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- Innovative technologies in industry
- Occupational diseases
- Development of national economies
- Legal aspects in the system of industrial relations

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Conference date 30.10.2020
Format 60×84 1/8

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ANALYSIS OF THE IMPACT OF SPECIAL CONSTRUCTIONS OF GAP SEALS ON THE DYNAMICS OF CENTRIFUGAL MACHINES

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ARTICLE INFO

Article history:

Received date 10.10.2020

Accepted date 19.10.2020

Published date 30.10.2020

Section:

Machine building and metal processing

DOI

10.21303/2313-8416.2020.001485

KEY WORDS

gap seals
floating rings
deformable seals
labyrinth seals
rotor dynamics

ABSTRACT

The object of research: the influence of the design features of special gap seals on the dynamic characteristics of centrifugal machines.

Investigated problem: harmonization of the consumption and dynamic characteristics of the seals of the rotors of high-speed machines by applying special design methods.

Main scientific results: The mechanism and operating conditions of seals with floating rings are described. It is determined that the most effective from the point of view of dynamic characteristics is the variant of the semi-movable ring. Expressions for determining the conditions of angular and radial immobility of a floating ring are obtained. The design options for deformable gap seals, including deformable floating rings, deformable interwheel seals and seals with an axially movable deformable sleeve, have been investigated. The scope of their application for unique machines with high requirements for tightness and vibration reliability has been determined. Variants of the design of labyrinth seals have been investigated. The analysis shows that the dynamic properties of labyrinth seals significantly depend on the relative position of the ridges. Overlapping ridged seals have the worst dynamic performance of the labyrinth seal designs. The honeycomb seal has more favorable dynamic properties, and the well seal has the best combination of consumption and dynamic characteristics. The dynamic characteristics are especially important for the seals of high-speed rotors of centrifugal machines.

The area of practical use of the research results: Enterprises that manufacture centrifugal machines: pumps and compressors.

Innovative technological product: a methodology for the selection, design and calculation of special designs of gap seals with optimization of dynamic and flow characteristics.

Scope of application of the innovative technological product: The obtained research results will be useful in the design and manufacture of centrifugal pumps and compressors for any parameters.

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1. Introduction

Gap seals according to the accepted classification [1] belong to the class of non-contact. This means that during operation a guaranteed gap is maintained between their sealing surfaces.

Gap throttles separate the cavities in which the medium to be sealed is under different pressures. The flow rate is limited due to the expenditure of potential pressure energy to overcome local resistances, frictional resistance along the channel length, and sometimes inertial resistance. The greater these costs, the smaller the fraction of potential energy is converted into kinetic energy of the flow, the lower the average fluid velocity in the channel and its flow rate. Thus, gap seals do not completely eliminate, but only limit the flow.

1. 1. The object of research

The object of research is special designs of gap seals and the influence of their design features on the dynamic characteristics of rotary machines.

1. 2. Problem description

Gap seals work conditions and the functions assigned to them are very diverse. In addition to centrifugal pumps and compressors, they are widely used in hydraulic and pneumatic automa-

tion systems, in hydraulic and pneumatic drives (hydraulic cylinders, plungers, spools, adjustable throttles, valves), in devices with an unsealed piston, in shut-off, control and safety valves, in various piston machines (piston rings), in hydraulic, steam and gas turbines (labyrinth seals). Gap throttles are available as separate accessories for most other seal types. Radial and end gap throttles are integral elements of hydrostatic and gas support and thrust bearings, rotor axial balancing systems. In all these designs, both the consumption and the dynamic characteristics of the seals are of great importance [2].

The dynamic performance is especially important for high speed rotors. Gap seals, in addition to the function of sealing, perform an equally important function – to improve the vibration state of the rotor. Unfortunately, these functions, as a rule, are in mutual contradiction: constructive measures aimed at increasing the hydraulic resistance, most often worsen the dynamic qualities of seals, their hydrostatic stiffness and damping [3]. The efforts of the designers are aimed at harmonizing these functions.

1. 3. Suggested solution to the problem

In the process of creating centrifugal pumps for any parameters, in addition to developing an economical flow path, the primary tasks are to reduce vibrations, ensure the required reliability and durability of supports and drive couplings, and develop reliable and sufficiently tight seals. The peculiarity of centrifugal machines is that the listed tasks are interrelated and in most cases can be satisfactorily solved due to the correct choice of the design of the gap seals.

2. Materials and Methods

The energy of volumetric losses can be converted into useful energy if the gap seals are used simultaneously as hydrostatic bearings, capable of not only having high radial stiffness, but also effectively damping rotor vibrations. In this case, the energy of the leaks can not only provide the necessary bearing capacity of the supports, but also, most importantly, reduce the rotor vibration to an acceptable level even in the presence of significant imbalance [4].

The influence of the medium is especially significant in the presence of large gradients of velocities and pressures. Such conditions are just typical for small gaps of gap seals, at which large pressure drops are throttled, and one of the walls belongs to a rotating and vibrating rotor [5].

Thus, when choosing the design of gap seals, one must take into account not only their direct purpose – to reduce volumetric losses, but also their equally important function – to provide the necessary vibration characteristics of the rotor [6].

3. Results

Let's consider some of the results achieved in this direction in relation to the seals of rotors of centrifugal machines.

3. 1. Floating ring seals

The floating ring seal [7] (**Fig. 1**) is a combination of an O-ring B (non-contacting gap seal) and an end contact C, which acts as a mechanical end seal. The throttle B is formed by the surface of the rotating shaft 1 and the inner cylindrical surface of the floating ring 4. The preliminary compression of the ring to the bearing surface of the cover 2 is carried out by elastic elements (springs) 5 located in the sleeve 6 fixed in the housing 7.

Due to the sealed pressure p_1 , an axial force $F_c = A_e p_1$ is created on the loading surface A_e , which ensures the required density of the end contact C. The radial hydrodynamic force F_y arising in the gap seal B and proportional to the eccentricity of the ring relative to the shaft contributes to the self-centering of the ring if it exceeds friction force $R_c \cong fF_c$ in the end contact.

Due to the ability of the floating ring to self-centering, the radial clearance in the annular throttle can be made several times smaller than in conventional gap seals, without fear of contact of the ring with the rotating shaft and possible scoring. Because the flow through the throttle ring is proportional to the cube of the gap H^3 for laminar flow and $H^{3/2}$ for turbulent flow, floating ring seals are able to provide a significant reduction in leakage compared to conventional gap seals.

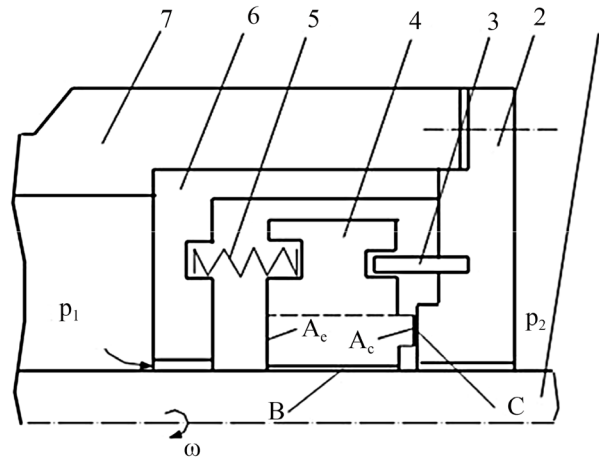


Fig. 1. Diagram of a gap seal with a floating ring

The tightness of the end joint C depends on the ratio of the contact pressure $p_c = F_c/A_c$ to the sealed pressure p_1 . The contact pressure, in turn, is determined by the load factor. When there is no back pressure $p_2 = 0$, $p_c = kp_1$, $k = A_g/A_c$. The design of the seal allows this coefficient to be varied within a wide range, satisfying the requirements of tightness. The floating ring does not rotate; therefore, the frictional power loss in the end joint is an order of magnitude less than in mechanical end seals. This eliminates the problem of heat removal from the contact surfaces, and the seal itself does not have severe restrictions on the circumferential speed of the shaft $v = \omega r$ and on the sealed pressure p_1 . In other words, the factor $p_1 v$ for floating ring gap seals is not decisive.

It follows from the mechanism of the seal that the ring floats if the self-centering condition is met, i. e. $F_{y\max} > R_c$. However, if this condition is not met and the ring does not float, then it is still displaced in the radial direction under the action of impacts from the side of the shaft. Bearing in mind that the impact energy is limited by the work of the friction force at the end joint, it is possible to select materials for which light episodic impacts are not dangerous. The ring relatively easily takes a neutral position, in which shockless operation is ensured. It is only necessary that the amplitude of the lateral vibrations of the shaft does not exceed the value of the radial clearance, and the material of the sealing surfaces resists scuffing during short-term contacts in transient modes. In many cases, such semi-movable or conditionally movable rings turn out to be more effective, since they have increased static and dynamic stability [1].

In real structures, floating rings do not always have the ability to float, but this does not mean that they are inoperative. For comparison, consider the possible modes of operation of the simplest design of a floating ring.

During operation, the floating ring is acted upon by hydrodynamic forces and moments arising in the gap seal and changing in magnitude and direction due to the radial and angular vibrations of the rotating shaft. An additional moment relative to the center of the ring creates a frictional force on the end contact surface C.

Under the action of these forces and moments, the floating ring can vibrate in its plane, as well as perform angular vibrations. Angular vibrations are accompanied by some displacement of the center of gravity of the ring in the axial direction. However, the amplitudes of these displacements are two times less than the amplitudes of the end gap in the joint C, which are measured with micrometers even during angular vibrations. Therefore, in the first approximation, axial vibrations can be ignored.

Thus, a self-centering floating ring can be considered as an oscillatory system with four degrees of freedom, performing forced oscillations under the action of kinematic excitation from the shaft. The mass of the ring is usually small compared to the mass of the rotor, so the reverse effect of ring vibrations on rotor vibration can be neglected.

The operation of such a classic design is accompanied by intense radial and angular vibrations. Angular vibrations lead to the formation of periodic, with the shaft rotation frequency, point contacts of the end surfaces. In the case of circular precession of the shaft, the ring motion has the character of a conical precession and the contact patch describes a circular trajectory. Contact stresses increase on the contact patches, which leads to frictional fatigue fractures of the end

surfaces. There are various constructive methods for suppressing angular vibrations [2], but they require a significant complication of the design and at the same time reduce its reliability.

The behavior of the floating rings is determined by the ratio of forces in the ring and end throttles. The characteristics of the end throttle can vary depending on the contact pressure p_c . If the contact pressure does not exceed the pressure of the sealed medium $p_c \leq p_1$, then a liquid friction mode is provided on the end surface. Otherwise, the friction regime becomes boundary and can approach the dry friction regime. In this case, if the self-centering condition is satisfied, the ring vibrations become nonlinear. The third option is that the self-centering condition is not met, the ring loses its radial mobility, and only angular oscillations are possible when the total moment acting on the ring opens the butt joint. Finally, an extreme case, when the systems of forces and moments acting on the ring are balanced, the ring is motionless in the absence of collisions with the shaft.

The last version of working conditions (conditionally movable ring) is the simplest and most reliable.

Let's write down the immobility conditions for the contactless operation mode (no collisions of the shaft with the ring). Radial and angular displacements of the ring can arise under the action of the radial hydrodynamic force F_y and the moment M_x in the annular gap, as well as under the action of gravity and its moment relative to the point of possible rotation a. **Fig. 2** shows the most unfavorable case, when the centering force F_y coincides in direction with the force of gravity. The same applies to the moments of these forces.

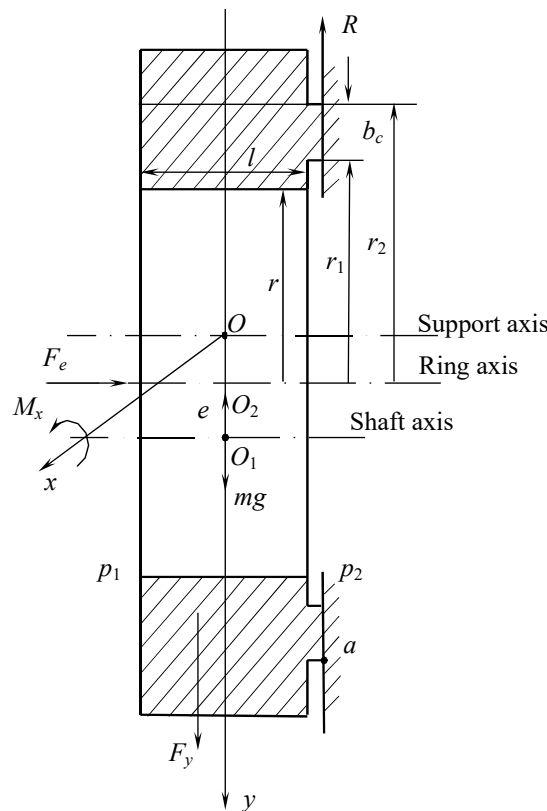


Fig. 2. Design diagram of a conditionally movable ring

Immobility conditions are as follows:

$$R_c \geq F_y + mg, \quad 0.5F_c(r_1 + r_2) \geq M_x + 0.5mgl. \quad (1)$$

The hydrodynamic force and its moment must be calculated for the maximum permissible eccentricity $e_* \approx (0.7 - 0.8)H$ and skew angle $0.5l\vartheta_x \approx 0.7(H - e_*)$, at which the non-contact operation of the seal can still be guaranteed. In the considered equilibrium position, only the hydrostatic force and moment are preserved

$$F_y = F_{py2} = k_p \left[(\theta_0 + N\chi_m)\varepsilon + (1 + 2\Delta\chi)\theta_x \right],$$

$$M_x = M_{px2} = k_p \frac{l}{6} (N\Delta\chi\varepsilon + 2\chi_m\theta_x),$$

where

$$\varepsilon = e/H, \quad \theta_0 = \vartheta_0 l/2H, \quad \theta_x = \vartheta_x l/2H, \quad \chi_m = \chi_1 + \chi_2, \quad \Delta\chi = \chi_1 - \chi_2,$$

$$\chi_1 = \varsigma_{11}/\varsigma_0, \quad \chi_2 = \varsigma_{12}/\varsigma_0, \quad N = 2(1+n)/(2-n), \quad k_p = \pi r_o \Delta p l/2.$$

The constant n characterizes the flow regime (n , C – exponent and constant in the Blasius formula $\lambda_0 = C \text{Re}_0^{-n}$; laminar flow: $n=1$, $C=96$, turbulent flow: $n=0.25$, $C=0.36$, self-similar area: $n=0$, $C=0.04$), ς_{11} , ς_{12} – coefficients of local hydraulic losses at the entrance to the annular gap and at the exit from it, $\varsigma_0 = (\varsigma_{11} - \varsigma_{12}) + \lambda l/2H$.

In general, the force of contact pressure

$$F_c = p_1 A_c + \Delta p (A_e - A_c) = \Delta p A_c (k + p_2/\Delta p), \quad k = A_e/A_c,$$

friction force $R_c = fF_c$. Using expressions for forces and moment, let's reduce relations (1) to the form

$$k + \frac{p_2}{\Delta p} \geq \frac{1}{f \Delta p A_c} \left\{ k_p \left[(\theta_0 + N\chi_m)\varepsilon + (1 + 2\Delta\chi)\theta_x \right] + mg \right\},$$

$$k + \frac{p_2}{\Delta p} \geq \frac{l}{6f \Delta p A_c r_2} \left[k_p (N\Delta\chi\varepsilon + 2\chi_m\theta_x) + 3mg \right]. \quad (2)$$

As a rule, the second condition is weaker, and the fulfillment of the first condition ensures both radial and angular immobility of the seal ring.

Short-term collisions of the ring with the shaft are possible during the start-up period if the ring lies freely on the shaft. Therefore, the cylindrical contact surfaces of the shaft and the ring must be scuff-resistant.

3. 2. Deformable gap seals

In high-pressure centrifugal machines, noticeable deformations of the elements of gap seals occur under the influence of large pressure drops, regardless of the will of the designer. Since the leakage and dynamic characteristics depend on the shape of the gap, attempts are being made to create such structures, the deformations of which would reduce the leakage and improve the dynamic properties of the annular throttles.

This problem is relatively easy to solve for floating rings [1] (**Fig. 3**). The ring has a box-shaped cross-section with annular stiffening ribs 1, 3 and a thin-walled cylindrical cage 2, forming a throttling gap with the shaft 4, 5. **Fig. 3** shows radial plots of the pressure acting on the ring in the gap 6 and on the outer surface 7. The transverse shading 8 denotes the unbalanced part of the pressure on the outer surface of the ring. The plots are shown for the initial undeformed state of the ring. Under the action of pressure 8, the cylindrical cage bends, acquiring the shape 9. The change in the shape of the gap entails a change in the pressure distribution in it 10 and a decrease in the external load 8. The equilibrium deformed state of the ring is determined by solving the static problem of hydroelasticity.

The deformation of the ring leads to a decrease in the flow area of the annular gap and to a decrease in leakage. It is also important that deformations grow with increasing compacted pressure, and this, in turn, slows down the growth of leaks. Contractor shape 9 of the main part of the gap increases its stiffness and damping properties.

It is more difficult to provide the required deformation of the front gap seals of the impellers. A relatively simple solution [8] is shown in Fig. 4. Sleeve 1 with a thin-walled cylindrical cage 2 forms a cavity A with the body, connected by holes 3 with a throttling annular gap 4. In the undeformed state of cage 2, the pressure along the length of the gap 4 varies linearly from the maximum

at the inlet to the minimum at the outlet. The pressure in cavity *A* is equal to the pressure in the place of the gap 4, where the holes 3. Thus, the radial pressure drop acts on the cage, increasing towards the exit from the gap 4. The radial deformations of the sleeve 1 under the action of this difference lead to an increase in the pressure in the gap 4 and, respectively, in cavity *A*. As a result, the pressure drop that deforms the sleeve decreases. The deformation effect is the same as in the floating ring.

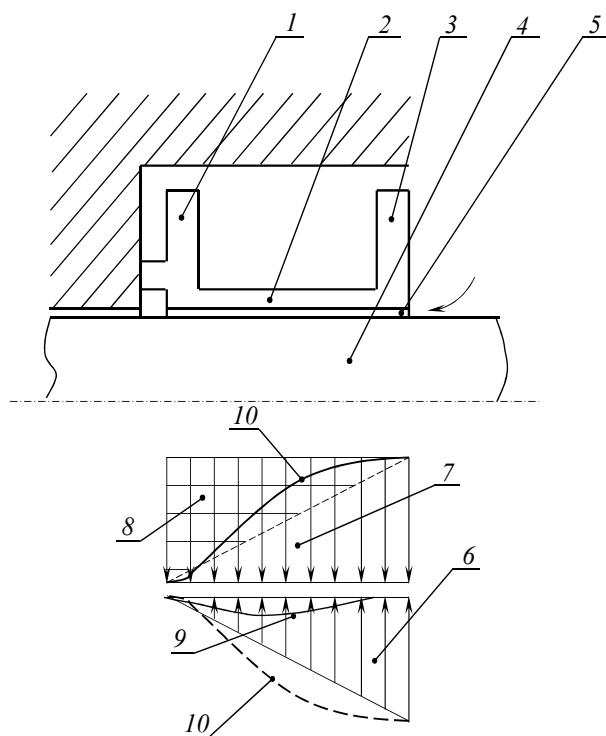


Fig. 3. Deformable floating ring and pressure curves

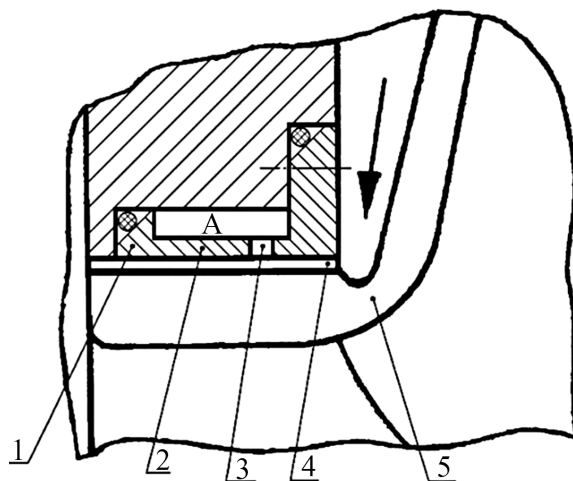


Fig. 4. Deformable impeller gap seal

Another design of the gap seal [9] is shown in **Fig. 5**. Axially movable deformable sleeve 3 with an annular shoulder 5 forms a cavity *A* in the housing 1, connected to the throttling gap 6 by holes 4. The pressure in the cavity *A* is constant along the length, and in the gap 6 decreases along the length.

In the equilibrium state, the axial pressure force in the cavity *A* together with the force of the spring 2 and the friction force balances the axial force of pressure on the end face 7. An increase

in the sealing pressure shifts the sleeve to the left. In this case, the sleeve is additionally deformed, the clearance at the outlet decreases, and the pressure in cavity A increases. The movement of the sleeve stops after the restoration of the conditions of its axial equilibrium.

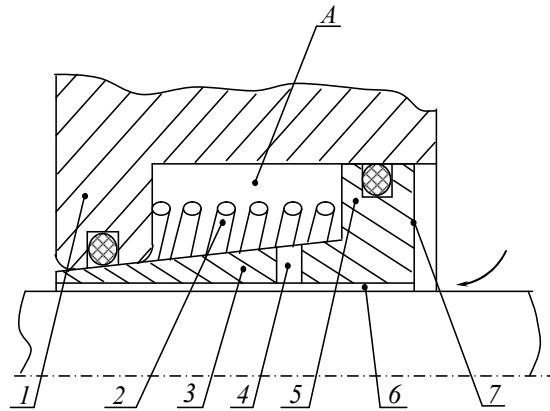


Fig. 5. Seal with deformable axially movable sleeve

3. 3. Labyrinth seals

The problem of ensuring the contactless operation of gap seals is especially relevant for pumps that pump flammable liquids, and for compressors that pump low-viscosity gases that do not have lubricating properties. There is a risk of fire in pumps, in compressors there is a risk of the rotor getting stuck in the seals.

To seal gaseous media in centrifugal compressors, in steam and gas turbines, various designs of labyrinth seals with minimal contact surfaces are used [10] (**Fig. 6**). The annular ridges in these seals are made of metal tape 0.15–0.2 mm thick. With such a thickness, possible contacts only crush the ridges, without causing excessive heating, enveloping and seizing.

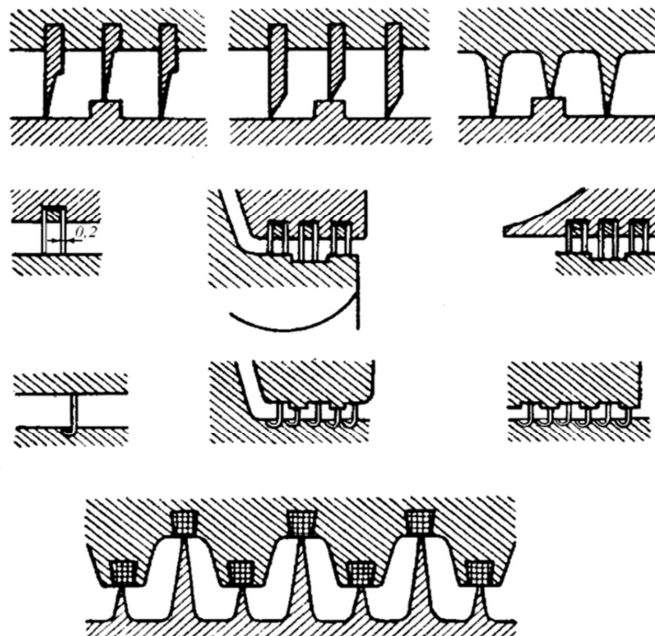


Fig. 6. Some designs of labyrinth seals for gas

The disadvantage of gas labyrinth seals is the low flexural rigidity of the ridges. This drawback is eliminated in special labyrinth seals, called honeycomb seals by the type of cellular structure of the sealing element [11] (**Fig. 7**). The seal is a sleeve, inside of which a honeycomb filler is fixed by high-temperature vacuum brazing with powder solders. It has the form of hexagonal cells

and is made of corrugated strips of steel corrosion-resistant foil, connected along the contacting edges by contact welding on automatic machines. Such a honeycomb structure has increased rigidity and does not crumple under high pressure drops. The depth of the cells is 4–6 mm, the facet size is 2–4 mm, and the foil thickness is 0.05–0.15 mm. The thinner thickness and improved heat dissipation mitigate the harmful effects of scuffing, allowing seals to be made with almost no radial clearance, thereby minimizing leakage of the sealed medium. The honeycomb cage is used in combination with a smooth shaft or a shaft with labyrinth ridges. The latter combination is used to seal the stages of gas turbine engines. In case of misalignment, the ridges located on the rotor easily cut into the honeycomb walls, causing their slight deformations and local heating. The gas flow rate remains almost unchanged, while if the ridges of a conventional labyrinth seal are damaged, the leaks increase significantly.

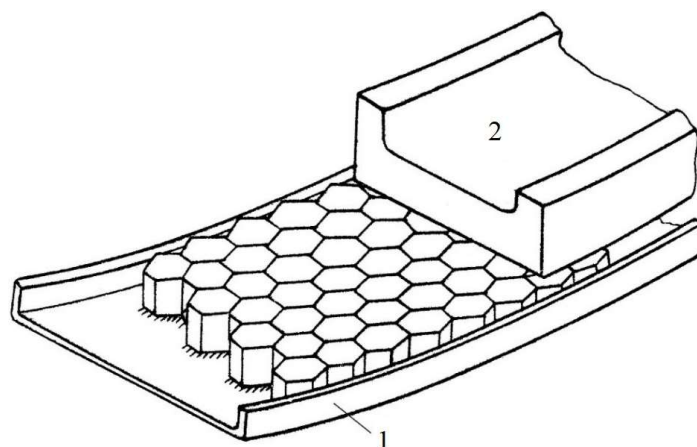


Fig. 7. Honeycomb seal

To reduce the risk of contacts between the rotating and stationary elements of the seals, the pumps use labyrinth seals with increased radial clearances up to 0.5 mm. To limit excessive leakage growth, seals are made with overlapping ridges (Fig. 8).

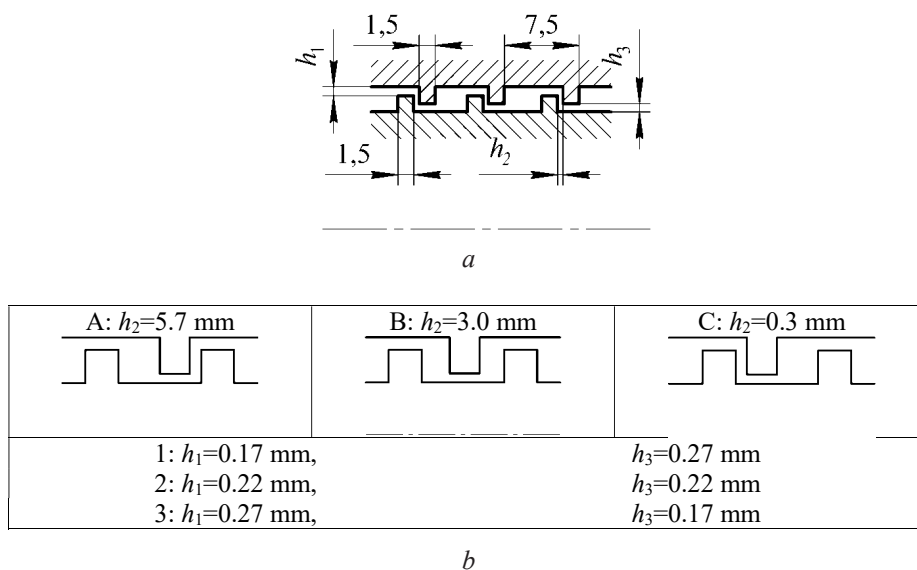


Fig. 8. Labyrinth seal with overlapping ridges: *a* – design diagram; *b* – versions

The dynamic properties of such seals substantially depend on the relative position of the ridges. Option C1 (Fig. 8) caused self-excited vibrations even of a non-rotating shaft. In this regard, as an alternative, it was proposed [12] construction of a well seal (Fig. 9). The well seal is a sleeve 1,

on the inner surface of which sickle-shaped wells are milled 2. In the axial direction, the rows of wells are separated by ridges 4, and in the circumferential direction, adjacent wells are separated by bridges 3. The ridges perform the same role as ridges in conventional labyrinth seals, and the bridges inhibit the circumferential flow.

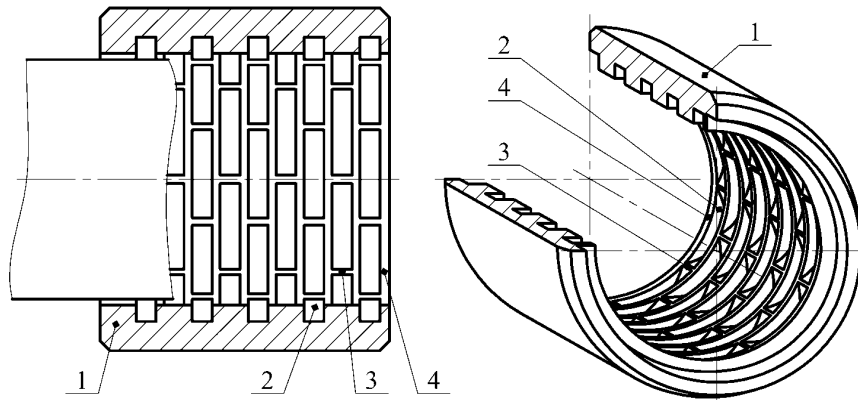


Fig. 9. Well seal

The role of the bridges is especially important, since, by slowing down the circumferential flow, they thereby reduce the circulating force, which is the main reason for the loss of dynamic stability of the rotor in the seals. In addition, the holes are semi-closed chambers that inhibit the displacement flow and increase the damping force, respectively.

A significant influence on the rigidity of labyrinth seals is exerted by the type of relative position of the ridges. The maximum rigidity is possessed by the A3 variant (**Fig. 8**), in which the channel resembles a contractor shape. Diffuser flow seals (option C1) can have negative stiffness. When testing this version at pressure drops greater than 0.5 MPa, the sleeve of the non-rotating rotor was pressed against the stator yoke, i.e. lost static stability. A further increase in the pressure drop to 4 MPa led to the emergence of intense self-excited oscillations, the amplitudes of which reached the value of the radial gap.

4. Discussion

The works of the creators of centrifugal machines [1–6] was devoted to the study of the relationship between the vibration characteristics of the rotor and the designs of gap seals. These works, as well as the needs of thermal and nuclear energy in feed, main circulation and other pumps for ever higher parameters stimulated a detailed study of the problems of hydrodynamics of gap seals and their effect on the vibration state of rotors of centrifugal machines [1, 2, 5, 6]. Work on the creation of turbopump assemblies for high-power rocket engines for reusable spacecraft further raised the interest of researchers in the dynamic characteristics of gap seals and vibrations of rotors in seals [7, 8, 10].

The results obtained in this work in many aspects confirm the qualitative picture of the physical processes occurring in various designs of gap seals, described by other researchers.

The peculiarity of the works of most researchers of the influence of seals on the dynamics of a centrifugal machine is that the rotor and seals are considered as a closed hydromechanical system, in which the role of a connecting link is played by the flow of the pumped medium in throttling channels, inertial and hydrodynamic characteristics of the flow [3–6].

The positive qualities of gap seals are realized provided that the non-contact mode of operation is maintained, when there is no danger of scoring. And for this it is necessary that the initial clearance value (for radial seals) exceeds the total eccentricity of the shaft relative to the sealing ring. Eccentricity can appear due to manufacturing and assembly errors (runout, radial and angular misalignment), as a result of force and temperature deformations, and also due to shaft vibrations. For these reasons, the gap has to be assigned in the range of at least 0.2–0.4 mm. Therefore, the leakage through gap seals of new centrifugal pumps reaches 5 % of the pump flow. During opera-

tion, leaks can increase significantly due to erosional erosion of the sealing gaps, and this leads to a corresponding decrease in the efficiency.

A conditionally movable floating ring works as a stationary gap seal, and the hydrodynamic forces arising in the annular gap are completely transferred to the rotor, predetermining its vibration state. Dynamic problems, which are of prime importance for floating rings, are eliminated in this case. Due to the correct choice of the shape of the gap, it is possible to increase the coefficients of hydrostatic stiffness and damping and thereby reduce the amplitudes of lateral vibrations of the rotor. Considering that shaft vibrations in the area of the seals can be several times greater than on bearings, then even relatively small radial clearances of 0.05–0.1 mm ensure non-contact operation of semi-movable floating rings. Thus, seals with conditionally movable rings make it possible, under certain conditions, to exclude collisions between the shaft and the ring even with small (less than 0.1 mm) gaps between them. The results obtained in some aspects are confirmed by the results published in [7].

All the described designs of deformable impeller seals require careful manufacturing and fine-tuning, and their optimal design requires solving the corresponding problems of hydroelasticity. Therefore, it is not economically feasible to use them for ordinary serial machines, and for unique machines with high requirements for tightness and vibration reliability, such seals can be indispensable. An example is the turbopump units of rocket engines, the power of which is measured in hundreds of megawatts at extremely low mass and dimensional characteristics. The efficiency of using deformable gap seals in the design of turbopump units of rocket engines was confirmed in [8].

The dynamic properties of labyrinth seals substantially depend on the relative position of the ridges. The results of the study of labyrinth seals presented in this work in a number of fundamental nuances developed and supplemented the studies [10, 11].

Labyrinth seals with overlapping ridges have extremely low radial stiffness, which is primarily due to the free circumferential fluid flow through relatively large channels between the ridges. As a result, the circumferential pressure is equalized and the radial force is reduced. This remark applies to both straight-through labyrinth seals and screw seals. Thus, labyrinth seals with annular grooves represent a potential hazard to high-pressure pumps and compressors. The test results of the labyrinth seals of a high-pressure compressor, confirming the research results, are given in [12].

If vibration and leakage mitigation is equally important for a particular pump, well seals should be used. In terms of hydraulic resistance, they are not inferior to labyrinth and honeycomb ones, and in terms of elastic damping properties they significantly surpass them. At the same time, they are less prone to scuffing and seizure than conventional O-ring gap and labyrinth seals. It should be borne in mind that the coefficient of hydrostatic stiffness of well seals is approximately two times less than that of conventional gap seals.

5. Conclusions

Floating ring seals are often more effective when the rings are not floatable.

Deformable impeller seals are advisable to be used for unique machines with high requirements for tightness and vibration reliability.

Of the labyrinth seal designs described, overlapping ridge seals have the worst dynamic performance. The honeycomb seal has more favorable dynamic properties, and the well seal has the best combination of consumption and dynamic characteristics.

