rye (Secale cereale) plants", J. Plant Nutr., vol. 39, pp. 765-780, 2016. https://doi.org/10.1080/01904167.2015.1087566

[17] S. Landi, R. Berni, G. Capasso, J.-F. Hausman, G. Guerriero and S. Esposito, "Impact of nitrogen nutrition on *Cannabis sativa*: an update on the current knowledge and future prospects", Int. J. Mol. Sci., vol. 20, article 5803, 2019. https://doi.org/10.3390/ijms20225803

[18] M. Maļceva, M. Vikmane and V. Stramkale, "Changes of photosynthesis-related parameters and productivity of *Cannabis sativa* under different nitrogen supply", Environ. Exp. Biol., vol. 9, pp. 61-69, 2011. http://eeb.lu.lv/EEB/201108/EEB_9_Malceva.pdf

[19] A. Osvalde, "Optimization of plant mineral nutrition revisited: the roles of plant requirements, nutrient interactions, and soil properties in fertilization management", Environ. Exp. Biol., vol. 9, pp. 1-8, 2011. http://eeb.lu.lv/EEB/201108/EEB_9_Osvalde.pdf

[20] P. Papastylianou, I., Kakabouki and I. Travlos, "Effect of nitrogen fertilization on growth and yield of industrial hemp (Cannabis sativa L.)", Not. Bot. Horti Agrobot. Cluj-Napoca, vol. 46, pp. 197-201, 2018. https://doi.org/10.15835/nbha46110862

[21] E. M. J. Salentijn, Q. Zhang, S. Amaducci, M. Yang and L. M. Trindade, "New developments in fiber hemp (*Cannabis sativa* L.) breeding", Industr. Crops Prod., vol. 68, 32-41, 2015. https://doi.org/10.1016/j.indcrop.2014.08.011

[22] R. Sausserde and A. Adamovics, "Industrial hemp for biomass production", J. Agric. Eng., vol. 44 (s2), article e123, 2013. https://doi.org/10.4081/jae.2013.365

[23] M. R. Schlemmer, D. D. Francis, J. F. Shanahan and J. S. Schepers, "Remotely measuring chlorophyll content in corn leaves with differing nitrogen levels and relative water content", Agron. J., vol. 97, pp. 106-112, 2005. https://doi.org/10.2134/agronj2005.0106

[24] J. R. Seemann, T. D. Sharkey, J. L. Wang and C. B. Osmond, "Environmental effects on photosynthesis, nitrogen-use efficiency, and metabolite pools in leaves of sun and shade plants", Plant Physiol., vol. 84, pp. 796-802, 1987. https://doi.org/10.1104/pp.84.3.796

[25] E. Small, T. Pocock and P. Cavers, "The biology of Canadian weeds. 119. *Cannabis sativa* L.", Can. J. Plant Sci., vol. 83, 217-237, 2003. https://doi.org/10.4141/P02-021

[26] I. Stafecka, V. Stramkale, A. Stramkalis, I. Kroica and S. Ivanovs, "Impact of the agro-environmental factors on the seed yield and yields components productivity of Latvian original hemp", J. Res. Appl. Agric. Eng., vol. 61, pp. 164-167, 2016.

[27] R. J. Strasser, A. Srivastava and M. Tsimilli-Michael, "The fluorescence transient as a tool to characterise and screen photosynthetic samples" in Probing photosynthesis: mechanisms, regulation and adaptation, M. Yunus, U. Pathre and P. Mohanty, Eds. London: CRC Press, 2000, pp. 445-483.

[28] K. Tang, P. C. Struik, S. Amaducci, T.-J. Stomph and X. Yin, "Hemp (*Cannabis sativa* L.) leaf photosynthesis in relation to nitrogen content and temperature: implications for hemp as a bio-economically sustainable crop", GCB Bioenergy, vol. 9, 1573-1587, 2017. https://doi.org/10.1111/gcbb.12451

[29] K. Tang, P. C. Struik, X. Yin, C. Thouminot, M. Bjelková, V. Stramkale and S. Amaducci, "Comparing hemp (*Cannabis sativa* L.) cultivars for dual-purpose production under contrasting environments", Industr. Crops Prod., vol. 87, 33-44, 2016. https://doi.org/10.1016/j.indcrop.2016.04.026

[30] W. Wei, Y. Yan, J. Cao, P. Christie, F. Zhang and M. Fan, "Effects of combined application of organic amendments and fertilizers on crop yield and soil organic matter: An integrated analysis of long-term experiments", Agric. Ecosyst. Envrion., vol. 225, pp. 86-92, 2016. https://doi.org/10.1016/j.agee.2016.04.004

[31] L. Xiaozhai and R. C. Clarke, "The cultivation and use of hemp (*Cannabis sativa* L.) in ancient China", J. Int. Hemp Assoc., vol. 2, pp. 26-33, 1995.

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Evaluation of Calcium Carbonate Content in Eggshells of Avian, Turtle, Snail, and Ostrich Using Chemical Analysis and Scanning Electron Microscopy

Inta Umbraško
Institute of Life Science and Technologies, Daugavpils University, Parades Str. 1A, 121, Daugavpils, Latvia. inta.umbrasko@du.lv

Aleksandrs Petjukevičs
Institute of Life Science and Technologies, Daugavpils University, Parades Str. 1A, 122, Daugavpils, Latvia. aleksandrs.petjukevics@du.lv

Anna Batjuka
Institute of Life Science and Technologies, Daugavpils University, Parades Str. 1A, 121, Daugavpils, Latvia. anna.batjuka@du.lv

Nadežda Harlamova
Institute of Life Science and Technologies, Daugavpils University, Parades Str. 1A, 121, Daugavpils, Latvia. nadezda.harlamova@du.lv

Abstract **- In the present study, different eggs were collected and analyzed from five various animal species: European pond turtle (*Emys orbicularis* (Linnaeus, 1758)), giant African land snail (*Achatina fulica* (Bowdich, 1822)), common ostrich (*Struthio camelus* (Linnaeus, 1758)), white, light-brown, and dark-brown laying hen *(Gallus gallus domesticus* (Linnaeus, 1758) and European quail (*Coturnix coturnix* (Linnaeus, 1758). The typical mineral shell mainly composed of the calcite polymorph of $CaCO_3$ but the eggshell consists of membranes, that composed mainly of proteins. The shell quality also could be assigned by several external and internal factors such as oviposition time, animal genotype and age, housing system (for poultry), and mineral nutrition complex. The $CaCO_3$ content was determined by the standard titration method, coz the titration could provide a reliable method for evaluation of $CaCO_3$ content in different types of eggshells. The structural surface characterization of eggshells was performed by scanning electron microscopy (SEM) with a field emission gun. In terms of chemical composition, ostrich eggshells generally did not differ much from those of laying hen, turtles, giant snails, or quail eggs, but the concentration of calcium carbonate was the highest. The average calcium carbonate content of various eggshells is between 84 and 98%. The thickness of the eggshell ranges from 0.08 to 1.89 mm, and it is not the same over the entire surface of the egg. At the sharp end of the egg, the shell is slightly thicker than at the blunt end. The purpose of this study was to study the quantitative content of calcium carbonate in various eggshells of different animals to draw further conclusions in which animals the eggshell contains the maximum amount of biological calcium carbonate.**

Keywords **- Avian Eggshells; *Achatina fulica*; *Emys orbicularis*; *Gallus gallus domesticus; Struthio camelus*; *Coturnix coturnix*; bio calcium carbonate ($CaCO_3$)**

I. Introduction

Determination of calcium carbonate (CaCO3) composition between different eggshells is an important step towards the better understanding of detection and characterization of shell components of various avian and animal's species. The shells of eggs are the perfect complex bio-mineral that superposes functionality, mechanical stiffness, and aesthetic appearance and contains all that an embryo requires for safe development through to hatching in harsh environmental conditions. The chicken eggshell mainly consists of calcium carbonate (95% w/w), hydroxyapatite crystals (1% w/w) in the outermost

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calcified layer of the chicken eggshell, organic matrix (2 % w/w of the palisade layer), pigments as colorants (0.15–1200 nmol/g) and more than 10% (v/v) void cavities with about 0.4% (w/w) of adsorbed water [1], [2]. The surface of the inner shell consists of two membranes followed by interstitial calcite columns, a so-called mammillary layer that is a regular array of cones, each with a core of concentration of organic matter that had been described as neutral mucopolysaccharide [1]. The eggshell of the European pond turtle consists mostly of calcium carbonate in aragonite form, while eggshells of other reptiles and birds contain mostly calcium carbonate in calcite form [3]. Compared to chicken eggs, the ostrich eggs weigh approximately 1.5 kg and 97% of the ostrich shell is of mineral origin allocated among calcium carbonate (97.4%), magnesium phosphate (1.9%), and tricalcium phosphate, TCP (0.7%) [4]. Moreover, it is worth mentioning that a female ostrich is able to produce approximately 60 eggs per year. However, the shell of quail eggs consists of 90% calcium carbonate and contains a lot of essential minerals, like zinc, copper, iron, potassium, calcium, magnesium, sodium, sulfur, phosphorus, and others. In addition, quail egg weighs about 10 g and their eggshell colors vary from white to blue and green which have brown or reddish-brown patterned areas on a light background [5]. It is noteworthy that the weight of giant African land snail eggs ranges from 1.54 – 2.45 g and they are capable of laying 4 -18 eggs in 1- 2 minutes [6].

The structure of the avian shells has mainly been investigated with imaging methods e.i. X-ray microscopy (XRM) [7], scanning electron microscopy (SEM) [8], transmission electron microscopy (TEM) [9] and optical light microscopy (LM) [10]. Despite the widely recognized importance of the chemical identification of various avian eggshell pigments and the detection of the pesticides on shells using various imaging methods, researching the morphology of the calcareous layer of eggshells as well as calcium carbonate content between different eggshells is an important step towards the better understanding of detection and characterization of shell components of avian eggs. Therefore, the present study was undertaken to evaluate the calcium carbonate content and the structural surface characterization of the calcareous layer of eggshells from five various animals species: European pond turtle (*Emys orbicularis* (Linnaeus, 1758)), giant African land snail (*Achatina fulica* (Bowdich, 1822)), common ostrich (*Struthio camelus* (Linnaeus, 1758)), white and brown laying hen (*Gallus gallus domesticus* (Linnaeus, 1758) and European quail (*Coturnix coturnix* (Linnaeus, 1758) using chemical analysis and SEM.

II. MATERIALS AND METHODS

Eggshell samples

Five different types of eggshells: European pond turtle (*Emys orbicularis* (Linnaeus, 1758)), giant African land snail (*Achatina fulica* (Bowdich, 1822)), common ostrich (*Struthio camelus* (Linnaeus, 1758)), white, light-brown, and dark-brown laying hen (*Gallus gallus domesticus* (Linnaeus, 1758) and European quail (*Coturnix coturnix* (Linnaeus, 1758) were analyzed with scanning electron microscopy (SEM) and chemical analysis.

The eggs were cracked by hand and their shells were separated from egg white, egg yolk, and the inner membranes.

Sample preparation and scanning electron microscopy (SEM)

For scanning electron microscopy (SEM), eggs were slowly air-dried at room temperature (20 °C ±2°C) over a period of several days and their surface structure was observed. We mounted dried, untreated eggshell fragments onto aluminium stubs, allowing the visualization of the shell surface, which we then sputter-coated with Ag (10.5 g/m3) conductive coating on the sample surface used turbomolecular pumped coater (Quorum EMS150T ES, UK). Scanning electron micrographs were taken at a working distance of 1.58-2.38 mm with an accelerating voltage of 2.0 kV. For examination of non-ground fragments of eggshells TM-1000 (Hitachi Tabletop Microscope, Japan) and MAIA 3 (TESCAN, Czech Republic) were used at a magnification up to 15 kx. The main concern was a detailed investigation and analysis of the visibility of as many as possible eggshell structures in order to compare and determine differences among animal species. A small fragment of the different eggshells (at least 1000 × 1000 μm) was taken.

Determination of calcium carbonate composition of eggshells

The calcium carbonate ($CaCO_3$) content in the eggshell powder was determined by the titration method. For the measurement of $CaCO_3$ content, pieces of eggshells from seven different eggs were collected and the protein-membrane was removed on the inside of the eggshells. The pieces were air-dried and the eggshells were then grounded into fine powder by mortar and pestle. 1g of eggshell powder was weighed accurately by using an electronic balance and it was transferred to a conical flask by adding several drops of ethanol which acted as a wetting agent and helped the HCl dissolve the $CaCO_3$. 10mL of 1.0M HCl solution was pipetted to dissolve the eggshell powder. The solutions were heated until they begin to boil and then were allowed to cool. i.e. for complete digestion. Phenolphthalein indicator was added to each flask, using a funnel, a clean burette was partly filled 0.1M NaOH solution to rinse it and was empty into the sink then the burette was again filled with NaOH solution and run some solutions out to remove all of the bubbles from the tip. The initial volume of the burette was constituted ± 0.01mL. The samples were titrated with NaOH solution to the first persistent pink color, when it was close to the endpoint, the color faded slowly and the remaining NaOH was added drop-wise until the color remains for some seconds where the final volume was recorded. The percentage of $CaCO_3$ in each eggshell was calculated.

Statistical analysis

The content of $CaCO_3$ was calculated on the average values of three replicate samples. Data are expressed as means ± standard errors of means (SEM), and $p < 0.05$ was considered to be statistically significant.

III. RESULTS AND DISCUSSION

It is well established that the eggshell is a highly specialized mineralized structure, which comprises inner and outer membranes, composing mainly of proteins and glycoproteins, and the mineral shell mainly consisting of the calcite polymorph of $CaCO_3$ [11,28]. The quality of the shell is tightly linked to many internal and external factors including oviposition, age, and genotype as well as housing system, nutrition, microclimate, etc. [12]. The comparative analysis of $CaCO_3$ content was carried out for eggshells of laying hen (white eggshell $CaCO_3$ content: 93.72%, light-brown eggshell: 94.44%, and dark-brown: 95.48%), turtle ($CaCO_3$ content: 96.21%), giant African land snail ($CaCO_3$ content: 84.33%), ostrich ($CaCO_3$ content: 98.79%), and quail ($CaCO_3$ content: 96.51%) by using the back titration method (Fig.1).

According to our experimental analysis of eggshell samples, the chemical composition of ostrich eggshells did not differ significantly compared to other eggshells, but the concentration of $CaCO_3$ was the highest, also significant morphological features were observed in the pore distribution and surface structure of the ostrich eggshell during SEM (Fig.2). The increased or decreased calcium levels in birds and animals might be depending upon their habitat. In addition, the calcium level was not influenced by the weight of eggs. Furthermore, the calcium levels of different eggshells change in pre-laying and laying phases [13,21,22]. The dynamics of changes in the eggshell properties in hens are related to physiological processes of mineral metabolism before, during, and after molting. During the pre-laying period, young hens create reserves of mineral substances especially calcium, which is stored in bones and other tissues [14]. However, during the laying period, the Ca reserves in medullar bones reduce, and an insufficient intake of Ca through the feed, the eggshell quality deteriorates, the incidence of nonstandard and broken eggs increased, and also shell-less eggs can be laid [14]. Moreover, it is worth mentioning that dark-colored eggshells contain a higher percentage of $CaCO_3$ when compared to white-colored eggshells and this may be due erence in hens' diet [15], indicating that brown egg has a higher strength than a white one. Similar results have been noticed by prior researchers [16].

The holes or micropores on the surface of eggshells which can be seen in this image (Fig.2) enable the gaseous exchange of the developing embryo. Most of the eggshell material is calcium carbonate which accounts for about a tenth of the egg's weight, this $CaCO_3$ presents in the eggshells as a calcite mineral and about 3.5% (by weight) organic material (including H_2O). Among hundreds of proteins identified by proteomics and various other means in the eggshell organic matrix, osteopontin is a major shell matrix protein and a member of a group of mineral-binding proteins. On the other hand, ostrich eggs are pitted with larger pores (Fig.2) and the uniformity of shell thickness contributes towards an overall increase in shell strength [17,23,24]. The eggshell of the African land snail, on the other hand, had a lower content of calcium carbonate in comparison with other samples, which was also noticeable in micrographs - the shell surface was not uniform, there were various irregularities and bulges on the surface (Fig.2). European pound turtle and European quail eggshells have almost the same concentration of calcium carbonate, a little less in a turtle, but an electron micrograph shows significant differences in the surface of the eggshell. The surface of the European quail (Fig.3) is more uniform, smooth, formed, which may indicate that its nutrition was more balanced, calcium carbonate was most likely added to the feed daily. The turtle eggshell (Fig.3) has small growths and depressions, cracks, this indicates that the nutrition was very different and this did not contribute to the formation of a uniform surface of the eggshell. It was noted that the average $CaCO_3$ content of various eggshells was between 84 and 98% and the thickness of the eggshell ranged from 0.08 to 1.89 mm, and it was not the same over the entire surface of the egg. At the sharp end of the egg, the shell is slightly thicker than at the blunt end. Eggshell thickness is considered as one of the major indirect parameters for the evaluation of eggshell quality [18].