References

- [1] Martsinkovskii, V. A., Shevchenko, S. S.; Shevchenko, S. S. (Ed.) (2018). *Nasosy atomnykh elektrostantsii: raschet, konstruirovaniye, ekspluatatsiia*. Sumy: Universitetskaya kniga, 472.
- [2] Martsynkovskiy, V. A. (1980). *Beskontaktnie uplotneniya rotornikh mashyn*. Moscow: Mashynostroeniye, 200.
- [3] Kim, S. H., Ha, T. W. (2016). Prediction of leakage and rotordynamic coefficients for the circumferential-groove-pump seal using CFD analysis. *Journal of Mechanical Science and Technology*, 30 (5), 2037–2043. doi: <http://doi.org/10.1007/s12206-016-0410-4>

- [4] Vijaykumar, A., Morrison, G. (2010). Numerical Simulation of the Flow Field in a Statically and Dynamically Eccentric Annular Seal With Non-Circular Whirl Orbits. ASME 2010 3rd Joint US-European Fluids Engineering Summer Meeting: Volume 1, Symposia – Parts A, B, and C, 731–761. doi: <http://doi.org/10.1115/fedsm-icnmm2010-30839>
- [5] Wang, J., Shen, H. P., Ye, X. Y., Hu, J. N., Feng, Y. N. (2013). The influence of annular seal clearance to the critical speed of the multistage pump. IOP Conference Series: Materials Science and Engineering, 52 (2), 022034. doi: <http://doi.org/10.1088/1757-899x/52/2/022034>
- [6] Bojko, M., Kozubkova, M., Kozdera, M., Zavila, O. (2014). Investigation of the influence of radial grooves on the flow in an eccentrically deposited annulus using CFD numerical simulation. EPJ Web of Conferences, 67, 02009. doi: <http://doi.org/10.1051/epjconf/20146702009>
- [7] Badun, O. P., Deshevykh, S. A., Ivanov, Ia. N. (2016). Osobennosti ispolzovaniia plavaiuschikh kolets v kislorodnykh nasosakh. Vestnik dvigatelestroeniia, 2, 115–121.
- [8] Suleimanov, R. I., Nazarov, V. P. (2011). Analiz vozmozhnosti primeneniia schelevogo uplotneniia rotora TNA s deformiruemoi vtulkoi. Aktualnye problemy aviatsii i kosmonavтики, 7, 66–67.
- [9] Martsinkovskii, V. A., Gulii, A. N., Melnik, V. A. (1988). A. s. 1372138. Uplotnenie vala.
- [10] Makarov, A., Zaytsev, N. (2015). Engineering and theoretical problems of labyrinth seals application in high-speed rotor machines. Perm National Research Polytechnic University Aerospace Engineering Bulletin, 42, 61–81. doi: <http://doi.org/10.15593/2224-9982/2015.42.05>
- [11] GAO, R. (2012). Computational Fluid Dynamic and Rotordynamic Study on the Labyrinth Seal. Ph.D. Dissertation in Mechanical Engineering. Virginia Polytechnic Institute and State University.
- [12] Martsinkovskii, V. S., Kukharev, I. E., Bilyk, Ia. I., Lazarenko, A. D. (2016). Resheniia problem germetizatsii protochnogo trakta tsentrobezhnogo kompressora. Kompessornoe i energeticheskoe mashinostroenie, 4, 5–14.

STUDY OF THE INFLUENCE OF COMPOUNDS OF THE ANO_3 AND $\text{ANO}_3 \cdot n\text{H}_2\text{O}$ TYPES ON RHEOKINETIC AND COLLOID-CHEMICAL PROPERTIES OF ALUMINOSILICATE ADHESIVES FOR WOOD

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ARTICLE INFO

Article history:

Received date 08.10.2020

Accepted date 19.10.2020

Published date 30.10.2020

Section:

Chemical & petrochemical industry

DOI

10.21303/2313-8416.2020.001493

KEYWORDS

aluminosilicate adhesive
 ANO_3 and $\text{ANO}_3 \cdot n\text{H}_2\text{O}$ modifiers
rheokinetic and chemical-colloidal
properties
wood

ABSTRACT

In the technology of gluing solid wood, various adhesives are used, which, in addition to ensuring the strength of the gluing, must also be characterized by a number of rheological and colloidal-chemical properties, namely: have acceptable viscosity, low contact angles, have good spreading and enveloping ability, penetrate deep into the wood, providing reliable cohesive-adhesive contact and much more. Today, adhesives based on PVA dispersions and urea formaldehydes are used, the properties of which have been sufficiently studied and tested in practice. An alternative to organic-based adhesives is mineral adhesives, in particular aluminosilicate adhesives, which are non-flammable and have high mechanical strength.

Object of research: rheokinetic patterns and processes of formation of colloidal-chemical structures of aluminosilicate adhesives modified with compounds of the ANO_3 and $\text{ANO}_3 \cdot n\text{H}_2\text{O}$ type.

Investigated problem: Considering that aluminosilicate adhesives are multiphase reactive suspensions, the viscosity of which changes over time and affects their viability, the issue of viscosity stabilization due to the introduction of electrolyte salts into their composition is relevant, and will also contribute to improving the wettability and spreading of the adhesive during applying them to substrates and gluing samples from various types of wood.

Main scientific results: The effect of the concentrations of compounds of the ANO_3 and $\text{ANO}_3 \cdot n\text{H}_2\text{O}$ type on the rheokinetic and chemical-colloidal properties of the aluminosilicate adhesive has been established, which will make it possible to use aluminosilicate adhesives in practice for gluing wood of various species, as well as to work out possible technological methods of their application, taking into account the obtained data on the viscosity, wetting and spreadability of the modified adhesive on the surface of the wood substrate.

Area of practical use of the research results: woodworking enterprises for the production of glued solid wood products.

Innovative technological product: aluminosilicate adhesives modified with ANO_3 and $\text{ANO}_3 \cdot n\text{H}_2\text{O}$ nitrate additives for gluing wood of various species.

Scope of application of an innovative technological product: the application of these approaches will make it possible to obtain glued materials from wood from different species with improved technological and physical and mechanical properties of the glue seam and, accordingly, to increase the quality and reliability of products.

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1. Introduction

According to the data of works [1, 2], wood is a natural polymer of the cellular-fibrous structure, which is characterized by uneven density, significant porosity and hydrophilicity. Due to the different structure of coniferous and deciduous wood, the application of mineral glue to the surface of substrates has its own specifics, first of all, associated with wetting and spreading, and secondly, penetration deep into the substrate.

1. 1. The object of research

The object of research is the rheokinetic patterns and processes of the formation of colloidal-chemical structures of aluminosilicate adhesives modified with compounds of the AlNO_3 and $\text{AlNO}_3 \cdot n\text{H}_2\text{O}$ type, intended for gluing wood.

1. 2. Problem description

The problem is simple – the rheokinetic and chemical-colloidal properties of aluminosilicate adhesives for gluing solid wood have not been studied due to the novelty of this product and insufficient experience of its use in gluing technology.

There are only a few works devoted to the use of mineral adhesives, especially aluminosilicate composition, for gluing wood of different species. They mainly reflect the physical and mechanical aspects that describe the properties of the adhesive joint depending on the composition of the aluminosilicate adhesive [3], and also provide data confirming the incombustibility of the adhesive seam with ensuring the bearing capacity (strength) of glued wood products in a fire [4].

In works [5, 6] attention is paid to the physical and mechanical characteristics of composite board materials obtained on the basis of aluminosilicate adhesives, as well as similar materials with increased resistance to fire [7].

In [8, 9], the influence of the Si/Al molar ratio on the microstructure and mechanical properties of ultra-low density wood fiber composite material was noted.

In one of the first works [10], on the problem under consideration, a relationship was established between the concentrations of an organomineral complex with the stability of the colloidal-chemical properties of aluminosilicate dispersion as a basis for adhesives for gluing wood. Subsequent work [11] provides data on the effect of organic and mineral modifiers of a high-silica aluminosilicate binder (Si/Al=5...6) on the rheological properties of adhesives for wood.

In the process of practical approbation of aluminosilicate adhesive (gluing solid wood, making plywood, fiberboard and other wood materials), problems of a purely technological nature arose associated with the fluidity of the adhesive, its viability, high adhesion properties to metal feed paths, uniform distribution over the substrate surface, wettability of surfaces and others.

Therefore, it was decided to search for and study the effect of a number of mineral compounds on rheokinetics and chemical-colloidal properties of the initial (base) composition of the aluminosilicate adhesive in order to eliminate the above technological problems.

1. 3. Suggested solution to the problem

The solution to the problem can be started with the question of studying the effect of modifying additives – compounds of the AlNO_3 and $\text{AlNO}_3 \cdot n\text{H}_2\text{O}$ type on the rheokinetic and chemical-technological properties of aluminosilicate adhesives.

The aim of research is to study rheokinetic patterns and processes of formation of colloidal-chemical structures of aluminosilicate adhesives modified with compounds of the AlNO_3 and $\text{AlNO}_3 \cdot n\text{H}_2\text{O}$ type.

2. Materials and methods

To obtain an aluminosilicate adhesive, a binder of $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot (4,5-6)\text{SiO}_2 \cdot (17,5-20)\text{H}_2\text{O}$ type was used with the ratio of the main structure-forming oxides $\text{SiO}_2/\text{Al}_2\text{O}_3=6$ and $\text{SiO}_2/\text{H}_2\text{O}=20$. Correction of the composition of the binder for alkaline oxides was carried out using their aqueous solutions.

To control the physical and rheological characteristics of the aluminosilicate adhesive, chemically pure compounds of the AlNO_3 and $\text{AlNO}_3 \cdot n\text{H}_2\text{O}$ type, namely: $\text{LiNO}_3 \cdot 3\text{H}_2\text{O}$, NaNO_3 , KNO_3 and NH_4NO_3 were introduced into its composition.

The preparation of an aluminosilicate adhesive with functional additives was carried out in a laboratory dissolver. To analyze the effect of modifiers on colloidal-chemical and rheokinetic properties, the following parameters were chosen as the initial parameters: the work of the forces of adhesion, cohesion and wetting, spreading and wetting coefficients, dynamic and plastic viscosity, surface tension and contact angle on substrates of pine, beech and oak wood treated to a surface roughness of Rz60.

The choice of substrates is due to the following assumptions, namely: pine wood as the main material in the manufacture (gluing) in industrial conditions of massifs and various structural

elements and products; beech wood as the main substrate for testing the physical and mechanical properties of adhesive joints in accordance with EN: oak wood as the main substrate for the physical and mechanical properties of flooring materials, in particular parquet.

The numerical values of the parameters were obtained on devices and according to the methods used in paintwork. The dynamic viscosity was determined using a Brookfield LVDV2T viscometer using an LV-3C (67) spindle. Surface tension, contact angle, work of forces of adhesion, cohesion and wetting, as well as the values of the coefficients of spreading and wetting were calculated by the formulas given in [12]. The error in measuring the values of the surface tension and the contact angle, when using the instruments and devices described in [12], did not exceed 10 %.

3. Results and experimental confirmation

3.1. Influence of nitrate concentration on the change in the dynamic and plastic viscosity of adhesives

The amount of adhesive applied per unit area of the glued surfaces depends primarily on its concentration and viscosity, and secondly, on the required thickness of the adhesive layer, the temperature of the wood and the environment, and the quality of preparation of the glued surfaces.

In the original aluminosilicate adhesive, the dry matter concentration is 62.3 %, and the dynamic viscosity is 51222 cP.

Let's consider how the concentration of nitrate additives, which change the concentration of the adhesive on dry matter from 62.8 to 63.8 %, affects the change in the dynamic values in the range of low spindle speeds. In general, the nature of the curves is related to the pseudoplastic state of fluids. With an increase in the spindle rotation speed, the values of dynamic viscosities decrease (**Fig. 1**).

So, the introduction of lithium nitrate hydrate in an amount from 0.5 to 1.5 wt. % promotes an increase in the initial values of dynamic viscosity from 56400 to 97200 cP, which, on average, is 1.4 times higher than the viscosity of the initial adhesive. In the range of speeds from 0.3 to 2 RPM, the influence of concentrations on the change in the viscosity of adhesives is still visible, then, starting from a speed of 5 RPM and higher, the differences in the values of viscosities are insignificant (**Fig. 1, a**). In general, the addition of 0.5–1 % lithium nitrate hydrate does not significantly increase the viscosity value over the original adhesive.

The introduction of sodium nitrate in an amount from 0.5 to 1.5 wt. % contributes to a sharp increase in the initial values of the dynamic viscosity from 103,200 to 136,800 cP, which, on average, is 5.3 times higher than the viscosity of the initial adhesive. Sodium nitrate helps thicken the adhesive. In the range of speeds from 0.2 to 5 RPM, the viscosity curves of adhesives containing sodium nitrate in an amount of 0.5–1.5 % coincide, and at a spindle speed of 50 RPM and higher, they coincide with the curve of the viscosity change of the initial adhesive (**Fig. 1, b**).

The introduction of potassium nitrate in an amount from 0.5 to 1.5 wt. % promotes not as sharp as in the previous variant, an increase in the initial values of the dynamic viscosity from 85200 to 100800 cP, which, on average, is 1.8 times higher than the value of the initial adhesive viscosity. In the range of speeds from 0.2 to 2 RPM, the viscosity curves of adhesives containing sodium nitrate in an amount of 0.5–1 % coincide, and at a spindle rotation speed of 40 RPM and higher, they coincide with the curve of changes in the viscosity of the initial adhesive (**Fig. 1, c**).

The introduction of ammonium nitrate is 0.9 times compared with the viscosity of the original adhesive, and in an amount from 1–1.5 wt. % promotes an increase in the initial values of dynamic viscosity from 75,000 to 129,600 cP, which, on average, is 2.8 times higher than the viscosity of the initial adhesive. In the range of speeds from 0.2 RPM and higher, the viscosity curves of the initial and adhesive containing ammonium nitrate in an amount of 0.5 wt. % coincide, and at a spindle rotation speed of 40 RPM and above, the curves of viscosity change also coincide at other values of the additive concentration (**Fig. 1, d**).

In general, regardless of the types of additives, the pattern of changes in the dynamic viscosities of adhesives is identical.

The effect of the concentration of nitrate additives on changes in the values of plastic viscosity [10], determined from the cotangent of the slope of the curves in the dependence $v=f(M)$ (**Fig. 2**), is more clearly seen.

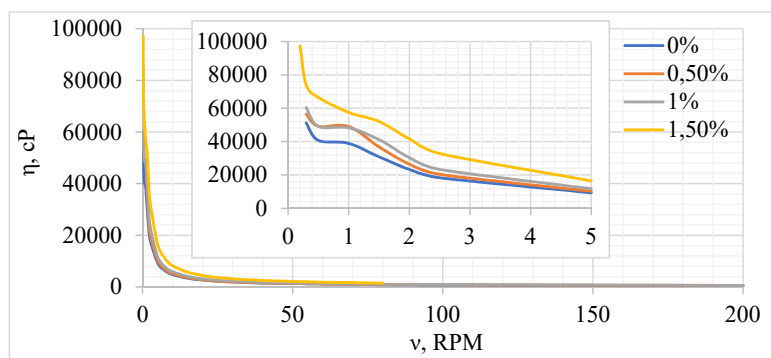
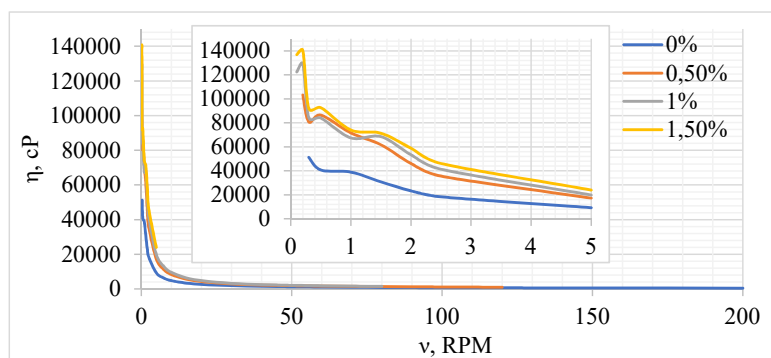
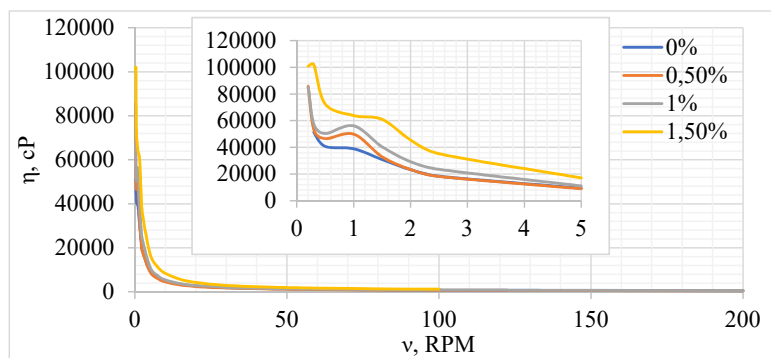
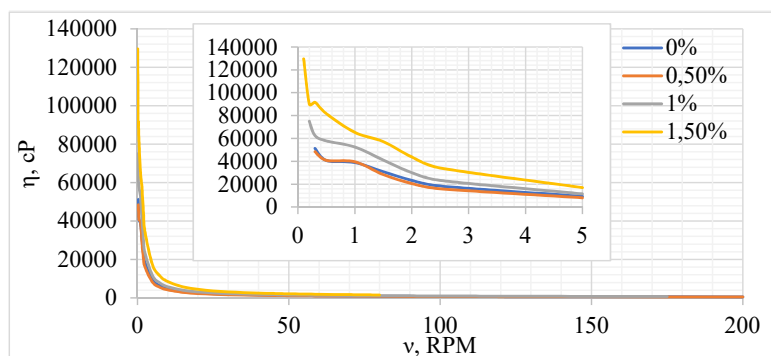
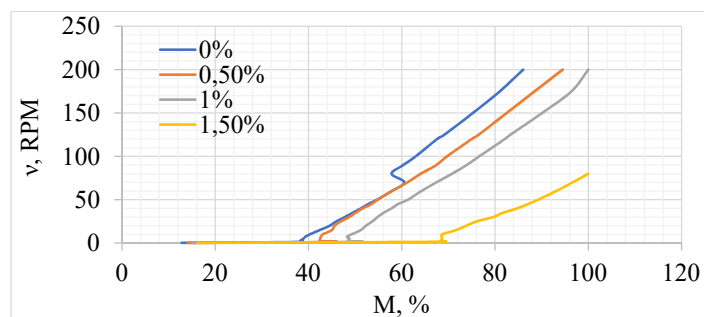
*a**b**c**d*

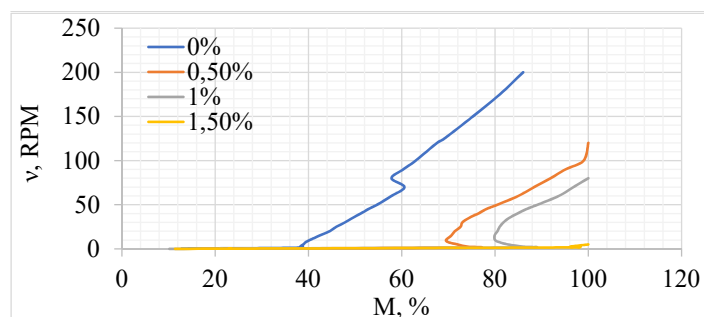
Fig. 1. The kinetics of changes in the dynamic viscosity of the aluminosilicate adhesive depending on the type and concentration of nitrates (%): *a* – $\text{LiNO}_3 \cdot 3\text{H}_2\text{O}$; *b* – NaNO_3 ; *c* – KNO_3 ; *d* – NH_4NO_3

In the speed range from 10 to 200 RPM, the amount of plastic viscosity is significantly influenced by the spindle torque. So, with the introduction of lithium nitrate hydrate and potassium nitrate

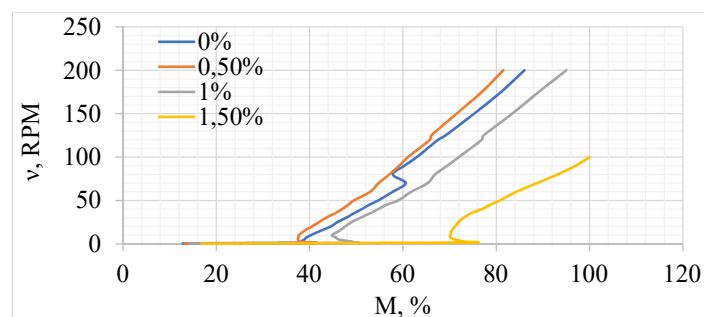
into the adhesive in an amount of 0.5–1.5 wt. % the values of plastic viscosities practically coincide. The plastic viscosity of the initial adhesive has a value of 50.95 cP, with the addition of the above nitrates in the amount of 0.5 wt. %, on average, 61.6 cP; at 1 wt. % – 70.02 cP; at 1.5 wt. % – 118.13 cP (**Fig. 2, a, c**).



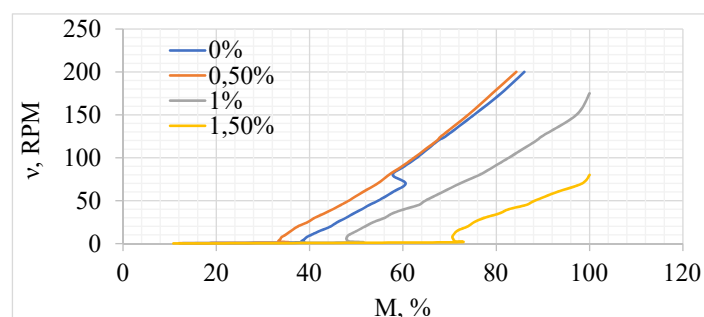
a



b



c



d

Fig. 2. Kinetics of changes in the plastic viscosity of the aluminosilicate adhesive depending on the speed and torque of the spindle, the type and concentration of nitrates (%):
a – $\text{LiNO}_3 \cdot 3\text{H}_2\text{O}$; b – NaNO_3 ; c – KNO_3 ; d – NH_4NO_3

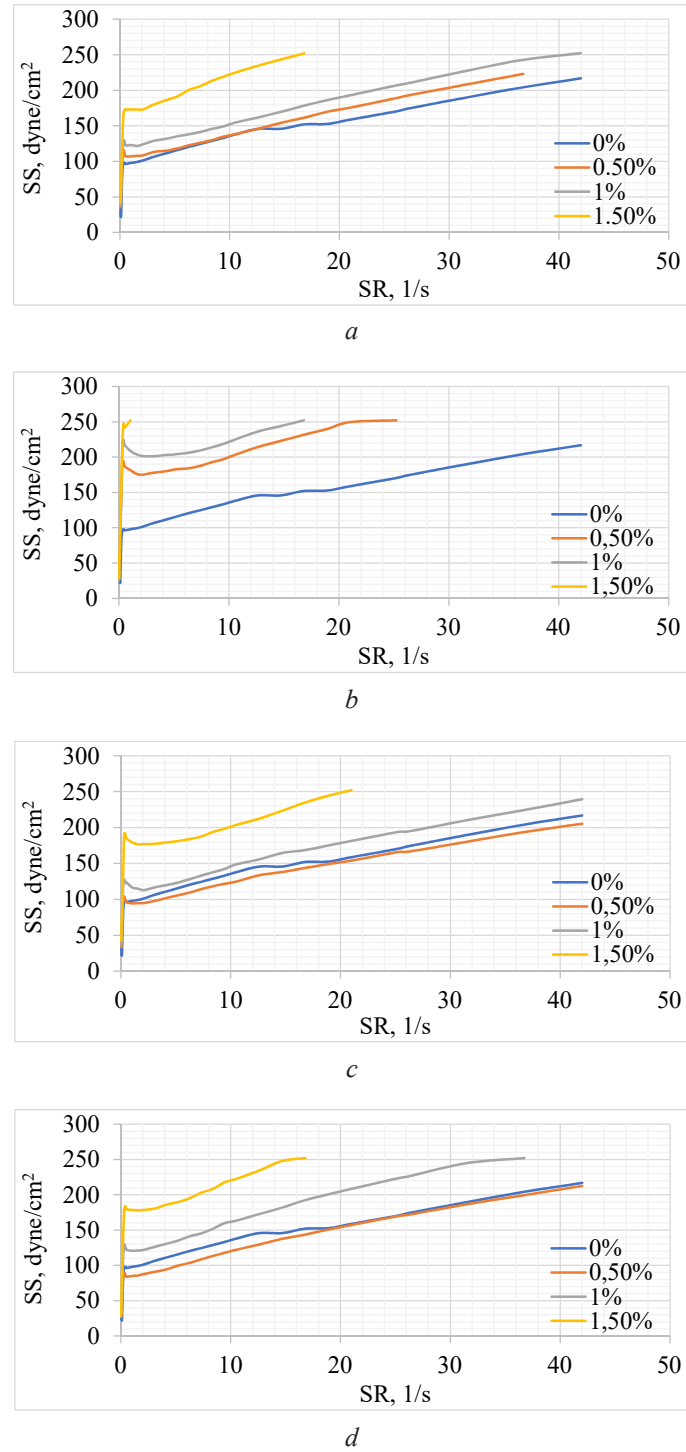


Fig. 3. Kinetics of change in the shear force of the aluminosilicate adhesive depending on the shear rate, type and concentration of nitrates (%):
a – LiNO₃·3H₂O; *b* – NaNO₃; *c* – KNO₃; *d* – NH₄NO₃

3.2. Influence of nitrate concentration on the change in the chemical and colloidal properties of adhesives

According to [10], the more completely the substrate is wetted by the adhesive, the greater the loss of energy (from the wetting condition):

$$S = s_c - s_a - s_a - c \geq 0.$$

The higher the spreading coefficient s , the more complete the wetting. And for this, it is necessary that the free surface energy at the adhesive-substrate (s_a-c) interface be minimal, which is possible only if the molecular nature of the adhesive and the substrate is close. Considering that the molecular nature of the mineral adhesive and the substrate is far from close, many factors must be taken into account for complete wetting and spreading of the substrate, namely: surface tension, contact angle, work of forces of adhesion, cohesion, wetting, etc. Critically, this assumption can be displayed as follows: $\Theta_{av} < 70^\circ$, $s \rightarrow \max$ and $f \rightarrow \min$.

Let's consider the effect of the concentration of lithium nitrate hydride on changes in the chemical and colloidal properties (**Table 1**). As can be seen from the data presented, the introduction of lithium nitrate hydrate in an amount from 0.5 to 1.5 wt. % promotes a 1.2-fold increase in the surface tension of the adhesive compared to the initial one and a decrease in these values with an increase in the amount of lithium nitrate hydride in the adhesive. On substrates of pine, beech and oak, the initial adhesive has the lowest contact angle and the highest flow coefficient. The closest to these values is the adhesive, which contains $\text{LiNO}_3 \cdot 3\text{H}_2\text{O}$ in an amount of 0.5 wt. %. Changes in the indicators of the work of the forces of adhesion, cohesion and wetting are relevant similar to the change in the previous indicators and will be taken into account when determining the physical and mechanical properties of adhesives.

Table 1Chemical-colloidal properties of aluminosilicate adhesive modified with $\text{LiNO}_3 \cdot 3\text{H}_2\text{O}$

$C, \%$	$\gamma, \text{mN/m}$	Θ_{av}	$\cos\Theta_{av}$	$W_a, \text{mN/m}$	$W_k, \text{mN/m}$	$W_w, \text{mN/m}$	s	$f, \text{mN/m}$
pine								
0	49.93	48°	0.66913	83.34	99.86	33.41	0.83457	-16.52
0.5	58.67	$50^\circ 67'$	0.63383	95.86	117.34	37.19	0.81694	-21.48
1	57.42	$54^\circ 67'$	0.57828	90.63	114.84	33.2	0.78918	-24.21
1.5	53.68	$55^\circ 67'$	0.56401	83.96	107.36	30.28	0.78204	-23.4
beech								
0	49.93	$51^\circ 67'$	0.62019	99.86	99.86	30.97	0.81013	-18.96
0.5	58.67	48°	0.66913	97.93	117.34	39.26	0.83458	-19.41
1	57.42	$60^\circ 67'$	0.48989	85.55	114.84	28.13	0.74495	-29.29
1.5	53.68	52°	0.61566	86.73	107.36	33.05	0.80784	-20.63
oak								
0	49.93	47°	0.681998	83.98	99.86	34.05	0.84098	-15.88
0.5	58.67	49°	0.65606	97.16	117.34	38.49	0.82802	-20.18
1	57.42	$50^\circ 33'$	0.63832	94.07	114.84	36.65	0.81914	-20.77
1.5	53.68	55°	0.57358	84.47	107.36	30.79	0.78679	-22.89

Note: C – concentration of nitrate compounds, %; γ – value of surface tension, mN/m ; Θ_{av} – the average value of the wetting angle of the substrate with the adhesive; W_a , W_k , W_w – work of forces of adhesion, cohesion and wetting, mN/m ; s , f – coefficients of wetting and spreading of the adhesive over the surface of the substrate, mN/m .

Also similar in terms of performance adhesives, including 1.5 wt. % $\text{LiNO}_3 \cdot 3\text{H}_2\text{O}$, and adhesives containing 1 wt. % $\text{LiNO}_3 \cdot 3\text{H}_2\text{O}$ by their characteristics fall out of the general pattern (**Table 1**).

The introduction of NaNO_3 in an amount from 0.5 to 1.5 wt. % promotes a 1.5-fold increase in the surface tension of the adhesive in comparison with the initial one. On substrates of pine, beech and oak, the initial adhesive has the lowest contact angle and the highest flow coefficient. The closest to these values is characterized by the adhesive, which contains NaNO_3 in an amount of 0.5 wt. % (**Table 2**).

The introduction of KNO_3 in an amount of 0.5 and 1.5 wt. % increases the surface tension of the adhesive by a factor of 1.1 as compared to the initial one. With the content of KNO_3 in the amount of 1 wt. %, the surface tension values are identical. On substrates of pine, beech and oak, the initial adhesive has the lowest contact angle and the highest flow coefficient. The closest to these values on the pine substrate is the adhesive, which contains NaNO_3 in an amount of 0.5 wt. %; on a substrate of beech and oak, characterized by an adhesive containing 1 and 1.5 wt. % potassium nitrate (**Table 3**).

Table 2Chemical and colloidal properties of aluminosilicate adhesive modified with NaNO_3

<i>C</i> , %	γ , mN/m	Θ_{av}	$\cos\Theta_{av}$	Wa , mN/m	Wk , mN/m	Ww , mN/m	<i>s</i>	<i>f</i> , mN/m
pine								
0	49.93	48°	0.66913	83.34	99.86	33.41	0.83457	−16.52
0.5	72.4	52°67′	0.60640	116.3	144.8	43.9	0.80318	−28.5
1	74.9	55°67′	0.56396	117.14	149.8	42.24	0.78198	−32.66
1.5	74.9	56°	0.55919	116.78	149.8	41.88	0.77957	−33.02
beech								
0	49.93	51°67′	0.62019	99.86	99.86	30.97	0.81013	−18.96
0.5	72.4	58°	0.52992	110.77	144.8	38.37	0.76499	−34.03
1	74.9	57°67′	0.53479	114.96	149.8	40.06	0.76742	−34.84
1.5	74.9	57°	0.54464	115.69	149.8	40.79	0.772296	−34.11
oak								
0	49.93	47°	0.681998	83.98	99.86	34.05	0.84098	−15.88
0.5	72.4	52°67′	0.60640	116.3	144.8	43.9	0.80318	−28.5
1	74.9	49°67′	0.64719	123.37	149.8	48.47	0.82356	−26.43
1.5	74.9	60°33′	0.49500	111.98	149.8	37.08	0.74753	−37.82

The introduction of NH_4NO_3 in an amount of 0.5 to 1 wt. % promotes a 1.2-fold increase in the surface tension of the adhesive as compared to the initial one (**Table 4**).

Table 3Chemical and colloidal properties of aluminosilicate adhesive modified with KNO_3

<i>C</i> , %	γ , mN/m	Θ_{av}	$\cos\Theta_{av}$	Wa , mN/m	Wk , mN/m	Ww , mN/m	<i>s</i>	<i>f</i> , mN/m
pine								
0	49.93	48°	0.66913	83.34	99.86	33.41	0.83457	−16.52
0.5	52.43	45°33′	0.70302	89.29	104.86	36.86	0.85152	−15.57
1	49.93	65°33′	0.41739	70.77	99.86	20.84	0.70869	−29.09
1.5	53.68	56°33′	0.55441	83.44	107.36	29.76	0.77720	−23.92
beech								
0	49.93	51°67′	0.62019	99.86	99.86	30.97	0.81013	−18.96
0.5	52.43	54°	0.58779	83.25	104.86	30.82	0.79392	−21.61
1	49.93	54°	0.58779	79.28	99.86	29.35	0.79391	−20.58
1.5	53.68	55°	0.57358	84.47	107.36	30.79	0.78679	−22.89
oak								
0	49.93	47°	0.681998	83.98	99.86	34.05	0.84098	−15.88
0.5	52.43	56°67′	0.54946	81.24	104.86	28.81	0.77475	−23.62
1	49.93	51°	0.62932	81.35	99.86	31.42	0.81464	−18.51
1.5	53.68	51°	0.62932	87.46	87.46	33.78	0.81464	−19.9

With an NH_4NO_3 content of 1.5 wt. %, the surface tension values are identical. On substrates of pine, beech and oak, the initial adhesive has the lowest contact angle and the highest flow coefficient. The closest to these values on the pine substrate is characterized by an adhesive containing 1.5 wt. % NH_4NO_3 ; on a beech substrate is characterized by an adhesive containing 0.5 and 1.5 wt. % ammonium nitrate; on the oak substrate is characterized by an adhesive containing 0.5 wt. % ammonium nitrate (**Table 4**).

Table 4Chemical and colloidal properties of aluminosilicate adhesive modified with NH_4NO_3

<i>C</i> , %	γ , mN/m	Θ_{av}	$\cos\Theta_{av}$	<i>W</i> _a , mN/m	<i>W</i> _k , mN/m	<i>W</i> _w , mN/m	<i>s</i>	<i>f</i> , mN/m
pine								
0	49.93	48°	0.66913	83.34	99.86	33.41	0.83457	−16.52
0.5	53.68	54°33′	0.58312	84.98	107.36	31.3	0.79154	−22.38
1	62.42	50°	0.64279	102.54	124.84	40.12	0.79154	−22.38
1.5	49.93	55°67′	0.56396	78.09	99.86	28.16	0.78199	−21.77
beech								
0	49.93	51°67′	0.62019	99.86	99.86	30.97	0.81013	−18.96
0.5	53.68	46°67′	0.6862	90.52	107.36	36.84	0.84314	−16.84
1	62.42	50°33′	0.63836	102.27	124.84	39.85	0.81921	−22.57
1.5	49.93	49°33′	0.6517	82.47	99.86	32.54	0.82586	−17.39
oak								
0	49.93	47°	0.681998	83.98	99.86	34.05	0.84098	−15.88
0.5	53.68	51°	0.62932	87.46	107.36	33.78	0.81464	−19.9
1	62.42	49°33′	0.6517	103.1	124.84	40.54	0.82586	−21.74
1.5	49.93	55°	0.57358	78.57	99.86	28.64	0.78680	−21.29

4. Discussion

The significance of the results of the work is quite obvious and, first of all, is aimed at practical originality, which will help to solve the problem of stabilizing the rheokinetic properties of aluminosilicate adhesives modified with compounds of the ANO_3 и $\text{ANO}_3 \cdot n\text{H}_2\text{O}$ type, namely: the values of dynamic and plastic viscosity in the range of working speeds of the adhesive the surface of coniferous and deciduous wood substrates; ensure the formation of colloidal-chemical structures with minimum contact angles and maximum values of the spreading coefficient.