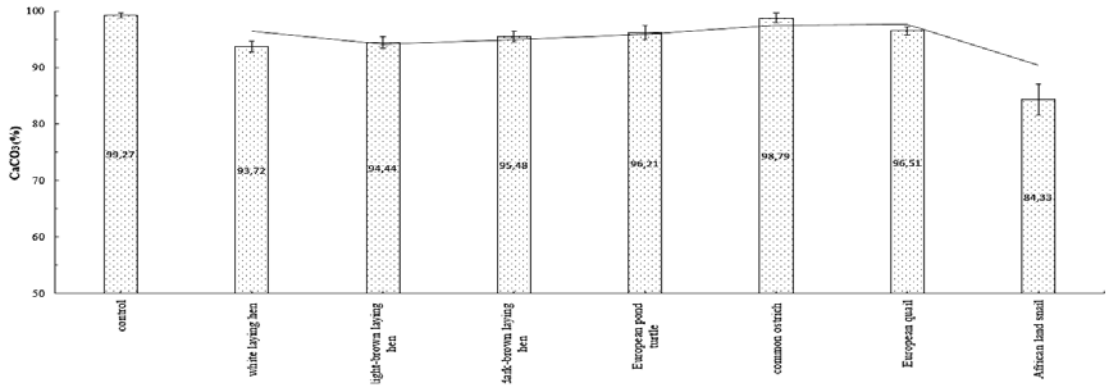
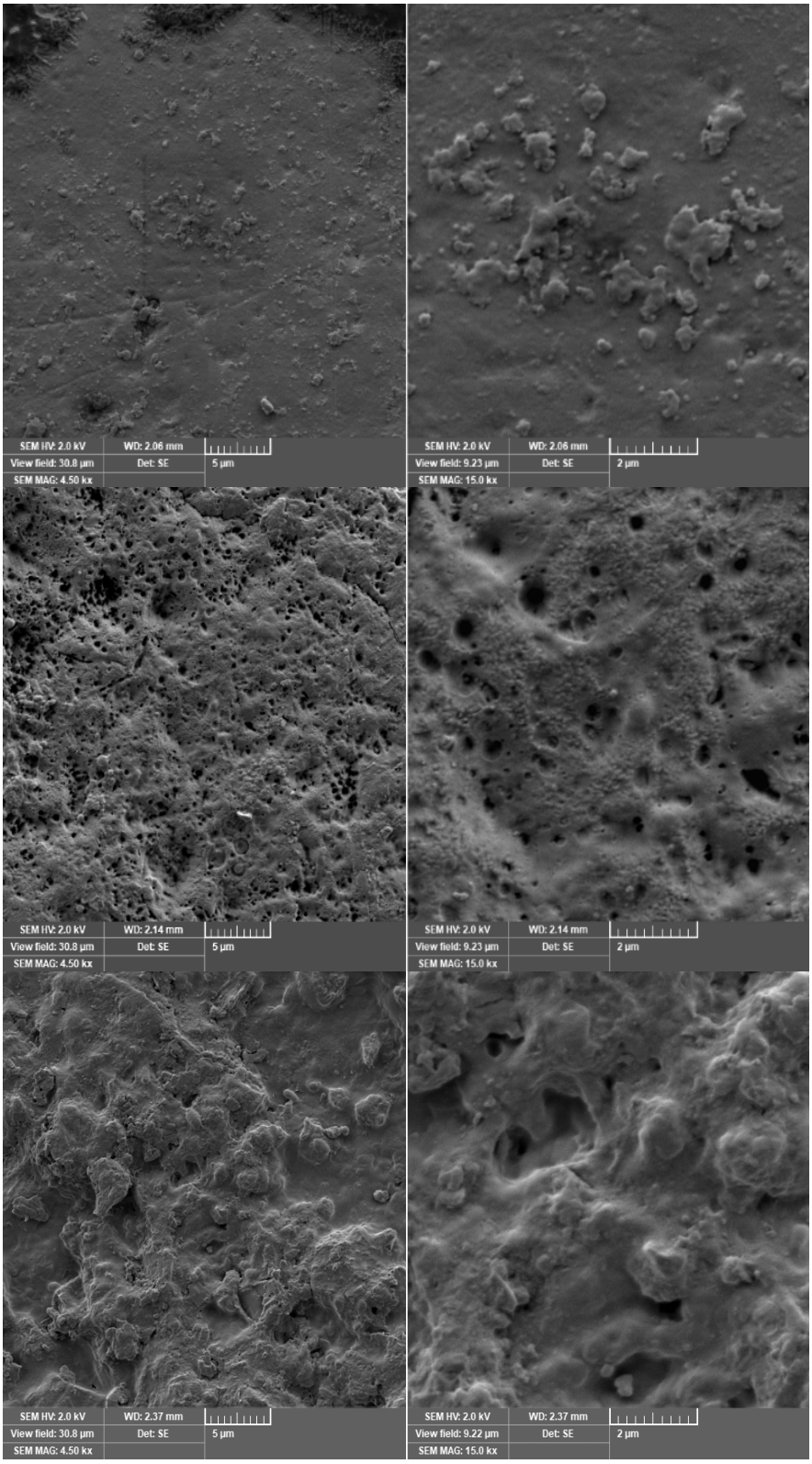


Fig.1. The concentration of calcium carbonate in different eggshells of various animal species.

Fig.2. Uncolored scanning electron micrograph (SEM) of eggshell surface (left side:4.5 kx, right side:15.0 kx): common ostrich (*Struthio camelus* (Linnaeus, 1758)) **(a)**, white laying hen (*Gallus gallus domesticus* (Linnaeus, 1758) **(b)**, giant African land snail (*Achatina fulica* (Bowdich, 1822)) **(c).**



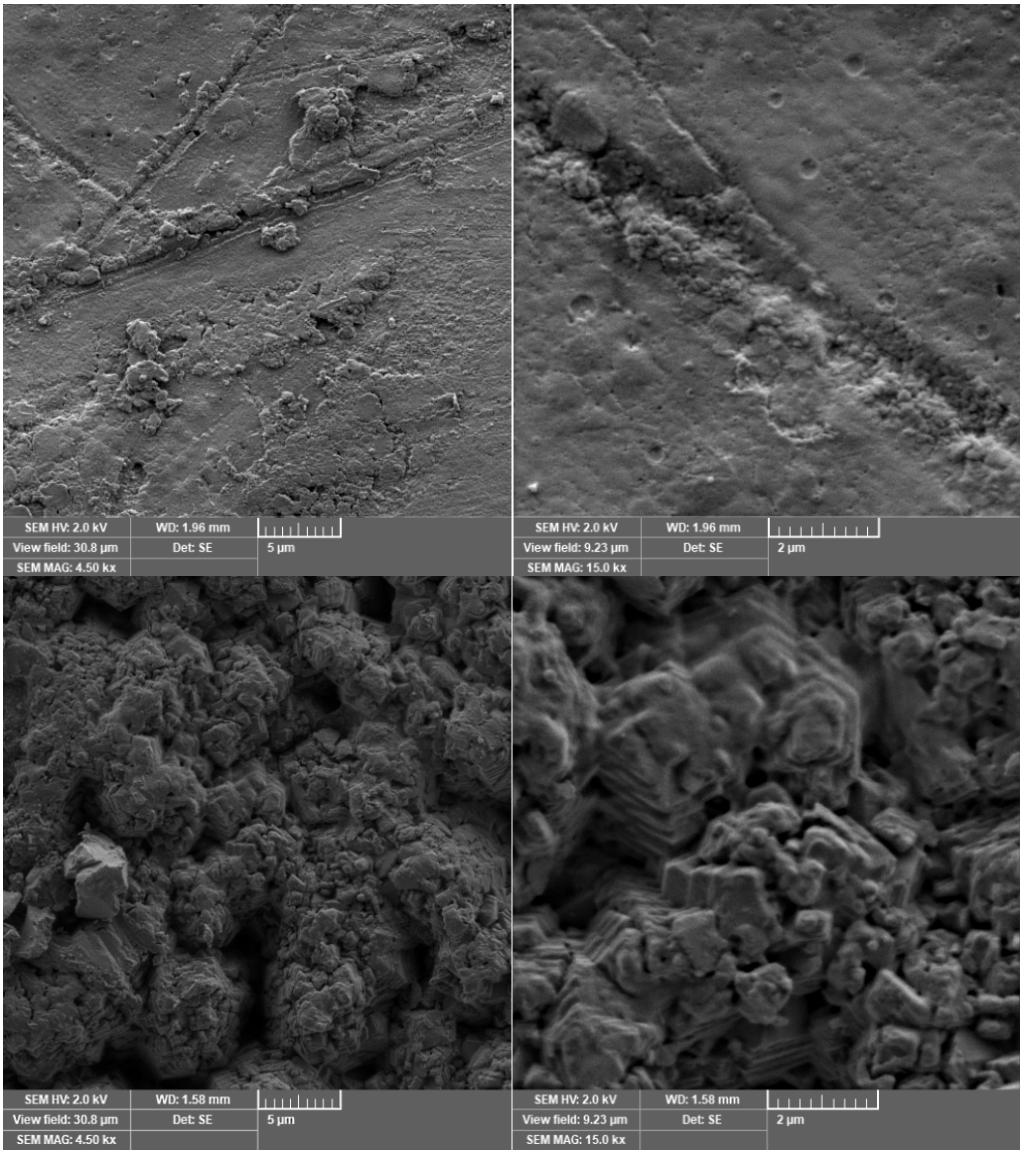


Fig.3. Uncolored scanning electron micrograph (SEM) of eggshell surface (left side:4.5 kx, right side:15.0 kx): European quail (*Coturnix coturnix* (Linnaeus, 1758), **(a)**, European pond turtle (*Emys orbicularis* (Linnaeus, 1758)) **(b)**.

Thicker eggshells at the sharp end of the egg can be explained with more calcium carbonate and other minerals [19]. The previous study has also shown that although the thickness is the main factor contributing to the mechanical strength of an eggshell, thicker does not guarantee stiffer or stronger eggs [20,25,26]. Moreover, it has been noted that increases in calcium levels improved the egg weight and eggshell thickness [13]. Additionally, increasing eggshell thickness means more mineral consumption from the feed [18,27].

IV. CONCLUSIONS

Calcium carbonate ($CaCO_3$) is one of the main factors contributing to eggshell quality that in turn is a feature of the obviously successful reproductive strategy. The comparative analysis of calcium carbonate ($CaCO_3$) content and structural surface characterization obtained from different laying hen eggshells and other animal species was studied by chemical analysis and scanning electron microscopy (SEM). Taken together, the data clearly showed that the eggshell of the white laying hens has less $CaCO_3$ content comparing with light-brown and dark-brown laying hens. Furthermore, the highest content of $CaCO_3$ and the strength of the eggshell were determined in the common ostrich. The results indicated that the least

$CaCO_3$ content was obtained in the eggshell of the African land snail. Our results about the structural surface characterization of various eggshells provide valuable clues towards further analyses of the physiological and genetic bases that may perhaps elucidate the causes of intraspecific variation.

REFERENCES

[1] M.T. Hincke, Y. Nys, J. Gautron, K. Mann, A.B. Rodriguez-Navarro, M.D. McKee, ″ The eggshell: structure, composition and mineralization,‟ Front. Biosci., vol. 17, pp. 1266-1280, 2012. https://doi: 10.2741/3985

[2] E. Ostertag, M. Scholz, J. Klein, K. Rebner, D. Oelkrug, ″ Pigmentation of white, brown, and green chicken eggshells analysed by reflectance, transnmittance, and fluorescence spectroscopy, ‟ ChemistryOpen, vol. 8, pp. 1084-1093, 2019. https://doi.org/10.1002/open.201900154

[3] S. Mitrus, ″ The calcareous layer eggshell of the turtle Emys orbicularis: ultrastructure and composition,‟ Ital. J. Zool., vol. 70, pp. 13-16, 2003. https://doi: 10.1080/11250000309356490

[4] J.R.M. Ferreira, L.H.L. Louro, A.M. Costa, J.B. de Campos, M.H. Prado da Silva, ″ Ostrich eggshell as calcium source for the synthesis of hydroxyapatite and hydroxyapatite partially substituted with zinc, ‟ Cerâmica, vol. 62, pp. 386-391, 2016. http://dx.doi.org/10.1590/0366-69132016623642002

[5] M. Sezer, O. Tekelioglu, ″ Quantification of Japanese quail eggshell colour by image analysis, ‟ Biol. Res., vol. 42, pp. 99-105, 2009. http://dx.doi.org/10.4067/S0716-97602009000100010

[6] B. Okon, L.A. Ibom, I.E. A.E. Ebenso, ″ Bassey, Developmental stages and quality traits of giant African land snails [Archachatina marginata (swainson)] eggs,‟ Nat. Sci., vol. 5, pp. 1121-11256, 2013. https://10.4236/ns.2013.510137

[7] D.C. Fecheyr-Lippens, B. Igic, L. D'alba, D. Hanley, A. Verdes, M. Holford, G.I.N. Waterhouse, T. Grim, M.E. Hauber, M.D. Shawkey, ″ The cuticle modulates ultraviolet reflectance of avian eggshells, ‟ Biol. Open, vol. 4, pp. 753-759, 2015. https://doi: 10.1242/bio.012211

[8] R.L. Mitchell, M. Coleman, P. Davies, L. North, E.C. Pope, C. Pleydell-Pearce, W. Harris, R. Johnston, ″ Macro-to-nanoscale investigation of wall-plate joints in the acorn barnacle Semibalanusbalanoides: correlative imaging, biological form and function, and bioinspiration,‟ J. R. Soc., Interface, vol.16, pp. 1-12, 2019. https://doi.org/10.1098/rsif.2019.0218

[9] B. Willoughby, L. Steyn, L. Bam, A.J. Olivier, R. Devey, J.N. Maina, ″ Micro-focus X-ray tomography study of the microstructure and morphometry of the eggshell of ostriches (StruthioCamerus), ‟ Anat. Record, vol. 299, pp. 1015-1026, 2016. https://doi:10.1002/ar.23354

[10] M. Moreno-Azanza, B. Bauluz, J.I. Canudo, J.M. Gasca, F.T. Fernández-Baldor, ″ Combined use of electron and light microscopy techniques reveals false secondary shell units in Megaloolithidae Eggshells,‟ PLoS ONE, vol. 11(5), pp. 1-17, 2016. https://doi: 10.1371/journal.pone.0153026

[11] M. Kristl, S. Jurak, M. Brus, V Sem. J. Kristl, ″ Evaluation of calcium carbonate in eggshells using thermal analysis,‟ J Therm. Anal., vol. 138(2), pp. 1-8, 2019. https://doi.org/10.1007/s10973-019-08678-8

[12] M. Ketta, E. Tumová, ″ Eggshell structure, measurements, and quality-affecting factors in laying hens: a review,‟ Czech. Anim. Sci., vol. 61, pp. 299-309, 2016. https://doi: 10.17221/46/2015-CJAS

[13] E.A. Rodrigues, M.C. Oliveira, L.C. Cancherini, K.F. Duarte, L.F. Santana, O.M. Junqueira, ″ Calcium in pre-laying and laying rations on the performance and quality of laying hens' eggshell,‟ Acta Sci., vol. 35(2), pp. 153-157, 2013. https://doi.org/10.4025/actascianimsci.v35i2.16555

[14] H. Arpášová, M. Halaj, P. Halaj, ″ Eggshell quality and calcium utilization in feed of hens in repeated laying cycles,‟ Czech J. Anim. Sci., vol. 55, pp. 66-74, 2010. https://doi.org/10.17221/90/2009-CJAS

[15] A. Nimisha, K.P. Shahanamol, A.U. Arun, S. Shalu, ″Quantitative variation in calcium carbonate content in shell of different chicken and duck varieties‟, Adv. Zool. Bot., vol. 8, pp. 1-5, 2020. https://doi: 10.13189/azb.2020.080101

[16] J. Gautron, M. Bain, S. Solomon, Y. Nys, ″Soluble matrix of hen's eggshell extracts changes in vitro the rate of calcium carbonate precipitation and crystal morphology,‟ Br, Poult, Sci., vol. 37, pp. 853-866, 1996. https://doi: 10.1080/00071669608417914

[17] J. Sales, D.G. S.C. Poggenpoel, Cilliers, ″Comparative physical and nutritive characteristics of ostrich eggs,‟ Poult. Sci., J. vol. 52, pp. 45-52, 1996. https://doi: 10.1079/WPS19960004

[18] Y.Y. Yan, C. J. Sun, L. Lian, J.X. Zheng, G.Y. Xu, N. Yang, ″ Effect of uniformity of eggshell thickness on eggshell quality in chickens, ‟ Poult. Sci. J., vol. 51, pp. 338-342, 2014. https://doi:10.2141/jpsa.0130032

[19] C.J. Sun, S.R. Chen, G.Y. Xu, X.M. Liu, N. Yang, ″ Clobal variation and uniformity of eggshell thickness for chicken eggs,‟ Poult. Sci., vol. 91, pp. 2718-2721, 2012. https://doi: 10.3382/ps.2012-02220

[20] M.M. Bain, ″Recent advances in the assessment of eggshell quality and their future application,‟ Poult. Sci. J., vol. 61(2), pp. 1-10, 2005. https://doi: https://doi.org/10.1079/WPS200459

[21] W.T. Tsai, J.M. Yang, C.W. Lai, Y.H. Cheng, C.C. Lin, C.W. Yeh,″Characterization and adsorption properties of eggshells and eggshell membrane,‟Bioresource Technology, vol. 97, pp. 488-493, 2006. https://doi.org/10.1016/j.biortech.2005.02.050

[22] A. Schaafsma, A. I. Pakan, G.J. Hofstede, F.A. Muskiet, E. Van Der Veer, P.J. De Vries, ″ Mineral, amino acid, and hormonal composition of chicken eggshell powder and the evolution of its use in humam nutrition, ‟ Poult. Sci., vol. 79, pp. 1833-1838, 2000. https://doi:10.1093/ps/79.12.1833

[23] F.S. Murakami, P.O. Rodrigues, C.M. Teixeira de Campos, M.A. Segatto Silva, ″ Physicochemical study of CaCO3 from egg shells, ‟ Food Sci. Technol, vol. 27(3), pp. 658-662, 2007. https://doi.org/10.1590/S0101-20612007000300035

[24] P. Cassey, G.H. Thomas, S. J. Portugal, G. Maurer, M.E. Hauber, T. Grim, P.G. Lovell, I. Mikšík, ″ Why are birds' eggs colourful? Eggshell pigments co-vary with life-history and nesting ecology among British breeding non-passerine birds,‟ Biol. J. Linn. Soc., vol. 106, pp. 657-672, 2012. https://doi.org/10.1111/j.1095-8312.2012.01877.x

[25] R.M. Kilner, ″ The evolution of egg colour and patterning in birds, ‟ Biol. Rev. Camb. Philos. Soc., vol. 81, pp. 383-406, 2006. https://doi: 10.1017/S1464793106007044

[26] A.B. Rodríguez-Navarro, N. Domínguez-Gasca, A. Muñoz, M. Ortega-Huertas, ″ Change in the chicken eggshell cuticle with hen age and egg freshness,‟ Poult. Sci., vol. 92, pp. 3026-3035, 2013. https://doi.org/10.3382/ps.2013-03230

[27] G. Maurer, S.J. Portugal, M.E. Hauber, I. Mikšík, D.G. Russell, D., P. Cassey, ″ First light for avian embryos: eggshell thickness and pigmentation mediate variation in development and UV exposure in wild bird eggs,‟ Funct. Ecol., vol. 29, pp. 209-218, 2015. https://doi.org/10.1111/1365-2435.12314

[28] Y.C. Chien, M.T. Hincke, H. Vali, M.D. McKee, ″ Ultrastructural matrix–mineral relationships in avian eggshell, and effects of osteopontin on calcite growth in vitro,‟ J. Struct. Biol., vol. 163, pp. 84–99, 2008. https://doi.org/10.1016/j.jsb.2008.04.008

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The use of Digital Communications Tools by Latvian Environmental NGOs

Denis Vasiliev
Department of Commerce
Turiba University
Riga, Latvia
denisksil@gmail.com

Abstract **- Successful nature conservation requires engagement of diverse groups of stakeholders. Attracting attention of general public and engagement of local communities that underpin sustainable development are between the most important aspects of effective communications by environmental non-governmental organizations (ENGOs). In the modern world digital tools provide unprecedented opportunities for broadening reach of ENGO communications. In Latvia, many organizations including ENGOs use digital tools as a part of their communications mix. However, it is important to understand to what extent the power of digital strategies is utilised by these organisations. For this purpose, analysis of Latvian ENGO digital strategies was undertaken. The analysis involved evaluation of digital usage by top Latvian ENGOs in comparison to application of online communications tools by similar organizations in Western Europe and in the USA. It was found that while Latvian ENGOs actively use digital communications tools, in comparison with western organizations a range of approaches that make online strategies effective is still underutilised. This may generally reduce reach of the communications and their public appeal. Ultimately, underuse of opportunities provided by digital communication tools may weaken effectiveness of nature conservation at a regional scale. Thus, it is suggested to enhance digital communications taking an example from Western ENGOS by introducing more educational and engaging content in a variety of formats, ranging from audio to video materials. Detailed recommendations based on findings of present review are provided.**

Keywords - nature conservation, environmental governance, adaptive management, publicity strategies.