When gluing solid wood from pine, beech and oak substrates along the length, tenon joints are usually used. Horizontal studs are used in joints that do not require high strength properties, vertical studs in structural joints. The application of the adhesive can be done by brush, dipping, or comb-type glue rolls. The above rheokinetic properties of adhesives modified with lithium nitrate trihydrate and potassium nitrate in an amount of 0.5 wt. % and ammonium nitrate in the amount of 1 wt. % are quite applicable for the first two methods in the speed range from 0.3 to 5 RPM (Fig. 1); when using comb rollers, taking into account their rotation speed (usually in the range of 0.2–0.6 m/s), it is possible to use adhesives containing up to 1 wt. % lithium nitrate trihydrate, potassium and ammonium nitrates. The noted concentration of nitrates in the considered range of velocities will provide acceptable values of the shear force, varying in the range of 150–250 dyne/cm² (Fig. 3).

When gluing solid wood from pine, beech and oak substrates across the width, the adhesive is applied to the surface by the contact method (comb-type glue rollers) and the pouring method. The adhesive in the method of pouring the substrate is supplied through slots or nozzles under pressure. It is possible to assume that the considered regularities of changes in viscosity values in the range of speeds of 0.2–0.6 m/s and colloidal-chemical properties of adhesives (spreadability coefficient 0.76–0.84, Tables 1–4) modified with lithium nitrate trihydrate and potassium nitrate in an amount of 0.5 wt. % and ammonium nitrate in the amount of 1 wt. % are quite applicable for this method.

The use of sodium nitrate as a modifier is impractical, since its introduction contributes to the thickening of the aluminosilicate adhesive regardless of concentration.

In the future, studies will continue on the effect of the same compounds: on the fluidity of adhesives at elevated pressures; on the physicochemical and deformation properties of the glue seam, as well as on the study of the physicochemical processes occurring in the aluminosilicate adhesive in order to form water-resistant phases with a low value of the elastic modulus, to identify the features of the formation of the contact zone between the substrate and the adhesive, to determine the depth of penetration of the adhesive into the structure substrate.

In this context, the compounds of nitrates of alkaline earth elements will also be considered with the identification of their role in the above described phenomena and processes.

5. Conclusions

As a result of the research, the effect of compounds of the AlNO_3 and $\text{AlNO}_3 \cdot n\text{H}_2\text{O}$ type was studied on the rheokinetic and chemical-colloidal properties of aluminosilicate adhesives for laminating wood of various species. According to the effectiveness of the effect on changes in dynamic viscosity, plastic viscosity, surface tension, contact angle and wetting and spreading coefficients, nitrate additives can be placed in the row: $\text{LiNO}_3 \cdot 3\text{H}_2\text{O} > \text{KNO}_3 > \text{NH}_4\text{NO}_3 > \text{NaNO}_3$. It was found that 0.5 wt. % nitrates $\text{LiNO}_3 \cdot 3\text{H}_2\text{O}$, KNO_3 , NH_4NO_3 is the optimal amount to stabilize the change in the dynamic and plastic viscosity of the aluminosilicate adhesive over time, as well as to ensure the wetting and stability of the flow of adhesives on a pine, beech and oak substrate.

References

- [1] Shields, J. (1980). Adhesives: a reference book. Moscow: Mashinostroenie, 368.
- [2] Kovalchuk, L. M. (1987). Production of glued timber structures. Moscow: Forest industry, 248.
- [3] Krivenko, P., Petropavlovsky, O., Vozniuk, G. (2018). Alkaline Aluminosilicate Binder for Gluing Wood Board Materials. Key Engineering Materials, 761, 11–14. doi: <http://doi.org/10.4028/www.scientific.net/kem.761.11>
- [4] Guzii, S. G., Krivenko, P. V., Bondarenko, O. P., Kopylova, T. (2019). Study on Physico-Mechanical Properties of the Modified Alkaline Aluminosilicate Adhesive-Bonded Timber Elements. Solid State Phenomena, 296, 112–117. doi: <http://doi.org/10.4028/www.scientific.net/ssp.296.112>
- [5] Tsapko, Y., Zavialov, D., Bondarenko, O., Pinchevs'ka, O., Marchenco, N., Guzii, S. (2019). Design of fire-resistant heat- and soundproofing wood wool panels. Eastern-European Journal of Enterprise Technologies, 3 (10 (99)), 24–31. doi: <http://doi.org/10.15587/1729-4061.2019.166375>
- [6] Berzins, A., Morozovs, A., Gross, U., Iejavs, J. (2017) Mechanical properties of wood–geopolymer composite. Engineering for rural development, 16, 1167–1173. doi: <http://doi.org/10.22616/erdev2017.16.n251>
- [7] Bahrami, M., Shalbafan, A., Welling, J. (2019). Development of plywood using geopolymer as binder: effect of silica fume on the plywood and binder characteristics. European Journal of Wood and Wood Products, 77 (6), 981–994. doi: <http://doi.org/10.1007/s00107-019-01462-3>
- [8] Chen, T., Wu, Z., Niu, M., Xie, Y., Wang, X. (2015). Effect of Si–Al molar ratio on microstructure and mechanical properties of ultra-low density fiberboard. European Journal of Wood and Wood Products, 74 (2), 151–160. doi: <http://doi.org/10.1007/s00107-015-0986-x>
- [9] Chen, T., Xie, Y., Cai, L., Zhuang, B., Wang, X. A., Wu, Z. et. al. (2016). Mesoporous Aluminosilicate Material with Hierarchical Porosity for Ultralow Density Wood Fiber Composite (ULD_WFC). ACS Sustainable Chemistry & Engineering, 4 (7), 3888–3896. doi: <http://doi.org/10.1021/acssuschemeng.6b00691>
- [10] Guzii, S., Kryvenko, P., Guzii, O., Yushkevich, S. (2019). Determining the effect of the composition of an aluminosilicate binder on the rheotechnological properties of adhesives for wood. Eastern-European Journal of Enterprise Technologies, 6 (6 (102)), 30–38. doi: <http://doi.org/10.15587/1729-4061.2019.185728>
- [11] Guzii, S. G., Guzii, O. I., Yushkevich, S. V., Bazhelka, I. K. (2020). Study of the influence of organic and mineral modifiers on physical and rheological properties of aluminosilicate adhesives for gluing of wood. Bulletin of Odessa State Academy of Civil Engineering and Architecture, 79, 70–77. doi: <http://doi.org/10.31650/2415-377x-2020-79-70-77>
- [12] Glazacheva, E. N., Uspenskaya, M. V. (2015). Colloidal chemistry. Methodical instructions for laboratory work. Saint Petersburg: ITMO University, 62.

STUDY OF THE INFLUENCE OF SYSTEMIC FACTORS ON THE LEVEL OF LAND USE OF THE REGIONAL NATURE RESERVE FUND

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ARTICLE INFO

Article history:

Received date 10.09.2020

Accepted date 19.10.2020

Published date 30.10.2020

Section:

Information Technology

DOI

10.21303/2313-8416.2020.001495

KEY WORDS

land use
objects of natural reserve fund
mathematical modeling
integral indicator
method of neural networks
system factors

ABSTRACT

An urgent issue is the determination of the functional purpose and increasing the efficiency of using the lands of the natural reserve fund.

The object of research: lands of the natural reserve fund.

Investigated problem. According to the legal framework, which was used in the study, it was determined certain aspects of their functioning in the context of environmental protection measures. The processes of using the lands of the natural reserve fund should be considered as a complex process; therefore, the influence of systemic factors on the level of use of the lands of the natural reserve fund of the regions is studied. To carry out the analysis, methods of mathematical modeling were used as a mechanism for coordinating the influence of a set of indicators and determining their relationships.

Main scientific results. The results of mathematical modeling have been obtained, which provide an opportunity to predict changes in the integral indicator of the level of land use of objects of the natural reserve fund of regions, depending on the relevant factors, and to offer scientifically substantiated recommendations for the development and implementation of monitoring of the formation of lands of objects of the natural reserve fund of regions. The integral indicator was developed on the basis of the analysis and assessment of a set of factors that are defined as parameters for assessing the lands of the natural reserve fund. The analysis of the adequacy of the developed mathematical models of the influence of factors on the integral indicator of the level of land use of objects of the natural reserve fund of the regions using the neural network method made it possible to confirm the completeness and reliability of the established relationships based on low values of the relative error of the test sample.

The area of practical use of research results. Thus, the practical significance of the developed model for the formation of a methodology for assessing the processes of using lands of the natural reserve fund has been determined.

Innovative technological product: an integral model for assessing the lands of the natural reserve fund.

Scope of application of an innovative technological product. This technique makes it possible to increase the efficiency and rationalize the processes of using the lands of the natural reserve fund in order to protect them and ensure integrated functioning.

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1. Introduction

1. 1. The object of research

The object of research is the lands of the nature reserve fund. The formation of land use directions at the regional level, their impact on the livelihoods of the population depends on the creation and use of objects of the natural reserve fund, taking into account environmental factors. At the present stage, the tasks of developing the lands of the objects of the natural reserve fund of the regions have not been solved, a system of information-analytical and spatial support for their determination has not been built, and the level of efficiency of their use is reduced. In such conditions, it becomes necessary to monitor the use of lands of objects of the natural reserve fund on the basis of information and analytical support, using the tools of geoinformation systems.

1. 2. Problem description

In modern conditions, the formation of areas of land use, their protection and rational use is of particular importance. In recent years, the influence of anthropogenic factors on all natural processes, including land resources, has been growing. Irrational use of lands leads to their degradation, which is caused by excessive plowing, limited use of organic and mineral fertilizers, insufficient protection of soils by agroforestry measures and low quality of soil use technologies. Rational use and protection of lands is a scientifically based process that takes into account the natural properties of lands for their intended purpose, while observing the directions of their protection. To solve the presented tasks, it is proposed to monitor land use based on the formation and use of information and analytical support.

1. 3. Suggested solution to the problem

The rational use and protection of lands of the natural reserve fund is an important scientific, theoretical and practical task. The processes of using the lands of the natural reserve fund should be considered as a complex process; therefore, the influence of systemic factors on the level of use of the lands of the natural reserve fund of the regions is studied. The methodology developed in the article makes it possible to increase the efficiency and rationalize the processes of using the lands of the natural reserve fund in order to protect them and ensure integrated functioning.

Characterizing the theoretical provisions for determining the influence of systemic factors on the use of lands of objects of the natural reserve fund, it should be noted that there are no unified approaches to its substantiation. Special attention should be paid to the legal approach to determining the influence of systemic factors on the use of lands of objects of the natural reserve fund. In their scientific developments, the authors [1–3] investigated the influence of the legal regime on the use and monitoring of protected lands in Ukraine. Special attention should be paid to a constructive approach to the definition of monitoring of lands of objects of the natural reserve fund, within the framework of which the authors [4, 5] determine the structural elements of the eco-network of Ukraine, comparing it with international analogues.

Special mention should be made of the opinion of the authors [6, 7], who point to the need to create a perfect system for monitoring the influence of systemic factors on the ground of objects of the natural reserve fund. At the same time, in work [8], the author highlights certain technologies for its creation and implementation.

The analysis of existing theoretical approaches to determining the influence of systemic factors on the ground of objects of the natural reserve fund, which showed their fragmentation and the lack of uniform provisions. It should be noted that in the existing scientific developments in the system of influence on the land use of the objects of the natural reserve fund of the regions, the tools for its development and implementation are not taken into account [9, 10, 12]. They are based on the complex application of modern instrumental base, in particular, geodetic, geoinformation systems, space survey results, modern specialized software [9, 11].

So, the presented studies require a thorough study and systematization of scientific provisions with the subsequent development of recommendations on the impact of systemic factors on the use of lands of the natural reserve fund of the regions.

The aim of research. To determine the influence of systemic factors on the level of use of lands of the natural reserve fund by developing information and analytical support for the formation and implementation of monitoring of lands of objects of the natural reserve fund of regions using methods of mathematical modeling.

2. Materials and methods

The development of information and analytical support for monitoring the land use of objects of the natural reserve fund of the regions is carried out on the basis of mathematical modeling of the influence of system factors on the integral indicator of the level of land use.

Mathematical modeling of the influence of systemic factors on the integral indicator of the level of land use of objects of the natural reserve fund of regions is carried out in accordance with the developed stages. As a result of the research:

– a mathematical model that determines the degree of impact of the systemic factor in the development of information and analytical support for the formation and implementation of monitoring of lands of objects of the natural reserve fund of regions (EL_2) on the integral indicator of the level of land use of objects of the natural reserve fund of regions (I_{EL}) (**Fig. 1**);

– mathematical model, determines the degree of impact of the system factor of the level of rational use and protection of natural resources, the factors influencing the development of monitoring the formation of lands of objects of the natural reserve fund of regions (EL_3) on the integral indicator of the level of land use of objects of the natural reserve fund of regions (I_{EL}), c.u. (**Fig. 2**).

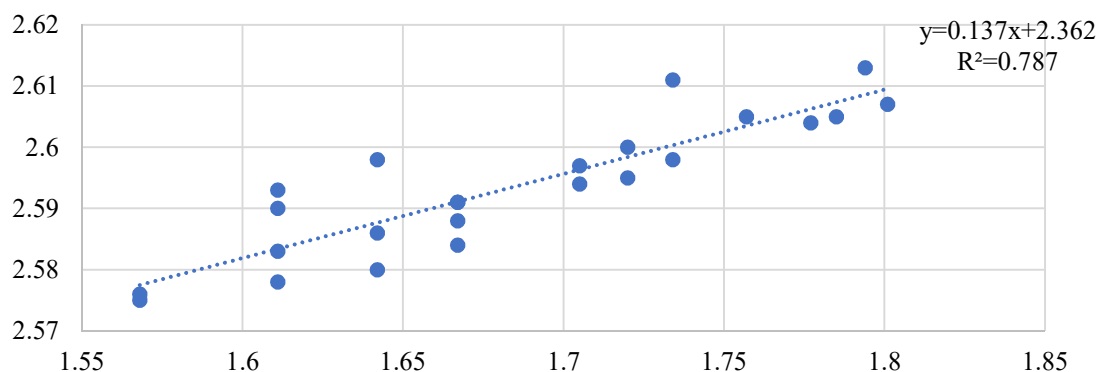


Fig. 1. The mathematical model determines the degree of impact of the systemic factor in the development of information and analytical support for the formation and implementation of land monitoring of NRF facilities in regions (EL_2) on the integral indicator of the level of land use at NRF facilities in regions (I_{EL}), rel. unit

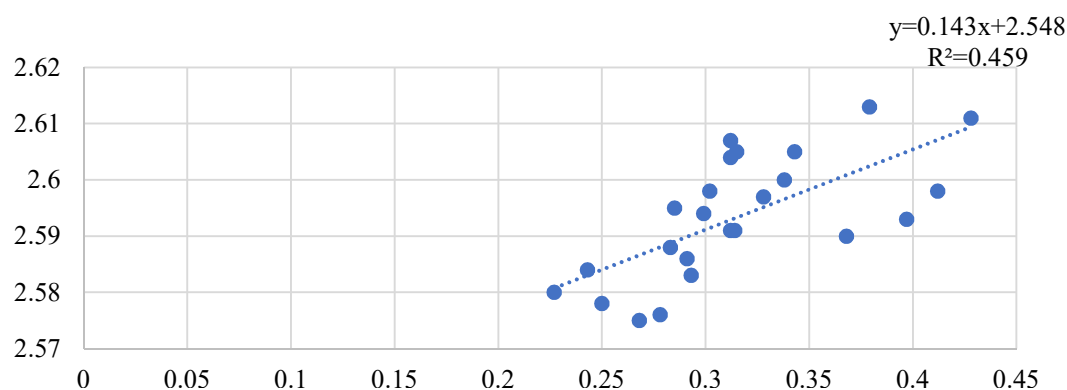


Fig. 2. The mathematical model determines the degree of influence of the systemic factor of the level of rational use and protection of natural resources, influencing the development of monitoring the formation of land in NRF facilities in regions (EL_3) on the integral indicator of the level of land use in NRF facilities in regions (I_{EL}), c. u.

As a result of mathematical modeling, it was found that changes in the system factor for the development of information and analytical support for the formation and implementation of monitoring of lands of objects of the natural reserve fund of regions (EL_2) by 78.7 % causes changes in the integral indicator of the level of land use of objects of the natural reserve fund of regions (I_{EL}). This indicates a high level of influence of information and analytical support and requires the development of appropriate scientifically grounded measures for their growth.

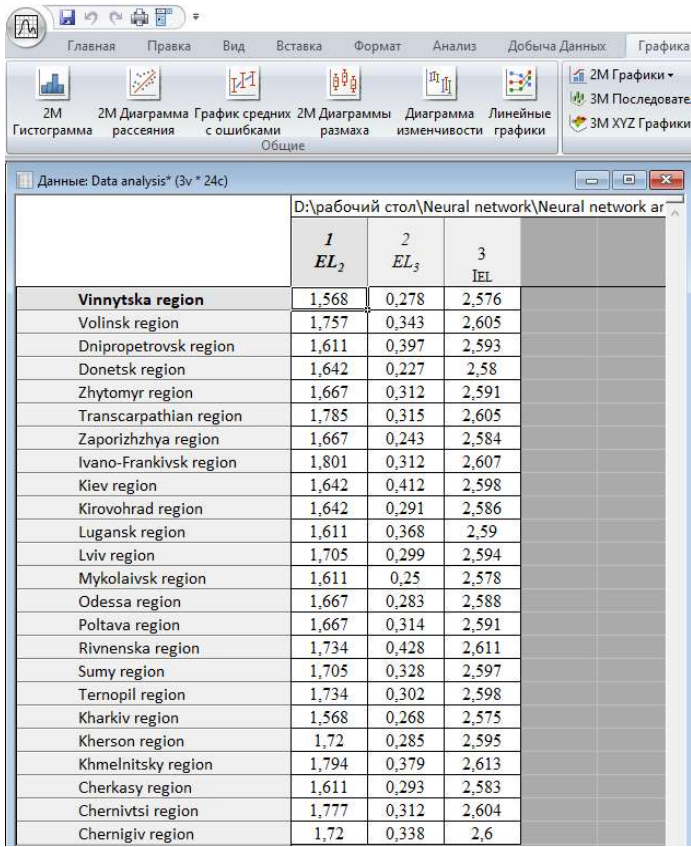
A change in the systemic factor of the level of rational use and protection of natural resources, influencing the development of monitoring the formation of lands of objects of the natural reserve fund of regions (EL_3) by 45.9 %, causes changes in the integral indicator of the level of use of lands of objects of the natural reserve fund of regions (I_{EL}). This is a profound meaning, indicating the need to take action to increase the direction of implementation of the rational use and protection of natural resources.

3. Results

The results of mathematical modeling provide an opportunity to predict changes in the integral indicator of the level of land use in the objects of the natural reserve fund of the regions, depending on the relevant factors and to offer scientifically grounded recommendations for the development and implementation of monitoring of the formation of lands of the objects of the natural reserve fund of the regions.

To confirm the adequacy of the established links between the integral indicator of the level of land use of objects of the natural reserve fund of regions and factors, the method of neural networks is used based on the STATISTICA Neural Networks software package. Neural networks allow to model and reproduce complex nonlinear dependencies, while simultaneously requiring a lower level of knowledge than when using traditional statistical methods.

The study involves solving a regression problem. As the initial data, let's take the indicators EL_2 , EL_3 , which act as independent predictors and affect the final result. The dependent variable is the I_{EL} indicator (**Fig. 3**). The neural network will work with two input elements and one output variable. The sample was formed on the basis of available data for all regions of the country.



	1 EL_2	2 EL_3	3 I_{EL}
Vinnyska region	1,568	0,278	2,576
Volinsk region	1,757	0,343	2,605
Dnipropetrovsk region	1,611	0,397	2,593
Donetsk region	1,642	0,227	2,58
Zhytomyr region	1,667	0,312	2,591
Transcarpathian region	1,785	0,315	2,605
Zaporizhzhya region	1,667	0,243	2,584
Ivano-Frankivsk region	1,801	0,312	2,607
Kiev region	1,642	0,412	2,598
Kirovohrad region	1,642	0,291	2,586
Lugansk region	1,611	0,368	2,59
Lviv region	1,705	0,299	2,594
Mykolaivsk region	1,611	0,25	2,578
Odessa region	1,667	0,283	2,588
Poltava region	1,667	0,314	2,591
Rivnenska region	1,734	0,428	2,611
Sumy region	1,705	0,328	2,597
Ternopil region	1,734	0,302	2,598
Kharkiv region	1,568	0,268	2,575
Kherson region	1,72	0,285	2,595
Khmelnitsky region	1,794	0,379	2,613
Cherkasy region	1,611	0,293	2,583
Chernivtsi region	1,777	0,312	2,604
Chernigiv region	1,72	0,338	2,6

Fig. 3. Formation of a data sample for regression analysis, c.u.

Let's construct a neuromechanical model for the presented data using the Automated Neural Networks package of automated neural networks and data analysis Regression. Let's select the necessary variables for analysis: continuous target and continuous input (**Fig. 4**).

At this stage, the strategy for creating a network model is determined, the sizes of the learning, control and test subsamples are established, and the like. Choosing an automated neural network requires a minimum amount of settings. The network architecture is based on the multilayer perceptron (MLP). This type of network is adopted as a model for regression analysis of indicators of territorial development of land use in the region. The main advantages of MLP, namely ease of use and the necessary generalizing properties, ensure its widespread use. Each network element builds a weighted sum of its inputs, corrected as a term, and passes this activation value through the transfer function, having received the initial value of this element. The elements are organized in a

layered topology with direct signal transmission. This type of network is based on the input-output model, in which the weights and threshold values are the free parameters of the model [12].

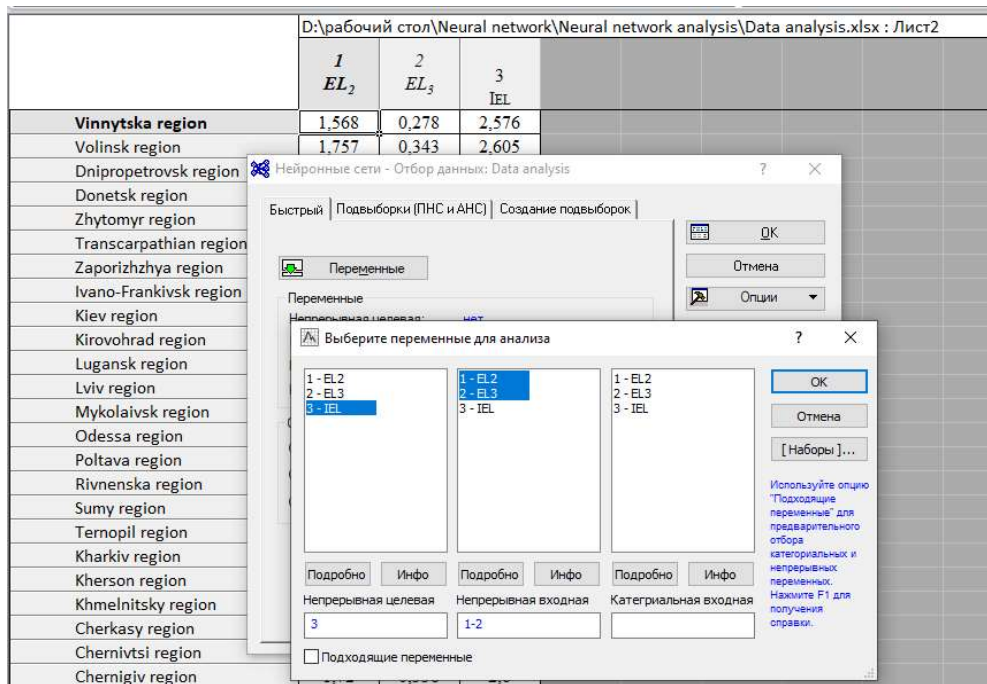


Fig. 4. Selecting variables for analysis

When designing MLP, an important process is determining the number of intermediate layers and the number of elements in them. Let's accept the minimum value of the number of hidden neurons as a half-sum of input and output elements. In our case, the minimum value will be 2, and the maximum number of hidden neurons will be set at 10 (Fig. 5).

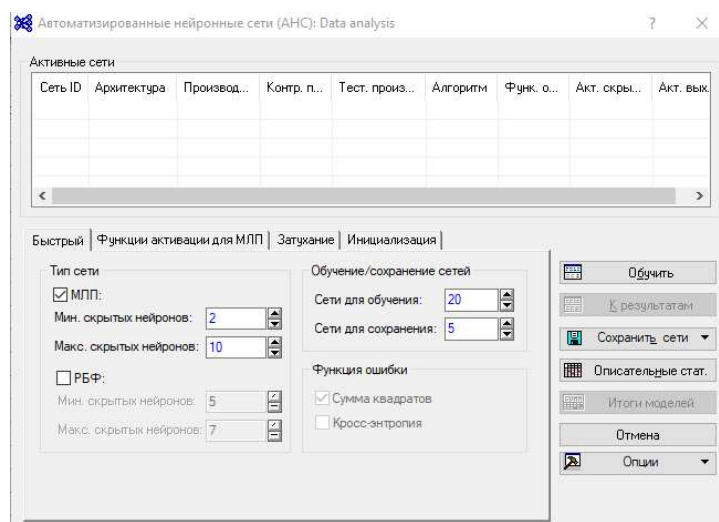


Fig. 5. Choice of settings for building a network with multilayer perceptron (MLP) architecture

The initial value of the multilayer perceptron is calculated by the formula:

$$y = F\left(\sum_{j=1}^n \vartheta_j h_j - b\right), \quad (1)$$

where n – the number of neurons in the hidden layer;

ϑ_j – the weight of the synapse of the neuron j of the hidden layer to the original neuron;

h_j – the initial value of the neuron j of the hidden layer;

b – the threshold of the output neuron;

F – activation function of the output neuron.

For each layer of the neural network, let's define the activation functions of the neural network - functions that convert the level of neuron activation into an output signal. Let's consider the hyperbolic tangent as the activation function of the hidden layer:

$$f(x) = \frac{2}{1 + e^{-2x}} - 1. \quad (2)$$

The hyperbolic tangent at the input takes an arbitrary real number, at the output it gives a number in the interval $(-1; 1)$. The hyperbolic tangent can saturate, and the output of this function is centered relative to zero, which in practice expands the possibilities of its use.

The value of the neuron of the hidden layer at the output is determined by the formula:

$$h_j = F_2 \left(\sum_{i=1}^m w_{ij} x_i - b_{2j} \right), \quad (3)$$

where w_{ij} – the weight from the j -th neuron at the input to the j -th neuron of the hidden layer;

x_i – input value;

b_{2j} – the value of the threshold of the first neuron of the hidden layer;

F_2 – hidden layer activation function.

In the neural network model chosen in the study with the highest performance, the activation function of the output layer also has a hyperbolic tangent with a range of values in the interval $(-1; 1)$.

Let's carry out the process of learning networks (Fig. 6).

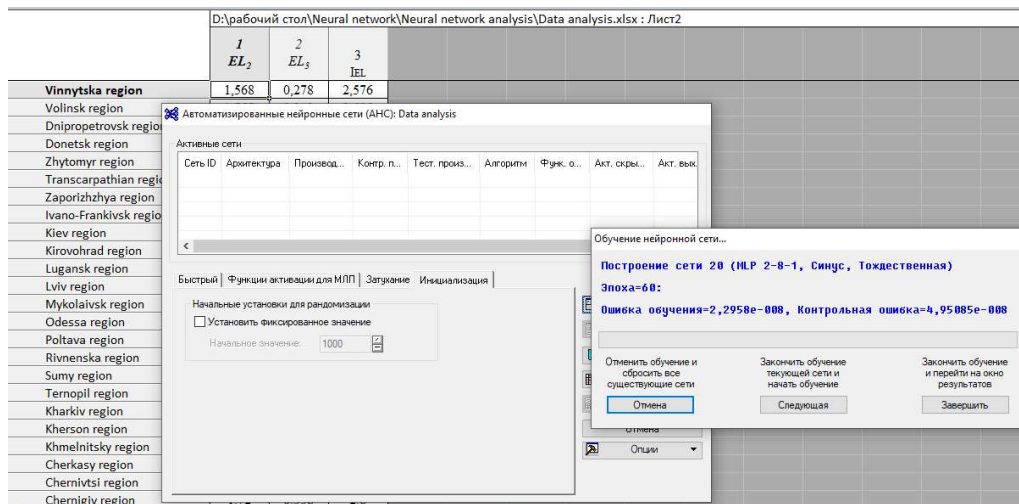


Fig. 6. The process of learning a neural network, c.u.

The dialog box provides information for learning the network, namely the network ID, its architecture and activation functions for the hidden and incoming layers, the number of algorithm iterations and learning errors. As learning outcomes, have the best neural networks that were selected from the total number of networks that went through the learning process. In our study, let's assume five networks. Having received a window of results, we go to various modes of learning the network. Let's carry out learning using the user's neural network method and the method of multiple subsamples. The learning results allow to compare the architecture of each network and analyze the performance of learning the network on the learning, control and test samples. This value is characterized by the coefficient of determination (the closer to one, the better the model)

and shows how this model approximates the data. The learning errors, learning algorithm, error functions and activation functions are indicated (**Fig. 7**).

N	Архитектура	Производительность обуч.	Контр. производительность	Тест. производительность	Ошибка обучения	Контрольная ошибка	Тестовая ошибка	Алгоритм обучения	Функция ошибки	Ф-я актив. скрытых нейр.	Ф-я актив. выходных нейр.
1	MLP 2-8-1	0.942768	0.997544	0.999997	0.000007	0.000002	0.000002	BFGS 9	Сум. квадрат	Синус	Экспонента
2	MLP 2-2-1	0.999754	0.999957	0.999834	0.000000	0.000000	0.000000	BFGS 35	Сум. квадрат	Логистическая	Токдественная
3	MLP 2-2-1	0.999324	0.999985	0.999847	0.000000	0.000000	0.000000	BFGS 229	Сум. квадрат	Гиперболическая	Гиперболическая
4	MLP 2-2-1	0.999700	0.999985	0.999901	0.000000	0.000000	0.000000	BFGS 48	Сум. квадрат	Экспонента	Синус
5	MLP 2-2-1	0.996808	0.999987	0.999870	0.000000	0.000000	0.000000	BFGS 32	Сум. квадрат	Логистическая	Экспонента
6	MLP 2-3-1	0.998642	0.999990	0.999595	0.000000	0.000000	0.000000	BFGS 26	Сум. квадрат	Гиперболическая	Гиперболическая
7	MLP 2-3-1	0.998989	0.999948	0.999961	0.000000	0.000000	0.000000	BFGS 38	Сум. квадрат	Гиперболическая	Гиперболическая
8	MLP 2-3-1	0.998546	0.999909	0.999745	0.000000	0.000000	0.000000	BFGS 44	Сум. квадрат	Гиперболическая	Гиперболическая
9	MLP 2-3-1	0.998917	0.999936	0.999867	0.000000	0.000000	0.000000	BFGS 37	Сум. квадрат	Гиперболическая	Гиперболическая
10	MLP 2-3-1	0.999069	0.999993	0.999796	0.000000	0.000000	0.000000	BFGS 59	Сум. квадрат	Гиперболическая	Гиперболическая
11	MLP 2-3-1	0.999873	0.999385	0.999994	0.000000	0.000000	0.000000	BFGS 87	Сум. квадрат	Гиперболическая	Токдественная
12	MLP 2-3-1	0.999700	0.999938	0.999870	0.000000	0.000000	0.000000	BFGS 22	Сум. квадрат	Гиперболическая	Токдественная
13	MLP 2-3-1	0.999840	0.999929	0.999753	0.000000	0.000000	0.000000	BFGS 19	Сум. квадрат	Гиперболическая	Токдественная
14	MLP 2-3-1	0.997938	1.000000	0.996664	0.000000	0.000000	0.000001	BFGS 10	Сум. квадрат	Гиперболическая	Токдественная
15	MLP 2-3-1	0.999704	0.999998	0.999999	0.000000	0.000000	0.000000	BFGS 26	Сум. квадрат	Гиперболическая	Токдественная

Fig. 7. Results of learning neural networks, c.u.

On the Graphs tab, using graphical analysis, let's determine the neural networks that have the most adequate behavior. Let's build a histogram of residuals for each individual network. Most of the data is concentrated in a small interval (**Fig. 8**).

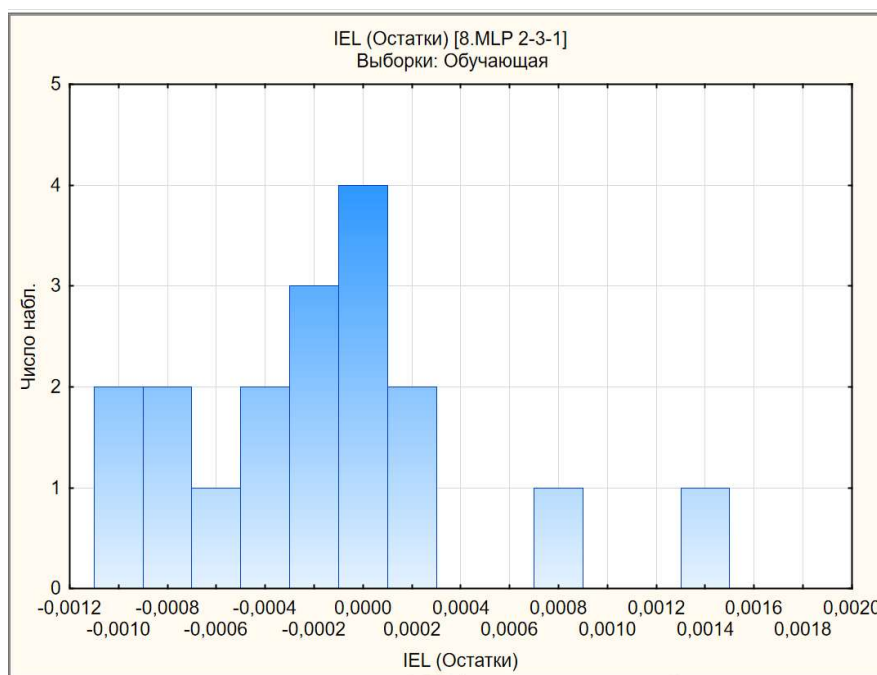


Fig. 8. Histogram of residuals for each individual network, c.u.

Let's build a scatter diagram of the target and initial values of each network. The graph shows all grids and the original Y value. Ideally, all the original grid values are located on the line Y . The scatter diagram shows a small range of data spread (**Fig. 9**).

Let's build a response surface for EL_2 , EL_3 , and the initial value I_{EL} . The sigmoid S-shape reflects the dependence of the data without significant deviations of the points from the surface of the curve (**Fig. 10**).

The Analysis Summary tab provides weights, correlation coefficients, forecast statistics, and global and local sensitivity analyzes for each network (**Fig. 11**). The results of the global sensitivity analysis characterize the importance of the value of each variable. All networks showed the importance of indicators EL_2 , EL_3 (**Fig. 11**).

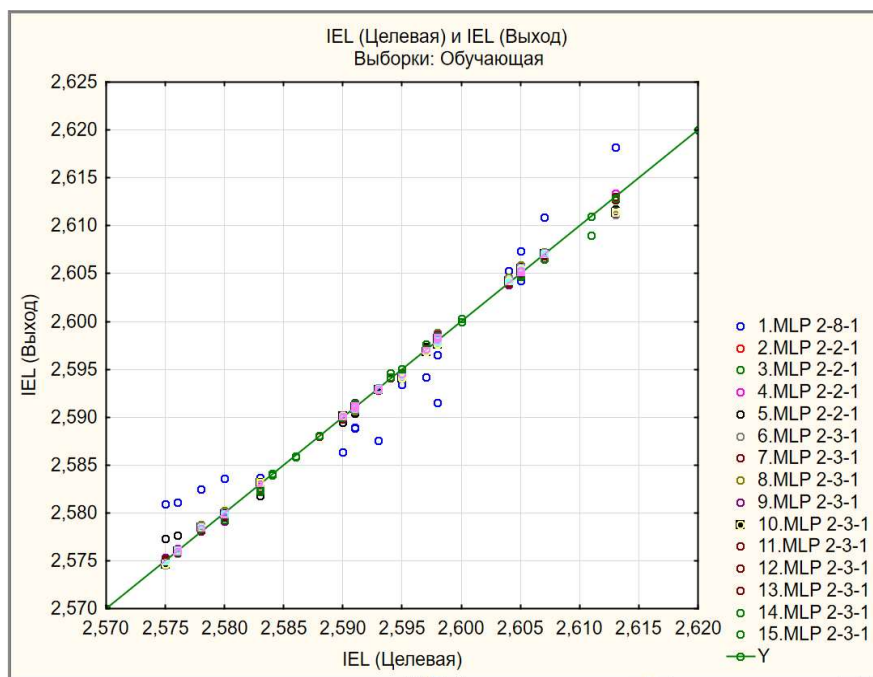


Fig. 9. Scatter diagram of target and initial values of networks, c.u.

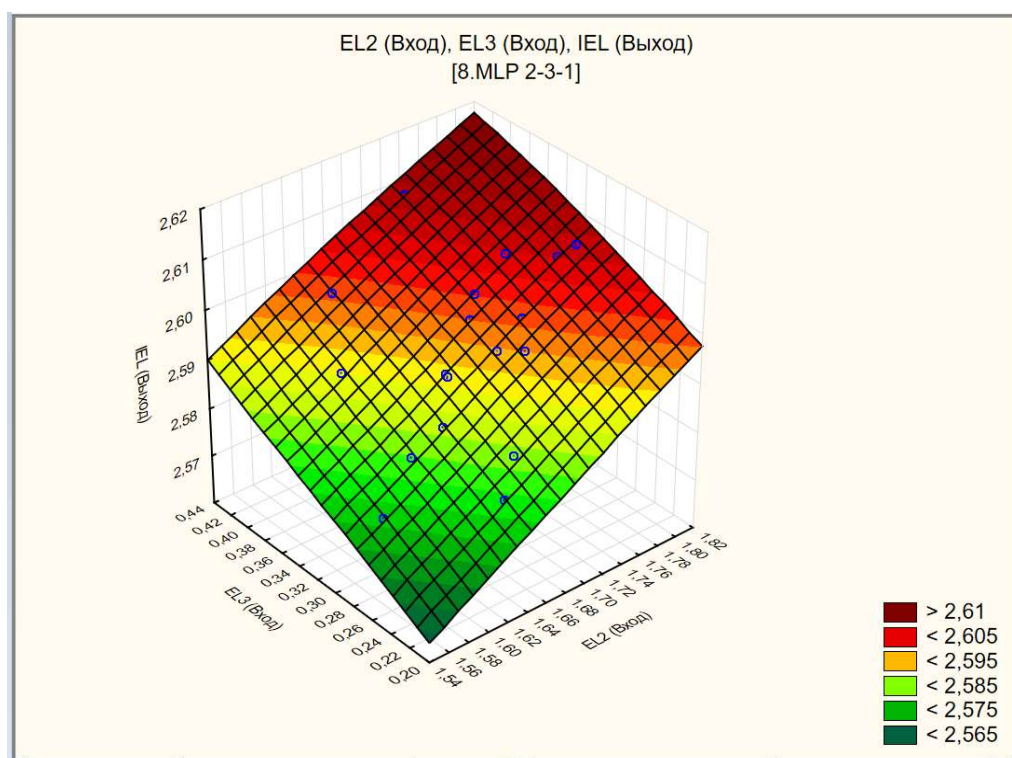


Fig. 10. The surface of the neural network response, c.u.

Having indicated the number of new observations that need to be predicted, let's enter the data and obtain the value for predicting each of the networks (Fig. 12).

For a detailed determination of the quality of the model, let's select one model with the highest performance per control sample. Let's evaluate the quality of the selected model 8MLP 2-3-1 for test sample, including absolute residuals in the calculation. The resulting data table is only for test observations (Fig. 13).

Сети	Чувствительность (Data analysis)	
	Выборки: Обучающая	
	EL ₂	EL ₃
1.MLP 2-8-1	7,349	1,8984
2.MLP 2-2-1	1377,499	373,2679
3.MLP 2-2-1	481,850	127,9374
4.MLP 2-2-1	1119,334	304,4717
5.MLP 2-2-1	94,651	27,2886
6.MLP 2-3-1	249,250	65,8721
7.MLP 2-3-1	332,691	85,6142
8.MLP 2-3-1	235,248	62,0204
9.MLP 2-3-1	285,649	76,9058
10.MLP 2-3-1	347,725	93,3768
11.MLP 2-3-1	2515,471	767,3191
12.MLP 2-3-1	1131,673	306,0096
13.MLP 2-3-1	1705,126	643,0726
14.MLP 2-3-1	138,040	63,1119
15.MLP 2-3-1	909,504	529,9037
Среднее	728,737	235,2047

Fig. 11. Global sensitivity analysis of neural networks, c.u.

Значения пользователя для входных переменных									
Значения пользователя для входных переменных		1.IEL	2.IEL	3.IEL	4.IEL	5.IEL	6.IEL	7.IEL	8.IEL
1	1,705	2,594220	2,597219	2,596856	2,597018	2,597415	2,596909	2,597015	2,597140
2	1,734	2,596546	2,598024	2,597618	2,597848	2,598241	2,597613	2,597766	2,597858
3	1,568	2,580898	2,575167	2,574689	2,575307	2,577287	2,574548	2,575038	2,575088

Fig. 12. Forecasting data on new observations, c.u.

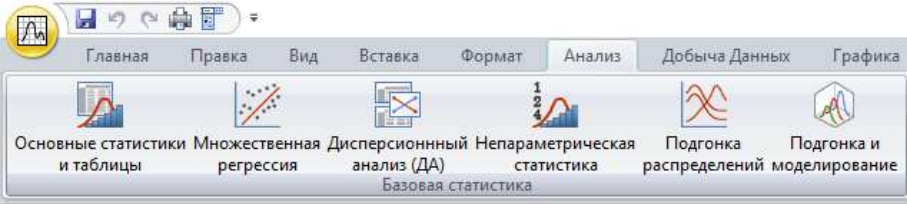
Анализ				Добыча Данных				Графика				Сервис				Данные				Рабочая книга				Справка			
Математическая статистика		Подгонка		Подгонка и распределений		Подгонка и моделирование		Углублённые методы		Нейронные сети		Многомерный анализ		PLS, PCA, ...		Анализ мощности		Оценка дисперсии		Карты КК		Многомерный КК		Прогноз КК		Анализ процессов	
Углублённая статистика		Углублённая статистика		Углублённая статистика		Углублённая статистика		Углублённая статистика		Углублённая статистика		Углублённая статистика		Углублённая статистика		Углублённая статистика		Углублённая статистика		Углублённая статистика		Углублённая статистика		Углублённая статистика		Углублённая статистика	
Наблюд. номер #		Целевая		IEL - Выход		IEL - Абс. Ост.		8. MLP 2-3-1		8. MLP 2-3-1																	
Lviv region		2,594000		2,593842		0,000158																					
Odessa region		2,588000		2,587853		0,000147																					
Chernigiv region		2,600000		2,600318		0,000318																					

Fig. 13. Predicted values of the test sample, c. u.

To assess their quality and determine the relative error, it is necessary to introduce an additional variable MAPE, which will determine the relative value of the error. The average value of the relative error on the test set is 0.008 %, which indicates a good quality of the constructed model (Fig. 14).

The model is saved in PMML format in the STATISTICA system.

Thus, the analysis of the adequacy of the developed mathematical models of the influence of factors on the integral indicator of the level of land use of objects of the natural reserve fund of the regions using the neural network method made it possible to confirm the completeness and reliability of the established relationships based on low values of the relative error of the test sample.



Наблюд. номер #	Таблица предсказанных значений для IEL (Data analysis)				
	Выборки: Тестовая				
	1				
	MAPE				
СРЕДНЕЕ набл. 1-3	0.0000800461939				

Fig. 14. Average value of the relative error on the test sample, c.u.

4. Discussion

So, the integral indicator of the level of land use of the objects of the natural reserve fund of the regions using the neural network method made it possible to determine the following:

- the results of mathematical modeling provide an opportunity to predict changes in the integral indicator of the level of land use of objects of the natural reserve fund of the regions, depending on the relevant factors;
- the results of mathematical modeling provide an opportunity to offer scientifically grounded recommendations for the development and implementation of monitoring of the formation of lands of objects of the natural reserve fund of the regions;
- the integral indicator is developed on the basis of the analysis and assessment of a set of factors that are defined as parameters for assessing the lands of the natural reserve fund;
- the analysis makes it possible to confirm the completeness and reliability of the established relationships based on low values of the relative error of the test sample.

The limitations of the study are that the results of the analysis reflect the actual methodology only for the national system of natural reserve fund due to the limited system of national legislative regulation.

The area of practical use of research results. Thus, the practical significance of the developed model for the formation of a methodology for assessing the processes of using lands of the natural reserve fund has been determined.

Innovative technological product: an integral model for assessing the lands of the natural reserve fund.

Scope of application of an innovative technological product. This technique makes it possible to increase the efficiency and rationalize the processes of using the lands of the natural reserve fund in order to protect them and ensure integrated functioning.

5. Conclusions

As a result of mathematical modeling, it was found that changes in the system factor for the development of information and analytical support for the formation and implementation of monitoring of lands of objects of the natural reserve fund of regions (EL_2) by 78.7 % causes changes in the integral indicator of the level of land use of objects of the natural reserve fund of regions (I_{EL}). This indicates a high level of influence of information and analytical support and requires the development of appropriate scientifically grounded measures for their growth. A change in the systemic factor of the level of rational use and protection of natural resources, influencing the development of monitoring the formation of lands of objects of the natural reserve fund of regions (EL_3) by 45.9 %, causes changes in the integral indicator of the level of use of lands of objects of the natural reserve fund of regions (I_{EL}). This is a profound meaning, indicating the need to take action to increase the direction of implementation of the rational use and protection of natural resources. The results of mathematical modeling provide an opportunity to predict changes in the integral indicator of the level of land use in the objects of the natural reserve fund of the regions, depending on the relevant factors and to offer scientifically grounded recommendations for the development and implementation of monitoring of the formation of lands of the objects of the natural reserve fund of the regions.

To confirm the adequacy of the established links between the integral indicator of the level of land use of objects of the natural reserve fund of regions and factors, the method of neural networks is used based on the STATISTICA Neural Networks software package. Neural networks allow to model and reproduce complex nonlinear dependencies, while simultaneously requiring a lower level of knowledge than when using traditional statistical methods. The analysis of the adequacy of the developed mathematical models of the influence of factors on the integral indicator of the level of land use of objects of the natural reserve fund of the regions using the neural network method made it possible to confirm the completeness and reliability of the established relationships based on low values of the relative error of the test sample.

References

- [1] Miroshnychenko, O. V., Artamonov, V. A. (2013). Instytutsiini problemy stvorennia ta rozvytku ob'ektiv pryrodno-zapovidnoho fondu Ukrainy. Vseukr. ekol. liha. Kyiv: Aspekt-Polihrf, 6, 5–8.
- [2] Kovyazin, V. F., Demidova, P. M., Lan Anh, D. T., Hung, D. V., Quyet, N. V. (2020). Monitoring of Forest Land Cover Change in Binh Chau - Phuoc Buu Nature Reserve in Vietnam Using Remote Sensing Methods and GIS techniques. IOP Conference Series: Earth and Environmental Science, 507, 012014. doi: <http://doi.org/10.1088/1755-1315/507/1/012014>
- [3] Kalbarczyk, E., Kalbarczyk, R., Kasprzak, K., Krajewski, P., Raszka, B. (2016). National Parks in Poland. Bielsko-Biala: Wydawnictwo Dragon.
- [4] Chorny, M. H. (1993). Pro osoblyvosti ukrainskykh zapovidnykiv ta stratehiu zapovidnoi spravy v Ukraini. Pidsumky 70-richnoi diialnosti Kanivskoho zapovidnyka ta perspektyvy rozvytku zapovidnoi spravy v Ukraini. Kaniv, 20–22.
- [5] Vasyliuk, O., Kostushyn, V., Kolomytsev, H. (2011). Novi pidkhody do rozbudovy natsionalnoi ekomerezhi Ukrainy Pryrodno-resursnyi potentsial zbalansovanoho (staloho) rozvytku Ukrainy. Kyiv: Tsentr ekolohichnoi osvity ta informatsii, 2.
- [6] Mamonov, K. A., Hrek, M. O., Meteshkin, K. O. (2017). Rozrobka steikholderno-orientovanoho pidkhodu do otsinky vplyvu mistobudivnykh faktoriv na vykorystannia zemel. Visnyk Khmelnytskoho natsionalnoho universytetu. Tekhnichni nauky, 3 (249), 160–164.
- [7] Mamonov, K. A., Nesterenko, S. H., Viatkin, K. I. (2016). HIS-zabezpechennia u ratsionalnomu vykorystanni zemelnykh resursiv miskoi zabudovy. Naukovi visnyk budivnytstva, 86 (4), 323.
- [8] Leconte, J., Forget, F., Charnay, B., Wordsworth, R., Pottier, A. (2013). Increased insolation threshold for runaway greenhouse processes on Earth-like planets. Nature, 504 (7479), 268–271. doi: <http://doi.org/10.1038/nature12827>
- [9] Korniets, A. V., Savenko, V. Ya. (2017). Metodychni rekomendatsii shchodo realizatsii metodu otsinky heoekolohichnoho stanu vykorystannia zemel naselennykh punktiv. Avtomobilni dorohy i dorozhnie budivnytstvo, 103, 5–10.
- [10] Korniets, A. V., Mamonov, K. A. (2017). Suchasni aspekty formuvannia heoekolohichnoho monitorynhu vykorystannia zemel rehionu. Komunalne hospodarstvo mist. Seriya Tekhnichni nauky ta arkhitektura, 137, 31–33.
- [11] Fung, I., Doney, S., Lindsay, K., John, J.: Evolution of carbon sinks in a changing climate. Proc. Nat. Acad. Sci. U. S. Am. 102(32), 11201–11206 (2005)
- [12] Butko, M., Zelenskyi, S., Akymenko, O. (2005). Suchasna problematyka otsinky investytsiinoi pryvablyvosti rehionu». Ekonomika Ukrainy, 11, 30–35.

ADEQUACY EVALUATION OF THE SYNTHESIS OF MATHEMATICAL MODELS FOR ONE CLASS OF LINEAR DYNAMIC SYSTEMS WITH PARAMETERS, VARIABLE IN TIME AND IN SPACE

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ARTICLE INFO

Article history:

Received date 11.09.2020

Accepted date 21.10.2020

Published date 30.10.2020

Section:

Control systems

DOI

10.21303/2313-8416.2020.001486

KEYWORDS

linear dynamic system
time and space variable parameters
mathematical model
crane electric drive
variable moment of inertia of rotating masses
variable load moment
simulation

ABSTRACT

The object of research: the authors of this work have synthesized in previous publications a mathematical model of one class of linear dynamic systems with variable parameters in time and space, which includes the system for lifting and lowering a load with a crane in the case of taking into account the influence of longitudinal vibrations that arise in the cable of the lifting mechanism, and shift in time of the moment of inertia of the rotating masses reduced to the motor shaft.

Investigated problem: simulation models are synthesized in the Simulink graphical software environment of the MATLAB application package to assess the adequacy of the specified mathematical model. A calculation was carried out using the passport data and characteristics of all components of the crane structure to find the numerical values of the parameters of simulation models, including the electric motor, cable and gearbox.

The main scientific results: the results of modeling the dynamics of the electric drive system during acceleration, deceleration, the prevailing velocity are given. By comparing the results obtained on the simulation model with the results of experimental studies of the same class of dynamical systems carried out by other authors, the adequacy of the mathematical models synthesized by the authors of this work is proved. It is proved that the use of the classical equation of the dynamics of the electric drive system, which contains a constant moment of inertia and a constant moment of load, leads to errors in the estimates of the processes accompanying the lifting and lowering of loads by cranes. And this, in turn, does not allow predicting the behavior of the system in various operating modes with sufficient accuracy.

The area of practical use of the research results: enterprises of the machine-building industry, specializing in the production, modernization of lifting equipment.

Innovative technological product: a simulation model of a crane mechanism, which makes it possible to take into account the influence of longitudinal vibrations that arise in the cable of the hoisting mechanism, and the shift in time of the moment of inertia of the rotating masses reduced to the motor shaft.

Scope of application of the innovative technological product: design and development of control systems for electric drives of lifting equipment.

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1. Introduction

1.1. The object of research

The authors of this work have synthesized in previous publications a mathematical model of one class of linear dynamic systems with variable parameters in time and space, which includes the system for lifting and lowering a load by a crane in the case of taking into account the influence of longitudinal vibrations that occur in the cable of the lifting mechanism, and shifts in time the moment of inertia of the rotating masses reduced to the motor shaft.

1. 2. Problem description

Cranes and mine splinters, which, using ropes and electric traction drives, lift and lower loads, represent a wide class of linear dynamic systems with parameters that are variable in time and space (LDSPVTS).

Scientists have been studying the dynamics of this class of systems for a long time, and among the publications carried out 50 and more years ago, it is worth noting the publications of S. Kazak. In 1968, M. Gokhberg and in 1969, M. Komarova, in which the authors analyze the transient processes that occur in the elements of such systems, based on the representation of their structures in the form of two-mass dynamic objects with lumped parameters. In a later work, N. Lobov 1987, which is also devoted to research in this direction, retains the same approach as that of its predecessors, but with greater detail.

And even even in the studies carried out at the beginning of this century and published in [1–3], there is a tendency to use constant parameters in models, and to achieve detailed processes only by increasing the number of interconnected masses with lumped parameters.

And only in works [4–6] their authors are already trying to take into account the distribution of the parameters of these systems in space, emphasizing that taking into account the distributed parameters does not significantly add to the accuracy of determining the transient processes, since due to the components due to the distribution of parameters, they failed to add more than 4 %.

In our opinion, the most detailed work devoted to both the analysis of studies of the dynamics of a certain class of dynamical systems, obtained by those authors already mentioned, and devoted to obtaining their own results of studying this class of systems, is [7], in which, however, there are two disappointing conclusions that are worth quoting. So in one of the conclusions to section 1 of work [7] it is indicated that: “For research, it is acceptable to use dynamic models with lumped masses.” And the second conclusion, as a result of the analysis of publications known to the authors of [7], is set out in Chapter 2, and it has the form of an assertion that: “To study the dynamics of cargo movement by a bridge crane, two, three, four, seven and eight mass dynamic structures and their mathematical models, however, there are no recommendations for their use”.

But pointing out the shortcomings of the mathematical models synthesized by other researchers, the authors of [7], starting the synthesis of their own models, in Section 3 indicate that they create these models, proceeding from the fact that the radius of the rope winding drum is a constant value and the rotating masses on throughout the entire movement of the load remain constant, and therefore the moment of inertia of the rotating masses reduced to the traction motor shaft remains constant, that is, proceeding from the fact that the differential equation is valid for the traction electric drive system

$$J \frac{d\omega}{dt} = M_{ed} - M_w = \Delta M, \quad (1)$$

where M_{ed} – the traction moment created by the electric motor and predetermines the rotation of its shaft with angular velocity ω ; M_w – the moment of the load created by the load, which is raised or lowered, ΔM – the dynamic moment of the moving system, and J – the reduced moment of inertia of the rotating masses of the electric drive system, which is assumed constant by all the researchers, whose work were mentioned.

When winding the traction cable onto the drum and unwinding from the drum, the real winding radius changes and the length of the cable between the drum and the load changes (and significantly).

Therefore, the reduced moment of inertia of the rotating masses of the electric drive system also changes in the process of lifting and lowering the load, that is, it is a function of time $J(t)$. Therefore, as shown in our work [8], to analyze the transient processes in the electric drive of the crane, one should use the differential equation (1), and the differential equation

$$\frac{d(J\omega)}{dt} = J(t) \frac{d\omega}{dt} + \omega(t) \frac{dJ}{dt} = M_{ed} - M_w(t) = \Delta M(t) \quad (2)$$

with parameters:

$$\begin{cases}
 M(t_1) = M_p(1 + k_1\omega - k_2\omega^2), \\
 M(t_2) = M_p(1 + k_1\omega_y^* - k_2(\omega_y^*)^2), \\
 M(t_3) = -M_p(1 + k_1\omega - k_2\omega^2), \\
 \\
 M_w(t_1) = M_{w0} - \alpha_1^*t - \frac{\alpha_2^*}{2}t^2, \\
 M_w(t_2) = M_w(t_1) - \alpha_1^*(t - t_1), \\
 M_w(t_3) = M_w(t_2) - \alpha_1^*(t - t_2) - \frac{\alpha_2^*}{2}(t - t_2)^2, \\
 \\
 J(t_1) = J_0^* - c_1^*t_1 + \frac{c_2^*}{2}t_1^2, \\
 J(t_2) = J(t_1) - c_1^*t_{21} + \frac{c_2^*}{2}t_{21}^2, \\
 J(t_3) = J(t_2) - c_1^*t_{32} + \frac{c_2^*}{2}t_{32}^2 = J_0^{**},
 \end{cases} \quad (3)$$

where t_1, t_2, t_3 – in accordance with the moment when the angular velocity of the electric motor reaches a constant value after starting, the moment of completion of motion with a constant angular velocity and the moment of stopping the motion.

And in order to be able to assess the longitudinal vibrations arising in the cables, in our works [9, 10], it is proposed to integrate the models

$$\begin{aligned}
 \frac{\partial^2 v(x, t)}{\partial x^2} - nm \frac{\partial^2 v(x, t)}{\partial t^2} &= 0, \\
 \frac{\partial^2 F(x, t)}{\partial x^2} - nm \frac{\partial^2 F(x, t)}{\partial t^2} &= 0,
 \end{aligned} \quad (4)$$

in which $v(x, t)$, $F(x, t)$ – respectively, the linear velocity of the cable with specific mass $\left(\frac{\text{kg}}{\text{m}^3}\right)$ and compliance $\left(\frac{\text{m} \cdot \text{c}^2}{\text{kg}}\right)$ and the force that takes place in its section at a distance x from the origin of the spatial coordinate along the cable at the moment of time t . After all the necessary transformations, complementing models (2), (3) with models (4), let's obtain a solution to differential equation (2) in the form

$$\omega_i = \omega_y^* - \frac{\left(b_\omega^2 - \Delta_\omega^{(i)}\right) \left(e^{\sqrt{-\frac{4\Delta_\omega^{(i)}}{\Delta_t}} \text{arctg} \frac{2a_t \sqrt{\Delta_t} (t_i - t_2)}{\Delta_t + b_t^2 + 2a_t b_t (t_i - t_2)}} - 1 \right)}{2a_\omega \left(b_\omega \left(1 - e^{\sqrt{-\frac{4\Delta_\omega^{(i)}}{\Delta_t}} \text{arctg} \frac{2a_t \sqrt{\Delta_t} (t_i - t_2)}{\Delta_t + b_t^2 + 2a_t b_t (t_i - t_2)}} \right) + \sqrt{-\Delta_\omega^{(i)}} \left(1 + e^{\sqrt{-\frac{4\Delta_\omega^{(i)}}{\Delta_t}} \text{arctg} \frac{2a_t \sqrt{\Delta_t} (t_i - t_2)}{\Delta_t + b_t^2 + 2a_t b_t (t_i - t_2)}} \right) \right)}, \quad (5)$$

where:

$$\begin{cases}
 a_t = \frac{c_2^*}{2}, \\
 b_t = -c_1^*, \\
 c_t = J_0^*, \\
 \Delta_t = 4a_t c_t - b_t^2 = 2c_2^* J_0^* - (c_1^*)^2;
 \end{cases} \quad (6)$$

$$\begin{cases} a_{\omega} = -M_p k_2, \\ b_{\omega} = M_p k_1, \\ c_{\omega}^{(i)} = M_p - M_w(t_1, t_i), \\ \Delta_{\omega}^{(i)} = 4a_{\omega} c_{\omega}^{(i)} - b_{\omega}^2 = -4M_p k_2 (M_p - M_w(t_1, t_i)) - (M_p k_1)^2. \end{cases} \quad (7)$$

1. 3. Proposed way to solve the problem

All the above mathematical models, taken from our previous publications, in this work of ours serve as the initial prerequisites for the synthesis of a simulation model of the processes taking place in the crane electric drive system, which have chosen as a typical dynamic object with parameters that change both in time and in space. And the simulation model itself will be used to check the previously obtained theoretical results for adequacy by means of their computer simulation using the real parameters of a particular crane and its electric drive system.

2. Materials and methods

The synthesis of a simulation model for modeling processes in the electric drive system of a crane, as an object from the class of dynamic ones with parameters variable in time and space, is carried out using the example of a crane installation with an asynchronous electric drive, which implements the process of lifting a load with a mass $m_w = 400$ (kg) to a height $h = 10$ (m). Others, necessary parameters of the crane installation let's choose with an asynchronous electric drive have the following values: the diameter of the cable $D_T = 0.05$ (m) to which the load is suspended, the mass of its running meter is equal $m_{MT} = 5$ (kg), the diameter of the coil on which the cable is wound when the load is lifted $D_K = 0.2$ (m), the mass of the coil is equal $m_K = 15$ (kg), the gear ratio of the gearbox, by which the traction force from the electric motor is transmitted to the cable coil is equal to $z=24$, the distance between the gearbox axes, one of which is connected to the traction motor shaft, and the second to the coil on which the cable is wound, to which the load is suspended $l = 0.5$ (m), the number of parallel axes in the gearbox $k=5$, the distance between the axles $l_{ba} = 0.2$ (m), the radius of the larger gear on the axle is equal $r_{bg} = 0.12$ (m), the mass of the larger gear on the axle is equal $m_{bg} = 20$ (kg), the radius of the smaller gear on the axle is equal $r_{sg} = 0.08$ (m), the mass of the smaller gear on the axle is equal $m_{sg} = 11$ (kg), and the passport characteristics of the asynchronous traction motor are: nominal moment $M_N = 80$ (N·m), moment of inertia $J^* = 1.2$ (N·m), synchronous angular velocity of rotation of the rotor $\omega_c = 157$ (rad/s); efficiency $\eta_N = 0.86$, rated slip $s_N = 0.057$, critical slip $s_{kr} = 0.251$, starting torque $M_p = q_p M_N$, maximum torque $M_{\max} = q_{\max} M_N$, where depending on the type of electric motor $q_p \in [1.1 - 2]$, $q_{\max} \in [1.5 - 2.5]$.

Let's note that all quantities are set in the same SI system of units.

Listing of calculating the parameters of the mathematical model (2)–(7) in the PE Mathcad for a certain class of dynamic objects with parameters that are variable in time and space is shown in **Fig. 1**. And synthesized in the Matlab Simulink software environment using the numerical values of these parameters, the simulation model of the dynamic moment of the system, which sets the right side in the mathematical model (2), is shown in **Fig. 2**.

$$\begin{aligned} c_{1x} &:= \frac{\alpha_{1*} \cdot t_{12}}{\omega_{y*}} = 0.032 \frac{\text{kg} \cdot \text{m}^2}{\text{s}} & a_t &:= \frac{c_{2*}}{2} = 0.005 \text{ J} \\ c_{2*} &:= \frac{2(J_{0**} - J_{0*} - c_{1x}(t_1 + t_{12} + t_{23}))}{t_1^2 + t_{12}^2 + t_{23}^2 - 2 \cdot t_{12}(t_1 + t_{12} + t_{23})} = 0.009 \text{ J} & b_t &:= -c_{1*} = -0.016 \frac{\text{kg} \cdot \text{m}^2}{\text{s}} \\ J_{0*} &:= J_* + \frac{1}{z_i^2} \cdot J_i + (m_{\omega} + m_{MT} \cdot h_*) \cdot \frac{D_K^2}{z^2} = 0.177 \text{ kg} \cdot \text{m}^2 & c_t &:= J_{0*} = 0.177 \text{ kg} \cdot \text{m}^2 \\ & & \Delta_t &:= 4 \cdot a_t \cdot c_t - b_t^2 = 0.003 \frac{\text{kg}^2 \cdot \text{m}^4}{\text{s}^2} \\ & & a_{\omega} &:= -M_p \cdot k_2 = -0.8 \text{ J} \\ & & b_{\omega} &:= M_p \cdot k_1 = 1.6 \text{ J} \end{aligned}$$

Fig. 1. Listing of the calculation of the parameters of the mathematical model of the electric drive system of the crane for the simulation model of the processes of lifting loads with this crane and their lowering

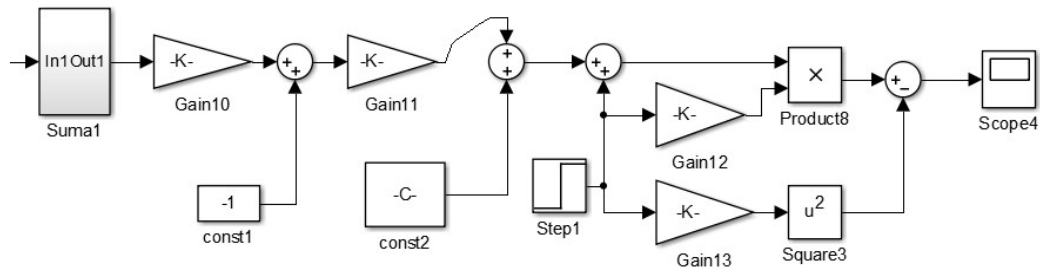


Fig. 2. Simulation model of the dynamic moment on the traction motor shaft of a crane electric drive system

The result of modeling the dynamic moment using the one shown in **Fig. 2** of the simulation model is shown in **Fig. 6** in the next section of this article devoted to the analysis of the entire set of results obtained.

Fig. 3–5 shows the simulation model synthesized by authors, with the help of which the operation of the system is simulated according to a typical tachogram for crane mechanisms, given in [8].

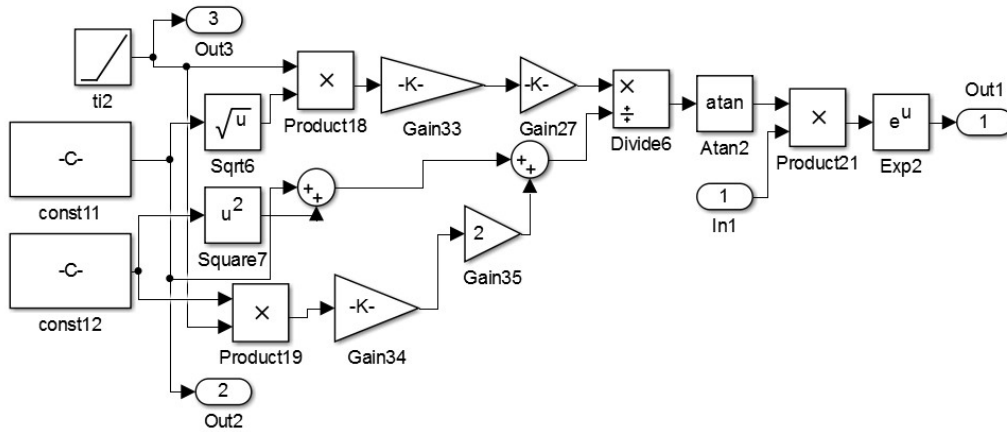


Fig. 3. The first part of the simulation model in the “Exp2” block of the electric drive system of the crane, taking into account the longitudinal vibrations of the load during its movement

To simulate a full cycle of lifting a load by a crane, it was taken into account that the equation of dynamics (2) for the period of motion of an electric drive with a steady angular velocity, as shown in our works [9, 10], takes the form:

$$(c_1 + c_2(t - t_1))\omega_{\phi}^* = \alpha_1(t - t_1) + R \left(\frac{G_w + G_T(at_1, t_1)}{g} \right) g_{ll} \left(\frac{2}{\pi} \sum_{k=0}^5 \frac{1}{2k+1} \left[\sin \frac{(2k+1)\pi at}{l} \right] \right). \quad (8)$$

And for the period of braking of the system during lifting, the equation for changing the load moment takes the form:

$$-M_w(t_2, t) = R \left(\frac{G_w + G_T(at_2, t_2)}{g} \right) g_{ll} \left(-1 + \frac{2}{\pi} \sum_{k=0}^5 \frac{1}{2k+1} \left[\sin \frac{(2k+1)\pi at}{l} \right] \right) + \alpha_1(t_2 - t_1). \quad (9)$$

It is quite obvious that for the numerical determination of all coefficients in mathematical models, from model (2) to model (9), let's use the listing of parameters shown in **Fig. 2**.

The results of modeling dynamic processes using the one shown in **Fig. 3–5** of the simulation model are also presented in the next section of this article, devoted to the analysis of the entire set of results obtained, in **Fig. 7, 8**.