I. INTRODUCTION

The recent UN Global Biodiversity Outlook [1] has revealed that the World fails to protect biodiversity. The report suggests that majority of famous Aichi Biodiversity Targets [2] have not been achieved, including the Target 1 – "Increasing awareness of biodiversity". This target is particularly important for ENGOs, because biodiversity awareness building is among key tasks of such organizations. Moreover, success of conservation interventions undertaken by ENGOs often depends on collaboration with multiple stakeholder groups and public engagement, which is a part of effective adaptive management [3]. In the modern world most effective communication methods are based on application of digital tools [4]. Social media and other digital tools, such as websites and blogs tend to be not only much more cost effective than traditional off-line communication methods but also often more influential [5]. Moreover, it was found that digital communications maximise effectiveness of off-line communications, when used together [6]. It is therefore important to understand to what extent ENGOs harness opportunities of digital communications.

However, evaluation of digital communication strategies in non-for-profit sector is much less straightforward than in commercial sector. In business, effectiveness of digital marketing communications is usually evaluated based on its contribution to company turnover and/or profits, using metrics such as Return on Investment (ROI) or lead generation. While such approach to evaluation of digital communication strategies is relatively straightforward, it is unapplicable to activities undertaken by ENGOs, because the ultimate goal of these organizations is not to generate sales and profits, but to increase awareness of biodiversity issues and ensure stakeholder engagement in nature conservation [7]. Therefore, aspects important for digital communications by ENGOs may include range of digital tools deployed, quality and diversity of the content, frequency of communications. However, to evaluate these parameters it is essential to deploy benchmarking approaches, comparing different NGOs. In this study, I decided to compare digital communications deployed by prominent

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Latvian ENGOs with similar organizations in Western European countries and in the USA.

Latvia has is between the leading counties in Europe in terms of internet speed and penetration [8, 9], outperforming even highly developed European counties, such as France, Germany, or the UK. This creates an ideal environment for ENGOs to use digital communications tools for engagement with diverse stakeholder groups. Generally, Latvian ENGOs are well known for successful management of communications campaigns influencing policymakers. For instance, thanks to famous communications activities of ENGOs Latvia currently is GMO free country [10]. These campaigns however, used a range of off-line and online tools with heavy emphasis on outdoor media. At the same time, Western European and American ENGOs have demonstrated extremely successful usage of digital tools. For instance, British ENGO "Buglife", has managed to implement national scale landscape connectivity network for pollinators called B-Lines mainly through engaging multiple stakeholder groups and general public using digital communications [11]. Thus, it is important to understand whether there is a space for further enhancement of communications strategies through the use of digital tools for Latvian ENGOs following examples of western colleagues. The aim of present study is to reveal the areas of potential enhancement of digital communications for Latvian ENGOs through comparing their strategies with the ones used in the Western European Countries – the UK, Germany, Ireland, and in the USA.

II. Materials and Methods

In this study three prominent Latvian ENGOs: "Latvijas Zemes Draugi" ("Latvian Friends of Earth") [12], "Latvijas Dabas Fonds" ("The Latvian Fund for Nature") [13] and "Vides aizsardzibas klubs" ("Latvian nature conservation club") [14]. These organizations were selected from the list provided by LETA media agency in Latvia, that provided ranking of the most significant nature conservation organizations in Latvia [15]. From this list only non-governmental, non-for-profit organizations were selected. In order to compare selected Latvian ENGOs similar organizations were selected from three Western European countries (the UK, Ireland and Germany) as well as from the USA, using Google search for top ENGOs in each country. One of such organizations was selected from each country: "Green Alliance" from the UK [16], "Friends of the Irish Environment" from Ireland [17], "Bund" from Germany [18] and "The Nature Conservancy" [19] from the USA. Websites and social media pages of the selected organizations from Latvia and from Western Europe and the USA were analysed using Excel spreadsheet with the following columns: name of the ENGO, country of origin, presence on social media platforms, local vs global appeal, content diversity, frequency of content publication, content quality. It was decided not to compare number of followers on social media platforms of the ENGOs, because of significant differences in population sizes of the selected countries and global appeal of some organizations. Digital strategies used by each organization were compared and evaluated. Evaluation criteria used for the analysis of ENGO websites included: website design clarity, whether the website is static or dynamic, whether it is translated to foreign languages, thereby having global appeal, whether the website has a blog and if yes whether this blog is regularly updated. For evaluation of ENGO performance at social media networks the following criteria were used: number of social media platforms at which each ENGO is present, frequency and number of posts, number of followers, type and quality of content shared at each platform, considering whether the content is dominated by text or includes photographic, audio, or video materials. Content quality as evaluated based on its nature – text, images or videos, as well as the quality of each content type, e.g. how professionally are photographic materials made, or how engaging is the content of video materials. Number of followers on social media networks was also considered, when evaluating content quality, based on an assumption that the higher content quality is the more followers will be attracted by the content.

III. Results

Results of present study suggest that Latvian actively use ENGOs digital tools, including webpages and a broad range of social media platforms. The Website of "The Latvian Fund for Nature" has translation to English, the other two ENGOs have their websites and social media pages only in Latvian. All three selected organizations have clear, well developed webpages with a blog, which tends to be regularly updated. Furthermore, these ENGOs have Facebook landing pages, where they upload posts several times a week. Both "The Latvian Fund for Nature" and "Latvian nature conservation club" maintain pages at the popular local social media platform Draugiem.lv. In addition to that "The Latvian Fund for Nature" is present on Twitter, Instagram, LinkedIn and Vimeo, and uses RSS. However, Instagram, LinkedIn and Vimeo pages are not actively maintained with very small number of posts (12 posts on Instagram, 5 on LinkedIn and just 4 on Vimeo).

All three selected Latvian ENGOs have YouTube channels. However, it is important to note, that they have relatively small number of videos on YouTube channels, with "The Latvian Fund for Nature" having 95 videos, "The Latvian Friends of Earth" having 8 videos and "Latvian nature conservation club" – just 4 videos. Videos range from less than 2-minute short ones up to 5 hours long, with different type of content, ranging from interviews and expert opinions to documental films on nature and records of events. A very interesting feature on the "The Latvian Fund for Nature" YouTube channel are live translations from bird nests. This channel has more than 18 000 subscribers and, as could be concluded from the live chat, this audience includes foreign viewers.

All foreign ENGOs considered in present study had robust websites with a blog and presence on social media.

Websites of the organizations tended to be static, except for "The Nature Conservancy" website, which is dynamic and has very high-quality design. It is also important to note, that German ENGO "Bund" has very high quality of website design, too. Interestingly, all websites of the ENGOs considered in this study are only in one language – with "Bund" having a website in German and all other ENGOs – in English. Still, as clearly from the website content "The Nature Conservancy" has global appeal, unlike other ENGOs that focus mainly on local environmental issues.

Considering social media presence, all ENGOs have YouTube channels and Facebook pages. In addition, the ENGOs are present on photo sharing social networks, with "Green Alliance" present on Flickr and all other ENGOs having Instagram pages. Twitter tends to be used by "Green Alliance", "Bund" and "The Nature Conservancy", but not by "Friends of the Irish Environment". Interestingly, the British "Green Alliance" and the American "The Nature Conservancy" are also represented at LinkedIn, while other ENGOs do not use this platform. "Green Alliance" also uses less popular social media platform – Wakelet. Interestingly, this organization also has its own podcast. RSS is used only by "Green Alliance" and "Friends of the Irish Environment". All foreign ENGOs explored in this study regularly post on Facebook (several times a week). Those ENGOs that have Twitter pages also update them regularly. Other social media channels tend to be maintained less intensively. Nevertheless, "The Nature Conservancy" and "Bund" very actively maintain YouTube channel with the former uploading videos weekly and the latter – monthly. At the same time "Green Alliance" generates monthly podcasts.

Quality and diversity of audio visual content posted by foreign ENGOs is generally very high. German ENGO "Bund" and American ENGO "The Nature Conservancy" produce a broad range of video content, including translation using live-cameras, engaging workshops, large scale migrations of birds and animals, educational content – explanations of ecological problems, case studies, episodes from live of indigenous people, interviews, community events etc. Audio content produced by the UK ENGO "Green Alliance", also excites with its diversity as it includes educational podcasts, podcasts considering policy issues, interviews, event records, discussions of environmental justice etc. Interestingly video materials were predominantly short, not exceeding 10 min. Audio podcasts tended to be about half an hour long. It is also important to note that photos shared by foreign ENGOs on Instagram and Flickr are of a very high quality, too.

IV. Discussion

As follows from findings of the present study suggest that Latvian ENGOs actively use digital communications tools. However, comparison with leading foreign EBGOs has revealed that there is a scope for further development in this area. One really important area for improvement is the use of high-quality diverse video, photographical and audio content. Indeed, foreign ENGOs have substantial representation at such social media platforms as YouTube, Instagram and Flickr, and even use audio podcasts. Although Latvian ENGOs are represented at some of these platforms, quantity and diversity of the content tends to be relatively limited. This is an important issue, that may reduce effectiveness of digital communications. Recent scientific studies suggest that video and audio content, as well as images tend to be particularly effective in engaging target audiences and influencing their behaviour [20]. In addition to that, diversity of communications tools and the content itself tends to increase engagement with the target audiences and attract attention of a broader range of stakeholders with variety of interests, tastes, and preferences [21]. As follows from the results of the present study foreign ENGOs use a broad range of video or audio content, that has a great potential to be of interest to different social groups. For instance, "The Nature Conservancy" YouTube channel is full of high-quality video content that demonstrates aspects of animal life, educates people about most pressing environmental problems, tells stories about lives of indigenous people and teaches different useful skills, such as design etc. Positive effect from adding content diversity was also observed at "The Latvian Fund for Nature" YouTube channel, where the ENGO included live translations from bird nests. The page has a huge number of followers and attracts not only local but also foreign audiences. It is therefore recommended for Latvian ENGOs to produce more videos, images and, perhaps, audio content, with greater variety of topics. Clearly, producing high quality video and photographical content requires substantial financial investment and skills, which may not be available to ENGOs. However, in order to address this issue it is possible to harness European funds that are intended to building and increasing NGO capacity or other funding sources, that could be used for acquiring high quality equipment and paying for work invested in producing the content. Still, employing skilful employees on a permanent basis may be problematic for ENGOs with limited budgets, thus it is worth considering outsourcing production of the audio-visual content to professional organizations or engaging with volunteers [22].

Another area of potential need for further development in digital communications of Latvian ENGOs is consistency and frequency of the communications activities on social media. Although, all Latvian ENGOs explored in present study regularly update Facebook pages, activity on other social media platforms seems to be less regular and consistent in comparison with western ENGOs, which tend to produce regular posts across channels. It is well established, that communication frequency strongly affects its effectiveness [23]. Understandably, regularly producing and posting high-quality content is a highly labour intensive task. However, it is worth the effort, as engaged stakeholders are likely to

become supportive of the organization's values, thereby contributing to nature conservation [24]. The problem of lack of human resources may be resolved either through attracting additional funding or through collaboration with other stakeholders. As was mentioned earlier, ENGOs may attract volunteers. Another possible solution could be to establish collaboration with educational organisations, that could engage their students into ENGO communication activities.

One more important issue that requires attention is the broadness of appeal of ENGO communications. Interaction only with local environmentally conscious people may not be sufficient for mobilization of a broader society and implementation of effective adaptive management [25]. As was already discussed increasing variety of the content may increase broadness of organization`s appeal. In addition to that using content translation, may attract international audiences to support ENGOs. Interestingly, however, all ENGOs considered in the present study, both Latvian and foreign, had their websites and social media pages in just one language. Still, American and British ENGOs use English language in their digital communications, allowing them to secure international appeal without translating the content. For instance, American ENGO "The Nature Conservancy" is well known for its global activity. Results of present study revealed that Latvian ENGO ("The Latvian Fund for Nature" is already engaging with international audiences, by placing interesting content on its YouTube channel. However, translating content on the websites and social media platforms in English could broaden international appeal, potentially benefiting Latvian ENGOs.

V. Conclusions

The aim of present study was to reveal the areas of potential enhancement of digital communications for Latvian ENGOs by comparing their strategies with the ones used by foreign organizations. It was found that Latvian ENGOs in general are active users of digital media, however, there are still areas that need to be addressed in order to increase communications effectiveness. First of all, Latvian ENGOs need to use more video content and images and regularly post them on such popular social media platforms as YouTube and Instagram. This could substantially increase effectiveness of digital communications strategies. It is also important to note that increasing diversity of the content most likely will increase appeal of the communications facilitating public engagement in nature conservation activities. Secondly, frequency of content posting on social media platforms used by Latvian ENGOs needs to be increased, making it consistent across channels. Finally, broadness of the communications appeal could be magnified through translation of the content into foreign languages. All these improvements may be operationalised through harnessing European funds and other sources of funding, as well as through collaboration with other organizations and stakeholder groups.

References

[1] Secretariat of the Convention on Biological Diversity. *Global Biodiversity Outlook 5*. Montreal, the United Nations, 2020.

[2] Aichi Biodiversity Targets [Online]. Available: https://www.cbd.int/sp/targets/ [Accessed: Feb. 10, 2021]

[3] M. Kaplan-Hallam and N.J. Bennett, "Adaptive social impact management for conservation and environmental management", Conservation Biology, vol. 32(2), pp. 304-314 Jul. 2017, DOI: 10.1111/cobi.12985.

[4] S. Pavelle and C. Wilkinson, "Into the Digital Wild: Utilizing Twitter, Instagram, You Tube, and Facebook for Effective Science and Environmental Communication". Frontiers in Communication, vol. 5(575122), Oct. 2020, DOI: 10.3389/fcomm.2020.575122.

[5] A. Lieberman and J. Schroeder "Two social lives: How differences between online and offline interaction influence social outcomes", Current Opinion in Psychology, vol. 31, pp. 16–21, Feb. 2020 , DOI: 10.1016/j.copsyc.2019.06.022

[6] Q. Shi, C. Wang, J. Chen, Y. Feng, C. Chen, "Location driven influence maximization: Online spread via offline deployment", Knowledge-Based Systems, vol. 166, pp. 30-41, Feb. 2019, DOI: 10.1016/j.knosys.2018.12.003.

[7] P. Pacheco-Vega and A. Murdie, "When do environmental NGOs work? A test of the conditional effectiveness of environmental advocacy", Environmental Policies, vol. 30(1-2), pp. 180-201, DOI: 10.1080/09644016.2020.1785261.

[8] Factmetrics, "Average Internet Speeds By Country". [Online]. Available: https://www.fastmetrics.com/internet-connection-speed-by-country.php#top-10-worldwide [Accessed: Feb. 17, 2021].

[9] Tefficient, "USA, Latvia and Finland combine: High mobile data usage with fast growth". [Online]. Available: http://media.tefficient.com/2016/06/tefficient-industry-analysis-3-2016-mobile-data-usage-and-pricing-FY-2015-final2.pdf [Accessed: Feb. 18, 2021].

[10] GMO free Europe, "Latvia". [Online]. Available: https://www.gmo-free-regions.org/gmo-free-regions/latvia.html [Accessed Feb. 12, 2021].

[11] Buglife, "B-Lines". [online]. Available: https://www.buglife.org.uk/our-work/b-lines/ [Accessed Feb 14, 2021].

[12] Latvijas Zemes Draugi (in Latvian). [Online]. Available: http://www.zemesdraugi.lv/ [Accessed Feb. 20, 2021]

[13] Latvijas Dabas Fonds (in Latvian). [Online]. Available: https://www.ldf.lv/ [Accessed Feb. 16, 2021]

[14] Vides aizsardzibas klubs (in Latvian). [Online]. Available: http://www.vak.lv/ [Accessed Feb 15, 2021].

[15] Latvijas Zala Josta (in Latvia). [Online]. Available: http://www.zalajosta.lv/lv/biedriba-latvijas-zala-josta-viena-no-lielakajam-vides-aizsardzibas-organizacijam-latvija [Accepted Feb. 20, 2021].

[16] Green Alliance. [Online]. Available: https://green-alliance.org.uk/ [Accessed Feb. 19, 2021].

[17] Friends of the Irish Environment. [Online]. Available: https://www.friendsoftheirishenvironment.org/ [Accessed Feb. 20, 2021].

[18] Bund (in German). [Onlie]. Avaiable: https://www.bund.net/ [Accessed Feb. 22, 2021]

[19] The Nature Conservacy. [Online]. Available: https://www.nature.org/en-us/ {Accessed Feb: 22, 2021].

[20] D. Grewala, D. Herhausenb, S. Ludwigc anf F.V. Ordenesd, "The future of digital communication research: Considering dynamics and multimodality", Journal of Retailing, 18 Feb. 2021, [Online serial]. Available: https://www.sciencedirect.com/science/article/pii/S0022435921000075 [Accessed Accessed Feb. 2, 2021].

[21] R. Dolan, J. Conduit, C. Frethey-Bentham, J. Fahy and S. Goodman, "Social media engagement behavior: A framework for

engaging customers through social media content", European Journal of Marketing, vol.53(10), pp. 2213-2243, Oct. 2019, DOI: 10.1108/EJM-03-2017-0182.