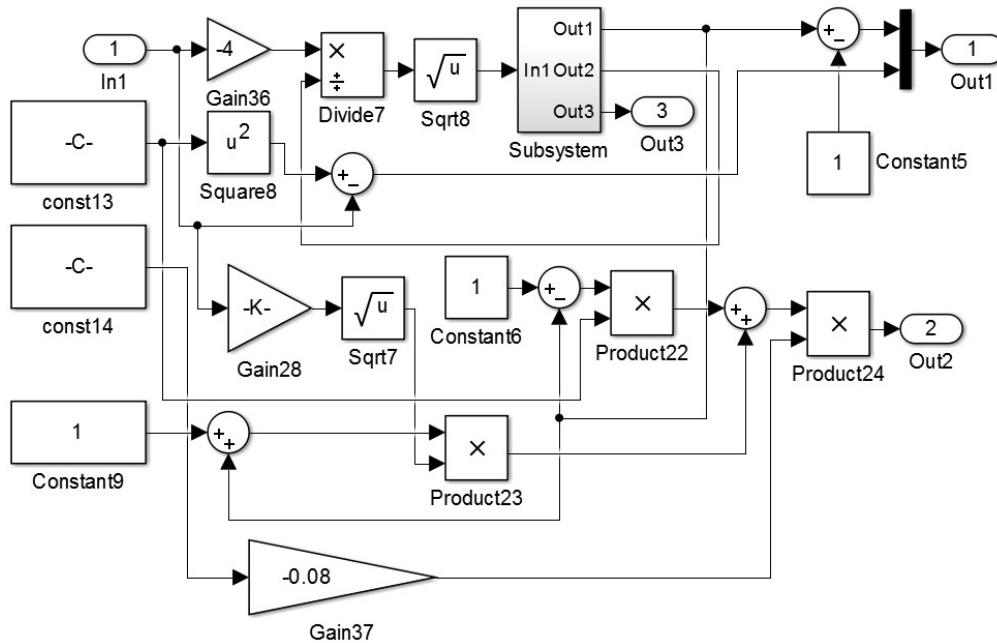


Fig. 4. The second part of the simulation model into the “Mux” block of the electric drive system of the crane taking into account the longitudinal vibrations of the load during its movement

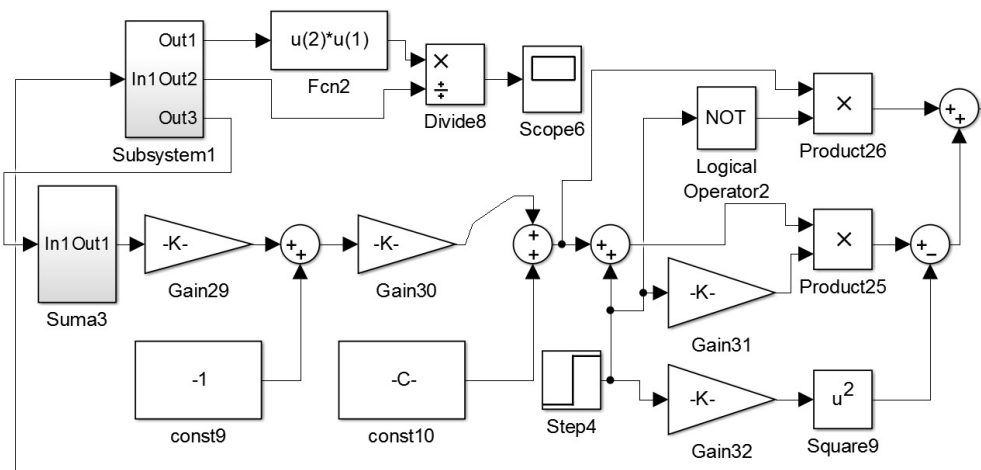


Fig. 5. General minimized simulation model of the electric drive system of the crane taking into account the longitudinal vibrations of the load during its movement

3. Results

Fig. 6 shows a graph of the change in time of the dynamic moment acting at the input of the system, obtained using the simulation model shown in **Fig. 2**. This graph clearly shows the significant dependence of this moment on the variables in time and space of the parameters of this system. Let's recall that the change in time of the parameters is due to the change in time of the reduced moment of inertia of the rotating masses, caused by the change in the radius of the winding drum and the variable mass of both that part of the cable that is wound on the drum, and that which shortens or lengthens between the drum and the load in the process of moving the latter. A change in the parameters of this system in space is due to longitudinal vibrations that arise in the cable during the movement of the load after it is detached from the platform, as well as with any change in the angular velocity of the traction motor.

And **Fig. 7** shows a graph of the increase in the angular velocity of rotation of the traction motor shaft after starting to lift the load, obtained using the simulation model shown

in **Fig. 3–5**. As it is possible to see that the fluctuations in the angular velocity on this graph are significantly smaller in terms of the fluctuations in the dynamic moment, since the angular velocity is the integral of the dynamic moment related to the reduced moment of inertia, that is, the electric drive system plays in our case the role of a high-frequency filter. But, even despite the filtering, on the graph of the angular velocity, it is possible to see fluctuations within 10 %, caused by changes in the parameters of the electric drive system in time and space. For a more visual representation of the oscillations in the same **Fig. 7**, the lower curve shows the same graph, and the upper one, but on an enlarged scale and only in the range close to the steady velocity.

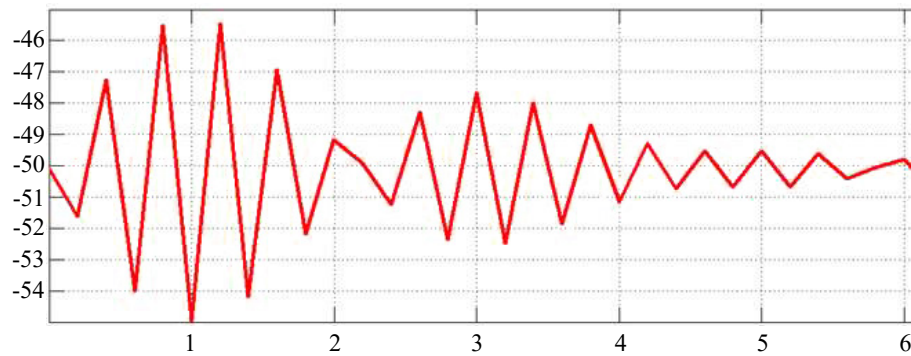


Fig. 6. Results of modeling the change in the dynamic moment of the crane electric drive system

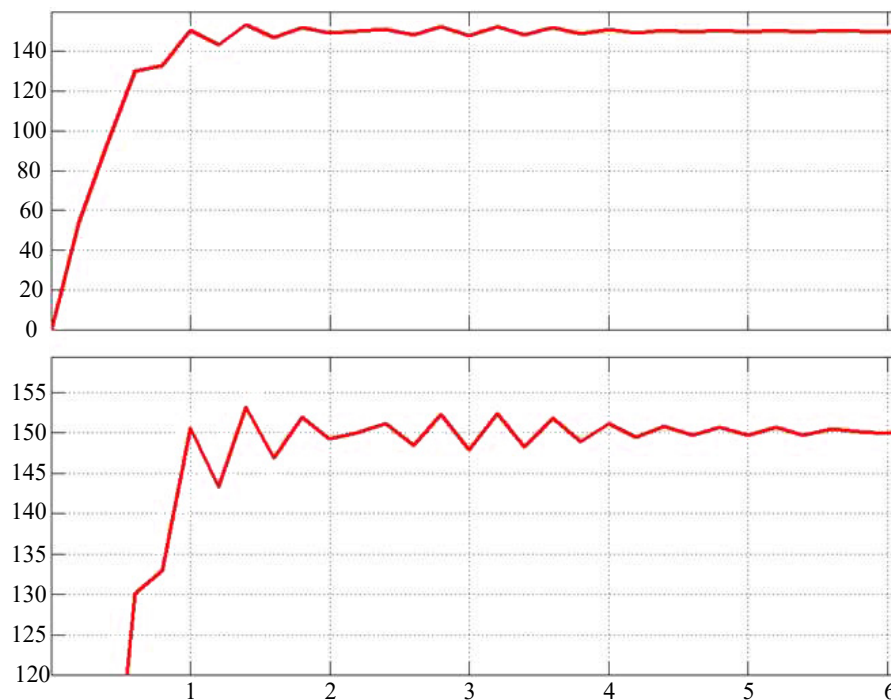


Fig. 7. The results of modeling the change in the angular velocity of the crane mechanism, namely the process of lifting the load, taking into account longitudinal vibrations in the cable

Fig. 8 shows the complete simulation cycle, which also covers the process of decreasing the angular velocity when lifting a load on the final section of the trajectory. From this graph it is easy to see that due to the variable parameters of the system, oscillations arise in the final phase of lifting the load, which can lead to undesirable contacts of the load with the boom or overpass of the crane.

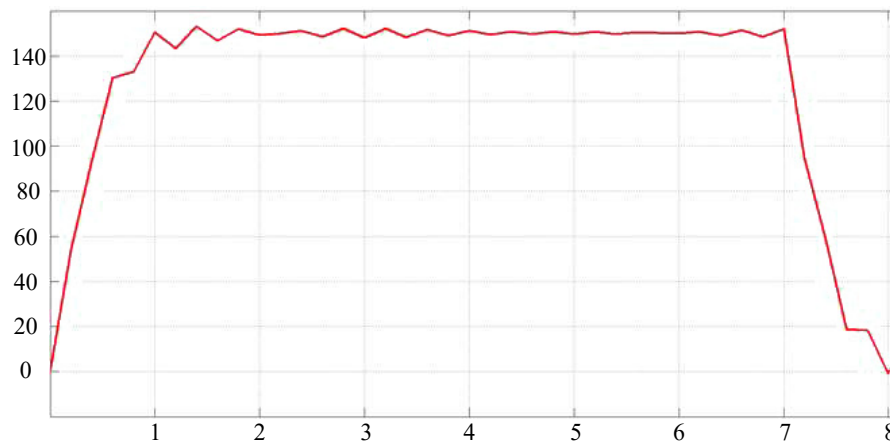


Fig. 8. Graph of the full cycle of changes in the angular velocity of the electric drive of the crane when lifting the load, taking into account longitudinal vibrations in the cable and changes in time of the reduced moment of inertia of the rotating masses

4. Discussion of research results

If the graphs of the processes in the electric drive system of the crane, which are shown in **Fig. 6–8**, and obtained by simulation using the mathematical models synthesized in [8–10], taking into account time and space variables, to compare with the graphs of processes in the electric drive system of the crane with approximately the same characteristics, obtained experimentally by the authors of the work [7], then it is possible to see that they are the same character and only slightly differ in scale, which indicates the adequacy of our mathematical models to real processes that take place in this class of dynamical systems. And at the same time, if there are graphs of processes, obtained by the authors of [7] using mathematical models with stable parameters both in time and space for the two-mass structure of the object, then it is easily possible to make sure that they have a different nature. It indicates the inadequacy of mathematical models with stable parameters to real processes that take place in this class of dynamical systems.

Despite the fact that the adequacy of the mathematical models of one class of objects with variable parameters in time and space, proposed by the authors of this article in previous works, has been proved by comparing the results of simulation modeling performed in this work with the results of experimental studies of the same class of objects by other authors, the practical value of the mathematical models synthesized by the authors can be confirmed only after their use is used to synthesize an automatic control system for objects of this class, which will damp the vibrations that arise in the crane cable due to the influence of changes in time and space of the parameters of the system of its traction electric drive. But the synthesis of such a control system will be carried out already in our next work, which will be a continuation of this work.

5. Conclusions

1) Simulation models are synthesized to assess the adequacy of the proposed by the authors of this work in previous publications of mathematical models of one class of linear dynamic systems with variable parameters in time and space, which include systems for lifting and lowering cargo with cranes in the case of taking into account the influence of longitudinal vibrations that arise in the hoisting cable mechanism, and the shift in time of the moment of inertia of the rotating masses reduced to the motor shaft.

2) The simulation in this work is performed in the Simulink graphical software environment of the MATLAB application package, and the results of modeling the dynamics of the electric drive system during acceleration, deceleration and movement at a steady velocity are presented.

3) The way to compare the results obtained on the simulation model with the results of experimental studies of the same class of dynamical systems performed by other authors, the adequacy of the mathematical models synthesized by the authors of this work is proved.

References

- [1] Grabski, J., Strzałko, J. (2003). Dynamic analysis of the load hoisting process. *Journal of theoretical and applied mechanics*, 4, 853–872.
- [2] Matyja, T., Ślaskowski, A. (2007). Modelling of the Lift Crane Vibration Caused by the Lifting Loads. *Zdvihaci Zarizeni v Teorii a Praxi 2007*. Brno, 98–105.
- [3] Pu, H., Xie, X., Liang, G., Yun, X., Pan, H. (2011). Analysis for Dynamic Characteristics in Load-lifting system of the Crane. *Procedia Engineering*, 16, 586–593. doi: <http://doi.org/10.1016/j.proeng.2011.08.1128>
- [4] Budikov, L. Ia. (1997). *Mnogoparametricheskii analiz dinamiki gruzopodemnykh kranov mostovogo tipa*. Lugansk: Izd-vo VUGU, 210.
- [5] Loveikin, V. S., Chovniuk, Yu. V., Dikteruk, M. H., Pastushenko, S. I. (2004). *Modeliuvannia dynamiky mekhanizmiv vantzahopidiomnykh mashyn*. Kyiv-Mykolaiv: RVV MDAU, 286.
- [6] Vladić, J., Malešev, P., Nostakov, R., Brkljač, N. (2008). Dynamic Analysis of the load lifting. *Journal of mechanical engineering*, 10, 655–661.
- [7] Loveikin, V. S., Romasevych, Yu. O., Holdun, V. A., Krushelnytskyi, V. V. (2019). *Dynamika ta optimalne keruvannia rukhom mostovykh kraniv*. Kyiv: TsP «KOMPRINT», 460.
- [8] Mokin, O., Mokin, B., Kryvonis, O. (2017). Synthesis of mathematical models for one class of electromechanical systems with variable parameters. 2017 IEEE First Ukraine Conference on Electrical and Computer Engineering (UKRCON). Kyiv. doi: <http://doi.org/10.1109/ukrcon.2017.8100504>
- [9] Mokin, B. I., Mokin, O. B., Kryvonis, O. M. (2018). Method of Identification of the Mathematical Model of a Single Class of Linear Dynamic Systems with Variable Parameters. *Visnyk of Vinnytsia Politechnical Institute*, 141 (6), 62–76. doi: <http://doi.org/10.31649/1997-9266-2018-141-6-62-76>
- [10] Mokin, B. I., Mokin, O. B., Kryvonis, O. M. (2019). System Approach to the Analysis of the Processes of Moving Cargoes with a Crane. *Visnyk of Vinnytsia Politechnical Institute*, 144 (3), 21–31. doi: <http://doi.org/10.31649/1997-9266-2019-144-3-21-31>

DEVELOPMENT OF METHODS FOR ASSESSMENT AND SELECTION OF UNMANNED AERIAL VEHICLE FOR MINE RECONNAISSANCE

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ARTICLE INFO

Article history:

Received date 14.09.2020

Accepted date 22.10.2020

Published date 30.10.2020

Section:

Control systems

DOI

10.21303/2313-8416.2020.001496

KEY WORDS

mines reconnaissance
unmanned aerial vehicle
methods of system analysis
expert review
technique for a drone assessing and sampling

ABSTRACT

Object of research: comparative assessment and selection of an unmanned aerial vehicle for mine reconnaissance sample.

Investigated problem: substantiation of the methodological apparatus for comparative assessment and selection of an unmanned aerial vehicle for mine reconnaissance sample, taking into consideration the presence of both quantitative and qualitative indicators.

Main scientific results: the methods of comparative assessment and selection of an unmanned aerial vehicle for mine reconnaissance sample is developed. The technique is based on an expert method, which allows a drone sample to be evaluated and selected objectively, taking into consideration the presence of both quantitative and qualitative indicators. At the same time, group interaction and discussion of experts are realized. When the judgments do not coincide, an artificial consensus is not imposed. The number of experts is not limited. The experts are not linked in any way. The need to ensure transitive consistency (10–12 %) makes it possible to record attempts by an expert (experts) to artificially overestimate the indicators of one of the drone samples (or the one being evaluated), therefore, the indicators of another sample will automatically deteriorate. The principle of impartiality and fairness is maintained. A well-trained objective coordinator is not required, and the reality is that the absence of the disrupting the problem solution possibility is due to a change in the psychological situation among the experts. **Area of practical use of research results:** humanitarian demining in the interests of ensuring the detection of mines for various purposes by sappers from a safe distance. At the same time, an increase within the probability of mines detecting is ensured due to special equipment installed onboard the drone.

Innovative technological product: a technique has been developed that allows not only assessing the drone samples for mine reconnaissance objectively, but making an objective choice of a sample for specific requirements also.

Scope of application of the innovative technological product: clearance of the terrain remaining after the end of hostilities. With the help of unmanned aerial vehicles, a significant acceleration of the demining process is possible, especially in those territories where mines are installed and being for a sufficiently long time.

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1. Introduction

1.1. The object of research

The object of research is a comparative assessment and selection of an unmanned aerial vehicle for mine reconnaissance sample while using quantitative and qualitative indicators.

1.2. Problem description

The territory of Ukraine, which is considered to be contaminated with explosives, is approximately 16,000 km². By 2019 almost 300 military and more than 2,500 civilians died since the beginning of hostilities due to the explosion of mines and explosive objects.

The threat of a mine situation to troops, border guards and the civilians indicates the existence of a discrepancy. On the one hand, these are requirements for the relevant level of technical means for area engineering reconnaissance conducting for the mines presence, taking into consideration the achievements of modern scientific and technological progress. On the other hand – the

moral obsolescence of ground-based technical means of mines searching left over from the times of the Soviet Union.

Elimination of this discrepancy is possible through the development of more effective technical means of engineering reconnaissance of mines. New approaches are needed for timely and safe remote detection of mines, taking into consideration the latest achievements of scientific and technological progress.

One of these innovative approaches was the idea of using an unmanned aerial vehicle (hereinafter – UAV) for mine reconnaissance. The payload of the drone is a view (with image formation) technical means of mine reconnaissance.

With the help of such reconnaissance drones, it is possible to accelerate the demining process significantly, especially in those territories where mines have been installed and being for a sufficiently long time. Such studies are currently being carried out by the scientists of a number of leading countries of the world: the USA, Great Britain, Israel, Russia, China, Switzerland, etc.

The use of specific technical means of UAVs for mine reconnaissance is an urgent dimension of scientific research. This requires the development of the methods for comparative assessment and selection of UAVs based on the results of the study of system analysis.

1. 3. Suggested solution to the problem

A number of Ukrainian and foreign specialists and scientists were involved in various issues related to research on the use of unmanned aircraft for solving the problems of military facilities reconnaissance: A. Ananin, L. Artiushin, M. Dougherty, V. Kirilenko, V. Kolesnikov, M. Mitrakhovich, S. Mosov, S. Saliy, A. Samkov, A. Selyukov, V. Silkov, A. Feschenko and others.

S. Mosov and V. Kolesnikov in their work [1] gave the system requirements for the selection of unmanned aerial systems for performing reconnaissance and surveillance tasks. At the same time, these requirements are of a general nature, although they can be used to determine quantitative indicators for evaluating UAV samples.

A team of authors in [2] presented the results of research related to unmanned aerial systems from the standpoint of a comparative assessment of their combat capabilities. The methodological approaches proposed in [2] do not consider the issue of assessment and sampling of UAVs with specified equipment for reconnaissance of mines.

A team of authors in [3] analyzed the use of unmanned aircraft in military conflicts of our time, highlighting the features of the use of unmanned aircraft systems of various purposes. At the same time, the issues of using UAVs for detecting mines are not covered in the monograph.

A feature of work [4] is the mathematical apparatus of multi-criteria choice of reconnaissance unmanned aircraft systems. At the same time, the given mathematical apparatus uses only quantitative indicators.

A. Ananiev in [5] proposed a set of tactical and technical requirements for unmanned aircraft systems and defined their tasks in the system of protecting the state border. Among the tasks, the detection of mines is not defined, which today is important for the protection of the state border on the south-eastern border of Ukraine.

In collective work [6] the authors provide approximate calculations of the main parameters and characteristics of unmanned aerial vehicles, which do not take into consideration the tasks of conducting aerial reconnaissance (observation).

V. Neroba in [7] systematized the conditions and factors that would affect the specific technical means of UAV in terms of mines reconnaissance, allowed to determine the quantitative parameters for assessing the samples of UAVs.

M. Dougherty [8] cited the features of the use of unmanned aircraft in local wars and conflicts in the civilian sphere, without parameters systematizing, which can be used to assess and select samples of unmanned aerial vehicles.

The analysis results show that the issue of using the specific technical means of reconnaissance (hereinafter – STMR) installed on UAVs to solve the tasks of mines reconnaissance as objects of aerial reconnaissance remains in the topical arsenal. Only quantitative indicators are used to assess the UAV. The issues of assessment and selection of UAVs for mine reconnaissance require research. This requires the development of a comparative assessment methods and the choice of a

UAV model, on which specific technical means of mine reconnaissance are installed, while taking into consideration quantitative and qualitative indicators.

The aim of the article. To develop a methods for comparative assessment and selection of an UAV sample, on which STMR are installed for mine reconnaissance, while taking into consideration quantitative and qualitative indicators.

2. Materials and methods

The development of the methods for the comparative assessment and selection of an UAV sample for mine reconnaissance based on the results of the study of system analysis methods.

3. Research results

One of the specific features of the task of comparative assessment and selection of a specific UAV sample from a certain set of existing is a significant number of possible alternative solutions based on the indicators of their technical improvement.

To compare several samples, methods of expert assessments are most often used, as well as theoretical methods associated with solving single-criterion or multi-criteria problems.

Objectification of the selection of UAVs for mine reconnaissance is aimed, firstly, the application of a systematic approach in the process of assessing various UAVs, and, secondly, the introduction or development of new effective methods for comparing and selecting UAVs.

To ensure objectivity in the assessment and selection of UAVs for mine reconnaissance, it is advisable to develop a method of comparative assessment and selection based on the results of the study of system analysis methods.

One of these methods is the rather well-known Delphi method, which is a method of establishing expert judgments on the basis of the anonymity of experts and their physical separation, as well as the presence of controlled feedback [9]. To maintain anonymity and physical separation, this method aims to avoid some of the potential pitfalls of group decision making, and the purpose of feedback is to allow each expert to read the average opinion of other experts.

If there are sufficient positive aspects, the method has corresponding disadvantages. The first drawback should be attributed to the fact that the separation of experts practically excludes the possibility of the emergence of new approaches to solving the problem, which can be developed and tested in the course of discussions. Another disadvantage lies in the way of constructing the questionnaire, according to which the survey of experts is carried out. If the questionnaires are not constructed sufficiently, then the conclusions of the experts who answer the question will also be not objective due to the fact that the conclusions are actually determined by the questions that are asked.

Another well-known systemic method of assessment and selection is the Strategic Assumption Surfacing and Testing (hereinafter – SAST) method, which is based on preliminary “polishing” of assumptions (elimination of inconsistency), which are subsequently used to solve the problem, as well as their ranking [10]. The method is well adapted to the analysis of poorly structured problems, in which the development of a solution is based on acutely conflicting assumptions. However, it requires such an objective arbiter, proficient in the art of interpersonal dialogue and experienced in group dynamics theory. Otherwise, the application of the SAST method is doomed to failure. Moreover, the use of the method requires the involvement of a sufficiently large number of experienced qualified experts.

Another systematic procedure is the hierarchy analysis method (hereinafter – HAM) [11]. In contrast to the Delphi method, HAM supports group interaction and discussions. Thus, during exploration of the assumptions underlying individual decisions, new and important knowledge emerges.

The expediency of this approach is confirmed by the experience of conducting business games during the USSR period [12]. In case of disagreement, the HAM does not impose an artificial consensus, since it does not withdraw, but takes into consideration the opinions that fall out of the general channel in the calculations (the value of the discrepancy is allowed).

Comparison of HAM with SAST allows to conclude that they are similar at the stage of the problematic task structuring. At the same time, a well-trained objective coordinator is not required, and it is real that there is no possibility of disrupting the solution of the problem due to a change in the psychological situation among experts.

Thus, according to the results of the analysis, it can be concluded that the HAM is the most well-known of the acceptable system methods, which is advisable to use in terms of methods for

assessing and sampling of UAVs for mines reconnaissance developing. The theoretical work [2] confirms this conclusion. The software implementation of the HAM is available online on the Internet resource [13].

The first step of the HAM is to decompose the problem of assessing and selecting a UAV model for mine reconnaissance and presenting it in the form of a hierarchy (**Fig. 1**). At the first (highest) level, there is a common target z – the best UAV model for mine reconnaissance. At the second level, there are indicators $K=\{k_i\}$, which clarify the goal, and at the third (lower) level, there is a set of applicants $A=\{d_j\}$ from among the UAV samples that must be evaluated.

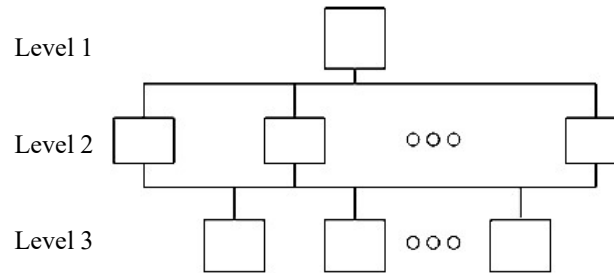


Fig. 1. Scheme of decomposition of tasks, estimation and visualization of UAVs

At the second step, it is necessary to establish the local priorities of the k_j indicators by concluding square matrices of pairwise comparisons (**Table 1**) and conducting expert comparisons using the scale for assessing the relative importance w (**Table 2**). Square matrices are inversely symmetric, that is, the matrix element $b_{ji}=w_j/w_i=1/b_{ij}$. Similar matrices should be constructed for paired comparisons of each d_j sample of the UAV at the third level in relation to the indicators k_i of the second level (**Table 3**).

Sets of local priorities are formed from the groups of matrices of pairwise comparisons, indicating the relative influence of a set of elements on an element of the level adjacent from above. The process of forming local priorities is based on calculating eigenvectors for each matrix and normalizing the result to one:

$$u_i = \frac{1}{\sum_{i=1}^s \sqrt[s]{\prod_{j=1}^s \frac{w_i}{w_j}}} \sqrt[s]{\prod_{j=1}^s \frac{w_i}{w_j}}, \quad (1)$$

u_i – the local priority of the i -th element of the column of the matrix of pairwise comparisons; s – the number of elements of the matrix of pairwise comparisons in the column.

Table 1

Setting local priorities for indicators k_j

Indicators	k_1	k_2	...	$k_{(n-1)}$	k_n	Local priority
k_1	1	w_{k_1}	...	w_{k_1}	w_{k_1}	u_{k_1}
		w_{k_2}	...	$w_{k_{(n-1)}}$	w_{k_n}	
k_2	w_{k_2}	1	...	w_{k_2}	w_{k_2}	u_{k_2}
	w_{k_1}			$w_{k_{(n-1)}}$	w_{k_n}	
...	...	...	...	...	...	...
$k_{(n-1)}$	$w_{k_{(n-1)}}$	$w_{k_{(n-1)}}$	...	1	$w_{k_{(n-1)}}$	$u_{k_{(n-1)}}$
	w_{k_1}	w_{k_2}	...		w_{k_n}	
k_n	w_{k_n}	w_{k_n}	...	w_{k_n}	1	u_{k_n}
	w_{k_1}	w_{k_2}	...	$w_{k_{(n-1)}}$		

Table 2The scale for assessing the relative importance w

w	1	3	5	7	9	2, 4, 6, 8
Advantage degree	Equal importance	Moderate importance	Essential	Significant	Very strong	Intermediate

Table 3

Pairwise comparison matrices

k_1	$d_1 d_2 \dots d_m$	Priority vector	k_2	$d_1 d_2 \dots d_m$	Priority vector
d_1	$1 \frac{w_{d_1}}{w_{d_2}} \dots \frac{w_{d_1}}{w_{d_m}}$	$u_{k_1 d_1}$	d_1	$1 \frac{w_{d_1}}{w_{d_2}} \dots \frac{w_{d_1}}{w_{d_m}}$	$u_{k_2 d_1}$
d_2	$\frac{w_{d_2}}{w_{d_1}} 1 \dots \frac{w_{d_2}}{w_{d_m}}$	$u_{k_1 d_2}$	d_2	$\frac{w_{d_2}}{w_{d_1}} 1 \dots \frac{w_{d_2}}{w_{d_m}}$	$u_{k_2 d_2}$
...	...	...	...	...	...
d_m	$\frac{w_{d_m}}{w_{d_1}} \frac{w_{d_m}}{w_{d_2}} \dots 1$	$u_{k_1 d_m}$	d_m	$\frac{w_{d_m}}{w_{d_1}} \frac{w_{d_m}}{w_{d_2}} \dots 1$	$u_{k_2 d_m}$
...	$d_1 d_2 \dots d_m$	Priority vector	k_n	$d_1 d_2 \dots d_m$	Priority vector
d_1	$1 \dots \dots$	...	d_1	$1 \frac{w_{d_1}}{w_{d_2}} \dots \frac{w_{d_1}}{w_{d_m}}$	$u_{k_n d_1}$
d_2	$\dots 1 \dots$	...	d_2	$\frac{w_{d_2}}{w_{d_1}} 1 \dots \frac{w_{d_2}}{w_{d_m}}$	$u_{k_n d_2}$
	$\dots \dots 1$	...	...	...	...
d_m		...	d_m	$\frac{w_{d_m}}{w_{d_1}} \frac{w_{d_m}}{w_{d_2}} \dots 1$	$u_{k_n d_m}$

In the process of pairwise comparisons, to identify and eliminate possible violations of transitive consistency, the value of the consistency index r should be determined to calculate the consistency ratio χ :

$$r = \frac{\lambda_{\max} - s}{s - 1}, \quad \chi = \frac{r}{r_0} 100 \%, \quad (2)$$

r – the index of random consistency [14]:

$$r_0 = 1.67e^{-\frac{1.0808}{s}}, \quad (3)$$

$\lambda_{\max}$ – the maximum eigenvalue of the matrix:

$$\lambda_{\max} = \sum_{i=1}^s u_i \sum_{j=1}^s \frac{w_j}{w_i}. \quad (4)$$

The value χ should not exceed 10–12 %, otherwise it will be necessary to additionally check the judgments of experts [11].

In the case where experts do not have sufficient experience in making judgments or a sufficient level of professional training to carry out the process of setting local priorities, the criteria should be pre-ranked.

The penultimate step in determining z is the implementation of the principle of synthesis. The priorities are synthesized starting from the second level down. Local priorities $u_{k_i d_j}$ are multiplied by the priority u_{k_i} of the corresponding indicator at the highest level and summed up for each element in accordance with the criteria that this element affects:

$$(l_{d1}, l_{d2}, \dots, l_{dm}) = (u_{k1}, u_{k2}, \dots, u_{kn}) \begin{pmatrix} u_{d1} & u_{k1d1} & \dots & u_{k1dm} \\ u_{k2d1} & u_{k2d2} & \dots & u_{k2dm} \\ \dots & \dots & \dots & \dots \\ u_{knd1} & u_{knd2} & \dots & u_{kndm} \end{pmatrix}. \quad (5)$$

The procedure for synthesizing local priorities is carried out to the lowest level, as a result of which the global priorities l_j of each UAV sample – d_j are determined. The ranking of the obtained priorities allows to determine the UAV sample with the highest priority value, which will be the most pleasant among the UAV samples that are evaluated.

4. Discussion of research results

The proposed technique allows, firstly, not only to evaluate the UAV samples for mine reconnaissance objectively, but to carry out an objective selection of the UAV sample also. Secondly, the need to ensure transitive consistency makes it possible to record attempts to artificially overestimate the indicators of one of the UAV samples (or the one being evaluated), therefore, the indicators of another UAV sample will automatically deteriorate and the consistency ratio will go beyond the acceptable limits. This allows the principle of impartiality and fairness to be maintained.

When applying the methods, it is proposed to add the following to the composition of indicators $K=\{k_i\}$, which clarify the goal – the choice of a UAV model for mines reconnaissance: the presence of a stabilized platform on board the UAV sample for placing a STMR; maximum payload weight of the UAV sample; operating temperature (winter, summer) of the UAV sample; time spent in the air of the UAV sample; controllability of the UAV sample by the external pilot (pilot-operator); purchase cost of the UAV sample; the cost of operating a UAV sample; the maneuverability of the UAV sample; resistance of the UAV sample to wind gusts; maintainability of the UAV sample; operational reliability of the UAV sample; diagnostic ability to the state of a UAV sample.

The composition of indicators $K=\{k_i\}$ may vary depending on the goal being achieved.

The technique can be applied in the context of comparative assessment and selection of UAVs for mines reconnaissance, which are equipped with STMR: RGB– cameras, infrared cameras, multi- and hyper spectral cameras.

To ensure the objectivity of obtaining the results of applying the methods, the value of the agreement ratio should not exceed 10–12 %.

The technique can be used in conditions when it is necessary to evaluate each (or one) UAV sample. In this case, a “normative” UAV model should be used as an additional UAV sample. After determining the global priority of the “normative” UAV sample, the level of the UAV sample is compared, evaluated relative to the normative by calculating the difference between the global priorities of the “normative” UAV sample and the UAV sample estimated, or calculating the percentage between them.

The direction of further research should be considered the development of recommendations for organizing the training of external pilots and UAV operators for mine reconnaissance. Another promising area may be the development of recommendations for technical operation of an unmanned aircraft complex designed organizing to carry out mine reconnaissance tasks.

5. Conclusions

A methods of comparative assessment and selection of a UAV sample for mine reconnaissance have been developed, based on the well-known expert method for analyzing hierarchies. The methods have several advantages. The first is to support group interaction and discussion. Second, if the judgments do not coincide, an artificial consensus is not imposed, because opinions that fall out of the general channel in the calculations are not withdrawn, but taken into consideration. Third, a well-trained objective coordinator is not required, and the reality is that the lack of the possibility of disrupting the solution of the problem is due to a change in the psychological environment among experts. Fourth, both quantitative and qualitative indicators are compared simultaneously through quantitative formalization.

References

- [1] Mosov, S. P., Kolesnikov, V. O. (2016). Vymohy do vyboru bezpilotnykh aviatsiinykh kompleksiv dlia vykonannya zavdan rozvidky ta sposterezhennia. Zbirnyk naukovykh prats Tsentru voienno-stratehichnykh doslidzhen Natsionalnoho universytetu oborony Ukrainy imeni Ivana Cherniakhovskoho, 1 (56), 24–28.
- [2] Mitrakhovich, M. M., Silkov, V. I., Samkov, A. V., Burshtynskaia, Kh. V. et. al.; Silkov, V. I. (Ed.) (2012). Bepilotnye aviatsionnye komplekсы: metodika sravnitelnoi otsenki boevykh vozmozhnostei. Kyiv: TSNII VVT VS Ukrainy, 288.
- [3] Mosov, S. P., Pohoretskyi, M. V., Salii, S. M., Sieliukov, O. V., Feshchenko, A. L.; Mosov, S. P. (Ed.) (2019). Bepilotna aviatsiia u viiskovii spravi. Kyiv: Interservis, 324.
- [4] Kyrylenko, V., Artiushyn, L., Steshenko, P. (2018). Matematychnyi aparat bahatokryterialnoho vyboru rozvidualnykh bezpilotnykh aviatsiinykh kompleksiv. Zbirnyk naukovykh prats Natsionalnoi akademii Derzhavnoi prykordonnoi Ukrainy. Serii: viiskovi ta tekhnichni nauky, 1 (75), 115–133.
- [5] Ananin, O. (2016). Taktyko-tekhnichni vymohy do bezpilotnykh aviatsiinykh kompleksiv ta yikh zavdannia v systemi okhorony derzhavnoho kordonu. Zbirnyk naukovykh prats Natsionalnoi akademii Derzhavnoi prykordonnoi Ukrainy. Serii: viiskovi ta tekhnichni nauky, 2 (68), 181–194.
- [6] Iliushko, V. M., Mitrakhovich, M. M., Samkov, A. V., Silkov, V. I. et. al. Silkov, V. I. (Ed.) (2009). Bepilotnye letatelnye apparaty: metodiki priblizhennykh raschetov osnovnykh parametrov i kharakteristik. Kyiv: TSNII VVT VS Ukrainy, 302.
- [7] Neroba, V. R. (2019). Systematyzatsiia umov i faktoriv, shcho vplyvatymut na vydovi tekhnichni zasoby rozvidky min bezpilotnoho litalnoho aparatu. Zbirnyk naukovykh prats Viiskovoi akademii, 2 (12 (1)), 48–54.
- [8] Dogerti, M. (2017). Drony: pervii illiustrirovannii putevoditel po BPLA. Moscow: Izd-vo «E», 224.
- [9] Pill, J. (1971). The Delphi method: Substance, context, a critique and an annotated bibliography. Socio-Economic Planning Sciences, 5 (1), 57–71. doi: [http://doi.org/10.1016/0038-0121\(71\)90041-3](http://doi.org/10.1016/0038-0121(71)90041-3)
- [10] Mitroff, I. I., Sagasti, F. (1973). Epistemology as General Systems Theory: An Approach to the Design of Complex Decision-Making Experiments. Philosophy of the Social Sciences, 3 (2), 117–134. doi: <http://doi.org/10.1177/004839317300300202>
- [11] Saati, T. (1993). Priniatie reshenii: metod analiza ierarkhii. Moscow: Radio i sviaz, 320.
- [12] Schedrovitskii, G. P. (1995). Izbrannye trudy. Moscow: Shk. Kult. Polit., 800.
- [13] Metod analiza ierarkhii onlain. Available at: <https://axd.semestr.ru/upr/hierarchies.php> Last accessed: 20.09.2019
- [14] Zahorka, O. M., Mosov, S. P., Sbitniev, A. I., Stuzhuk, P. I. (2005). Elementy doslidzhennia skladnykh system viiskovoho pryznachennia. Kyiv: NAOU, 100.

ANALYSIS OF FACTORS AND DEVELOPMENT OF METHODS FOR MANAGING THE ENVIRONMENTAL AND CIVIL SAFETY OF TRANSBOUNDARY TRANSPORTATION OF OIL AND OIL PRODUCTS THROUGH PIPELINES

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ARTICLE INFO

Article history:

Received date 09.09.2020

Accepted date 15.10.2020

Published date 30.10.2020

Section:

Waste Management and Disposal

DOI

10.21303/2313-8416.2020.001484

KEYWORDS

environmental safety

civil protection

emergency

oil transportation by pipelines

ABSTRACT

Transportation of oil and oil products through main pipelines is accompanied by the outpouring of these components into the environment, which creates risks of reducing the level of environmental safety and emergencies.

The object of research is the factors and methods of environmental and civil safety management of cross-border transportation of oil and oil products through pipelines.

Investigated problem is the analysis of environmental and civil safety management factors for cross-border transportation of oil and oil products through pipelines has been carried out and new technical and organizational solutions have been proposed to improve the level of management. The environmental safety of oil and gas facilities is defined as the state of environmentally safe functioning of oil and gas facilities and the absence of harmful environmental impact on these facilities. On the basis of the analysis of emergency situations on the linear part of the main oil pipelines, five main reasons leading to depressurization have been identified and ranked. The oil pipeline emergency is presented in a mathematical form. The analysis of depressurization of main oil pipelines in the world and in the Lviv region is carried out. The international normative legal acts regulating the management aspects of environmental and civil safety of cross-border transportation of oil and oil products are analyzed.

Innovative products – in case of water pollution as a result of a catastrophic inflow of oil products, it is proposed to use a patented installation for modeling the process of pollution of running water and a method of physical modeling of the process of spreading pollution as a result of a single discharge of oil products into the river. In the case of soil contamination with oil products, it was proposed to use a patented installation for modeling the process of filtration of contaminated solutions through the soil or bottom sediments. The advantages of the proposed new technical solutions based on known analogues are shown.

The area of practical use of the research results is the subdivisions of the Ministry of Environmental Protection and Natural Resources of Ukraine, the State Service of Ukraine for Emergency Situations, NJSC Naftogaz of Ukraine, higher educational institutions, research institutes of oil and gas ecological profile.

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1. Introduction

Transportation of oil and oil products through trunk pipelines is a complex organizational and technical process. Depressurization of oil pipelines causes pollution of environmental components, reduces the level of environmental safety and creates risks of emergencies. Improving the management of this process, including by introducing new technical solutions and ways facilitates the level of environmental and civil safety.

1. 1. The object of research

The object of research is the factors and methods of environmental and civil safety management of cross-border transportation of oil and oil products through pipelines.

1. 2. Problem description

The development of the oil and gas industry is impossible without the development of pipeline transport infrastructure. In such areas, the anthropogenic load is much higher and is comparable to agricultural or residential areas.

According to statistics, Ukraine annually consumes up to 10 million tons of oil and oil products, 40 thousand tons of which are officially recorded losses as a result of the outpourings [1]. Such outpourings are sources of soil, groundwater and surface water pollution [2, 3]. In case of contamination of territories near drinking water intakes, conditions for an emergency are created [4]. Therefore, the study of factors that lead to a decrease in the level of environmental and civil safety of transportation of oil and oil products through pipelines and the development of methods for managing these factors is an urgent task. The urgency of this task is significantly increasing in border areas, where an oil spill may subject the country to tough international sanctions.

1. 3. Suggested solution to the problem

The oil and gas industry of Ukraine is represented by 6 oil refineries with a total primary processing capacity of 51–54 million tons of oil per year [5]. The system of main oil pipelines of Ukraine includes 4767 km of oil pipelines (in single-line terms) with a diameter of up to 1220 mm inclusive [6].

In order to increase the level of environmental and civil safety at the enterprises of NJSC “Naftogaz of Ukraine”, a management policy has been developed. The elements of such management are emergency response units and services, voluntary fire brigades, persons responsible for the fire condition, regulations and instructions, conducting briefings and testing knowledge on fire and technological safety. The safety of work and emergency response at drilling, production, transportation, storage and processing facilities for oil and gas is ensured by emergency recovery and repair teams, a site, line maintenance services, and other emergency response units that are part of the structural units of enterprises. To prevent and eliminate emergencies, in 2018, helicopters overflew the pipeline route, bypassed pipeline sections by services, performed scheduled preventive and preventive maintenance, and reviewed hazardous areas [5]. All these measures significantly increase the level of environmental safety and civil security, however, the risks of emergencies of environmental genesis in such territories are still significant.

The aim of research is to analyze the factors of environmental and civil safety of cross-border transportation of oil and oil products through pipelines.

2. Materials and methods of research

To achieve the aim of research, the appropriate general scientific and special methods of scientific knowledge based on the principles of an objective, comprehensive and complex analysis of natural and technical processes and phenomena were used. The dialectical method made it possible to comprehensively and volumetrically study the formation of environmental and civil safety management factors for cross-border transportation of oil and oil products through oil pipelines, as well as to determine the objective causes of problems in the process of organizing the control system. The general scientific method of analysis made it possible to identify the causes of depressurization of oil pipelines, and the mathematical method of vector analysis – to mathematically describe an emergency situation on oil pipelines that occurs at a certain point in time. Methods of physical modeling and setting up experiments were used in the development of installations and a method of physical modeling. Generalization and induction methods are applied in the process of formulating conclusions.

3. Research results

Environmental safety of oil and gas facilities can be defined as the state of environmentally safe operation of oil and gas facilities and the absence of harmful environmental influ-

ences on these facilities. In areas with a high concentration of oil and gas facilities, environmental safety issues are closely interconnected with civil protection issues, since large-scale outpourings of oil and oil products lead to emergencies.

Having analyzed emergency situations on the linear part of the main oil pipelines, it is possible to identify and rank five main reasons leading to depressurization (**Fig. 1**).

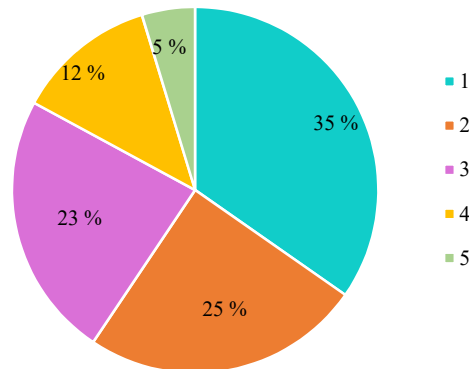


Fig. 1. Scheme of the main reasons for depressurization of main oil pipelines:

1 – external physical (force) actions on pipelines, including criminal tie-ins, which led to the origins – 34.7 %; 2 – violation of the norms and rules of work during construction and repair, deviations from design solutions – 24.7 %; 3 – corrosion damage to pipes, shut-off and control valves – 23.5 %; 4 – violation of technical conditions in the manufacture of pipes and equipment – 12.4 %; 5 – erroneous actions of the operating and maintenance personnel – 4.7 % (processed according to [7])

Proceeding from this and modifying the vector, an emergency situation on oil pipelines was proposed in [8], which occurs at a certain moment in time $E(t)$, can be represented in a tuple of the form:

$$\langle O(t), F(t), M(t), L(t) \rangle,$$

where $O(t)$ – the vector of state variables of the object at which the emergency occurred; $F(t)$ – vector of external destabilizing factors; $M(t)$ – the vector of control impacts aimed at reducing the scale of emergency situations; $L(t)$ – plan of emergency liquidation (localization), moreover:

$$F(t) = \begin{pmatrix} 0.347x_1(t) \\ 0.247x_2(t) \\ 0.235x_3(t) \\ 0.124x_4(t) \\ 0.047x_5(t) \end{pmatrix},$$

where x_1 – external physical (force) actions on pipelines, including criminal tie-ins that led to the origins, x_2 – violation of the rules and regulations for work during construction and repair, deviations from design solutions, x_3 – corrosion damage to pipes, shut-off and control valves, x_4 – violation of technical conditions in the manufacture of pipes and equipment, x_5 – erroneous actions of operating and maintenance personnel.

Losses of oil and oil products occur at all stages of oil usage. The most dangerous threats to the environment are associated with emergency oil outflows that occur during the operation of oil pipelines and are accompanied by the ingress of spilled oil into water bodies.

According to the Lviv State Inspection for 2016–2019, on the territory of the Lviv region there were 6 emergency situations caused by illegal tie-ins into pipeline transport. As a result of such incisions, 7502 m² of land and surface waters of the Yablunivka and Struga rivers were polluted.

In world history, there are numerous examples of emergencies caused by the leakage of oil or oil products. According to [7], December 5, 2014, on the Ashkelon-Eilat oil pipeline in southern Israel, as a result of unsuccessful repair work on a ruptured pipe, 21.9 thousand barrels of oil spilled into the Arava desert, which caused economic damage in the amount of 7.6 million USD, catastrophic pollution of environmental zones, hospitalization of more than 80 people (Fig. 2).



Fig. 2. Results of the accident at the Ashkelon-Eilat oil pipeline (photo by the Israeli Ministry of Ecology): *a* – view from a height of 1.5 m; *b* – view from a height of 600 m

Technical solutions and measures have been developed to improve the level of environmental and civil safety management of cross-border transportation of oil and oil products through pipelines.

In case of water pollution as a result of a catastrophic inflow of oil products, an installation has been developed for modeling the process of pollution of running water [9] and a method for physical modeling of the process of spreading pollution as a result of a single discharge of oil products into the river [10].

In contrast to the known analogous installations for modeling, the proposed installation makes it possible to simulate the propagation of contamination in two-phase system water - bottom sediments and to control the speed of water movement, which increases the reliability of the results (Fig. 3). Taken together, the patented installation and method make it possible to quickly predict the dynamics of a natural-man-made system that has undergone man-made impact, including as a result of depressurization of the oil pipeline.

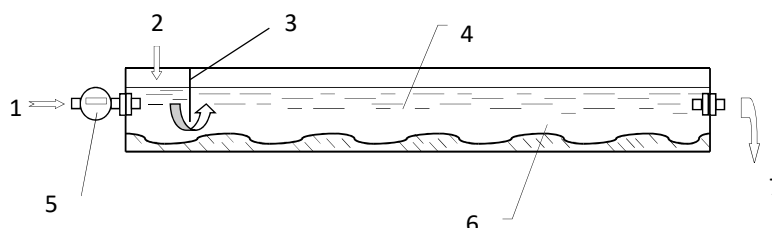


Fig. 3. Longitudinal section of the installation, physically simulates the process of river pollution by emergency discharge of pollutants:
1 – water supply hole, 2 – section for introducing pollutant, 3 – partition,
4 – water flow with pollutant, 5 – water meter, 6 – bottom sediments,
7 – water outlet

In case of soil contamination, let's propose to use an installation for modeling the process of filtration of contaminated solutions through the soil or bottom sediments [11]. The installation makes it possible to physically simulate the penetration of pollutants through the soil (Fig. 4).

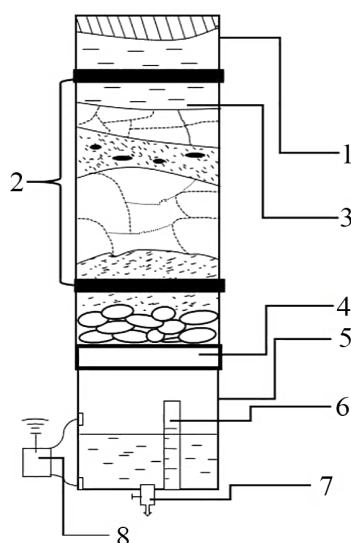


Fig. 4. Cross-section of an installation that simulates the process of soil pollution by emergency discharge of pollutants: 1 – container with chemically inert material, 2 – fastening system, 3 – first compartment, 4 – filter system, 5 – second compartment, 6 – filling level scale, 7 – tap for collecting and draining water, 8 – water level sensor

4. Discussion

At the present stage, the problems of environmental and civil security go far beyond national borders and have a transboundary, regional or even global character. The world community is trying to solve such problems by means of instruments for the adoption and implementation of international legal acts. International treaties are the main source of international law. In Ukraine, they are part of national legislation and are applied in the manner prescribed for the norms of national legislation [12]. The authors analyzed the international normative legal acts that regulate aspects of environmental and civil security of cross-border transportation of oil and oil products. The main ones are:

- international Convention on Intervention on the High Seas in Cases of Oil Pollution Accidents;
- convention for the Protection of the Black Sea against Pollution. Protocol on Cooperation in Combating Pollution of the Black Sea Marine Environment by Oil and Other Harmful Substances in Emergency Situations;
- international Convention on Civil Liability for Oil Pollution Damage.

International conventions and protocols are analyzed that make a positive contribution to improving environmental and civil safety in water bodies, but none of these documents contain mechanisms to compensate for the harm that can occur as a result of industrial accidents on an international scale.

Since September 1, 2017, the Association Agreement between Ukraine and the EU is in effect. Cooperation in the field of environmental protection is provided for in Articles 292–293 of Chapter 13 “Trade for Sustainable Development”, Chapter 6 “Environment” of Section V “Economic and Industrial Cooperation” of the Association Agreement, and Annexes XXX and XXXI.

Cooperation aims at preserving, protecting, improving and reproducing the quality of the environment, protecting public health, prudent and rational use of natural resources and encouraging measures at the international level aimed at solving regional and global environmental problems. The parties pay special attention to issues of a transboundary nature [13].

According to the Transition Book 2019 “European and Euro-Atlantic integration” [14], the main tasks for Ukraine, among others, are the rational management of water resources.

The proposed solutions have a number of limitations. International treaties are capable of increasing the level of environmental and civil safety only if they are unconditionally fulfilled by all parties. The proposed installations of physical modeling, which are designed to reduce the time and increase the validity of management decisions in the event of an oil spill, do not provide for the possibility of changing pressure, which makes it impossible to use them for physical modeling in conditions of deep horizons.

Prospects for further research lie in the area of developing a methodology for managing environmental and civil security of cross-border transportation of oil and oil products through pipelines.

6. Conclusions

1. Transportation of oil and oil products through main pipelines creates risks of lowering the level of environmental safety and emergencies.

2. Environmental safety of oil and gas facilities, this is the state of environmentally safe operation of oil and gas facilities and the absence of harmful environmental influences on these facilities.

3. An emergency situation on oil pipelines that occurs at a certain point in time $E(t)$ can be represented in a tuple of the form $\langle O(t), F(t), M(t), L(t) \rangle$, where $O(t)$ – vector of state variables of the object on which the emergency occurred; $F(t)$ – vector of external destabilizing factors; $M(t)$ – vector of control impacts aimed at reducing the scale of emergency situations; $L(t)$ – plan of emergency liquidation (localization).

4. In the case of water pollution as a result of a catastrophic inflow of oil products, it is advisable to use an installation for modeling the process of pollution of running water and a method of physical modeling of the process of spreading pollution as a result of a single discharge of oil products into the river.

5. In the case of soil contamination, it is advisable to use an installation for modeling the process of filtration of contaminated solutions through the soil or bottom sediments.

References

- [1] Derzhavna sluzhba statystyky Ukrainy (2016). Statystychnyi shchorichnyk Ukrainy. Kyiv. Available at: <http://www.ukrstat.gov.ua/>
- [2] Sokolov, Y. V., Shevchenko R. I., Madani, M. M. (2020). Ecological assessment of the territorial complexes of Tatarbunars'kyi District of Odessa region. Visnyk of V. N. Karazin Kharkiv National University, Series «Geology. Geography. Ecology», 52, 216–235. doi: <http://doi.org/10.26565/2410-7360-2020-52-16>
- [3] Malovanyy, M., Petrushka, K., Petrushka, I. (2019). Improvement of Adsorption-Ion-Exchange Processes for Waste and Mine Water Purification. Chemistry & Chemical Technology, 13 (3), 372–376. doi: <http://doi.org/10.23939/chcht13.03.372>
- [4] Karabyn, V., Popovych, V., Shainoha, I., Lazaruk, Ya. (2019). Long-term monitoring of oil contamination of profile-differentiated soils on the site of influence of oil-and-gas wells in the central part of the Boryslav-Pokuttya oil-and-gas bearing area. Petroleum and Coal, 61 (1), 81–89.
- [5] Ministerstvo zakhystu dovkillia ta pryrodnykh resursiv Ukrainy (2019). Natsionalna dopovid pro stan navkolyshnoho pryrodnoho seredovyshcha v Ukraini u 2018 rotsi. Kyiv. Available at: <https://mepr.gov.ua/timeline/Zviti.html>
- [6] Ukrainnyi naukovo-doslidnyi instytut tsyvilnoho zakhystu. (2019). Analitichnyi ohliad stanu tekhnogennoi ta pryrodnoi bezpeky v Ukraini za 2018 rik. Kyiv. Available at: <https://www.dsns.gov.ua/ua/Analitichnyi-oglyad-stanu-tehnogennoi-ta-prirodnoi-bezpeky-v-Ukrayini-za-2015-rik.html>
- [7] Zhdek, A. Ya. (2017). Otsinka vtrat nafty vid vytokiv pry transportuvanni i rozrobka zakhodiv yikh skorochennia. Ivano-Frankivsk, 165.
- [8] Skrypnyk I. V. et. al. (1997). Ydentyfikatsiya y modelyrovanye upravliayushchykh system. NAN Ukrainy. Kyiv: Naukova dumka.
- [9] Karabyn V. V., Sysa L. V., Rak Yu. M. (2018). Pat. No. 123043 UA. Ustanovka dlia modeliuvannia protsesu zabrudnennia protichnoi richkovoï vody. MPK: G09B 23/12, G01N 33/24, G01N 33/18. No. u 2017 07530. declared: 17.07.2017; published: 12.02.2018, Bul. No. 3.
- [10] Karabyn, V. V., Sysa, L. V., Rak, Yu. M. (2017). Pat. No. 123350 UA. Sposib fizychnoho modeliuvannia protsesu poshyrennia zabrudnennia vnaslidok odnorazovoho skydu naftoproduktiv u richku. No. u201708610; declared: 23.08.2017; published: 26.02.2018, Bul. No. 4. Available at: <https://base.uipv.org/searchINV/search.php?action=viewdetails&IdClaim=244532>
- [11] Shuryhin, V. I., Karabyn, V. V., Sysa, L. V. (2020). Pat. No. 143139 UA. Ustanovka dlia fizychnoho modeliuvannia protsesu filtratsiyi zabrudnennykh rozchyniv cherez tovshchu gruntu abo donnykh vidkladiv. No. u202001006; declared: 17.02.2020; published: 10.07.2020, Bul. No. 13. Available at: <https://base.uipv.org/searchINV/search.php?action=viewdetails&IdClaim=269733>
- [12] Andrusyevych, A., Andrusyevych, N., Kozak, Z. (2009). Dovidnyk chynnykh mizhnarodnykh dohovoriv Ukrainy u sferi okhorony dovkillia. Lviv, 203.
- [13] Uhoda pro asotsiatsiiu mizh Ukrainoiu, z odniiei storony, ta Yevropeiskym Soiuzom, Yevropeiskym spivtovarystvom z atomnoi enerhii i yikhnyimi derzhavamy-chlenamy, z inshoi storony. Rozd. VI st. 361 (2014). Available at: https://zakon.rada.gov.ua/laws/show/984_011#Text
- [14] Yevropeiska ta yevroatlantychna intehratsiia (2019). Kabinet Ministriv Ukrainy. Kyiv. Available at: <https://www.kmu.gov.ua/storage/app/sites/1/17-prezentation-2019/8.2019/transition-book-final-stisnuto.pdf>

INTEGRATED USE OF MAGNETITE IN ENVIRONMENTAL PROTECTION MEASURES

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ARTICLE INFO

Article history:

Received date 23.09.2020

Accepted date 20.10.2020

Published date 30.10.2020

Section:

Waste Management and Disposal

DOI

10.21303/2313-8416.2020.001462

KEY WORDS

iron-containing solutions
ferrite method
magnetite
flue gases
carbon monoxide
build-up method
catalyst
red lead

ABSTRACT

The object of research: magnetite obtained by using the ferritic method for the purification of iron-containing solutions.

Problem to be solved: a comprehensive solution to the problem of using magnetite, obtained as a result of using the ferrite method for purifying iron-containing solutions, as a catalyst for the oxidation of carbon monoxide and its further utilization in the production of building materials.

The main scientific results: it has been shown that the magnetite precipitate formed during the processing of pickling solutions by the ferrite method can be used as a cheap, affordable and effective catalyst for the oxidation of carbon monoxide from flue gases of industrial enterprises, the disposal of which after long-term use does not create problems due to its stability and inertness.

Field of practical use of research results: the use of the ferrite method in the purification of pickling solutions of metallurgical enterprises provides not only an increase in the efficiency of water purification, but also leads to the introduction of waste-free technology. The decisive factor will be the use of magnetite as sludge of the use of ferrite technology to solve the problem of reducing flue gas emissions from the production of electrodes for the metallurgical industry, which include toxic carbon monoxide.

Innovative technology product: waste-free technology for the processing of pickling solutions by the ferrite method with the formation of a product with magnetic and catalytic properties, further processing of which consists in using red lead iron as a pigment in the production of building materials.

Scope of the innovative technology product: oxidation of carbon monoxide from industrial flue gases, followed by the use of red lead as a pigment.

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1. Introduction

1.1. The object of research

Magnetite obtained as a result of the use of the ferrite method for the purification of iron-containing solutions.

1.2. Problem description

To date, the pace of development of metallurgical production in Ukraine is significantly ahead of the development and implementation of the latest technologies for wastewater treatment and processing of formed sludge. The widespread introduction of reagent cleaning technology has led to the accumulation of millions of tons of liquid waste in the environment, the cost of which

increases annually. In addition, existing disposal methods do not always provide reliable isolation of sludge from the environment [1]. The use of the ferrite method even at already existing treatment facilities can provide not only an increase in the efficiency of water treatment, but also lead to the introduction of waste-free technology. Only such technology can be considered environmentally friendly if its application does not lead to environmental pollution with harmful residues. In the event of the formation of such residues, they must be converted into substances that are safe for the biosphere, or even better, reused after additional processing in other technologies. According to the authors' conclusion [2], the operating costs for the implementation of the ferrite method are slightly higher than when using the traditional reagent method. Therefore, it may turn out that the regeneration of magnetite is not economically viable. Only with the use of large-scale, continuously operating enterprises can this process become feasible.

1.3. Suggested solution to the problem

As studies show [3, 4], the use of ferritic sludge has a good potential for environmental use as a valuable raw material for catalysts for CO oxidation. The total number of applications of nanoferrite technologies for catalytic purposes is still relatively small; therefore, the development of effective solutions can become an ideal research niche for the introduction of ferritic nanomaterials into production for the neutralization of flue gas carbon monoxide [4]. After being used as an oxidizer with a low sensitivity to catalytic poisons, the direction of disposal of the residues of such technologies is determined, first of all, by their toxicity. The value of ferrite as a promising material from the point of view of environmental catalysis is undeniable, since if it is used, there will be no problems with its operation and utilization, since ferrite is not toxic and has limited biodegradability [3].

Despite the fact that in Ukraine there are several industrial plants using the ferritic method of water purification, there are practically no data on the feasibility of its industrial application, given the further handling of the formed sludge. The essence of the ferrite method for purifying iron-containing solutions is to treat them with appropriate reagents, which, upon further regulation of the conditions in the solution, cause the formation of highly dispersed magnetite particles with magnetic properties. When synthesizing magnetite, it was found that the maximum magnetic properties are possessed by particles obtained with the ratio $K=[Fe^{2+}]/[Fe^{3+}]=0.5$, that is, in accordance with the ratio in magnetite of natural origin, contains 31.03 % FeO and 68, 97 % Fe_2O_3 . Obviously, with such a ratio, magnetite has the most ordered structure [5]. Magnetite is a fairly stable compound [6], insoluble in water either at 20 or at 100 °C. It is also insoluble in ethyl alcohol, diethyl ether and reacts weakly with acids. When heated in air to 150 °C, magnetite transforms into iron oxide Fe_2O_3 [1].

The process of obtaining magnetic particles of high dispersion from a mixture of divalent and trivalent iron ions by precipitation with alkali with constant stirring is currently well developed and is of industrial importance. Despite the fact that the process of magnetite synthesis from a mixture of iron salt solutions is rather fast, the influence of various factors on its course remains significant. In this regard, it is possible to obtain precipitation with strictly planned characteristics in advance only if the corresponding conditions are strictly observed. However, the mechanisms of formation of magnetite particles and their aging have not yet been sufficiently studied in this case. The main reason here is the complexity of ferritization processes and their dependence on many technological factors. Of great importance in ferritization processes is the reagent used for precipitation. In the series KOH, NaOH, LiOH, NH_4OH , the magnetic properties of the deposited particles increase [7]. Magnetite precipitated with ammonia has the maximum magnetic properties. In order to accelerate the process and improve the quality of the precipitate, it is necessary to maintain the ratio between ferrous and ferric iron as 1:2, and sedimentation should be carried out at pH=9–11 [8]. In real technologies, the amount of alkali is always taken in excess compared to the stoichiometric one. Therefore, when obtaining magnetite by this method, the pH of the mixture is controlled. In most real technologies, these boundaries are significantly narrowed and, of course, pH=9–10, which is associated with the need to comply with the total content of anions in the treated waters at levels below the MPC.

The aim of research is to substantiate the complex use of magnetite obtained by using the ferrite method of water purification in a closed cycle in various environmental technologies.

2. Materials and methods

Magnetite was obtained by chemical condensation. For the synthesis of magnetite particles, weighed portions of $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ and $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ salts with a total concentration of iron ions of 5 g/dm^3 at a concentration ratio $K=[\text{Fe}^{2+}]/[\text{Fe}^{3+}]=0,01\text{--}3$ were dissolved in distilled water and at a temperature of $30\text{--}35^\circ\text{C}$, the resulting mixture was treated with an ammonia solution until a pH value of $9,5\text{--}10$ was established. As a result of such treatment, fractions of magnetite were formed in the solution in accordance with the reaction:



The resulting suspension of magnetite particles for “maturation” was left in the mother liquor for 30 minutes, after which the solid phase was separated by decantation, washed with distilled water until neutral and dried at room temperature with access to atmospheric air.

Measurements of the magnetic characteristics of the deposit were carried out using the method [9]. The diagram of the device for measuring the relative magnetic characteristics is shown in **Fig. 1**.

The operation of the device is based on measuring the increase in the inductance of the coil when a sample of a magnetite suspension is introduced into its working volume. The growth rate was determined by the formula:

$$L = L_i - L_o, \quad (2)$$

where L_i – the inductance of the coil when a test tube with sediment is inserted into it; L_o – the inductance of the coil before the test tube is inserted into it.

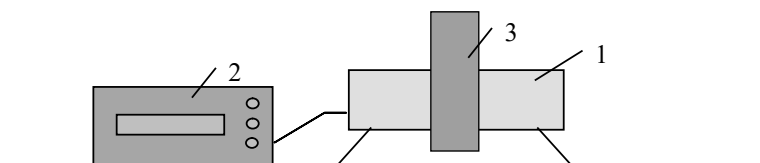


Fig. 1. Diagram of the device for measuring the relative magnetic properties of colloidal solutions: 1 – inductance coil; 2 – AC bridge; 3 – test tube with magnetite suspension solution

The relative magnetic properties of the sediment were calculated using the formula:

$$\chi/\chi_{\max} = L/L_{\max}, \quad (3)$$

where L – an increase in the inductance of the coil of a separate measurement of this series of studies when a test tube with sediment is introduced into it; $L_{\max}$ – the maximum increase in the inductance of the coil according to the measurements of this series of studies when a test tube with sediment is introduced into it.

At all stages of research on the presence of magnetic properties, the actual value of the Cochran criterion was greater than the calculated one.

The granulometric composition of the solid phase was determined by the photoelectric method according to [10].

When studying the processes of washing from excess magnetite salts obtained by chemical condensation, the sediment was washed several times with distilled water, the volume of which was equal to the volume of the separated mother liquor with a proportional decrease in the amount of precipitate taken for analysis, to a neutral reaction, and dried at room temperature with access to atmospheric air.

The size of the synthesized magnetite particles was increased by growing layers by mixing these particles with a similar dose of the initial solution of iron ions and re-precipitating the suspension with alkali. The granulation of the magnetite suspension by freezing was carried out at a temperature of -10°C . The thawing process proceeded until the liquid phase completely drained off at a temperature of 20°C .

To study the conversion of CO to CO₂ using catalysts based on magnetite, let's use the laboratory device shown in **Fig. 2**. The device consists of a heat chamber 4, made of a stainless steel pipe 6 and a ceramic pipe 7, inside which a heating element is located 3. A system for maintaining a given temperature during the experiment, including thermocouples 5 and a temperature controller 8. By adjusting the duration of the heating element 3, the system maintains the set temperature. A sample of the catalyst under study was poured into a cylindrical container 2 and fixed in a metal tube 6 in such a way as to exclude the passage of a model gas mixture past the catalyst. The volumetric velocity of the model gas flow was changed in the range of 1–5 dm³/min and was measured using gas flow meters 9. During the experiment, using a gas analyzer 1, the content of the components of the gas mixture at the inlet and outlet of the heat chamber was determined. In some cases, molecular nitrogen was additionally used as an inert gas. The concentration of the components of the gas mixture before and after the reaction was analyzed with an accuracy of ± 20 ppm or ± 5 % of the measured values. To stabilize the conditions of the experiment, before carrying out the catalyst, the proportions of the catalyst were calcined without oxygen for 2 hours at a temperature of 450 °C, determining the weight loss of the catalyst. The studies were carried out in the temperature range 200–400 °C. The molar fraction of carbon monoxide in the model gas mixture at the reactor inlet was maintained at 1.1.

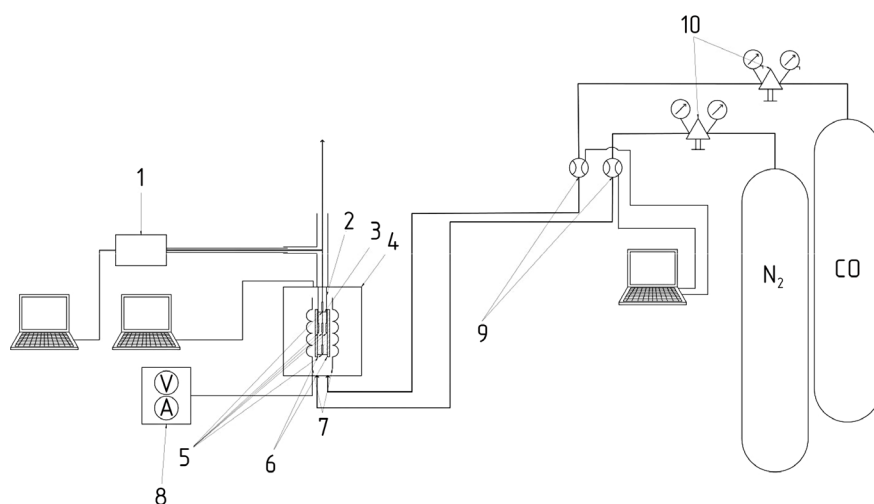


Fig. 2. Diagram of a laboratory device for studying the processes of catalytic oxidation of carbon monoxide: 1 – gas analyzer VARIO PLUS industrial analyzer MRU air fair (Germany); 2 – catalyst container made of stainless steel mesh; 3 – heating element; 4 – heat chamber; 5 – thermocouples; 6 – stainless steel pipe; 7 – ceramic pipe; 8 – temperature controller; 9 – gas flow meters; 10 – reducers

The oxidation state of carbon monoxide was calculated in accordance with the formula:

$$X_{\text{CO}} = \frac{C_{\text{CO}}^{\text{in}} - C_{\text{CO}}^{\text{out}}}{C_{\text{CO}}^{\text{in}}} \cdot 100 \%, \quad (4)$$

where $\tilde{N}_{\text{Ni}}^{\text{in}}$ – the mole fraction of CO at the reactor inlet; $\tilde{N}_{\text{Ni}}^{\text{out}}$ – the mole fraction of CO at the reactor outlet.