[22] M. Kumaran, "Organizational Capacity Building and Strategic Growth for Environmental NGOs: A Primer", WEIS (World Environment and Island Studies), vol. 8(1), pp. 11-21, Mar. 2018.

[23] C. Fill, "Essentially a Matter of Consistency: Integrated Marketing Communications", The Marketing Review, vol. 1, pp. 409-425, Jul. 2001.

[24] F. Miriam, L.S.G. Piccolo, D. Maynard, M. Wippoo, C. Meili, and H. Alani, "Talking Climate Change via Social Media: Communication, Engagement and Behaviour". In: WebSci '16 Proceedings of the 8th ACM Conference on Web Science, ACM, New York, USA, pp. 85–94, May 2016, DOI: 10.1145/2908131.2908167.

[25] H. Murphy-Gregory, "Governance via persuasion: environmental NGOs and the social licence to operate", Environmental Policies, vol. 27(2), pp. 320-340, Sep. 2017, DOI: 10.1080/09644016.2017.1373429.

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Structural Investigation of the Intermediate Layer in a Bimetal Mill Roller Produced by the Method of Vertical Axis Centrifugal Casting

Angel Velikov
Institute of Metal Science, Equipment and Technologies with Centre of Hydroaerodynamics "Acad. A. Balevski"
Bulgarian Academy of Sciences
Sofia, Bulgaria
anmabg61@gmail.com

Peter Ivanov
"CENTROMET" JSC
Vratza, Bulgaria
petarv@abv.bg

Ivan Georgiev
Institute of Metal Science, Equipment and Technologies with Centre of Hydroaerodynamics "Acad. A. Balevski"
Bulgarian Academy of Sciences
Sofia, Bulgaria
ivan_georgiev51@abv.bg

***Abstract* - Subject of the investigation is a bimetallic mill roller with external, working layer from high chromium material and inner, supporting layer from ductile cast iron. The processes, accompanying the formation of a transition layer in bimetallic castings, produced by centrifugal casting have been investigated. Attention has paid to the structural changes in the transition zone, caused by the diffusion processes occurring during the casting and crystallization.**

Keywords - bimetal roller, centrifugal casting, mathematical model.

I. INTRODUCTION

The final structure of each cast material is a bearer the work properties of the casting. The requirements to the exploitation characteristics of castings type "roller" are that they must be with external work surface of high hardness and wear resistance, while the internal connecting, base surface must be of good workability and withstand heavy workloads. It is these requirements that lead to the idea that the casting must be made from two types of material: the external work surface of durable cast iron (in this case with high Cr content), and the inner one of ductile gray cast iron. Thus the machine processing is faced with some difficulties, so an additional requirement is set for the external surface to be in shape and dimensions as close as possible to those of a finished roller. This type of two-layer casting can be accomplished, applying the method of vertical axis centrifugal casting by successive pouring of the melts. For this purpose a special moulding equipment was constructed and made according to desired configuration of the casting. The values of the technological parameters for forming of the casting were determined, namely: the amount of the melts for the first and second layer, the mass rates of pouring the melts into the cavity of the metal mould, the type and thickness of the heat resistant [1] and at the same time thermally insulating coating on the working surfaces of the vertical shape, the pouring temperatures of the two types of melt, the angular velocity of the mould at forming of the casting, and the pause after the end of pouring of the first layer and the beginning of pouring of the second one.

A mathematical model of mould filling has been created. An experiment in real conditions was performed to determine the coefficient of heat transfer of the system "melt - refractory coating - metallic mould - environment".

From the experimental castings, metallographic specimens were cut, which were processed and prepared for structural testing.

The metallographic analysis was performed with an OPTON metallographic microscope.

II. MATERIALS AND METHODS

Technology requirements

The casting should be formed as follows:

1. First layer of alloy with high Cr content and chemical composition (table 1) with weight 1665kg;
2. Second layer of ductile cast iron with weight 2208 kg;
3. The two layers must be well soldered but not mixed and dissolved into each other.

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TABLE 1 FIRST LAYER OF ALLOY CHEMICAL COMPOSITION

Chemical element, %					
C	***Cr***	***Si***	***Mn***	***Ni***	***Mo***
2,0÷3,2	20÷25	0,5÷1,0	0,5÷1,5	0,5÷1,5	0,5÷2,0

Its geometry should be formed into a cylindrical mould represented schematically in Fig.1.

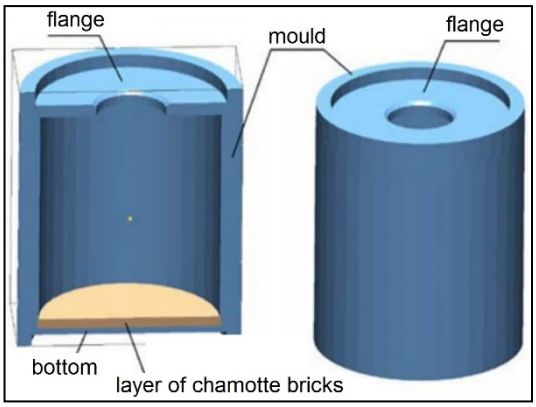

Fig. 1. Cylindrical mould

III. RESULTS AND DISCUSSION

A. *Mathematical modelling of the geometry of the free surface of the fluid at rotation with constant angular velocity the mould.*

The free surface equation is derived from the basic principle of the fluid's statics, which is that the resulting force is perpendicular to the free surface [2,3,4]. In the case of fluid with density ρ, rotating in a vessel with a vertical axis of rotation, the resultant force acting at a point of free surface and equal to the pressure is formed by the centrifugal force and the vertical component , balancing the weight of the fluid . These forces are shown schematically in Fig. 2.

For centrifugal force, written in components, we have:

$$\vec{F_c} = (-\rho\omega^2 r, 0) \tag{1}$$

On the other hand:

$$\vec{R} = -\vec{Q} = -(0, -\rho g) = (0, \rho g) \tag{2}$$

The magnitude of the pressure p is formed by the height of the fluid above the current point, i.e. $H - z(r)$ and therefore we will have:

$$p = |\vec{p}| = pg[H - z(r)] \tag{3}$$

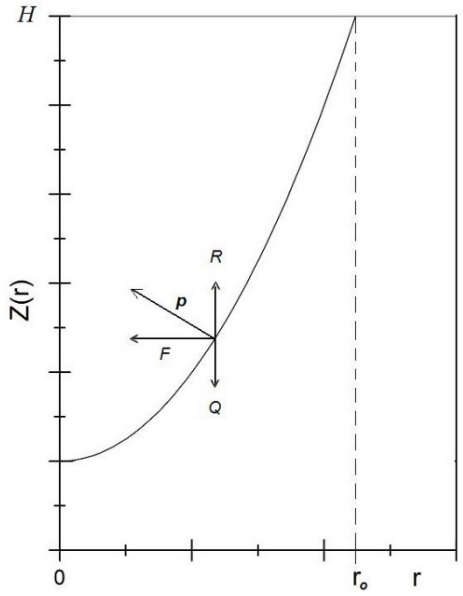

Fig. 2. Forces acting at a point of free surface

The normal single vector to the free surface can be found as follows:

First, we write the equation of the tangent to the curve of the surface at the current point. The equation turns out to be the following:

$$y = z(r) + z'(r)(x - r) \tag{4}$$

where: ***x*** and ***y*** are the current coordinates of the tangent corresponding to ***r*** and ***z***. After an elementary transformation, the last equation turns out to be:

$$-z'(r)x + y - z(r) + rz'(r) = 0 \tag{5}$$

It is known from analytical geometry that the coefficients before ***x*** and ***y*** set a vector perpendicular to the line determined by equation (3,5). Therefore the vector is collinear with $\vec{p}$ and perpendicular to the curve of surface. After its normalization of the type:

$$\vec{e}_n = \frac{(-z\prime(r),1)}{\sqrt{1+z\prime^2}} \tag{6}$$

For $\vec{p}$ we get:

$$\vec{p} = \frac{\rho g[H-z(r)]}{\sqrt{1+z\prime^2}}(-z', 1) \tag{7}$$

Further from the vector equation:

$$\vec{p} = \vec{F_c} + \vec{R} \tag{8}$$

Written in components, we get the following two differential equations:

$$\frac{g(H-z)}{\sqrt{1+z'^2}}z' = \omega^2 r$$
$$\frac{H-z}{\sqrt{1+z'^2}} = 1 \quad (9)$$

When substituting the second in the first it results in the following ordinary differential equation:

$$\frac{dz(r)}{dr} = \frac{\omega^2}{g}r \quad (10)$$

Its integration leads to the following solution:

$$z(r) = \frac{\omega^2}{2g}r^2 + C \quad (11)$$

determined to an accuracy of constant ***C***. It should be determined by the boundary condition:

$$z(r_0) = H \quad (12)$$

where: r_o is the radius at which the maximum height of the vessel (mould) is reached. Then it turns out that ***C*** is:

$$C = H - \frac{\omega^2}{2g}r_0^2 \quad (13)$$

Substituting in (11) for the surface curve, we finally get:

$$z(r) = H + \frac{\omega^2}{2g}(r^2 - r_0^2) \quad (14)$$

It is apparent from this equation that the fluid surface takes the form of a rotary paraboloid. By the proper integration of the kind:

$$V = 2\pi \int_0^{r_0} rz(r)dr \quad (15)$$

the volume of fluid below the paraboloid can be calculated, i.e. the volume of fluid filling the cylindrical mould. With the mathematical model thus presented, solutions can be obtained for the free surface of a fluid under conditions of rotation at a constant angular velocity ***ω*** and under the action of the earth's gravitational field, at different geometries of the mould, filled by the fluid and at different angular velocities.

B. Calculating the pressure exerted of the liquid layer on the solidified layer.

As a result of the active forces, a static pressure is formed at each point of the fluid, which changes both in radius and in height [3,5]. In this section, we will present a mathematical model that allows us to find this static pressure at any point in the fluid, and in particular on the wall of the mould or on an already solidified layer at formation of the casting at vertical axis centrifugal casting.

The static pressure in a point with coordinates (***r***, ***z***) located in the liquid layer is formed by two components, as shown in Fig.3.

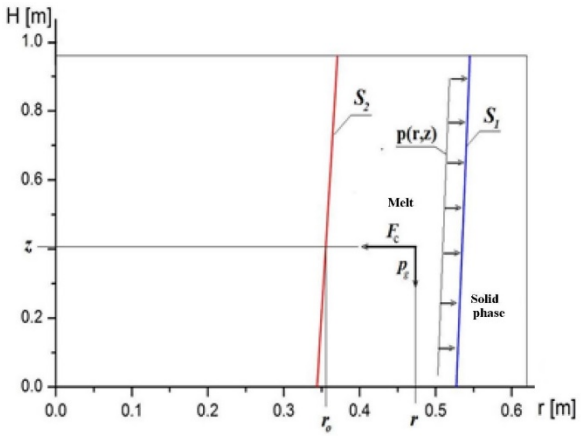

Fig. 3. Static pressure in a point with coordinates (r, z) located in the liquid layer

One is formed by the centrifugal force:

$$F_c(r,z) = \int_{r_0}^{r} \rho\omega^2 RdR = \frac{\rho\omega^2}{2}(r^2 - r_0^2) \quad (16)$$

and the other one by gravity:

$$p_m = \rho g(H - z) \quad (17)$$

where: ***ρ*** - is the mass density of the liquid layer; ***ω*** - angular velocity of rotation; ***g*** - earth acceleration.

Therefore, we can record the resultant pressure:

$$p = \rho\left[g(H - z) + \frac{\rho\omega^2}{2}(r^2 - r_0^2)\right] \quad (18)$$

The last formula allows us to calculate the pressure at each point of the fluid. When ***r*** and ***z*** are coordinates of a point from the surface S1 of Fig. 3, we will obtain the pressure exerted of the fluid on the solid phase or mould.

Based on the mathematical model, a simulation was performed using the MAGMA Soft software package to determine the optimum casting temperatures of the first and second layers of the casting, as well as the required intermediate time between the completion of casting of the first layer and the start casting of the second layer, so that the two layers to be fused but not mixed.

C. Structural observations of the formed intermediate layer.

The specimen has been prepared in accordance with the standard methodology for metallographic analysis. Fig. 4 shows the cut-off specimen for metallographic observations. The research is focused on the so-called transition zone, between the external (working) layer of material with high Cr content and the inner (bearing) layer of ductile iron - Fig.5 to Fig.7.

Fig. 4. Specimen for metallographic observations.

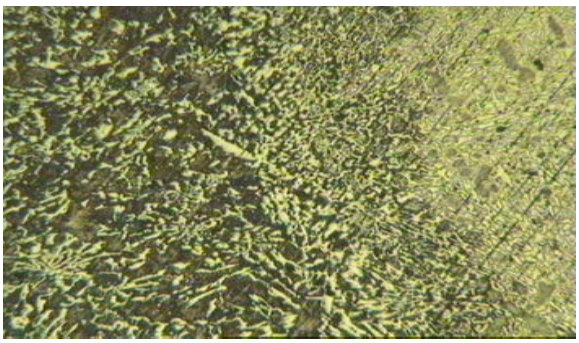

Fig. 5. Transition layer - x50

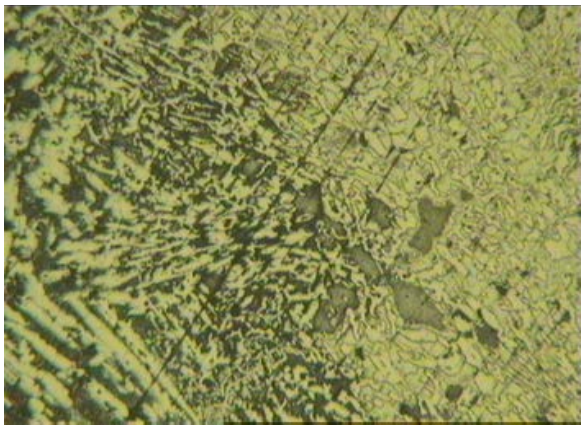

Fig. 6. Transition layer - x100

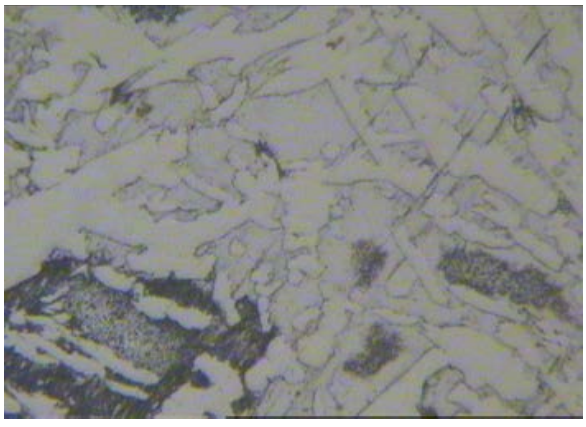

Fig. 7. Transition layer - x500

IV. Conclusions

1. The metallographic analysis shows that the transition zone is possibly maximally limited.

2. The two materials are fully fused in the presence of minimal structural changes in the depth of the second (bearing) layer of ductile cast iron, caused by the diffusion processes accompanying the casting process of the inner layer and altering the initial chemical composition of the material.

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References

[1] L.Gushev, V.Valkov and I.Georgiev “Modelling of the defining technological parameters in obtaining of heat-resistant coatings on molds for centrifugal casting”, *Sat. Scientific Papers*, vol. IX, pp. 177-187, Sept. 1986.

[2] G.Georgiev and I.Georgiev, “Mathematical modelling and computer simulation of two-component moulding”, *Scientific Proceedings*, year XXIII, vol. 2(165), June 2015.

[3] G. Georgiev, I. Georgiev, P.Ivanov, St. Tsenov and I.Panayotov, "Mathematical modelling and optimization of technology for the formation of two-layer casting by the method of centrifugal casting", *XXIV International Scientific and Technical Conference : FOUNDRY 2017 proceedings*, April 5-7, 2017, Pleven, Sofia, Scientific-technical union of mechanical engineering “Industry-4.0”, 2018, pp23-28.

[4] S. Yudin, M. Levin, and S. Rosenfeld, *Centrifugal Casting part 1*, Moscow, 1972.

[5] I.Georgiev and V.Valkov, “Theoretical - experimental researches for determination of technological parameters at vertical axis centrifugal casting with of two-layer shaped castings”, *Engineering Sciences*, book 2, pp.86-94, Sept. 2011.

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Mixing viscous liquids in settling tanks

Oleg Voroztsov
Institute of Engineering Sciences
Pskov State University
Pskov, Russia
voroz1968@mail.ru

Sergeu Tihonov
Institute of Engineering Sciences
Pskov State University
Pskov, Russia
s_tikhonov58@mail.ru

Aleksandr Bileev
Institute of Engineering Sciences
Pskov State University
Pskov, Russia
Alton81@mail.ru

***Abstract* - The study adresses the problem of maintaining the operability of settling tanks designed for storing contaminated liquids. The study provided a method of mixing of bottom sludge and a mathematical model for determining initial velocity of outflow from the flat orifice depending on physical, mechanical and rheological parameters of the bottom sludge.**

Keywords - mixing, bottom sludge, viscous non-Newtonian fluid, semi-restricted jet.

I. INTRODUCTION

The main function of slurry tanks, such as liquid manure storages, is maintaining homogeneous structure of the liquid medium in order to prevent sludging and tank siltation. Since sludge significantly thickens during siltation, removing sludge from tank becomes problematic.

Polluted liquid, e.g. sewage from livestock farms or municipal waste treatment facilities, can be described as a mixture of water and foreign inclusions. Without forced circulation they form bottom sludge with specific mechanical and rheological parameters. In this particular case the purpose of mixing is achieving homogeneous distribution of suspended particles or preventing their sedimentation. Propeller agitators are the most widespread mixers for periodic mixing of such liquids with the purpose of maintaining their homogeneous composition throughout the whole volume [1]. Main disadvantages of propeller agitators:

- significant energy dissipation in the radial direction;
- fluid jet, that possesses kinetic energy, can't impact bottom sludge directly.

For example, in 2010 a propeller agitator with the power of 15 kW and a propeller diameter of 850 mm was installed in film manure storage for the purpose of mixing liquid nonseparated manure. After three years of operation manure storage was significantly silted (fig. 1). It should be noted that it is impossible to mechanically clean film manure storage.

Fig. 1. Bottom sludge in a manure storage

Silting was caused by the following factors:

- limited rotation angle of the agitator due to the structure of the rack;
- operator must always be present during the agitator operation, which means additional possibility of malfunction caused by human factor;
- bottom sludge behind the agitator near the wall can't be mixed, which prohibits mixing of the large portion of slurry;
- energy of the flooded jet is insufficient to ensure mixing near manure storage walls.

Reducing power of agitators while keeping the same tank volume and maintaining sufficient homogenization can be ensured by the following solutions:

- applying stream directly on bottom sludge;
- increasing kinetic energy of the liquid jet by changing movement type from vortex-type to straight-type while keeping turbulent structure;
- decreasing distance during mixing.

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Mixing process with any type of agitator is based on liquid jet, possessing certain kinetic energy value E_k, impacting bottom sludge. In other words, liquid jet impacting bottom sludge must possess minimal average velocity V_{av} enough to move bottom sludge particles by certain distance. V_{av} -value depends on linear tank dimensions, bottom sludge height, physical, mechanical and rheological parameters of bottom sludge.

II. THEORETICAL BASIS OF THE MIXING PROCESS

From the point of view of hydraulics, the bottom sludge is a non-Newtonian fluid, which has an initial shear stress. The proposed method of ensuring mixing effect at minimal cost is to directly impact sludge by semi-restricted jet flowing from a flat orifice.

The proposed method of mixing is based on the hypothesis that in order to move the bottom sludge for a given distance, the flooded semi-confined jet should have sufficient kinetic energy.

Jet flow is characterized by the occurrence of boundary layer with thickness δ, where velocity is distributed according to the logarithmic law [2]. Movement of flooded semi-restricted jet is considered as liquid flowing from flat ofrice, restricted by flat wall (fig. 2).

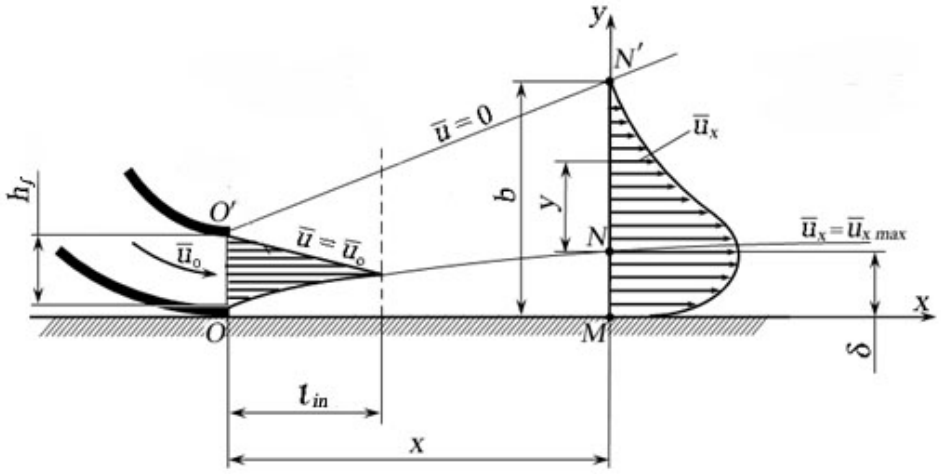

Fig. 2 Flooded semi-restricted jet outflow scheme:
h_f - flooded ofrice height during outflow; $\bar{u}_0$ - velocity of outflow from ofrice (velocity in the core);
$\bar{u}_x$ - velocity in any point of the flow cross section; $\bar{u}_{x\,max}$ - maximum velocity at the interface of boundary layer and free part of flooded semi-restricted jet; l_{in} - width of initial segment; b - flat jet height along the cross section; δ - boundary layer thickness

When flowing from flat ofrice (with height of h_f) hydraulic jet causes translational movement of initially immobile particles of surrounding liquid along with jet. Vertical jet expansion is caused by friction occurring at the boundary of jet and static surrounding liquid.

Semi-restricted jets have a specific property: existence of two zones - boundary layer and free part. Therefore semi-restricted jet flowing regularities have intermediate character between regularities inherent to the boundary layer near solid wall and jet free part [3].

Jet flow is considered:

- liquid movement can be considered as slowly changing;
- flat (two dimensional), when jet kinematic parameters depend only on two coordinates x and y;
- excess liquid pressure is constant ($dp = 0$).

Liquid is considered incompressible ($\rho = const$). The volumetric forces affecting the flow processes are the forces of gravity. Solid wall surface is considered hydraulically smooth.

Main task is complete emptying of slur tank with minimal height of the bottom sludge ($h_0 \to 0$). To solve main task following functional dependences are set:

$$\begin{cases} \bar{u}_{x\,max} = f\{x;\ \rho;\ \eta;\ \tau;\delta\} \\ \bar{u}_0 = f(\bar{u}_{x\,max}) \\ V_{ax} = f\left(\bar{u}_{x\,max}; x;\ \rho; \eta; h_f\right) \end{cases}, \qquad (1)$$

where x - is linear distance, m;
ρ - viscous fluid density, kg/m^3;
η - dynamic viscosity factor, Pa·s;
τ - shear stress, Pa.

Velocity $\bar{u}_{x\,max}$ at the interface of boundary layer and free part of the semi-conducted jet depends on such parameters as distance x along jet impact axis, density ρ, viscosity η, shear stress τ, and thickness of the boundary layer δ. By determining functional dependency of velocity $\bar{u}_0$ at the flat ofrice outlet from velocity $\bar{u}_{x\,max}$ it is possible to proceed to the average axial velocity V_{ax} at the flat ofrice outlet.

III. VALIDATION OF NEAR BOTTOM LAYER SELECTED ELEMENT MOVEMENT MODEL

Determine dependency of boundary layer thickness δ from maximum velocity $\bar{u}_{x\,max}$ by using equation of momentum change. For this purpose isolate part of the boundary layer with width Δx and height Δz using two infinitely close sections AB and $A'B'$ (fig. 3). Considering that the value is small the value is considered the same for two sections and equal to one ($\Delta z = 1$).

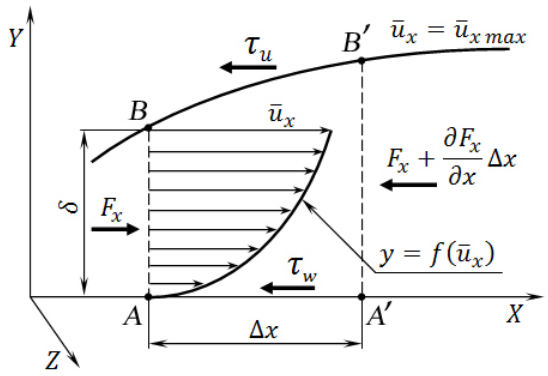

Fig. 3. Scheme for deriving equation of momentum change for boundary layer element

Determine mass of liquid m_1 that flows through section AB, and mass of liquid m_2, flowing through section $A'B'$ per time unit at $\Delta z = 1$:

$$\begin{cases} m_1 = \rho \cdot W_1 = \rho \cdot \int_0^\delta \overline{u}_x dy; \\ m_2 = m_1 + \frac{dm_1}{dx} \cdot \Delta x = \\ = \rho \cdot \int_0^\delta \overline{u}_x dy + \rho \cdot \Delta x \cdot \frac{d}{dx} \int_0^\delta \overline{u}_x dy. \end{cases} \quad (2)$$

Liquid masses m_1 and m_2 momentum will be equal:

$$\begin{cases} I_1 = \rho \cdot \int_0^\delta \overline{u}_x^2 dy; \\ I_2 = I_1 + \frac{dI_1}{dx} \cdot \Delta x = \\ = \rho \cdot \int_0^\delta \overline{u}_x^2 dy + \rho \cdot \Delta x \cdot \frac{d}{dx} \int_0^\delta \overline{u}_x^2 dy. \end{cases} \quad (3)$$

The increment $\frac{dm_1}{dx}$ occurs due to liquid mass flowing through section BB' because of flow continuity. This increment equals difference:

$$m_2 - m_1 = \rho \cdot \int_0^\delta \overline{u}_x dy + \rho \cdot \Delta x \cdot \frac{d}{dx} \int_0^\delta \overline{u}_x dy - \\ - \rho \cdot \int_0^\delta \overline{u}_x dy, \quad (4)$$

Increment of momentum of liquid mass that flows through section BB' can be defined as:

$$(m_2 - m_1) \cdot \overline{u}_{x\,max} = \rho \cdot \Delta x \cdot \overline{u}_{x\,max} \cdot \frac{d}{dx} \int_0^\delta \overline{u}_x dy, \quad (5)$$

where $\overline{u}_{x\,max}$ - is liquid flow velocity at the interface of flooded jet free part and boundary layer in projection on OX-axis.

Determine liquid mass momentum increment along OX-axis on selected segment Δx with length equal to time unit:

$$I_2 - [I_1 + (m_2 - m_1) \cdot \overline{u}_{x\,max}] = \rho \cdot \int_0^\delta \overline{u}_x^2 dy + \\ + \rho \cdot \Delta x \cdot \frac{d}{dx} \int_0^\delta \overline{u}_x^2 dy - \\ - \rho \cdot \int_0^\delta \overline{u}_x^2 dy - \rho \cdot \Delta x \cdot \overline{u}_{x\,max} \cdot \frac{d}{dx} \int_0^\delta \overline{u}_x dy = \\ = \rho \cdot \Delta x \cdot \left(\frac{d}{dx} \int_0^\delta \overline{u}_x^2 dy - \overline{u}_{x\,max} \cdot \frac{d}{dx} \int_0^\delta \overline{u}_x dy \right). \quad (6)$$

According to Euler's theorem for steady-state liquid movement, momentum increment per time unit must be equal to the resultant force acting along the axis on the selected segment of the boundary layer [4]. The resultant force will be the difference of axial forces applied to the end surfaces of the sections and the difference of friction forces acting on the lower and upper sides of the selected element:

$$F_x - \left(F_x + \frac{\partial F_x}{\partial x} \cdot \Delta x \right) - \tau_w \cdot \Delta x - \tau_u \cdot \Delta x, \Delta z = 1. \quad (7)$$

Increment of axial force $\frac{\partial F_x}{\partial x}$ is increment of pressure along OX-axis:

$$\frac{\partial F_x}{\partial x} = \frac{\partial p_x}{\partial x} \cdot \Delta x. \quad (8)$$

Sine abovementioned flow is non-pressurized (excess pressure during flowing of liquid with free part equals null and force F_x is created only by excess pressure), then:

$$p_x = const, \text{ and } \frac{\partial p_x}{\partial x} = 0. \quad (9)$$

Restricted layer consists of two parts: main turbulent layer and adjacent to wall thin laminar sublayer where Newton's law of friction is valid:

$$\tau_w = \eta \left(\frac{\partial \overline{u}_x}{\partial y} \right)_{y=0}, \quad (10)$$

where η - is dynamic viscosity factor:
τ_w - is tangential stress on the wall.

Since movement in question if layered movement of liquid with certain velocity $\overline{u}_x$, tangential stress $\tau_u \neq const$ within segment BB' and changes its value both along OX-axis and OY-axis. Although because Δx is small and velocity in question is in some point of cross-section, values $\frac{\partial \tau_u}{\partial x}$ and $\frac{\partial \tau_u}{\partial y}$ will be neglected.

During turbulent flow of non-Newtonian liquid tangential stresses are represented by the sum of viscous stresses τ_{lam} corresponding to stresses during laminar flow and tangential stresses τ_{tur}, occurring due to turbulent pulsations [2]:

$$\tau_u = \tau_{lam} + \tau_{tur}. \quad (11)$$

According to Shvedov - Bingham equation tangential stress τ_{lam} during laminar flow of non-Newtonian liquid depends from dynamic viscosity η, average velocity $\overline{u}_x$ of movement and breaking shear stress τ_0:

$$\tau_{lam} = \tau_0 + \eta \frac{\partial \overline{u}_x}{\partial y}, \quad (12)$$

where ∂y - is flooded jet boundary layer height increment.

Tangential stress τ_u, occurring at the interface of flooded jet boundary layer and free part, is determined by the formula:

$$\tau_u = \tau_0 + \eta \frac{\partial \overline{u}_x}{\partial y} + \tau_{tur}, \quad (13)$$

where τ_0 - is non-Newtonian liquid initial shear stress.

Tangential stresses τ_{tur} are determined according to Prandtl "mixing-length" theory [7]:

$$\begin{cases} \tau_{tur} = \eta_t \frac{\partial \overline{u}_x}{\partial y} = \rho \cdot l^2 \cdot \left(\frac{\partial \overline{u}_x}{\partial y} \right)^2; \\ \eta_t = \rho \cdot l^2 \cdot \frac{\partial \overline{u}_x}{\partial y}. \end{cases} \quad (14)$$

where η_t - is apparent viscosity, determined by the flow type;
l - Prandtl mixing length.

According Prandtl hypothesis mixing length in boundary layer is proportional to the distance to the wall:

$$l = c \cdot y, \qquad (15)$$

where c - is turbulence constant, the only empirical constant of Prandtl free turbulence theory.

Turbulence constant c depends on boundary layer turbulent structure and is determined only empirically according to the experiments of Prandtl and Nikuradze $c = 0{,}4$ [5].

Tangential stress τ_u will be equal:

$$\tau_u = \tau_0 + \eta \frac{\partial \overline{u}_x}{\partial y} + \rho \cdot c^2 \cdot y^2 \cdot \left(\frac{\partial \overline{u}_x}{\partial y}\right)^2. \qquad (16)$$

Substitute expressions (8), (9), (10) and (16) into equation (7), taking into account further reduction of left and right equation parts (6) and (7) by Δx, resulting in obtaining equation of external forces that impact selected segment of semi-restricted flooded jet boundary layer:

$$-\eta \left(\frac{\partial \overline{u}_x}{\partial y}\right)_{y=0} - \tau_0 - \eta \frac{\partial \overline{u}_x}{\partial y} - \rho \cdot c^2 \cdot y^2 \cdot \left(\frac{\partial \overline{u}_x}{\partial y}\right)^2. \qquad (17)$$

Equating momentum one-second change (6) to the resulting force (17) that causes this increment and at the same time dividing all equation parts by ρ will result in obtaining equation of momentum change for the boundary layer element:

$$\frac{d}{dx}\int_0^\delta \overline{u}_x^2 dy - \overline{u}_{x\,max} \cdot \frac{d}{dx}\int_0^\delta \overline{u}_x dy = -\frac{\tau_0 + \tau_w}{\rho} - \nu \frac{\partial \overline{u}_x}{\partial y} - c^2 \cdot y^2 \cdot \left(\frac{\partial \overline{u}_x}{\partial y}\right)^2. \qquad (18)$$

During developed turbulent movement when intensive mixing in liquid occurs ($\tau_{tur} \gg \tau_{lam}$) thus equation term $\nu \frac{\partial \overline{u}_x}{\partial y}$ (18) can be neglected. Thus final equation of momentum change will be following:

$$\frac{d}{dx}\int_0^\delta \overline{u}_x^2 dy - \overline{u}_{x\,max} \cdot \frac{d}{dx}\int_0^\delta \overline{u}_x dy = -\frac{\tau_0 + \tau_w}{\rho} - c^2 \cdot y^2 \cdot \left(\frac{\partial \overline{u}_x}{\partial y}\right)^2. \qquad (19)$$

The first term in the left part of the equation (19) represents one-second change of momentum for boundary layer element as a result of liquid mass entering and exiting through two boundaries of this element AB and $A'B'$ (fig. 2).

Second term of the equation left part (19) represents momentum, brought by mass $\rho \frac{d}{dx}\int_0^\delta \overline{u}_x dy$ through layer upper border BB' in one second.

Right part of the equation (19) represents impulse of viscosity forces attributed to the time unit and distance unit along the coordinate x.

Distribution law $\overline{u}_x$ along the cross-section of semi-restricted jet boundary layer is defined by the following ratio:

$$\overline{u}_x = \overline{u}_{x\,max} \left(\frac{y}{\delta}\right)^{\frac{1}{7}}, \qquad (20)$$

also, velocity profiles are similar. This similarity was identified as a result of numerous experiments [6] and was dubbed "one-seventh" law for velocity distribution.

After substituting the parameter $\overline{u}_x$ into obtained expression (19) and performing all conversions taking into account definition of boundary layer thickness by Schlichting formula [5], obtain:

$$(\overline{u}_{x\,max})_{min} \geq 6{,}24 \cdot \sqrt[9]{\left(\frac{\tau_0}{\rho}\right)^5 \cdot \frac{x}{\nu}}. \qquad (21)$$

Equation (21) represents mathematical movement model of viscous liquid semi-restricted jet and characterizes the dependence of velocity $\overline{u}_{x\,max}$ at the interface of boundary layer and jet free part from such parameters as density ρ, kinematic viscosity ν, initial shear stress τ_0 and coordinate x along the jet propagation axis.

IV. DETERMINING FLOW KINEMATIC PARAMETERS

To determine flow kinematic parameters, momentum equation for contour $OO'N'N$ is composed (fig. 2):

$$\bar{u}_0^2 \rho h_f - \rho \int_0^x \bar{u}_{x\,max} \frac{\partial}{\partial x}\left(\int_0^\delta \overline{u}_x(y)dy\right)dx = = \rho \int_\delta^b \bar{u}_x'^2(y)dy. \qquad (22)$$

where $\overline{u}_x(y)$ is function for boundary layer velocities distribution on the semi-restricted jet main segment along y-axis;

$\bar{u}_x'(y)$ - function for free part velocities distribution on the semi-restricted jet main segment along y-axis;

$\bar{u}_0^2 \rho h_f$ - material points momentum on the section OO' exit;

$\rho \int_0^x \bar{u}_{x\,max} \frac{\partial}{\partial x}\left(\int_0^\delta \overline{u}_x(y)dy\right)dx$ - liquid material points momentum that move through section ON;

$\rho \int_\delta^b \bar{u}_x'(y)dy$ - material points momentum on section $N'N$ exit.

Velocities distribution functions for boundary layer and free part on the semi-conducted jet main segment according to Abramovich turbulent jets theory [6]:

$$\text{- free part } \frac{\bar{u}_x'}{\overline{u}_{x\,max}} = \left[1 - \left(\frac{y-\delta}{b-\delta}\right)^{\frac{3}{2}}\right]^2 \text{ with } y \geq \delta. \qquad (23)$$

Further consideration needs determining ratio of boundary layer thickness δ and flat jet height along section b (fig. 2). Ratio δ/b will be determined during experiments (fig. 4). On the basis of conducted experiments it's possible to state that $b \approx 3{,}6 \cdot \delta$.