Determination of the physicochemical characteristics of the spent catalyst for use as a red lead pigment, such as the weight fraction of iron oxide, water and volatile substances, the weight fraction of substances soluble in water, the pH of the aqueous extract, the weight fraction of chlorine compounds in terms of Cl, total sulfur in terms of SO₄, oil absorption, hiding power of the pigment was carried out according to the methods given in DSTU 1438-94.

2. 1. Experimental procedures

Previous studies have established [1] that in the range of $K=0.01$ – 3.0 precipitation has magnetic properties. At $K>3.0$, no magnetic properties were recorded in the resulting precipitation. But

even in this narrow K range, the magnetic properties of precipitation vary rather unevenly (**Fig. 3**). Moreover, a stable relationship between the magnetic properties and the volume of the sediment was noted. At maximum magnetic properties, the sediment volume is minimal and vice versa. It is clear that the use of sediments obtained with a ratio of $K < 0.1$ and $K > 2.4$ is very problematic due to the low magnetic properties and in connection with the complication of the use of magnetic separation equipment for their removal. So, the best magnetic properties have precipitations obtained at $K = 0.5$, which fully confirms the conclusions of the authors [5].

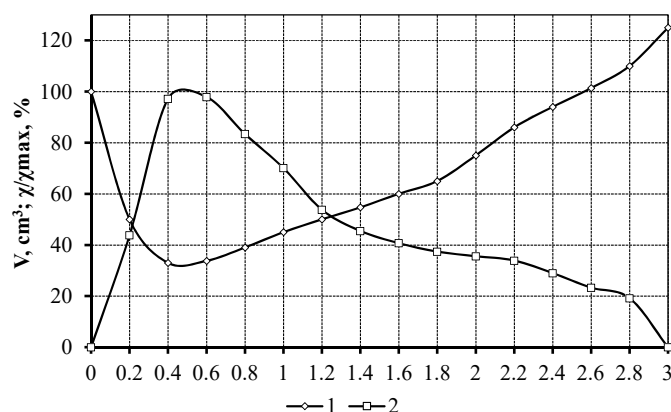


Fig. 3. Dependence of the relative magnetic properties of the magnetite deposit $1 - \chi/\chi_{\text{max}}$ and its volume (2 - V) on the concentration ratio $K = [\text{Fe}^{2+}]/[\text{Fe}^{3+}]$

As further studies show, in the case of using ammonia at its amounts lower than stoichiometric, the precipitate does not exhibit magnetic properties (**Fig. 4**). An increase in the amount of ammonia leads to an abrupt growth. Moreover, a significant increase in the amount of alkali practically does not change the magnetic properties of the sediment. Thus, when obtaining magnetite by this method, the pH of the mixture can fluctuate within the range of 9.0–12.0, however, in real technology, these boundaries must be maintained at $\text{pH} = 9.0$ – 10.0 , which is associated with the need to comply with the minimum salt content to reduce the cost of carrying out the processes of laundering magnetite. The expediency of maintaining the pH at this level is also justified from considerations of maintaining the total content of sulfate and chloride anions in purified iron-containing solutions at levels below the maximum permissible concentration for discharge into the sewer.

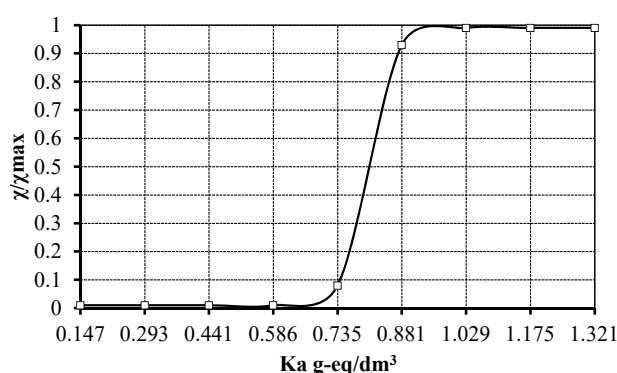


Fig. 4. Dependence of the relative magnetic properties of the magnetite suspension χ/χ_{max} on the ammonia concentration K_a

When studying the processes of washing magnetite obtained by chemical condensation from excess salts, it was determined (**Fig. 5**), after washing the sediment in a fivefold amount, the mass fraction of magnetite was increased from 69.84 to 94.49 %, and the mass fraction of sulfate and chloride anions decreased from 4.67 to 0.045 % and 3.59 to 0.12 %, respectively. The pH of the solution in this case varied from 11.4 to 7.4.

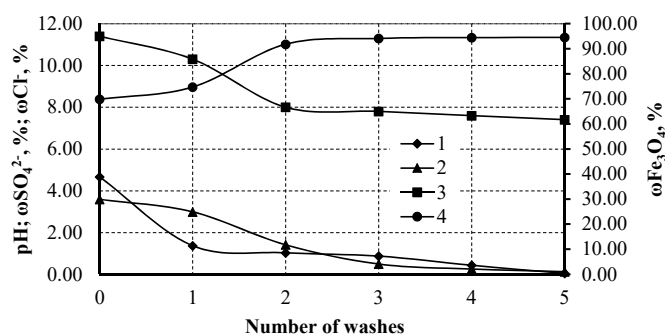


Fig. 5. Dependence of the mass fraction of sulfate anions ωSO_4^{2-} (1), chloride anions ωCl^- (2), pH (3) and the mass fraction of magnetite $\omega\text{Fe}_3\text{O}_4$ (4) on the number of washes

3. Results

When studying the processes of catalytic conversion of CO into CO_2 using wash from excess magnetite salts, it was determined that the oxidation state significantly depends on the rate of passage of the gas flow through the catalyst (**Fig. 6**). The maximum oxidation state of carbon monoxide is achieved at 400 °C and is 49 %.

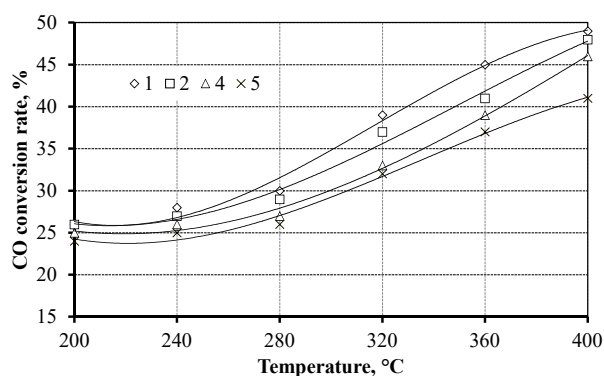


Fig. 6. Dependence of the oxidation state of carbon monoxide when using magnetite as a catalyst on temperature and volumetric gas flow rate in the range of 1, 2, 4, 5 dm^3/min

However, the use of magnetite as a catalyst causes difficulties from the technological point of view due to the significant energy consumption for creating the necessary excess pressure of the gas stream to pass through the highly dispersed material. As studies have shown (**Fig. 7**), the content of magnetite particles obtained by traditional chemical deposition with a size of 20, 30, and 40 μm is 38, 8, and 4 %, respectively, while the increase in the size of magnetite particles upon repeated processing by the method described above was not accompanied by significant effect. After three cycles of this treatment, the content of 20 μm particles decreased by 7 %, and the content of 40 μm particles increased by 5 %. According to the study of the passage of a gas flow using magnetite obtained by growing, then under the same experimental conditions the increase in speed is less than 1 %. Therefore, taking into account the complexity of the build-up process and the additional consumption of reagents, the use of the build-up method in the processes of obtaining a catalyst for the oxidation of carbon monoxide is irrational.

When applying the method of freezing and thawing a magnetite suspension (**Fig. 7**), it was determined that the content of magnetite particles with a size of 20, 30 and 40 μm was, respectively, 4, 30 and 7 %, and a significant increase in the content of particles of greater dispersion was also noted. At the same time, the indicated change in the granulometric composition of magnetite made it possible to increase the speed of the gas flow by 5–7 %, all other conditions being equal.

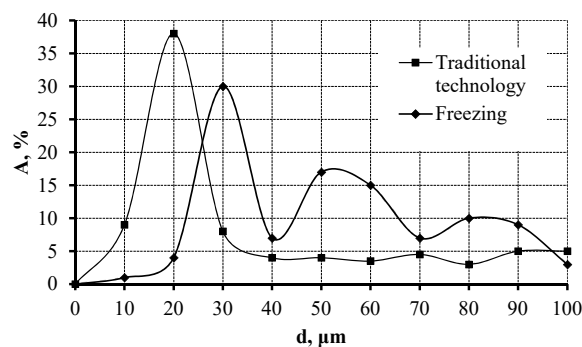


Fig. 7. Granulometric composition of magnetite obtained by the traditional method of chemical condensation and subsequent freezing

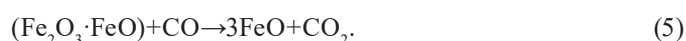
4. Discussion

Even in the case of an increase in the content of particles of greater dispersion, changes in the rate of passage of a gas flow through a highly dispersed material of magnetite are insignificant and can't radically affect the technological process. Unfortunately, massive iron oxides also have a small surface area, which, as a rule, does not exceed several m^2/g , which limits their effectiveness as catalysts for the complete oxidation of carbon monoxide [11]. An effective way to solve these problems is the nanostructuring of the active catalyst component by applying it to an inert matrix with a developed specific surface area.

Thus, for real catalytic installations, it will be more acceptable to apply magnetite on support granules with appropriate physical properties, for example, zeolite [11, 12], which will be considered in subsequent studies. As shown in [11], when deposited on microporous zeolite NaY iron oxides ($\gamma\text{-Fe}_2\text{O}_3$ and $\text{Fe}_2\text{O}_3 \cdot \text{FeO}$) with a content of 0.12 % at 300 °C, a level of 50 % CO conversion is achieved, and 100 % occurs at 350 °C.

In addition, during the industrial operation of catalysts for neutralizing CO gas emissions based on magnetite, emergency situations may arise due to significant changes in the composition of the gas being purified, as exemplified by a high CO_2 content. In this case, the activity of the catalyst can decrease by 15–20 % [13].

If to take into account that magnetite consists of $\text{Fe}_2\text{O}_3 \cdot \text{FeO}$, then the oxidation reaction of carbon monoxide using magnetite particles will be as follows:



Regeneration of the poisoned catalyst must be carried out with clean air for 4 hours at a temperature of 25 °C with a feed rate of 1 m^3/h [13] according to the reaction:



As studies show, when using the specified regeneration path, almost complete recovery of the catalyst activity is guaranteed and the ability to regenerate directly during operation without the need for unloading is confirmed [13]. But this technological operation leads to additional material costs for the process of catalytic oxidation of CO.

However, in spite of the above, it can be summarized that a significant advantage of catalytic systems based on magnetite is the presence of magnetic properties, which make it easy to remove them from the reaction medium using a magnet and reuse several runs with almost no loss of catalytic activity [14].

After using magnetite as a catalyst, it is necessary to ensure its further use in the production of building materials. An expedient way of utilizing ferrite material is its use as a pigment of "red lead", since when heated in air above 150 °C, magnetite transforms into iron oxide Fe_2O_3 . It was found that the characteristics of magnetite in almost most of the parameters meet the requirements of the DSTU 1438-94 standard [1]. Relatively slightly increased oil

content (35 g per 100 g of “red lead”) and hiding power (29 g/m²), which is especially typical for magnetite particles without additional processing, they can be neglected, given the relative cheapness of the pigment and the simultaneous solution of environmental problems. Thus, the magnetite precipitate can be used as a pigment for the preparation of oil paints of the MA-15 type “red lead”.

5. Conclusions

Thus, it follows from the above that magnetite is a material for complex use and can be used in a closed cycle in various environmental technologies based on:

1) the formation of high dispersion magnetic particles during the processing of pickling solutions by the ferrite method, which can significantly reduce the duration of the cleaning process, simplify it and increase the productivity of equipment. This also eliminates the need to control the course of the reaction of the formation of magnetic particles, since their characteristics are determined by the composition of the initial solutions and the conditions of their deposition;

2) the use of magnetite sediment as a cheap, affordable and effective catalyst for the oxidation of carbon monoxide from flue gases of industrial enterprises, the disposal of which after long-term use does not create problems due to its stability and inertness. By additional treatment of the magnetite sediment by washing from sulfate and chloride anions, the concentration of magnetite in the suspension is achieved, which significantly improves the physico-chemical parameters of the ferrite treatment sludge. To regulate the granulometric composition of the magnetic material, along with the growth method, it is better to use the freeze-thaw process, which eliminates the additional consumption of reagents and significant environmental problems with the formation of additional wastewater;

3) placement of magnetite as a catalyst for CO oxidation in containers of rectangular cross-section in the firing channels of furnaces for firing electrodes in chambers heated by flue gases;

4) utilization of magnetite in the manufacture of building materials as a pigment in the preparation of oil paints such as MA-15 “red lead”, which is confirmed by compliance with most of the indicators to the requirements of the DSTU 1438-94 standard. Due to the slightly increased oil content and hiding power, which is especially characteristic of magnetite particles without additional processing, they can be neglected, given the relative cheapness of the pigment and the simultaneous solution of environmental problems.

Thus, it is possible to summarize that the innovative technological product of this work is a fundamentally waste-free technology for processing pickling solutions by the ferrite method with the formation of a product with magnetic and catalytic properties, the further processing of which is used in the production of building materials. The ecological feasibility of creating such an innovative product is due to the possibility of widespread introduction into industrial production.

References

- [1] Radovenchyk, V. M., Ivanenko, O. I., Radovenchyk, Ya. V., Krysenko, T. V. (2020). Zastosuvannia ferytnykh materialiv v protsesakh ochyshchennia vody. Bila Tserkva: Vydavnytstvo O. V. Pshonkivskyi, 215.
- [2] Tekhnologiia ochistki stochnykh vod ot ionov tiazhelykh metallov metodom ferritizatsii. Available at: <http://www.aqua-promspb.ru/vou/reagentnaya-obrabotka> Last accessed: 25.10.2020
- [3] Lou, J.-C., Chang, C.-K. (2006). Catalytic Oxidation of CO Over a Catalyst Produced in the Ferrite Process. *Environmental Engineering Science*, 23 (6), 1024–1032. doi: <http://doi.org/10.1089/ees.2006.23.1024>
- [4] Ivanenko, O. I., Nosachova, Yu. V., Overchenko, T. A., Nakonechna, M. V. (2020). Features of the use of catalysts of various types in the processes of neutralization of carbon monoxide of flue gases. *Proceedings of the NTUU “Igor Sikorsky KPI”. Series: Chemical Engineering, Ecology and Resource Saving*, 1 (19), 22–42. doi: <http://doi.org/10.20535/2617-9741.1.2020.207808>
- [5] Kunevich, A. V., Podolskii, A. V., Sidorov, I. N. (2004). *Ferrity: Entsiklopedicheskii spravochnik. Magnity i magnitnye sistemy*. Vol. 1. Saint Petersburg: Izdatelstvo «Lik», 358.
- [6] Betekhtin, A. G. (2007). *Kurs mineralogii*. Moscow: Knizhnii dom “Universitet”, 721.

- [7] Petrakova, A. V., Urusov, A. E., Kostenko, S. N., Pridvorova, S. M., Vasilev, M. A., Zherdev, A. V. (2013). Sintez magnitnykh nanochastits oksida zheleza dlia primeneniia v immunoanalize. *Sovremennye problemy nauki i obrazovaniia*, 5. Available at: <http://www.science-education.ru/ru/article/view?id=10559> Last accessed: 25.10.2020
- [8] Hyeon, T. (2002). Chemical synthesis of magnetic nanoparticles. *Chemical Communications*, 8, 927–934. doi: 3<http://doi.org/10.1039/b207789b>
- [9] Dikanskii, Iu. I., Zakinian, A. R., Konstantinova, N. Iu. (2008). O magnitnoi pronitsaemosti magnitodielektricheskoi emulsii. *Zhurnal tekhnicheskoi fiziki*, 78 (1), 21–26.
- [10] Radovenchik, Ia. V., Romanenko, M. I., Radovenchik, V. M. (2017). Zalizomistki sorbenti dlia ochischennia vodi vid naftoproduktiv. *Ekologiya i promyshlennost*, 1 (50), 74–80.
- [11] Akhlebinina, A. A., Moskovskaia, I. F., Iuschenko, V. V., Romanovskii, B. V. (2006). Kataliticheskoe okislenie metanola na vysokodispersnom okside zheleza v mikro- i mezoporistykh molekuliarnykh sitakh. *Zhurnal fizicheskoi khimii*, 80 (1), 72–76.
- [12] Ivanenko, O., Gomelya, N., Panov, Y., Overchenko, T. (2020). Technical solutions for reducing emissions of carbon monoxide with flue gases of furnaces for baking electrodes. *Bulletin of the National Technical University «KhPI». Series: New Solutions in Modern Technology*, 3 (5), 45–52. doi: <http://doi.org/10.20998/2413-4295.2020.01.07>
- [13] Petrov, A. Iu., Sinitsin, S. A. (2014). Kataliticheskaiia detoksikatsiia dymovykh gazov v neftepererabatyvaiuschei promyshlennosti. *Tekhnologiya nefi i gaza*, 2 (91), 18–23.
- [14] Kharisov, B. I., Dias, H. V. R., Kharissova, O. V. (2019). Mini-review: Ferrite nanoparticles in the catalysis. *Arabian Journal of Chemistry*, 12 (7), 1234–1246. doi: <http://doi.org/10.1016/j.arabjc.2014.10.049>

WASTEWATER TREATMENT WITH BIOCONVERSION FOR MOTOR FUEL PRODUCTION

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ARTICLE INFO

Article history:

Received date 07.09.2020

Accepted date 12.10.2020

Published date 30.10.2020

Section:

Waste Management and Disposal

DOI

10.21303/2313-8416.2020.001460

KEY WORDS

motor biofuel
microalgae
wastewater treatment
economic efficiency
nitrogen compounds
phosphorous compounds
bioconversion
photobioreactor

ABSTRACT

The object of research: the process of wastewater treatment using bioconversion for subsequent motor fuel production.

Investigated problem: improving the efficiency of bioconversion process for biofuel production with simultaneous wastewater treatment by removing nitrogen and phosphorous compounds.

The main scientific results: providing the possibility of biofuel production with energy and economic inefficiency. It is done by combining the process of motor biofuel production with the process of treating wastewater from biogenic elements makes it perspective for commercial use. Traditional technology for the production of motor biofuels from microalgae includes cultivation, harvesting, dehydration and drying of biomass, extraction of oils from them and subsequent production of methyl esters and glycerol. Such technology is often not economically effective. It requires significant amount of energy for carrying out all necessary processes. In addition, it requires significant expenditures of water and nutrients. The use of nutrient-rich wastewater as a culture medium for the cultivation of microalgae allows not only to reduce costs, but also to purify wastewater from nitrogen and phosphorus compounds, which makes this process economically effective.

The area of practical use of the research results: Sewage and gray water treatment plants. Industrial and agricultural effluents treatment plants. Different types of enterprises, which have wastewater enriched with nitrogen and phosphorous compounds.

Innovative technological product: The technology of microalgae cultivation using wastewater as a culture medium. The technology allows effectively purifying used wastewaters from nitrogen and phosphorous compounds with no waste at the end.

Scope of the innovative technological product: Improved technology of motor biofuel production with simultaneous wastewater purification, which is economically effective and environmentally safe.

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1. Introduction

1.1. The object of research

The object of research is the process of wastewater treatment, in particular wastewater purification from nitrogen and phosphorous compounds using bioconversion.

1.2. Problem description

Energy consumption is increasing constantly [1]. At the same time, quality of traditional fuel is deteriorating. Progress in means of combustion products purification does not keep up with the increasing amount of harmful substances formed during energy production. As a result, the damage to the environment is becoming more significant. In addition, if humanity continues to consume fossil fuels at the current level (despite the steady increase in population), known oil and gas reserves may be depleted in the 2050s–2060s. Therefore, the search for alternative fuels undoubtedly comes to the fore today.

Bioconversion is the process of converting one chemical compound into another with the required chemical characteristics, with the participation of microorganisms. Its main processes are ox-

idation, condensation, decomposition and hydrolytic reactions. In addition to bioconversion of chemical compounds, bioconversion of solar energy is possible. This is the conversion of solar energy into chemical energy of organic matter in the form of biomass, through photosynthesis. In this case, solar energy is stored in the form of chemical energy, which can then be released in various ways.

1. 3. Suggested solution to the problem

Photoelectric transformations are performed by semiconductor and other elements with diode properties, i.e. a combination of p-n type semiconductors (p-n junction). There is separation of negatively charged electrons and positively charged holes takes place as a result of photon absorption under the action of solar radiation at the contact boundary of semiconductors, resulting in photo- electromotive force [2]. One of the disadvantages of this method is relatively low efficiency (15–20 %) and inconvenience of accumulation and storage of electricity, given that the flow of solar radiation is not uniform.

Thermodynamic transformations occur in accordance with thermodynamic cycles. Such transducers include: systems for capturing solar radiation and its concentration; systems for receiving radiation, which converts its energy into heat, which is transferred to heat carrier; heat exchangers that form a hot and a cold source of a heat engine. Solar energy can be converted directly into thermal, mechanical or electrical energy with the help of thermodynamic cycles. The efficiency of such transformations depends on many factors. It's mostly higher than for photovoltaic cells, but generally not very high. Additionally, the converters can have heat accumulators to store thermal energy, which only partially smooths out the uneven flow of solar energy. Moreover, heat accumulators are quite expensive.

Conversion of energy into biomass [3] is the conversion of radiant solar energy into chemical energy of biomass through traditional processes of photosynthesis. These processes occur constantly in nature. Their result is the planetary biomass of major producers. This mass is $1.8 \cdot 10^{12}$ tons of dry matter, which stores $3 \cdot 10^{22}$ J of chemical energy. Under artificial conditions, this can be done by introducing special technologies for growing biomass. Its chemical energy can be converted into other types and used to meet energy needs. The most promising transformation is the production of such types of fuel from biomass (biodiesel, bioethanol, biogas, etc.), which can be used to obtain useful energy in conventional internal combustion engines. Given this, the most promising types of energy producers can be considered oil crops with high content of hydrocarbons in the oil [4]. They can be divided into soil crops (rapeseed, sugar cane, etc.) and aquatic crops (varieties of algae and microalgae).

The disadvantage of growing soil crops is the need to allocate significant fertile areas, which could otherwise be used for growing food crops.

The advantage of aquatic energy crops is that they can be grown using only small areas of land, which can be completely barren. Among aquatic crops, microalgae deserve special attention. They inhabit places with high humidity. The main natural places of their reproduction are swamps, lakes, other reservoirs, including salt ones. Growth of microalgae, as well as the growth of other photosynthetic organisms, requires such components as light, carbon dioxide, biogenic compounds and heat. Some of them have fairly high growth rate and, despite the small size of individuals (from 2 to 50 microns), can double their biomass up to 8 times a day under favorable conditions [5]. The yield of the finished product (oil saturated with hydrocarbons) can reach 80 % of their initial mass. Some cultures of microalgae are more than 20 times more valuable than palm oil and almost 120 times more valuable than rapeseed oil in terms of energy containing products, which can be obtained out from them. Finished products do not contain sulfur (as petroleum fuels), do not contain toxic substances (such as lead) and are well decomposed by microorganisms in the nature conditions. In addition, their combustion does not increase the concentration of CO_2 in the atmosphere, like other types of biofuels, and, as a result, does not contribute to the development of the greenhouse effect.

Microalgae can also accumulate a variety of lipids and fatty acids, which are also valuable products. In addition, the significant content of fats, which are lighter than water, provides them with buoyancy, i.e. the ability to stay close to the water surface and have more access to light.

There are technologies today for cultivating microalgae in open water and in special installations – photobioreactors or photobioconverters.

The disadvantages of open water microalgae cultivation are possibilities to carry out the process only during the warm season and in the presence of sufficient sun irradiation. Therefore, such technology can be effectively used only in areas with warm climate. Cultivating processes can also be negatively affected by other weather factors, uncontrolled changes in the properties of the environment (water), such as its pollution, the appearance of various organisms in the water, changes in acidity, and so on. In addition, it is difficult to automate the processes of cultivation and harvesting in open water.

The technology of cultivation in bioreactors, as a rule, does not have these shortcomings. There are photobioreactors of various designs. Here are the main ones [6].

Photobioreactors, shaped in the form of open troughs with a relatively thin layer of water, in which algae are placed. Despite their advantages (the possibility to create an optimal environment for cultivating, efficient mixing, automation, etc.), they have a number of disadvantages inherent in open water bodies (for example, the impact of adverse weather conditions).

Photobioreactors, shaped in the form of transparent flasks and tubes filled with cultivating medium and algae. Such installations are less sensitive to weather conditions, but have other disadvantages. Access to the light required for photosynthesis through transparent walls is complicated over time due to plaque on the walls, which is formed inside, and the mass of microalgae near the walls also complicates the passage of light inside, as the number of microalgae increases.

Photobioreactors, shaped in the form of large tanks made out of transparent material. In general, they usually need artificial lighting because light does not penetrate well into the thickness of microalgae, even when mixing takes place.

Photobioreactors, shaped in the form of pyramidal containers, which are open horizontal troughs with cultivating medium and algae, located in a pyramidal body of transparent material. Given the advantages inherent in open troughs, these installations are not significantly affected by adverse weather factors. However, the disadvantage of such installations may be certain technological problems with the saturation of the environment with carbon dioxide and its efficient use, as well as problems with ensuring the continuity of the cultivation process.

The aim of the research is to show by economic calculation that combining the process of microalgae cultivation for biofuel production with the process of wastewater purification from nitrogen and phosphorous compounds makes the technology economically inefficient.

2. Materials and Methods

The authors propose a number of microalgae strains, based on the analysis of the properties of microalgae biomass growth, as well as the accumulation of lipids in them, suitable for cultivation for the subsequent production of motor biofuel. Among them, strains of *Botryococcus Braunii* and *Chlorella Vulgaris* may deserve special attention [7].

Specificity of *Botryococcus Braunii* strain is that the dry mass of these algae has a high content of hydrocarbons, which varies depending on the race. Therefore, they can be considered as a potential source of renewable fuel.

According to the characteristics of containing their dry weight hydrocarbons, there are three races of *Botryococcus Braunii*:

- race *A* – the hydrocarbon content is about 61 % of dry weight;
- race *B* – the hydrocarbon content varies from 26 % to 86 % of dry weight;
- race *L* – the hydrocarbon content of 2–8 % of dry weight.

These three races differ in some morphological and physiological characteristics (**Table 1**).

It is possible to conclude that the most promising and interesting for research are algae races *A* and *B*, because of having high content of hydrocarbons.

Another positive feature is that the hydrocarbons, obtained from *Botryococcus Braunii* have a high octane number. So, they can be used as fuel for various modes of transport.

However, these algae have some drawbacks. First, their growth rate is low, which creates the problem of their use on an industrial scale [8, 9]. To increase the rate of growth, it is necessary to create the optimal temperature, ensure the content of nutrients in the water and provide other favorable conditions.

Secondly, the known plants for their cultivation are not effective enough. In view of the above, it is necessary to conduct further research to find new efficient designs of solar energy

plants that can provide the most favorable conditions for the process of bioconversion of solar energy, namely the cultivation of algae *Botryococcus Braunii*.

Table 1

Distinctive characteristics of *Botryococcus Braunii* races

No	Characteristics of <i>Botryococcus Braunii</i> races	Race A	Race B	Race L
1	Nature of hydrocarbons	$C_{25}-C_{31}$ odd n-alkadienes	Triterpenes C_nH_{2n-10} , $n=30-37$	Tetraterpenes $C_{40}H_{78}$
2	Color of the colony stationary phases	Pale yellow or green	Orange-red or orange-brown due to the accumulation of carotenoids	
3	Long chain phenols of alkenes	Present	Absent	Absent
4	Nature of biopolymers	Very long aliphatic chains, connected by etheric bridges and fatty ethers		Tetraterpenoid, connected by etheric bridges

3. Results

Conventional technology for biodiesel production out of microalgae includes cultivation, harvesting, dehydration and drying of biomass, extraction of oils and further processing to obtain methyl esters and glycerin. Residual biomass (after extraction of oils) contains a significant part of organic matter and can be used for biogas production. This significantly increases the energy value of microalgae.

Cultivation process require energy, first of all electricity. According to the existing technologies, specific consumption of electricity during cultivation in open photobioreactors is about 1 W/m² of the cultivating area, for closed photobioreactors – 5 W/m².

The microalgae cells must be collected and dehydrated after cultivation. Filtration or centrifugation can be used for this purpose. There is a sufficient amount of equipment on the market to perform this processes, because necessity for dehydration of microorganisms often arises in various areas of economic activity.

The average values of energy costs per 1 m³ of culture medium, according to open sources, are: filter presses – 1.8 MJ/m³ (degree of dehydration 80 %); centrifuges – 3,6...14,4 MJ/m³ (degree of dehydration of 90 %).

The efficiency of removing oils from the dehydrated biomass of microalgae is 90 %. The energy required to extract oils from dehydrated biomass at large production volumes can be taken by analogy with the production of rapeseed oil from the initial biomass. The average specific energy cost per one kilogram of oil obtained is: 0.35 MJ/kg of electricity; 1.75 MJ/kg of thermal energy.

Energy efficiency of processing oils obtained from microalgae into biodiesel is 90 %. The average specific energy costs for the production of one kg of biodiesel, for large production volumes, can also be estimated by the existing conventional technologies: 0.043 MJ/kg of electricity and 0.75 MJ/kg of thermal energy.

The energy efficiency of processing the residual biomass of microalgae (after removal of oils) into biogas is 90 %. The average specific energy costs for the production of one normal m³ of biogas can be estimated according to the existing conventional technologies and are: 0.48 MJ/m³ of electricity and 1.5 MJ/m³ of heat.

The total amount of potentially obtained energy stored in energy sources made out of cultivated microalgae (biodiesel and biogas) is: for closed photobioreactors – 267.1 MJ/m²; for open photobioreactors – 76.41 MJ/m².

The total amount of potentially used electrical and thermal energy, respectively, spent on the microalgae cultivation and biofuels production out of them is: for closed photobioreactors – 172.38 MJ/m² and 19.72 MJ/m²; for open photobioreactors – 44.43 MJ/m² and 5.65 MJ/m².

The percentage of energy that is spent on biofuel production in relation to the energy stored in biofuel itself is: for closed photobioreactors – 72 %; for open photobioreactors – 66 %

A positive energy balance changes to a negative one, assuming that the electricity consumed is generated by thermal power plants, given their low efficiency. Let us assume that the electricity is generated at a thermal power plant with cogeneration, which operates with efficiency of 60 %. The amount of energy that is actually contained in the consumed electrical energy is: for closed photobioreactors – 287.3 MJ/m²; for open photobioreactors – 74.05 MJ/m².

The percentage of energy consumed in relation to store in biofuels in this case will be: for closed photobioreactors – 115 %; for open photobioreactors – 104 %. Thus, the production of biofuels from microalgae becomes energy and economically inefficient.

Biogenic are chemical elements that are permanent part of living organisms and perform certain biological functions in them. Biogenic elements include: oxygen, carbon, hydrogen, nitrogen, phosphorus, boron, sulfur, calcium, potassium, sodium, chlorine, as well as iodine, zinc, magnesium, manganese, iron and other chemical elements needed by organisms in small quantities.

An important resource necessary for the cultivation of microalgae is water, as the basis of the culture medium. Practice shows that the use of wastewater as the basis for the culture medium makes it possible to reduce the consumption of clean water for these purposes up to 90 %. In this case, the wastewater must be pre-treated, primarily to make it transparent.

4. Discussion

The main biogenic elements in municipal wastewater are nitrogen and phosphorus, which are in the form of various compounds. These compounds, getting into water bodies, lead to their eutrophication. They increase the rate of phytoplankton development on the water surface. It reduces the water permeability to light and oxygen. Insufficient light intensity leads to inhibition of deep plants growth and to their death. Insufficient oxygen amount causes the death of other aquatic organisms.

The consequence of eutrophication is not only the death of fish in water bodies used for fishery, but also lead to a decrease in environmental safety if the water bodies are used for recreational purposes (for water tourism), or as a source of drinking water. Cyanobacteria (blue-green algae) that accumulate on the surface of a water body produce secondary metabolites such as a wide range of toxins known as cyanotoxins. They are often considered pathogenic despite not developing in the body because they have the potential to adversely affect human health.

Production of motor biofuels from plant raw materials is considered very promising [10]. There are several generations of biofuels depending on the biological raw materials from which it can be made. The first generation – made from the biomass of soil plants specially cultivated for these purposes. The second generation – made from biomass waste. The third generation – made from the biomass of specially cultivated aquatic plants. Many researchers show that the most promising for the biofuel production can be microalgae due to their rapid growth rate and high lipid content of their biomass [11]. However, the authors often do not take into account the economic component. The cycle of biofuel production, starting from the cultivation of biomass to the finished product, includes many technological processes with significant energy and, consequently, economic costs [12–14]. If the economic component is taken into account, then the calculations by aggregated indicators, taking into account the costs of the entire production chain up to the finished product, the process is not profitable [15]. Energy and economic costs of fuel production exceed the energy and economic benefits of selling such fuel.

Practice shows that household wastewater that has undergone mechanical and biological treatment at conventional sewage treatment plants contains a large number of nitrogen and phosphorus compounds. Their concentration at the outlet of the treatment plant is not constant, but varies depending on many factors.

Microalgae are good absorbers of biogenic elements (phosphorus and nitrogen compounds are used in photosynthesis) [16]. Many studies show a fairly high efficiency of nitrates and phosphates removal out of wastewaters during their treatment by metabolism of microalgae [17, 18]. However, many authors also do not take into account the economic component and do not show any economic efficiency. The purification process is long-lasting and requires treatment facilities of large sizes. Despite the technical efficiency, this often makes such treatment economically unfounded.

Thus, the process of cultivating raw materials for the production of motor biofuel can be combined with the process of treating wastewater from biogenic elements. This combination takes advantage of both processes and reduces overall energy and economic costs. The process in this case becomes economically viable and preventing eutrophication of water bodies.

The main feature of the study is to confirm the prospects for the production of motor biofuels out of microalgae biomass. Despite the significant costs of cultivation and production process, which are estimated to exceed the profit from the sale of the fuel received, the ways, which can

change it, are shown. A common trend in the technological processes that are being developed is the reduction of the use of new resources and the reduction of waste generated. The use of secondary resources, such as wastewater, significantly reduces the cost of the technological process, and the manufacture of additional products along with the main one. It allows not only the reduction or complete elimination of waste, but also the possibility of getting additional profits from the sale of additional products. This makes it possible to turn the unprofitable process of biofuel production into a profitable one while reducing the negative impact on the environment.

The advantage of the study is the use of an approach to solving the problem, which provides the absence of waste. One of the processes of the proposed technology is wastewater treatment. The waste of this treatment is biomass of microalgae, which is considered as raw material that then can be used for producing biofuels and other additional products.