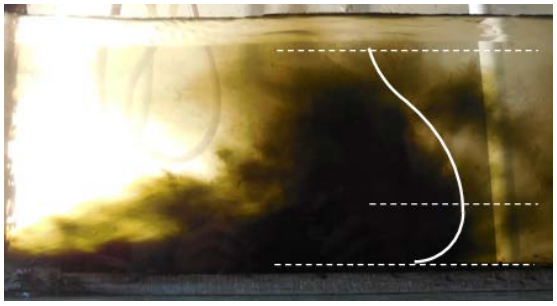

Fig. 4 Semi-restricted jet flow

All mathematical conversions will result in an expression for determining outflow speed at the exit if flooded ofrice:

$$\bar{u}_0 = 4{,}1\sqrt{\frac{\tau_0 x}{\rho h_f}}. \qquad (24)$$

Average liquid velocity V_{ax} at the flat ofrice exit is determined on the basis of velocities profile in flow cross-section. Velocities profile in the initial sector cross-section is considered same as in jet boundary layer, thus average velocity is determined as:

$$V_{ax} = \frac{\int_0^\delta \bar{u}_x dy}{\delta} = \frac{\int_0^\delta \overline{u}_{x\,max}\left(\frac{y}{\delta}\right)^{\frac{1}{7}} dy}{\delta} = 0{,}875 \cdot \overline{u}_{x\,max}; \qquad (25)$$

$$V_{ax} = 0{,}875 \cdot \overline{u}_0 = 3{,}59\sqrt{\frac{\tau_0 x}{\rho h_f}}. \qquad (26)$$

Numerical factor 3,59 in the obtained dependency (26) was determined theoretically. During experiments that validate correctness of obtained mathematical model this numerical ratio was corrected to the value 3,645.

V. CONCLUSION

The result of theoretical and experimental research is obtaining dependency of initial outflow velocity from geometrical parameters: flat ofrice height and mixing linear length as well as from physical, mechanical and rheological parameters of bottom sludge representing viscous non-Newtonial liquid. Device that ensures high-speed liquid flow at the flat ofrice exit can have various structure. It can be both hydrodynamic pump and a propeller agitator mounted in a head of appropriate strucure. To determine such a parameter as the flow rate of the pumping unit, the width of the flat orifice must be set. In this case, the flow rate can be defined as the initial outflow rate V_{ax} multiplied by the area of the flat orifice. The mixing time of the bottom sludge depends on its height and is determined experimentally.

This mixing method is characterized by the following statements:

- conversion of traditional vortex movement of liquid into linear movement, thus excluding inefficient energy distribution in radial direction;
- preserving flow turbulent structure;
- direct impact on bottom sludge.

To reduce mixing length installing nozzle in the tank center as the mixing device is possible. In this case mixing will be performed along the whole tank perimeter simultaneously. Pumping unit turning on frequency will depend on the time of settling of suspended particles and the time of formation of bottom sludge, that has parameters that were present during defining required capacity of pumping unit.

REFERENCES

[1] M. Hellstedt, A. - K. Teemu, "Storage of slurry in earth-banked basins in Finland," presented at 7th international scientific and practical conference "Ecology and agricultural machinery" in 3 volumes. V. 3. GNU SZNIIMESH Rosselhozakademii, 2011, pp. 23 … 24.

[2] Sternlicht D.V, Hydraulics. Textbook for universities. Ed. 3rd revised and supplementary, Moscow, KolosS, 2006.

[3] Vulis L.A, Kashkarov V.P., "Theory of Viscous Fluid Jets", Moscow: Nauka, 1965.

[4] Abramovich G.N, "Applied Gas Dynamics" In two parts. P. 1, 5th edition, revised and supplemented, Moscow: Nauka, 1991.

[5] Schlichting G, "Boundary Layer Theory", Moscow: Nauka, 1974.

[6] Abramovich G.N, "Theory of Turbulent Jets," A Reprint of the 1960 Edition, Moscow: Ecolit, 2011.

[7] Dobroselsky K. G, Prosyannik A.G., "Symmetry of Reynolds equations and semi-empirical theories of turbulent flooded jet," Systems Modeling, № 1(7), 2004.

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Procurement Management as a Condition of Increasing the Competitiveness of Agro-Processing Enterprises

Yahor Zhyluk
Department of Economics
Polotsk State University
Novopolotsk, Belarus
georg6504@yandex.ru

Daina Znotina
Faculty of Economics and Management
Rezekne Academy of Technologies
Rezekne, Latvia
Daina.Znotina@rta.lv

Alena Lisichonak
Department of Economics
Polotsk State University
Novopolotsk, Belarus
l.lisichonok@psu.by

Abstract **- The authors systematized approaches to the essence of the categories "product competitiveness", "enterprise competitiveness", "field competitiveness", "regional competitiveness" and "country competitiveness". The authors formulated the definition of competitiveness. The approaches to the classification of competitiveness factors are systematized. The authors' classification of factors was developed. The authors have proved that the main factor in the competitiveness of enterprises is raw materials. Obtaining raw materials by the enterprise is carried out through procurement. Thus, the management of procurement of goods, having the largest share in the cost of the final product, is the main factor affecting the competitiveness of the enterprise. The authors have systematized approaches to characterizing the essence, goals and objectives of procurement management and to the classification of purchases. The authors' definition of procurement management and the composition of its principles are proposed. The mechanisms of influence on the management of procurement and processing enterprises of the agro-industrial complex are investigated on the example of the open joint-stock company "Pukhovichi Plant of Grain Products" (Belarus). Possible ways to improve the procurement management of the studied organization are proposed. The recommendations proposed by the authors can be used by other organizations of the processing industry of the agro-industrial complex.**

Keywords **- agro-industrial complex, competitiveness, procurement management, purchases.**

I. INTRODUCTION

Enterprises of the agro-industrial complex play a major role in the stability and security of the country and are inextricably linked with the state power. In modern conditions of economic crisis and unreasonable state solutions to the agricultural sector is in decline, because is the levelling of the interests of small and medium agricultural producers, reducing their competitiveness and increasing threats to food security. Large state-owned agricultural enterprises are supported by various state mechanisms, but cannot compete with private producers on the basis of market methods. In 2019, the Republic of Belarus adopted legislation that allowed agricultural enterprises of the country not to pay for previously acquired debts, to receive instalments and deferrals, and not to bear any obligations in connection with late fulfilment of obligations. In 2020, this mechanism was re-applied. This situation gave rise to the collapse of the agro-industrial complex, a "vicious circle", since, without paying off the debts with the partner enterprise, the next time the neighbouring enterprise will also not be able to make payments. All this was a consequence of the lack of competition in the agricultural sector of the country. Belarusian agro-industrial enterprises face an important task, which consists in the need to increase competitiveness and stop the economic decline, which should have a positive impact on the state and dynamics of the national economy.

The sphere of procurement is the basis for the successful functioning of the enterprise in the market, however, following the Soviet traditions, the agricultural industry ignored the mechanisms of procurement management as a factor of increasing the competitiveness of products. The development of unified approaches to management, the study of the relationship between procurement and competitiveness is of high practical relevance.

General theories of competitiveness have been actively studied by Russian and foreign scientists. Also, a large number of scientists have studied the mechanisms of

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procurement activities in public and private companies. However, only one dissertation among the CIS countries reflects attempts to link procurement with industrial competitiveness. There are no fundamental works on this topic in Belarus. D. Belousov, E. Bratukhina, M. Kulish, E. Okoledova, V. Savchenko, N. Yashin published their thesis on the topics of competitiveness management [1-5]. There are fewer studies related to this activity in agriculture, because in the territory of the CIS countries, agriculture has long been in a completely uncompetitive environment with divided markets and unchanged suppliers. Thus, the analysis of this market and factors has a high theoretical relevance.

The effective functioning of the procurement management system at the enterprise affects all areas of economic activity of the enterprise. Procurement management, including both price and non-price components, has the greatest share in the final product, and therefore is the main factor affecting the competitiveness of the enterprise. These conclusions are confirmed by studies of various authors (M. Porter [7], A. Grishin [8], V. Savchenko [5], S. Makrak [9]).

II. MATERIALS AND METHODS

Object of the research is a procurement management as a factor that determines the ability of modern enterprises of the processing industry of the agro-industrial complex to compete in the modern market.

Subject of the research is a set of organizational and managerial relations that arise during the formation and development of the system of managing the competitiveness of agro-processing enterprises by influencing procurement activities on the example of the Open Joint Stock Company “Pukhavichy Bread Products Plant”.

The aim of the research is to study and develop the theoretical and methodological foundations of procurement management in order to increase the competitiveness of modern enterprises of the processing industry of the agro-industrial complex and practical recommendations aimed at improving the procurement system.

Tasks of the research

1. Explore the concept and essence of competitiveness. To formulate the author's approach to the characterisation of the essence of competitiveness.
2. Determine the factors that affect the competitiveness of organizations of the agro-industrial complex.
3. Identify the relationship between the effectiveness of procurement activities and the competitiveness of the enterprise.
4. Research the models and fundamentals of procurement activities in enterprises.
5. Analyse the procurement management at OJSC “Pukhavichy Bread Products Plant”, suggest ways to improve efficiency and competitiveness by improving the procurement system.

Hypothesis. Procurement management is the main factor in improving the competitiveness of enterprises of the processing industry of the agro-industrial complex.

Methods of the research. General scientific (material-dialectical, formal-logical, system, functional, hermeneutical and phenomenological analysis), special (historical, analytical, statistical, program-target), private (classification, cluster analysis and synthesis, structural and functional modelling, point-index estimates, economic and mathematical modelling).

Theoretical basis of the research. Theories, concepts and hypotheses presented in modern economic literature, scientific research and thesis on competitiveness, competitiveness management, procurement and procurement management.

Empirical basis of the research. Data provided by the National Statistical Committee of Belarus, the Analytical Centre under the Aegis of the President of Belarus, international statistical data. Data of business plans and statistical reports, the structure of enterprise management and quality management of enterprises of the processing industry of the agro-industrial complex of the Republic of Belarus, data on purchases and sales, reporting of OJSC “Pukhavichy Bread Products Plant”.

III. RESULTS AND DISCUSSION

Authors analysed various types of competitiveness: "product competitiveness", "enterprise competitiveness", "field competitiveness", "regional competitiveness", "country competitiveness".

Abstract and mathematical approaches of researchers can be distinguished to determine the competitiveness of enterprises.

Abstract approach assumes the ability to develop, manufacture and sell products of the best quality and price parameters, give priority to work with consumers, innovation, creativity, management mechanisms, service level to achieve the set goals of the company, the breadth and depth of the range, the image of the company. It presupposes the immaterial and incalculable superiority of some subjects over others. It is characterized by subjectivism and invalidity of research (V. Sinko [10], N. Yashin [6], A. Vladimirov and V. Kershenbaum [11], N. Grishakina [12], A. Blinov [13], V. Zakharov [14], Z. Vasilieva [15], Y. Rubin and V. Shustov [16]).

The mathematical approach connects the competitiveness of enterprises with the price and quality of goods (M. Mironov [17]), economic indicators of the state and dynamics of enterprise development (L. Kalashnikova [18]), the ability to cover losses and risks of the size of equity capital, the size of income and expenses (G. Chebotarev [19]), the share of the received solvent

demand (T. Kupriyanova [20]), indicators of the stock, financial and labour market (M. Starovoitov, B. Fomin [21]). It is characterized by objectivism and validity of research.

Authors have identified weaknesses in the studies presented in the review. Approaches to determining competitiveness do not cover the following factors:

- the territorial boundaries (given the globalization of the economy most appropriate to indicate that competitiveness is determined within pre-defined territorial boundaries (district, region, country), otherwise we should talk about global competitiveness. At the same time, competition in a given market is important, and sometimes in cases where the goods are not subject to movement, or transport costs are higher than the cost of the goods this geographically limited type of competition is the most interesting;
- the person who is able to conduct a comparative analysis of competitiveness (competitiveness indicators should be developed by an external independent person who also evaluates the data for compliance with these indicators);
- the period of time when the competitiveness of the enterprise can be fixed and during which the signs of competitiveness remain. It is also advisable to indicate that competitiveness is maintained within a predetermined period.

Taking into account the above-mentioned comments, the authors have formulated the following general definitions of the competitiveness of an enterprise, industry, country, region:

Competitiveness of the organization (enterprise) – estimated on the basis of statistical data and expert methods, the superiority of the level of development of an individual enterprise over the level of development of other analysed enterprises in a certain industry and period of time and within a certain territory, including the viability and development of the enterprise, profit and its excess over the level of possible risks, production and sales volumes, resource intensity, stability, income level of employees and other categories that are subject to accounting in accordance with national or international legislation and customs.

In authors' opinion, the competitiveness of the organization is the main concept of this study. The developed definition fully covers the range of issues that can be evaluated in competitiveness studies, and the range of problems that need to be resolved and processes that need to be improved. Also, the use of this definition allows the authors to make accurate verifiable calculations of the level of competitiveness and compare the impact of the implementation of the results of various studies on the change in the level of competitiveness of enterprises.

The competitiveness of an industry is the superiority of the level of development of a certain branch of the economy of a particular country (or region) over the corresponding industry in other analysed countries (or regions) over a certain period of time, estimated on the basis of statistical data and expert methods.

The competitiveness of a country is the superiority of the level of economic development of a certain country over the level of the economy of other analysed countries over a certain period of time, formed during the process of globalization and estimated on the basis of statistical data expert methods.

The authors have developed definitions of conditions and factors of competitiveness. Under the "condition of competitiveness" the authors understand the state of the system in which enterprises (industries) have the opportunity to compete with each other. Under the "competitiveness factor" the authors understand the causes and driving forces controlled by economic entities that promote competition between enterprises (industries).

The authors have developed their own classification of competitiveness factors:

- by area of operation (internal / external);
- according to the method of influence on the factor (strategic / functional / conjunctural / institutionalization / legal and administrative regulation / market parameters);
- on freedom of use (specific / commonly used);
- by the source of occurrence (resource / intra-question / intra-industry / inter-industry);
- by the entity that created this factor (organizational, investment, consumer, industry, state);
- according to the ability of verification and measurement (verifiable and calculable / non-verifiable and uncountable).

After analysing all the listed factors and characteristics of competitive organizations, it should be noted that competitive companies should take into account, work and act with all the listed factors, because each factor to a certain extent affects the achievement of the set organizational goals. Due to the presence of a large number of factors affecting competitiveness, the most competitive are large international enterprises that can affect all of the above factors. It is advisable for small businesses to work with the main factors, apply copying mechanisms, and focus on the use of specific factors.

Most researchers put raw materials in the first place among the factors affecting the competitiveness of enterprises (G. Antonov, M. Porter, M. Tarasov, S. Baronin, and other authors) [7, 22, 23, 24]. Then, according to the frequency of mention, there are human resources and financial resources (or investments).

Obtaining raw materials by the enterprise is carried out through procurement. Thus, the management of procurement of goods, having the largest share in the cost

of the final product, is the main factor affecting the competitiveness of the enterprise.

The effective functioning of the procurement management system at the enterprise affects all areas of economic activity of the enterprise. Procurement management, including both price and non-price components, has the greatest share in the final product, and therefore is the main factor affecting the competitiveness of the enterprise.

These conclusions are confirmed by studies of various authors (M. Porter [7], A. Grishin [8], V. Savchenko [5], S. Makrak [9]). Authors studied the concept of procurement in the economic sphere in the works of various authors.

Purchasing, logistics (in this case, the authors use the term "purchasing") refers only to the process of purchasing resources (including materials and semi-finished products). According to most authors, this term is used by the state and state-owned enterprises.

Procurement management, procurement logistics (in this case, the authors use the term "procurement") from the organizational point of view is the provision of supplies of material resources, semi-finished products, components and other items necessary for the enterprise to conduct its main (operational) activities. This definition is usually used in the analysis of the activities of modern market enterprises.

According to other scientists it is difficult to distinguish between the procurement and logistics of production, since in any case these actions are the responsibility of the procurement division (supply), and public procurement procedures (governed by law) and market purchases (on the free market) do not have fundamental differences. In these definitions, purchases, procurement, and procurement management are considered synonymous.

According to the authors, for the study of the mechanism of functioning of procurement in the organization, as well as their impact on improving competitiveness, all of the above definitions can be considered synonymous.

All definitions of procurement management have been divided into the following categories:
- by repeatability (one-time / systematic);
- by establishment period (tactical / operational / strategic);
- by functional orientation (as a goal achievement / as a process / as a purchase organization / as an external resource management / as an activity / as a resource / as a supplier management / as a division of the organization, a link in the production cycle);
- by content (economic / administrative);
- by measurability (measurable / unmeasurable);
- by environment (external / internal).

The authors have considered the views of researchers on the goals and objectives, principles, functions, classification and made the following conclusions.

The goal of procurement management is to meet the needs of production in materials with the maximum possible economic efficiency.

Procurement management tasks:
- determination of the nomenclature and volume of necessary resources;
- development of a procurement strategy within the framework of the company's development strategy;
- preparation of a procurement plan;
- calculation of current and total procurement costs;
- market research and identification of supplier opportunities;
- identification of the territorial characteristics of the supply;
- the division of labour and direction of procurement activities;
- organization of the process of movement of raw materials, materials, components and spare parts from the procurement market to the warehouses of the enterprise;
- optimization of delivery times;
- analysis of the condition and use of warehouses.

The main functions are planning, organization and control.

The authors have identified a number of criteria for classifying purchases: by type of purchased resource; by frequency of purchases; depending on the need for transportation; by complexity; by the presence of a special procedure; by the number of suppliers. Depending on the type of purchase, the structure of the procurement department, the procurement mechanism, and ways to improve efficiency are determined.

The authors have analysed the principles of procurement contained in a number of studies (M. Kulish [25], N. Kidlova [26], V. Savchenko [5]), supplemented the list of principles independently, the authors identified fourteen principles of procurement management: 1 – scientific; 2 – concreteness; 3 – constructivity; 4 – reliability; 5 – variability; 6 – complexity; 7 – the greatest caution; 8 – parity; 9 – customer's professionalism; 10 – openness; 11 – equality of rights, absence of restrictions; 12 – targeted spending of funds; 13 – strict reporting; 14 – cooperation between the customer and the supplier.

Taking into account the analysis, the authors have formulated the following general definition of procurement management: procurement management is a systematic activity of an enterprise aimed at meeting the production needs for materials at a certain time, on a certain territory, at a certain price with the maximum possible economic efficiency.

Studies of models of construction procurement can be

divided into three main types, in relation to the understanding “model”: "the model" as a hierarchical organizational system; "the model" as a system of business processes associated with supplier selection; "the model" as a mathematical algorithm for selecting a supplier.

The authors have identified four hierarchical models:
- centralized – effective in large organizations that have one main activity and do not have separate divisions;
- decentralized – effective in small and medium-sized organizations that do not have the funds to create a special purchasing unit;
- distributed – effective in holdings, associations, enterprises with separate divisions;
- hybrid – effective in large organizations (based on a centralized model) and in medium – sized organizations (based on a decentralized model) engaged in heterogeneous activities.

Models as a system of business processes related to the selection of a supplier allow you to implement scientifically based effective business processes in the existing procurement management system.

Mathematical models based on fuzzy logic, hierarchy analysis, linear and nonlinear programming are of the greatest interest for modern research. The history of these models is just over 20 years. Mathematical models try to minimize the subjectivity of the procurement mechanism and make decisions in unclear, inaccurate and uncertain situations.

The authors investigated the model of procurement management of OJSC "Pukhavichy Bread Products Plant". In the analysed organization, a hybrid model of procurement management functions, according to the type of decentralized model – for raw materials and equipment, according to the type of distribution model – for small goods. Under the condition of optimal division of rights, duties and responsibilities at the enterprise, the hybrid model can function effectively at the enterprise of the processing industry of the agro-industrial complex.

To confirm the successful functioning of the procurement management system at the enterprise, the authors investigated the volume of purchases of raw materials from 2015 to 2020, identified the main types of grain and non-grain raw materials, analysed market and non-market methods of purchasing raw materials, analysed manufacturers and suppliers, the structure of material costs, the organizational structure and procurement model of the organization.

The material consumption of the production of OJSC "Pukhavichy Bread Products Plant" varies from 662 to 742 rubles per 1000 rubles of gross output. There is a decrease in material consumption in 2019 and 2020. The material consumption of production of the agro-industrial complex in the Republic of Belarus varies from 719 to 1360 rubles per 1000 rubles of gross output. Accordingly, the authors recognize that the procurement management system of OJSC "Pukhavichy Bread Products Plant" is satisfactory.

The procurement management system at the enterprise is complex, it necessarily involves various departments and specialists: authorized persons (signing the contract and approving the transaction), performers (customers: purchasing engineer and commercial department), heads of shops and sections (compilers of applications), head of the production laboratory (in determining quality), warehouse manager (entrance control, acceptance, accounting, internal movement), chief economist (volume planning), chief accountant (budget planning and its execution, verification of details, payment), legal adviser (drafting and checking contracts for compliance with the requirements of the organization, claim and claim work).

Tasks of an effective procurement system at the enterprise is not only to select a supplier and deliver products, but it is also important that the main task is to form a set of activities during the procurement year of the enterprise: planning purchases, collecting current applications, distribution of available goods, evaluating the cost of purchased products taking into account product characteristics, prices and deliveries, selecting suppliers, concluding contracts, financing purchases, executing contracts, delivery, checking purchased products and services, monitoring. During the nine main stages of procurement activity, the authors identified the main shortcomings, ways to eliminate them, and also made conclusions about the effectiveness of eliminating the identified shortcomings. The results of the study are presented in Table 1.

The authors investigated the mechanisms of influence on the procurement management system of the enterprises of processing industry of the agro-industrial complex and possible ways of its improvement on the example of the refinement of the model of procurement of OJSC "Pukhavichy Bread Products Plant" on the basis of results of detection of shortcomings in the system of procurement management identified in the previous section of the study.

At the enterprise, the procurement system was reformed as an algorithm for influencing the existing procurement system. The results of the practical implementation of the algorithm are shown in Table 2.

Reform of the procurement system as an improvement of the internal procurement mechanism is an adaptation of the ten-level cyclical procurement process for enterprises of the processing industry of the agro-industrial complex: 1 – planning; 2 – creating a list of material requirements; 3 – analysis; 4 – strategy development; 5 – search for suppliers; 6 – evaluation of suppliers; 7 – selecting suppliers; 8 – signing the contract; 9 – delivery control; 10 – quality assessment.

TABLE 1. DISADVANTAGES OF THE PROCESS OF PROCUREMENT IN OJSC "PUKHAVICHY BREAD PRODUCTS PLANT"

Stage	Risk factor	Disadvantages	Ways to improve it
Planning	Increase in the price of agricultural products due to crop failure at the time of plan execution	Conclusion of framework contracts for agricultural products without an agreed price and volume (protocols of intent)	Determining the price of agricultural products for the purchase year at the planning stage. Price fixing in agreements with all potential producers
Distribution of available products	Lack of goods in stock when contacting the customer's division	Execution of unscheduled requests at the expense of goods available in the organization's warehouse	The release of goods on unscheduled requests is allowed only in agreement with the head and departments, according to whose requests the goods were purchased
Cost estimation	Corrupt (purchase at an inflated price)	The catalogue of priority manufacturers, suppliers, and price comparison algorithm is missing.	Approval of the procedure for comparing price offers, the list of Internet sites and catalogues required for price comparison
Monitoring	Lack of professionalism (purchase at an inflated price)	Lack of effective liability measures	Optimal distribution of responsibility, introduction of the stage of application of responsibility measures and incentives

The authors have developed a detailed description of each stage of procurement activity, defined the start and end dates of each period and their content.

Reform of the procurement system as an improvement in dealing with external and internal factors represents the response of the organization and its ability to adapt to the interaction of departments with each other and with the external environment.

In order to take into account, the largest number of factors, the authors have adapted the systems of external factors of the PESTEL (political, economic, social, technological, economic and legal factors of the external environment) and internal factors (ownership, selection method, pricing policy, division of responsibility, management system, risk distribution) into a single model to develop the best behaviour of the enterprise.

Elimination of the identified shortcomings and implementation of the proposed measures will improve the existing procurement system in the organization, which will strengthen the competitiveness of the organization, the industry, the region and the Republic of Belarus as a whole.

TABLE 2. ALGORITHM OF IMPACT ON THE PROCUREMENT SYSTEM OF OJSC "PUKHAVICHY BREAD PRODUCTS PLANT"

Stage according to plan	The measures taken
The allocation of priorities, and setting goals	A priority area is identified: control of procurement activities carried out by the logistics Department. The goal is defined: to improve the quality of procurement activities of this division. The following tasks are defined: - checking the competence of specialists and the validity of the choice of suppliers; - lowering the price of purchased products and eliminating delivery deadlines; - increasing control over the division's activities, introducing liability measures
Forming a team	The first Deputy Director and legal adviser have been given control over purchases made by the logistics Department.
Development of documents regulating purchases	Development of a new procurement regulation (detailing the procurement process: - mandatory request for price offers; - limitation of the number of persons who approve applications; -a list of Internet aggregators of suppliers, manufacturers ' databases is established; - the purchasing division is required to send price offers to these suppliers)
Updated procurement process	Control over the conclusion of all contracts concluded based on the results of purchases made. (- the activity of the procurement division was found unsatisfactory due to the low qualification of specialists, which led to an unjustified choice of suppliers; - the activities of the temporary procurement control team were terminated; - the procurement Department was reformed as a logistics engineer with the hiring of a new specialist; - the procurement regulations were approved).

III. CONCLUSIONS

The authors studied the essence of competitiveness. According to the authors, it is necessary to highlight “the competitiveness of the enterprise”, “the competitiveness of the industry”, “the competitiveness of the region”, “the competitiveness of the country”. The authors’ definition of the competitiveness of an organization (enterprise) is formulated. Definitions of conditions and factors of competitiveness have been developed. Approaches to the classification of factors of competitiveness in the sphere of functioning; by the way of influencing the factor; on freedom of use; by the source of occurrence; by the subject that created this factor; wherever possible, verifications and measurements are suggested.

Most researchers put raw materials in the first place among the factors influencing the competitiveness of enterprises. The receipt of raw materials by the enterprise is carried out through purchases.

Procurement management, procurement logistics is organizationally ensuring the supply of material resources that are necessary for the main activity. It seems to the

authors that the definitions of purchase, supply, procurement management in this study can be regarded as synonyms.

The authors formulated the goal, objectives and functions of the procurement management process. A general definition of procurement management is presented. Four hierarchical models of procurement management are highlighted. They are: centralized, decentralized, distributed, hybrid.

Reform of the procurement management system was considered in three main areas: the algorithm for influencing the existing procurement system at the enterprise; improving the internal procurement mechanism; improving work with external and internal factors.

REFERENCES

[1] D. V. Belousov, “Industrial enterprise competitiveness management”. Moscow: Moscow State Industrial University, 2006.
[2] E. A. Bratukhina, E.A. “Procurement management in the logistics system of industrial equipment manufacturing enterprises”. Samara: Samara State University of Economics, 2015.
[3] M. S. Kulish, “Balanced procurement model in the telecommunications industry”. Moscow: Russian University of Economics G.V. Plekhanov, 2016.
[4] E. Yu. Okoledova, “Management of the supply of material resources in the implementation of investment projects”. Voronezh: Voronezh State University of Architecture and Civil Engineering, 2003.
[5] V. V. Savchenko, “Ensuring the competitiveness of industrial enterprises through procurement management”. Moscow: Institute of Market Problems RAS, 2018.
[6] N. S. Yashin, “Research of the competitiveness of an industrial enterprise: methodology and experience”. Saratov: SGEA, 1997.
[7] M. E. Porter, “Competitive Advantage: How to Achieve High Results and Ensure its Sustainability”: a classic work devoted to the analysis of competitiveness. (translated from English). (5th ed.). Moscow: Alpina Publisher, 2017.
[8] A. V. Grishin, “Centralized supply in industrial holdings”, National Metallurgy No 2, 2017, pp. 60-63.
[9] S. V. Makrak, “Scientific basis for improving the system of material and monetary resources management in the production of agricultural products”, Vesci National Academy of Sciences of Belarus T. 57 No 2, 2019, pp. 135-150.
[10] V. Sinko, “Competition and Competitiveness: Basic Concepts”, Standards and quality No 4, 2000, pp. 54-59.
[11] A. I. Vladimirov and V. Ya. Kershenbaum, “Competitiveness and problems of the oil and gas complex”. Moscow: Scientific Research Institute "National Institute of Oil and Gas", 2004.
[12] N. I. Grishakina and N. N. Yurina, “Theoretical foundations of the study of the competitiveness of agricultural products”, Bulletin of Novgorod State University No 82, 2014, pp. 86-90.
[13] A. O. Blinov and V. Ya. Zakharov, “Image of an organization as a factor of its competitiveness”, Management in Russia and abroad No 4, 2003, pp. 20-24.
[14] A. N. Zakharov and A. A. Zokin, “Enterprise Competitiveness: Essence, Methods of Evaluation and Mechanisms of Increase”, Business and banks No 1-2, 2013, pp. 1-5.
[15] Z. A. Vasilieva, “Hierarchy of the concepts of competitiveness of market entities”, Marketing in Russia and abroad No 2, 2006, pp. 83-90.
[16] Yu. V. Rubin and V. V. Shustov, “Competition: Realities and Prospects”. Moscow: Knowledge, 1990.
[17] M. G. Mironov, “Your competitiveness”. Moscow: Alfa-Press, 2004.
[18] L. M. Kalashnikova, “Competitiveness of an enterprise and their products”, Mechanical engineer No 11, 2003, pp. 15-18.
[19] G. S. Chebotareva, “Methodological foundations for assessing the competitiveness of energy companies”, Economy of the region No 14, 2018, pp. 190-201.
[20] T. Kupriyanova, “Managed Competitiveness: How to Achieve It?”, Director's consultant No 22, 2001, pp. 17-29.
[21] M. K. Starovoitov and B. F. Fomin, “Practical tools for organizing management of an industrial enterprise”. Moscow: Higher School, 2002.
[22] G. D. Antonov, O. P. Ivanova, and V. M. Tumin, “Competitiveness Management of Organizations and Territories”. Moscow: INFRA-M, 2016.
[23] M. E. Tarasov et al., “Competition and competitiveness of business entities in the sectors of the economy”. Yakutsk: NEFU Publishing House, 2014.
[24] S. A. Baronin, and L. N. Semerkova, “Theory and methodology of managing the competitiveness of business systems”. Moscow: INFRA-M, 2017.
[25] M. S. Kulish, “Balanced model of procurement activities at enterprises of the telecommunications industry”. Moscow: Russian University of Economics G.V. Plekhanov, 2016.
[26] N. V. Kidlova, “Public Procurement Management as a Factor of Successful Implementation of National Projects”, Innovation and investment No 5, 2019, pp. 247-252.

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Comparison of As, Hg and Tl High-Frequency Electrodeless Lamps for Detection of Environmental Pollution

Natalja Zorina
Institute of Atomic Physics and Spectroscopy
University of Latvia
Riga, Latvia
natalja.zorina@lu.lv

Atis Skudra
Institute of Atomic Physics and Spectroscopy
University of Latvia
Riga, Latvia
atis.skudra@lu.lv

Gita Revalde
Institute of Technical Physics,
Riga Technical university,
Institute of Atomic Physics and Spectroscopy
University of Latvia
Riga, Latvia
gitar@latnet.lv

Zanda Gavare
Department of Physics
Latvia University of Life Sciences and Technologies
Jelgava, Latvia
zanda.gavare@gmail.com

Abstract **- Nowadays, there is an increasing necessity to determine the concentration of different substances in the environment in low concentrations, as more and more attention is paid to environmental pollution. This work is devoted to the comparison of main characteristics of high-frequency electrodeless light sources with different fillings for their use in high precision atomic absorption analysers.**

The spectral line intensities and profiles were studied in special design light sources, manufactured at Institute of Atomic Physics and Spectroscopy, with arsenic, mercury and thallium filling. Special attention is devoted to the UV lines of 193.7 nm and 197.2 nm of As, 276.8 nm, 377.6 nm of Tl and 253.7 nm of Hg spectral lines. The intensities and profiles were measured by means of a Fourier transform spectrometer.

The deconvolution procedure was implemented to obtain the real form of emitted profiles for further analysis, since in the case of low –pressure or cold plasma, the instrumental function is on the same order that experimental profile and it has to be taken into account. The instrumental function can distort the real spectral line shape significantly, for example, it changes the width of the spectral line that leads to the uncertainties in the determination of such important plasma parameters like temperature. The instrumental function can conceal a detailed structure of the spectral line, like the dip in the line center caused by the self-absorption (self-reversal) and characterizing the radiation trapping.

The integrated areas, values of self-absorption, and other parameters were obtained and compared for all fillings as a function of working regimes.

Keywords - detection of heavy metals (As, Tl, Hg) in environment, electrodeless light sources, UV spectral lines shapes, self-absorption.

I. INTRODUCTION

Since thallium, mercury, and arsenic exposure even at small doses can have adverse effects on humans and environment, their monitoring is of high importance. As with any highly toxic element, it is imperative to detect concentrations as low as possible.

The spectral line shape studies are necessary, to find appropriate spectral line for the application of high frequency electrodeless light sources (HFEDLs) in atomic absorption spectrometry (AAS) for determination of environmental pollution, as well as to optimize the HFEDLs operation. The main requirements for use of the line in AAS are the narrow and intense spectral line without self-absorption [1].

In this work we test in laboratory conditions high-frequency electrodeless lamps with arsenic, mercury and thallium fillings for their use in atomic absorption

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spectrometers for detection of arsenic, mercury and thallium in low concentrations in the environment.

II. Materials and Methods

A. Experimental

The spectral characteristics, such as accurate line positions, transition intensities, line shapes, and hyperfine structure patterns are very important for atomic absorption spectrometry.

For this study, special design light sources were manufactured at our laboratory, filled with working element (As, Hg or Tl) and Ar as a buffer gas. In Fig. 1 one may see the lamps used in this study, (a) - the example of Tl lamp and (b) – As lamp.

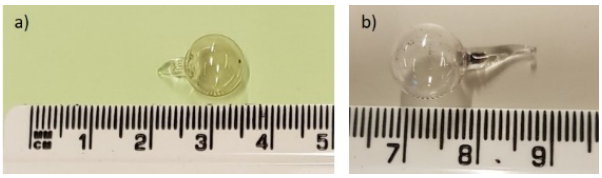

Fig. 1. Examples of Tl and As lamps.

Tl light source has been filled with Tl 205 isotope; the As and Hg light sources were filled with natural mixture of isotopes. Pressure of argon in all types of lamps was about 3 Torr. The plasma was excited by placing lamp in electromagnetic field of 100 MHz frequency. HFEDLs filled with Tl were operated with excitation generator power values between 13.7 W and 22.8 W, however for As lamps the range was from 4.7 W till 8.68 W and Hg lamps from 2.63 W till 9.05 W.

In the present work, the emission spectra from high frequency electrodeless discharge of Tl, As and Hg were studied in a spectral range from 190 nm till 400 nm The spectral line profile and intensity registration was performed using Fourier Transform spectrometer Bruker IFS-125HR (spectral resolution 0.015 cm^{-1}).

From spectra with more than 2 500 000 points about 100 points were selected for each wavelength for further calculation.

B. Theoretical approach

As well known, the measured profile f(x) is the convolution of the real spectral line y(s) and instrumental function A (x, s). It can be described by Fredholm integral equation of the first kind:

$$\int_a^b A(x,s)y(s)ds = f(x), c \le x \le d \qquad (1)$$

where: a, b and c, d - the limits of the real and measured (experimental) profiles accordingly.

The deconvolution of the real profile of the measured spectral lines is ill-posed inverse tasks and can't be solved directly. As shows our previous experience [2]-[6], the Tikhonov regularization approach is one of the most efficient methods regarding calculation time, stability, and accuracy of solution, as well as the amount of needed additional information. And method of deconvolution of spectral line based on it can be used for multicomponent spectra deconvolution as well. Using minimum of prior information, we will get a stable and accurate solution of the inverse ill-posed problem. The most important step in the Tikhonov regularization method is to find the regularization parameter α, which establishes the correspondence between the requirement of the stability of solution and its reliability, since inaccurate determination of α leads to major solution errors. Choosing the regularization parameter is the main difficulty of the regularization methods applying in practice.

In this work the regularization parameter was obtained by means of discrepancy minimization and the instrumental function was approximated by the Lorenz function with the FWHM (full width at half of maximum) of 0.03 cm^{-1}.

More detailed description of instrumental function approximation can be seen in [6].

III. Results and Discussion

A. HFEDL filled with thallium

Fig. 2 and Fig. 3 show the profile examples of thallium 377.6 nm and 276.8 nm spectral lines depending on excitation generator power values, namely 15.44 W, 19.3 W, and 22.8 W.

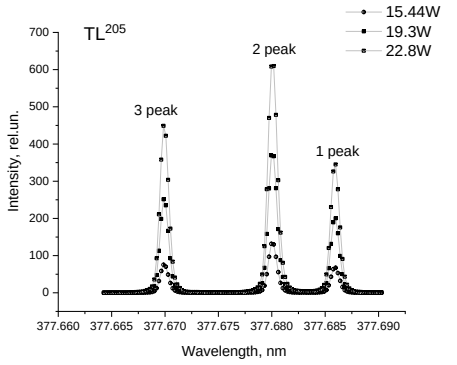

Fig. 2. Examples of Tl 377.6 nm line forms in dependence on power.

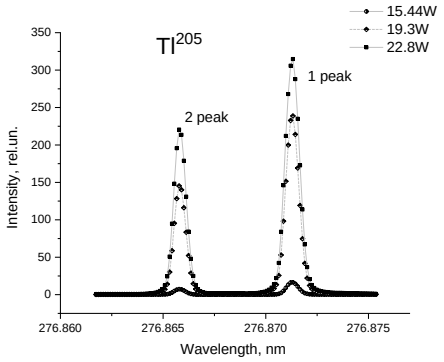

Fig. 3. Examples of Tl 276.8 6nm line forms in dependence on power.

In the Fig. 4 and Fig.5, we can see changes in relative intensities of thallium 377.6 nm and 276.8 nm spectral lines depending on excitation generator power values. Both spectral lines correspond to resonance transition (ending on the ground level) which makes them suitable for use in absorption spectrometers.

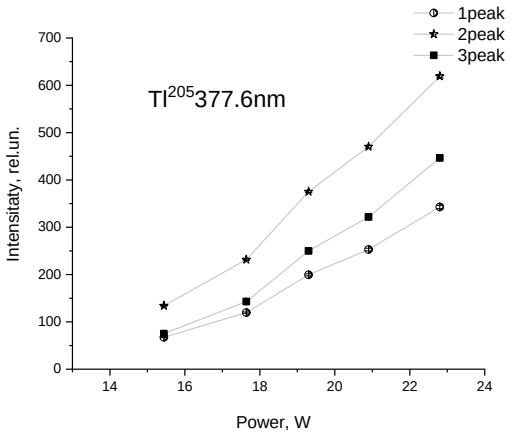

Fig. 4. Tl 377.6 nm line relative intensities dependence on power.

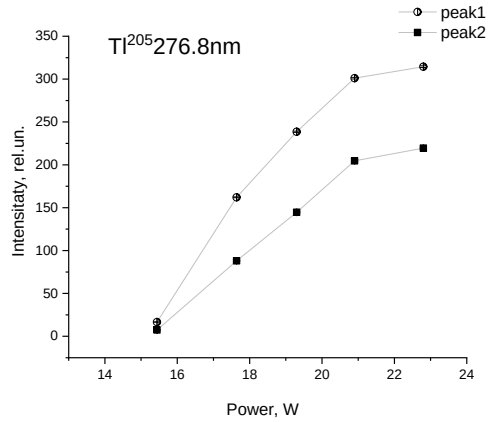

Fig. 5. Tl 276.8 nm line relative intensities dependence on power.

On the Fig. 6 and Fig. 7 we can see thallium 377.6 nm and 276.8 nm spectral line FWHM value dependences on the excitation generator power. The values of FWHM were obtained before deconvolution from measured profiles and after deconvolution procedure implementation.

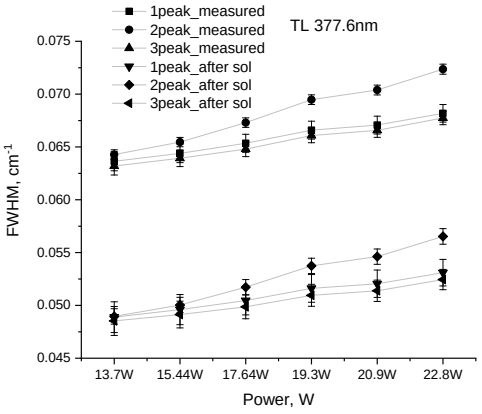

Fig. 6. Dependence of FWHM of measured and deconvoluted profiles on generator power for Tl 377.6nm.

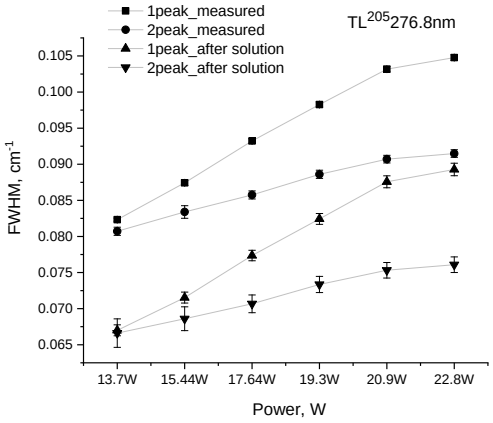

Fig. 7. Dependence of FWHM of measured and deconvoluted profiles on generator power for Tl 276.8nm.

For Tl lines we did not observe the self-reversal, so we can estimate the discharge temperature from the Doppler broadening of the deconvoluted lines. On the Fig. 8, the dependence of obtained values of the gas temperature on power is shown.

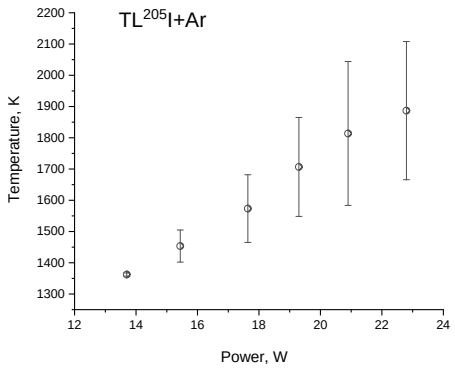

Fig. 8. Temperature dependence on power.

The gas temperature determined from the thallium spectral lines 377.6 nm and 276.8 nm was in the range from 1300 K to 1800 K, indicating the origin of the emission to be localized in the central part of the HFEDL. Similar results were reported in the previous study of the same type of discharge with the same filling [7] in which the analysis of the molecular emission of OH and C_2 molecules showed that the temperature in the central part of a thallium HFEDL can reach 1450 K while the gas temperature near the walls is significantly lower (by approximately 400 K).

B. HFEDL filled with arsenic

In the frame of this work, the dependence of the relative intensities of arsenic spectral lines on the power of the excitation generator was measured. The studied spectral lines were 193.7 nm and 197.2 nm. As in the case with thallium lines, these spectral lines of arsenic correspond to resonance transitions.

Fig. 9 shows the dependence of relative intensities at the line centre of As 197.2 nm and 193.7 nm spectral lines on generator power.

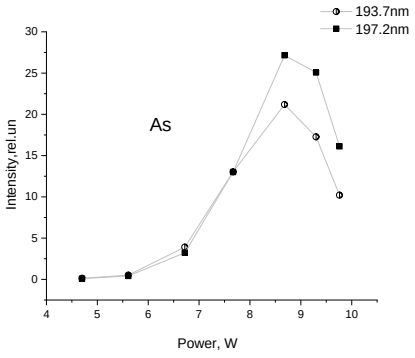

Fig. 9. Relative intensity values of As 197.2nm and 193.7nm lines in dependence on power .

Analysis of the arsenic 193.7 nm and 197.2 nm spectral line profiles in dependence on power showed that when increasing excitation generator power up to 8 W, relative intensities of these spectral lines are increasing, but afterwards the relative intensities decrease.

Fig. 10 shows the profile examples of As 197.2 nm spectral line at four different values of excitation generator power, namely 7.67 W, 8.68 W, 9.3 W and 9.76 W. As we can see, the dip in the line centre caused by the self-absorption is increasing with the rising of generator power, and it is also the explanation for the decrease of spectral line intensity for excitation generator power values starting from 8 W.

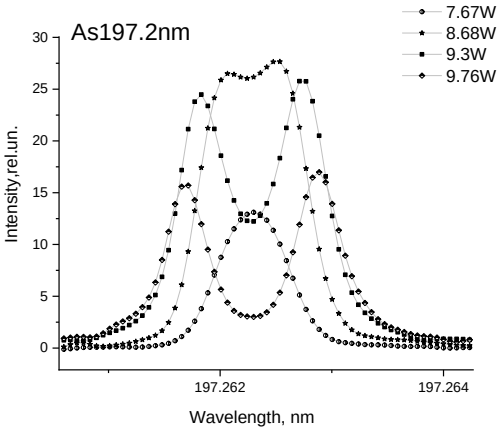

Fig. 10. Examples of As 197.2 nm line forms in dependence on power.

Analysis of deconvoluted As lines shows that the mean value of I_{max}/I_0 is larger compared to measured ones. The I_o is the intensity of the spectral line profile at the centre of the line; I_{max} is the intensity at the line maximum.

It means, that the self-absorption is better visible in profiles, obtained from solution of ill-posed inverse task, thus illustrating the concealing of detailed spectral line structure by the instrumental function. On Fig. 11 and Fig. 12 one may see the dependence of obtained rate of qualitative self- absorption of arsenic spectral lines on the excitation generator power for measured and deconvoluted (after implementation of deconvolution procedure) profiles, accordingly.

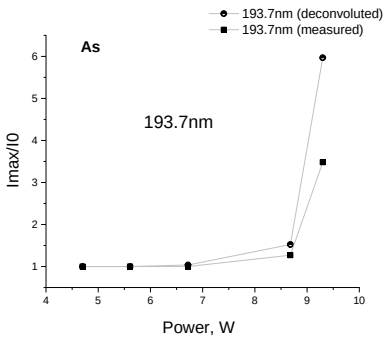

Fig. 11. The obtained qualitative rate of self- absorption of As 193.7 nm spectral line dependence on the excitation generator power for measured and calculated profiles.

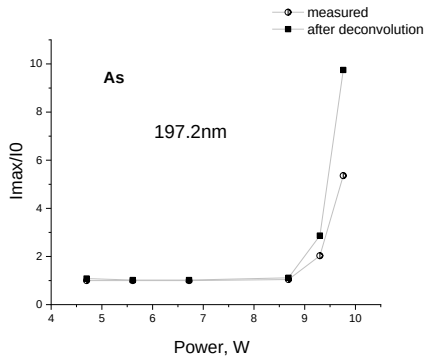

Fig. 12. The obtained qualitative rate of self- absorption of As 193.7 nm spectral line dependence on the excitation generator power for measured and calculated profiles.

On the Fig. 13 we can see an example of the comparison of integrated areas of measured and deconvoluted profiles of arsenic 197.2 nm spectral line.

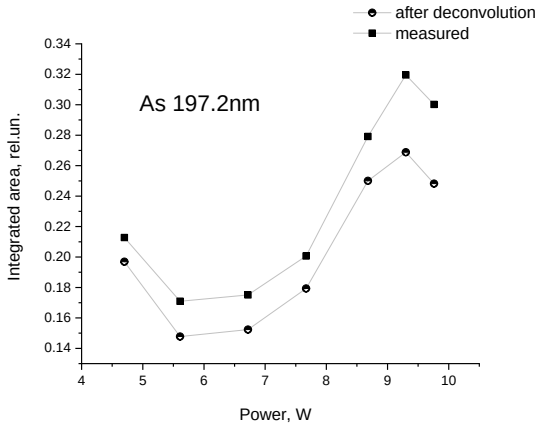

Fig. 13. The comparison of normalised integrated intensities of measured and deconvoluted profiles of As 197.2 nm on dependence of power.

As can be seen, values of integrated areas of calculated profiles are smaller than the measured ones. This shows that instrumental function changes the width of the spectral line, meaning that the appearance of the self-absorption in the light source increases the broadening of the spectral line, at the same time increases also the dip in the centre of the line, leading to the decrease in area. That is the explanation for the slow decrease of integrated spectral line area starting at around 8 W

C. HFEDL filled with mercury

On Fig. 14 we can see some examples of the complex structure of the Hg spectral line 253. 7 nm in dependence on excitation generator power. It is due to hyperfine splitting and isotopic shifts of the Hg isotopes in the natural composition of mercury in the filling. We can clearly observe that by small discharge power 2.626 W 4.16 W and 5.25 W still the resulting five components can be resolved but at 9.05 W power, the reabsorption starts to play, and the lines structure is becoming complex.

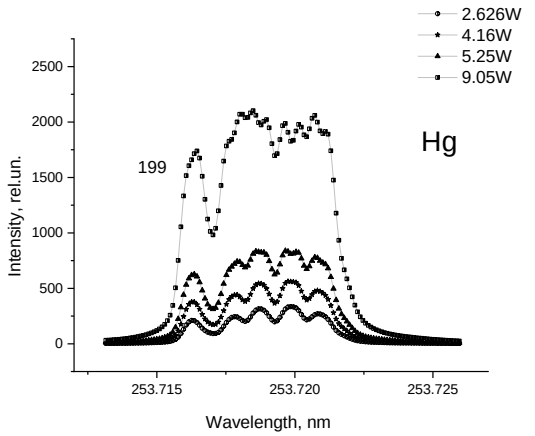

Fig. 14. Examples of measured Hg 253.7 nm line forms in dependence on power.

On the Fig.15 is shown the comparison of form of spectra of measured and deconvoluted profiles of Hg 253.7 nm at 2.62 W of generator power.

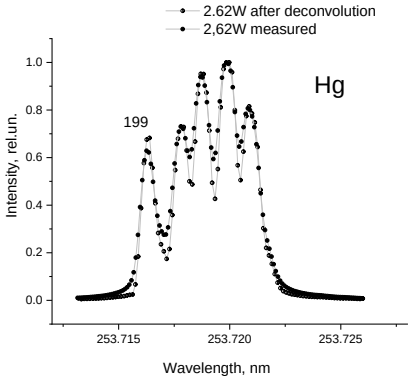

Fig. 15. The comparison of form of measured and deconvoluted spectral profiles of Hg 253.7 nm at 2.62 W of generator power.

After deconvolution procedure implementation the components of spectra, corresponding to different isotopes can be seen clearly, especially 199 isotope.

Fig. 16 shows the examples of form of natural composition of the Hg spectral line 253.7 nm in dependence on excitation generator power after deconvolution procedure implementation. There are three different values of excitation generator power: 2.62 W, 4.16 W and 9.05 W.

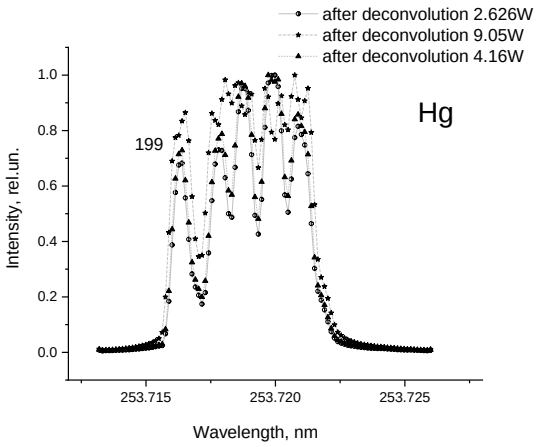

Fig. 16. The Examples of Hg 253.7 nm line forms after deconvolution in dependence on power .

It is interesting to observe that the five resulting components can be seen clearly after the deconvolution for the 2.62 W, 4.16 W power regimes that means that the self-absorption has small influence but by the 9.05 W, the individual components are becoming self-reversed and can't be resolved. That means that for the use of 253.7 nm line, the power regime not more than 4 W should be used.

CONCLUSIONS

The analysis has shown that the ratio of the intensity at the line centre to maximal line intensity, estimated from the deconvoluted spectral line profiles is a robust indicator of self-absorption and it can be easily used to detect the optimal power regimes for selected lines. In addition, the measurements of integral intensity should be taken into account to estimate the optimum working conditions with the right balance of brightness of line and influence of self-absorption.

The analysis of arsenic and mercury resonance spectral lines revealed the appearance of self-absorption at quite small values of excitation generator power, meaning that the working regime for this HFEDL needs to be chosen very carefully in order to use it in absorption spectrometers

We can conclude that for arsenic 197.2 nm line the optimal discharge power is about 8 W, for 193.7 nm about 7 W. For mercury 253.7 nm line the operating power should be not more than 4 W. However, we did not observe the self-absorption of thallium lines of 377.6 nm and 276.8 nm. Thus, they can be operated at power from 20 to 23 W.

The obtained results of temperature in thallium HFEDL correspond to the previous study of the same type of discharge with the same filling [7], where values of temperature were obtained by another independent method. To investigate further the distribution of emitting atoms inside the thallium HFEDLs, it is necessary to use tomographic approach as demonstrated in [8].

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REFERENCES

[1] A. Ganeev et al., "High-frequency electrodeless discharge lamps for atomic absorption spectrometry" Spectrochemica Acta B: Atomic Spectroscopy, 58, 5, pp.879-889, 2003.

[2] Zorina N., "Deconvolution of the spectral line profiles for the plasma temperature estimation", Nuclear Inst. and Methods in Physics Research A 623,pp.763-765, 2010

[3] Zorina N. et al., "Validity of the deconvolution method for multicomponent spectral lines" J. Phys.: Conf. Ser. 1289 012045, 2019. (doi:10.1088/1742-6596/1289/1/012045)

[4] G.Revalde N. Zorina, A. Skudra, "Multicomponent line profile restoring by means of ill-posed inverse task solution", J. Phys.: Conf. Ser. vol.810(1),012056 ,2017 (doi: 10.1088/1742-6596/810/1/012056)

[5] G. Revalde, N. Zorina, A. Skudra, "Deconvolution of multiple spectral lines shapes by means of Tikhonov's regularization metode", in Imaging and Applied Optics, OSA Technical Digest (Fourier Transform Spectroscopy, FTS 2013; Arlington, VA; United States; 23-27 June 2013 June 2013) (Optical Society of America, 2013), paper JTu4A.12. (http://dx.doi.org/10.1364/AOPT.2013.JTu4A.12)

[6] G. Revalde et al., "Deconvolution of the line spectra of microsize light sources in the magnetic field", Romanian Reports in Physics, Vol. 66, No. 4, pp. 1099–1109, 2014.(http://rrp.infim.ro/2014_66_4/A17.pdf)

[7] M. Zinge, Z. Gavare, and E. Gosko "Spectroscopic studies of Tl containing high frequency electrodeless lamps", Proc. SPIE 9421, Eighth International Conference on Advanced Optical Materials and Devices (AOMD-8), 94210G (22 October 2014)(https://doi.org/10.1117/12.2083948).

[8] N. Denisova, G. Revalde, A. Skudra, E. Bogans, "Tomographic diagnostics of high-frequency electrodeless lamps in argon–mercury mixtures" , *J. Phys. D: Appl. Phys., vol. 39, pp. 1069 – 1077, 2006. (https://doi.org/10.1088/0022-3727/39/6/012).*