Microalgae based biofuel production has also some restriction. Not all strains of microalgae that can absorb contaminants from wastewater pretty well, including nitrogen and phosphorus compounds, can be considered as raw materials for biofuels due to the insufficient content of lipids in their biomass. In addition, not all wastewater can be used as culture medium. Some types of industrial effluents can have significant concentrations of toxic elements, including heavy metals. When cultivating microalgae in such media, their biomass is saturated with these elements and becomes unsuitable for the production of motor fuels or other products. Therefore, among the limitations we can name the necessity to apply only strains of microalgae with high content of lipids, as well as to use wastewater with low concentrations of toxic substances.

The question arises of increasing the efficiency of cultivation in the future by increasing biomass growth rate and increasing the rate of lipid accumulation. The direction of further research should primarily be the search for strains of microalgae with the highest efficiency of biogenic elements absorption. Such strains must also have a high rate of biomass growth, high lipid content of the biomass, and be undemanding to the cultivation conditions. On the other hand, the direction of further research should also be the search for optimal cultivation conditions for the development of highly efficient production technologies.

5. Conclusions

Given the constant rise in prices for traditional energy sources, the problem of finding alternatives is one of the most actual. Solar energy, as an alternative source, has been used in various countries around the world for a long time. One of the most interesting technologies for the use of solar energy is its bioconversion, which is a relatively new but promising technology. This study can make a significant contribution to solving energy problems in the future.

Obtaining hydrocarbon fuels through bioconversion of solar energy is also a promising way to develop alternative energy in many countries, which can increase the country's energy independence and significantly reduce the negative impact on the environment associated with the use of coal and petroleum products.

References

- [1] Karpov, K. A. (2019). Development Trends of Global Energy Consumption. *Studies on Russian Economic Development*, 30 (1), 38–43. doi: <http://doi.org/10.1134/s1075700719010088>
- [2] Yousif, E. M. (2015). The Photoelectric Effects: Radiation Based With Atomic Model. *International Journal of Fundamental Physical Sciences*, 5 (1), 18–31. doi: <http://doi.org/10.14331/ijfps.2015.330082>
- [3] Shamanskii, S. I., Nestorjak, D. M. (2012). Bioconversion of Solar Energy as a Perspective Direction in Alternative Energy. *Green Energy*. Kyiv, 371–372.
- [4] Nigatu Gebremariam, S., Mario Marchetti, J. (2017). Biodiesel production technologies: review. *AIMS Energy*, 5 (3), 425–457. doi: <http://doi.org/10.3934/energy.2017.3.425>
- [5] Bhagea, R., Bhoyroo, V., Puchooa, D. (2019). Microalgae: the next best alternative to fossil fuels after biomass. A review. *Microbiology Research*, 10 (1), 12–24. doi: <http://doi.org/10.4081/mr.2019.7936>
- [6] Shamanskyi, S., Boichenko, S., Adeniyi, C. (2019). Photobioreactor for microalgae cultivation for biofuel production with simultaneous sewage water treatment. *Systemy i Środki Transportu Samochodnego. Wybrane Zagadnienia*. 16. Seria: Transport. Rzeszów: Politechnika Rzeszowska, 61–67.
- [7] Sasikanth, K., Jyotsna, T., Anjali, P., Sharma, M. C. (2014). Studies on cultivation of lipid accumulating *Botryococcus Braunii* from North Gujarat inland waters for generation of 3rd generation biofuels. *Indian journal of applied research*, 4 (9), 31–35.

- [8] Tran, H.-D., Do, T.-T., Le, T.-L., Nguyen, M.-L. T., Pham, C.-H. et. al. (2019). Cultivation of *Haematococcus pluvialis* for astaxanthin production on angled bench-scale and large-scale biofilm-based photobioreactors. *Vietnam Journal of Science, Technology and Engineering*, 61 (3), 61–70. doi: [http://doi.org/10.31276/vjste.61\(3\).61-70](http://doi.org/10.31276/vjste.61(3).61-70)
- [9] Silva, C. E. de F., Gris, B., Bertucco, A. (2016). Simulation of microalgal growth in a continuous photobioreactor with sedimentation and partial biomass recycling. *Brazilian Journal of Chemical Engineering*, 33 (4), 773–781. doi: <http://doi.org/10.1590/0104-6632.20160334s20150016>
- [10] Soh, L., Zimmerman, J. (2011). Biodiesel production: the potential of algal lipids extracted with supercritical carbon dioxide. *Green Chemistry*, 13 (6), 1422–1429. doi: <http://doi.org/10.1039/c1gc15068e>
- [11] Pruvost, J., Van Vooren, G., Le Gouic, B., Couzinet-Mossion, A., Legrand, J. (2011). Systematic investigation of biomass and lipid productivity by microalgae in photobioreactors for biodiesel application. *Bioresource Technology*, 102 (1), 150–158. doi: <http://doi.org/10.1016/j.biortech.2010.06.153>
- [12] Posten, C. (2007). *Principles of Mechanical Bioseparation*. Kaiserstraße: Shaker Verlag.
- [13] Uduman, N., Qi, Y., Danquah, M. K., Forde, G. M., Hoadley, A. (2010). Dewatering of microalgal cultures: A major bottleneck to algae-based fuels. *Journal of Renewable and Sustainable Energy*, 2 (1). doi: <http://doi.org/10.1063/1.3294480>
- [14] González-Fernández, C., Ballesteros, M. (2012). Microalgae autoflocculation: an alternative to high-energy consuming harvesting methods. *Journal of Applied Phycology*, 25 (4), 991–999. doi: <http://doi.org/10.1007/s10811-012-9957-3>
- [15] Schlagermann, P., Göttlicher, G., Dillschneider, R., Rosello-Sastre, R., Posten, C. (2012). Composition of Algal Oil and Its Potential as Biofuel. *Journal of Combustion*, 2012, 1–14. doi: <http://doi.org/10.1155/2012/285185>
- [16] Delgadillo-Mirquez, L., Lopes, F., Taidi, B., Pareau, D. (2016). Nitrogen and phosphate removal from wastewater with a mixed microalgae and bacteria culture. *Biotechnology Reports*, 11, 18–26. doi: <http://doi.org/10.1016/j.btre.2016.04.003>
- [17] Singh, R., Birru, R., Sibi, G. (2017). Nutrient Removal Efficiencies of *Chlorella vulgaris* from Urban Wastewater for Reduced Eutrophication. *Journal of Environmental Protection*, 8 (1), 1–11. doi: <http://doi.org/10.4236/jep.2017.81001>
- [18] Manea, R. G., Ardelean, I. I. (2016). Nitrogen and Phosphorus Removal from Municipal Wastewater Using Consortia of Photosynthetic Microorganisms. *Scientific Bulletin. Series F. Biotechnologies*, XX, 286–292.

RESEARCH OF THE INFLUENCE OF THE FOOD ADDITIVE “MAGNETOFOOD” ON THE QUALITY INDICATORS OF WHIPPED CONFECTIONERY PRODUCTS

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ARTICLE INFO

Article history:

Received date 09.09.2020

Accepted date 20.10.2020

Published date 30.10.2020

Section:

Equipment and technology of food production

DOI

10.21303/2313-8416.2020.001498

KEY WORDS

cottage cheese dessert
white-pink marshmallow
“Magnetofood” food additive
quality indicators

ABSTRACT

The results of the influence of the food additive “Magnetofood” on the quality indicators of whipped confectionery in the technologies of curd dessert and white-pink marshmallow (organoleptic characteristics, density, mechanical strength, effective viscosity, degree of overrun and volume kinetics during storage) are presented. It was found that the introduction of the additive “Magnetofood” into the prototypes of cottage cheese desserts and white-pink marshmallows (on agar and pectin) in an amount from 0.1 % to 0.2 % to the mass of the recipe mixture in comparison with the control improves the structure, texture and external type of whipped products; the distribution function of air bubbles by diameter is narrow and symmetric, the diameter $d=(45...50) \cdot 10^{-3} \text{ m}$ is a fundamental factor indicating the stabilizing effect of nanoparticles of the food additive “Magnetofood”. It was found that with an increase in the mass fraction of the food additive “Magnetofood”, the following increases (compared to the control): in curd desserts - the maximum shear stress by a factor of (1.18 ... 1.3) and the thixotropy coefficient by 1.26 times; in white-pink marshmallows – the strength of the foam structure is (1.1...1.2) times and the effective viscosity of the marshmallow masses is (1.35...1.55) times (which has a positive effect on the texture of the product and the extension of the period preservation of the freshness of finished products); as well as in marshmallow masses, they decrease: density by (1.12...1.15) times and the duration of whipping by (1.5...2.5) 60 s. The rational content of the additive “Magnetofood” in the recipes of curd dessert and marshmallow of white-pink marshmallow was determined – 0.15 % to the mass of the recipe mixture. The prospects of using “Magnetofood” as an improver and stabilizer of polyphase foam-like structures have been determined.

Object of research: production technology of cottage cheese desserts and white-pink marshmallows (on agar and pectin).

Investigated problem: obtaining stable polyphase food systems, in particular, a foam-like structure, with a deviation of the quality indicators of raw ingredients and technological parameters in production conditions.

Main scientific results: a deterioration in the quality of cottage cheese desserts and marshmallow products was revealed with a deviation of the physicochemical parameters of raw ingredients (in particular, cottage cheese, pectin, agar) and possible ranges of deviations of the initial values of the process parameters (temperature conditions, duration of whipping and gelation) leading to a deterioration the quality of finished products in terms of the following indicators: organoleptic characteristics, physicochemical, microbiological and functional and technological properties, shelf life. It is shown that improving the technology and increasing the stability of the polyphase structure of foam-like food products can be achieved by introducing a food additive of complex action “Magnetofood”. In particular, due to the structure-forming, stabilizing, water-retaining and bacteriostatic properties of the Magnetofood additive. As a result of the introduction of 0.15 % food additive “Magnetofood” into the recipe for cottage cheese dessert and white-pink marshmallow, the following improves: organoleptic, structural-mechanical and physical-chemical indicators; structure, consistency and appearance of the whipped product; storage periods are extended.

The area of practical use of the research results: food enterprises specializing in the production of whipped products (fermented milk desserts, pastel-marmalade products, sambucs).

Innovative technological product: technology for the production of cottage cheese dessert and marshmallow white-pink (on agar) and (on pectin) using the food additive “Magnetofood”.

Scope of application of the innovative technological product: food industry, restaurant enterprises.

1. Introduction

1.1. The object of research

The object of research is the technology of production of cottage cheese desserts and white-pink marshmallows (on agar and pectin).

1.2. Problem description

To ensure high consumer properties and competitiveness of whipped confectionery products, it is necessary to resolve a number of issues related to stabilizing the polyphase structure and maintaining product quality during transportation and storage [1–7]. The use of food nano-additives in whipped confectionery technology is a new and promising area of research [8–10].

1.3. Suggested solution to the problem

The authors solve the problem of stabilizing the polyphase structure of whipped confectionery and forming their quality by using the mineral nano-additive “Magnetofood” (based on ferrous and ferric iron: $\text{FeO} \times \text{Fe}_2\text{O}_3$). “Magnetofood” is an ultra-fine powder of dark brown or black color with a particle size of 70–80 nm, with a large specific surface; antioxidant, bacteriostatic, sorption, complex-forming, stabilizing, emulsifying, water and fat-retaining properties [8–10].

The aim of research is to form indicators of the quality of whipped confectionery products (cottage cheese dessert and white-pink marshmallow) when the food additive “Magnetofood” is added to the recipe.

To achieve the aim, the following objectives were solved: study of the effect of the food additive “Magnetofood” on the organoleptic characteristics of whipped curd and marshmallow products; microstructure and distribution of air bubbles by diameter, physicochemical and structural-mechanical indicators of prototypes of whipped curd and marshmallow masses.

2. Materials and methods

The subject of research is model curd and marshmallow masses with a mass fraction of the food additive “Magnetofood” 0.10 %, 0.15 %, 0.20 % to the mass of the recipe mixture. The food additive “Magnetofood” was introduced in the form of:

1) fat suspension (in curd desserts) with stirring of curd in an amount of 0.2 g; 0.3 g; 0.4 g per 100 g of the prescription mixture, which is 0 % (control - sample 1); 0.10 % (sample 2); 0.15 % (sample 3); 0.20 % (sample 4) food additive “Magnetofood”;

2) an aqueous suspension based on a 5 % aqueous solution of a gelling agent – agar or pectin (into marshmallows) at the stage of swelling-dissolution of the gelling agent in an amount of 20.0 g; 30.0 g; 40.0 g per 1,000.0 g of the prescription mixture, which is 0 % (control – sample 1); 0.10 % (sample 2); 0.15 % (sample 3); 0.20 % (sample 4) food additive “Magnetofood”.

2.1. Experimental procedures

To determine organoleptic (on a 5-point scale, taking into account the weight coefficients of each indicator), physicochemical (total acidity, mass fraction of moisture, density), structural and mechanical (effective viscosity using a Reotest-2 rotary viscometer, mechanical strength and ultimate shear stress – on the AP-4/1 penetrometer, the microstructure of the whipped mass using a microscope) indicators were used generally accepted and standard techniques [9, 10].

3. Results and discussion

The surface activity of nanoparticles of the food additive “Magnetofood” and their ability to form solvate complexes with protein molecules improves the consistency of the curd dessert, which is evident from the organoleptic characteristics (Fig. 1).

The introduction of the food additive “Magnetofood” into the recipe for the curd dessert provides sufficient stability of the product, which can be seen from the narrow distribution curve of the diameters of air bubbles (Fig. 2).

The narrow distribution of air bubbles in diameter helps to stabilize the foamy structure of the curd dessert. This is explained by the complementary properties of Fe atoms of the food additive “Magnetofood” and the formation of coordination and electrostatic bonds of “Magnetofood”

nanoparticles with curd proteins, which strengthens the foamy structure of the curd dessert (promoting foaming and fixing air bubbles in the system) [9].

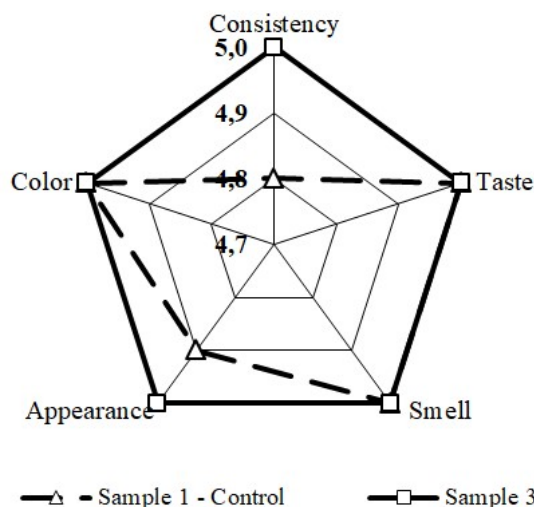


Fig. 1. Organoleptic characteristics of prototypes of curd dessert

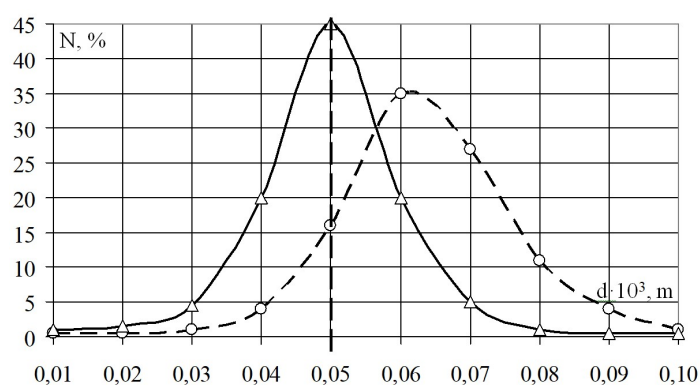


Fig. 2. Distribution of air bubbles by diameter in prototypes of curd dessert: —○— — control, —△— — dessert with 0.15 % food additive “Magnetofood”

In addition, the introduction of the food additive “Magnetofood” corrects the structural and mechanical characteristics of the curd dessert: with an increase in the mass fraction of the additive “Magnetofood”, the following increases: the maximum shear stress is 1.18...1.3 times (which characterizes the strength of bonds in associative complexes of polyphase structures with “Magnetofood” nanoparticles, which have a structure-forming ability), the thixotropy coefficient is 1.26 times compared to the control. As a result, the stability of the curd product increases and its structure softens somewhat (due to fat binding by “Magnetofood” nanoparticles and the formation of a structured-solvated system) (Fig. 3).

At the same time, the structural and mechanical characteristics of the dessert remain stable during the entire shelf life (24 hours).

Thus, the introduction of the food additive “Magnetofood” improves the organoleptic characteristics, stabilizes the foamy structure of the curd dessert, including during storage; promotes the formation of stable various forms of the product. The rational parameters of the technological process for the preparation of curd dessert have been determined: mixing ($n=2.0...2.2 \text{ s}^{-1}$) 50 % sour cream with a fat suspension of the food additive “Magnetofood” for $(3...4) \times 60 \text{ s}$, holding sour cream-fat-“Magnetofood” mixture $t=(27...30) \times 60 \text{ s}$ followed by whipping the mixture ($n=5.8...6.0 \text{ s}^{-1}$) for $(8...10) \times 60 \text{ s}$ with and stirring ($n=2.0...2.2 \text{ s}^{-1}$) with cottage cheese and sour cream whipped with powdered sugar for $(3...5) \times 60 \text{ s}$. Based on the research carried out, a recipe was com-

piled and a technological scheme of a curd dessert with the use of a food additive “Magnetofood” was developed.

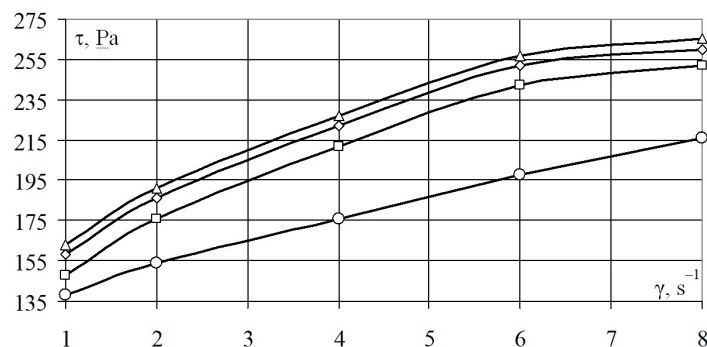


Fig. 3. Shear stress of test samples of curd dessert with different mass fraction of food additive “Magnetofood”: ○ – control – 0 %, □ – 0.1 %, ◇ – 0.15 %, ▲ – 0.2 %

It has been experimentally established that the introduction of the food additive “Magnetofood” in the amount of 0.10 %; 0.15 %; 0.20 % of the mass of raw materials affects: sedimentation stability, viscosity, thixotropic properties of aqueous suspensions, in particular agar and pectin. A rational amount of the food additive “Magnetofood” has been established – 0.15 % of the mass of raw materials. This served as the basis for the introduction of the food additive “Magnetofood” in gummy-pastilles in the form of suspensions based on a 5 % aqueous solution of a gelling agent (agar, pectin) – in a rational amount of 30.0 g of an aqueous suspension per 1,000 g of a recipe mixture [10].

The results of the organoleptic assessment of the quality of test samples of white-pink marshmallow are shown in **Fig. 4**.

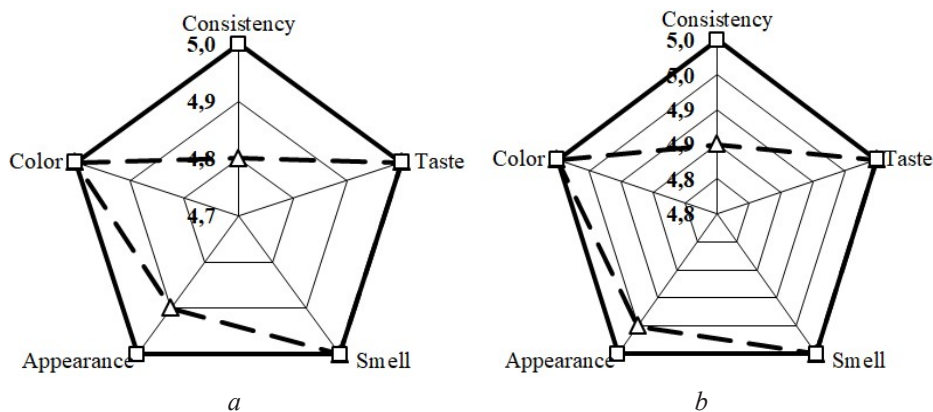


Fig. 4. Organoleptic indicators of test samples of white-pink marshmallow with various gelling agents in comparison with control samples: *a* – on agar; *b* – on pectin (—□— sample with 0.15 % “Magnetofood”, —▲— control – without “Magnetofood”)

From the data in **Fig. 4** it can be seen that the introduction of 0.15 % food additive “Magnetofood” improves the organoleptic characteristics of the product in comparison with the control: marshmallow is uniform, uniformly white with a cream shade and light pink color; has a soft, uniform consistency and fine-mesh structure; rounded, without deformation, with a clear outline; smooth surface without damage and hardening on the edges; pleasant pronounced taste and smell characteristic of marshmallows.

According to the organoleptic analysis data, the rational content of the food additive “Magnetofood” is 0.15 % of the mass of the recipe mixture, which is confirmed by studies of the foaming ability and foam stability of egg white on model systems with different gelling agents and with different amounts of the food additive “Magnetofood” using mathematical modeling [10].

Table 1 shows the main physical, chemical and technological parameters of prototypes of white-pink marshmallow with various gelling agents.

Table 1

Physicochemical and technological indicators of prototypes of white-pink marshmallow

Indicator	Prototypes of white-pink marshmallow			
	on agar		on pectin	
	Sample 1 – control	Sample 2 – with 0.15 % «Magnetofood»	Sample 3 – control	Sample 4 – with 0.15 % «Magnetofood»
Moisture content, %	17.0±0.8	17.4±0.8	17.0±0.8	17.5±0.8
Total acidity, deg.	0.7±0.03	0.6±0.02	5.90±0.3	5.30±0.2
Density, kg/m ³ (smallest value)	545±12	485±8	550±12	480±8
Whipping duration, ×60 s	16.0	14.0	10.0	8.0
Strength, kPa	9.0±0.5	10.8±0.6	6.5±0.3	7.4±0.4

Whence it can be seen that when the food additive “Magnetofood” is introduced, the density decreases by (1.12...1.15) times and the duration of whipping by (1.5...2.5)×60 s due to the interaction of the nanoparticles “Magnetofood” with molecules of egg white, which promotes the branching of the main chains of its macromolecules and slows down the process of liquid draining and thinning of the walls of air bubbles. The use of the food additive “Magnetofood” increases the strength of the foam by (1.1...1.2) times due to the “cluster-philicity” of the nanoparticles of the food additive “Magnetofood”, which increases the viscosity of the gelling agent in the Gibbs-Plateau channels, which slows down the syneresis process and stabilizes the gel frame foam-like structure.

Table 2 shows the kinetics of the volume of experimental samples of marshmallow masses during storage for a regulated period of 60 days.

Table 2

Kinetics of the volume of experimental samples of marshmallow masses during storage

Shelf life, days	The volume of prototypes of marshmallow masses, cm ³			
	on agar		on pectin	
	Sample 1 – control	Sample 2 – with 0.15 % «Magnetofood»	Sample 3 – control	Sample 4 – with 0.15 % «Magnetofood»
0	100±5	100±5	100±5	100±5
20	81.7±4	98.2±5	80.4±4	97.2±5
40	76.4±3	93.6±5	75.2±3	92.8±5
60	68.2±2	86.8±4	67.0±3	85.6±5

As can be seen from the data of the **Table 2** the introduction of the food additive “Magnetofood” stabilizes the structure of prototypes of marshmallow masses by improving the foaming and fixation of air bubbles in the system under the action of “Magnetofood” nanoparticles. The functionality of the food additive “Magnetofood” is manifested primarily in the reduction of surface tension. The destruction of the foam is caused by the processes of diffusion of air, the outflow of liquid from the walls of the bubbles (viscosity of the liquid) and the enlargement of bubbles due to fusion.

In addition, a rather narrow peak, both for control and for prototypes (2, 4) with 0.15 % food additive “Magnetofood” stabilizes, indicates a uniform overrun of marshmallows. Moreover, due to the higher viscosity and lower surface tension, the stability of the foam in the prototypes with the food additive “Magnetofood” is higher. That is, the food additive “Magnetofood” stabilizes the foamy structure of marshmallows, including during the storage period established by the regulations.

The viscosity and mechanical strength of experimental samples of marshmallow were studied. After the formation of the whipped mass, the frame is gradually fixed, since the liquid films separating the air bubbles contain a gelling agent, which ensures the transition of the mass into a gel-like state. **Fig. 5** shows the strength (t , kPa) of prototypes of marshmallow masses in the process of aging ($t \times 60$ s).

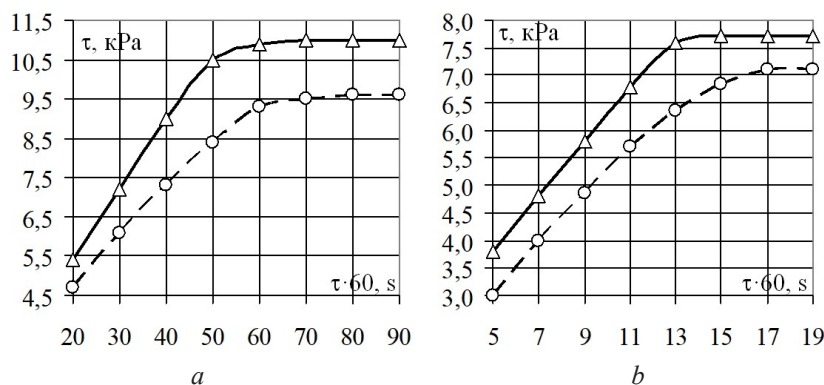


Fig. 5. Dependence of strength on the aging duration of prototypes of whipped masses:
a – on agar (—○— – sample 1 – control, —△— – sample 2 with 0.15 % “Magnetofood”);
b – on pectin (—○— – sample 3 – control, —△— – sample 4 with 0.15 % “Magnetofood”)

From **Fig. 5** it can be seen that the introduction of the food additive “Magnetofood” accelerates the gelation process by $(2.0...2.5) \times 60$ s on agar and by $(2.0...2.2) \times 60$ s on pectin; increases the maximum shear stress by $(11.9 ... 12.6) \%$ – on agar and $(8.2...9.1) \%$ – on pectin, which is associated with the formation of supramolecular associates with “Magnetofood” nanoparticles. As a result, the gelation process is accelerated and the strength of the whipped mass increases. In addition, the introduction of the food additive “Magnetofood” increases the effective viscosity of marshmallow masses by $(1.35...1.55)$ times compared to the control, which is associated with the structure-forming effect of nanoparticles “Magnetofood”, leading to the aggregation of polysaccharides and an increase in roughness of their channels. As a result, the stability of foam films increases, and an increase in the gel-forming ability of pectin and agar allows increasing the viscosity in the Gibbs-Plateau channels, stabilizes the gel frame of the foam structure and slows down the syneresis process [6].

On the basis of the research carried out, formulations were compiled and technological schemes for the production of white-pink marshmallows (on agar and pectin) using the food additive “Magnetofood” were developed.

5. Conclusions

1. The functionality of the food additive “Magnetofood” has been proven in technologies: curd dessert and white-pink marshmallow. Organoleptic indicators of finished products and dispersed characteristics of foam structures in curd dessert and in marshmallows were determined with the introduction of the food additive “Magnetofood”: the distribution function of air bubbles in diameter is narrow and symmetrical, diameter $d=(45...50) \times 10^{-3}$ m is a fundamental factor indicating the stabilizing effect of “Magnetofood” nanoparticles. A rational amount of the food additive “Magnetofood” in the formulations of whipped confectionery products (0.15 %) has been established.

2. It has been established that the food additive “Magnetofood” affects the structural and mechanical properties of whipped confectionery: in curd desserts, with an increase in the mass fraction of the food additive “Magnetofood”, the maximum shear stress is increased by $(1.18...1.3)$ times and the thixotropy coefficient is 1.26 times compared to the control; in white-pink marshmallows, they increase - the strength of the foam structure is $(1.1...1.2)$ times and the effective viscosity of marshmallows is $(1.35...1.55)$ times compared with the control. This has a positive effect on the texture of the product and extends the shelf life of its freshness.

3. It has been determined that with the introduction of the food additive “Magnetofood” in the marshmallow masses, the following decrease: the density is $(1.12...1.15)$ times and the duration of whipping by $(1.5...2.5) \times 60$ s by compared with control.

4. Recipes have been compiled and technological schemes have been developed for the production of cottage cheese dessert and white-pink marshmallow (on agar and pectin) using the food additive “Magnetofood”.

References

- [1] Hachak, Yu. R., Vavrychevych, Ya. S., Prokopiuk, N. I. (2016). Rozrobka retseptur syrkovykh mas iz krioporoshkamy «Morska kapusta» ta «Brokkoli» ta yikh tekhnolohichni kharakterystyky. *Naukovyi visnyk LNUVMBS im. S. Z. Hzhyskoho*, 18, 1 (65), 53–59.
- [2] Soloveva, M. S. (2013). Razrabotka tekhnologii tvorozhnykh desertov na osnove sukhikh molochnykh komponentov. *Molochnoe delo*, 5, 23–26.
- [3] Ramachandraiah, K., Choi, M.-J., Hong, G.-P. (2018). Micro- and nano-scaled materials for strategy-based applications in innovative livestock products: A review. *Trends in Food Science & Technology*, 71, 25–35. doi: <http://doi.org/10.1016/j.tifs.2017.10.017>
- [4] Ramos, L. R., Santos, J. S., Daguer, H., Valese, A. C., Cruz, A. G., Granato, D. (2017). Analytical optimization of a phenolic-rich herbal extract and supplementation in fermented milk containing sweet potato pulp. *Food Chemistry*, 221, 950–958. doi: <http://doi.org/10.1016/j.foodchem.2016.11.069>
- [5] Park, H., Lee, M., Kim, K.-T., Park, E., Paik, H.-D. (2018). Antioxidant and antigenotoxic effect of dairy products supplemented with red ginseng extract. *Journal of Dairy Science*, 101 (10), 8702–8710. doi: <http://doi.org/10.3168/jds.2018-14690>
- [6] Taghi Gharibzadeh, S. M., Koubaa, M., Barba, F. J., Greiner, R., George, S., Roohinejad, S. (2018). Recent advances in the application of microbial transglutaminase crosslinking in cheese and ice cream products: A review. *International Journal of Biological Macromolecules*, 107, 2364–2374. doi: <http://doi.org/10.1016/j.ijbiomac.2017.10.115>
- [7] Granato, D., Santos, J. S., Salem, R. D., Mortazavian, A. M., Rocha, R. S., Cruz, A. G. (2018). Effects of herbal extracts on quality traits of yogurts, cheeses, fermented milks, and ice creams: a technological perspective. *Current Opinion in Food Science*, 19, 1–7. doi: <http://doi.org/10.1016/j.cofs.2017.11.013>
- [8] Ilyukha, N., Tsykhanovska, I., Barsova, Z., Kovalenko, V. (2010). Production technology and quality indices of a food additive based on magnetite. *Eastern-European Journal of Enterprise Technologies*, 6 (10 (48)), 32–35. Available at: <http://journals.uraua/eejet/article/view/5847>
- [9] Alexandrov, A., Tsykhanovska, I., Kaida, N., Evlash, V. (2019). Development of reproduction of cheese dessert “Slononia” with the use of food additive “Magnetofood.” *Scientific Works of National University of Food Technologies*, 25 (1), 169–179. doi: <http://doi.org/10.24263/2225-2924-2019-25-1-17>
- [10] Tsykhanovska, I., Alexandrov, A., Kaida, N., Evlash, V., Kovalenko, Z. (2019). Improving the technology of white-pink marshmallow using food additive “Magnetofood.” *Scientific Works of National University of Food Technologies*, 25 (2), 186–203. doi: <http://doi.org/10.24263/2225-2924-2019-25-2-21>

SIMULATION OF THE RADIANT HEAT TRANSFER PROCESS IN THE ELEMENTS OF ROASTING EQUIPMENT

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ARTICLE INFO

Article history:

Received date 15.09.2020

Accepted date 23.10.2020

Published date 30.10.2020

Section:

Equipment and technology of food production

DOI

10.21303/2313-8416.2020.001474

KEY WORDS

infrared roasting
profiling
reflector
semi-finished meat product
steak

ABSTRACT

The object of the research is the process of radiation heat transfer, taking into account a single reflection of rays in the IR device of food production.

Investigated problem – the work is devoted to solving the problem of irregularity of radiation heat transfer during infrared roasting of food products.

Main scientific results. The inverse problem of heat transfer by radiation has been solved and a technique has been developed for determining the profiles of the ray flux reflectors for uniform irradiation of receivers of a convex section. Analytical modeling of all-round uniform irradiation of an elliptical receiver has been carried out. An experimental device with low-inertia temperature sensors for infrared roasting of semi-finished meat products has been developed, which makes it possible to use a reflector shaped according to the developed analytical technique. The verification of the created technique for determining the profiles of reflectors by means of a computer experiment using the TracePro and Mathcad software systems has been carried out.

The area of practical use of the research results: the use of an experimental device with a radiant flux reflector for roasting semi-finished meat products proves that the obtained technique for profiling reflectors of heat engineering systems is acceptable for the design of infrared equipment for food production and restaurant facilities. This technique allows simulating the profile of the radiant flux reflector depending on the shape of the receiver. Studies have shown that the use of a profiled reflector in the experimental device reduces the duration of roasting of natural portioned semi-finished beef products by 33 %.

Innovative technological product: a technique for determining the profiles of ray flux reflectors for uniform irradiation of receivers with a convex section. Device for infrared roasting of semi-finished meat products.

Scope of application of an innovative technological product. The study of an experimental device with a designed radiant flux reflector for roasting semi-finished meat products proves that the obtained technique for profiling reflectors of heat engineering systems is acceptable for the design of infrared equipment for food production and restaurant facilities. Using this approach allows to approach the solution of the problem of irregularity of irradiation of products during infrared roasting.

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1. Introduction

1. 1. The object of research

The object of research is the process of radiation heat transfer, taking into account a single reflection of rays in the IR device of food production.

1. 2. Problem description

One of the progressive methods of thermal processing of food products is thermal processing with infrared (hereinafter IR) radiation. The use of infrared radiation intensifies the technological processes of food production due to a significant increase in the density of the heat flux on the

surface of the product and the penetration of thermal energy into the material. The main advantage of infrared roasting is the shortening of the cooking time, which leads to a reduction in energy consumption and improves the quality of the product.

It should be noted that further intensification of IR roasting as an independent processing method has certain limitations. They are based on the fact that irregularities of IR irradiation can cause local overheating of the surface and the appearance of “burns”, which significantly impair the quality of finished products. Therefore, the main scientific and practical task in this direction is the creation of a local thermal zone at the heating object or in the working space of the technological process, minimizing heat losses for heating the environment and the surface outside the selected zone.

1. 3. Proposed solution of the problem

Scientists pay considerable attention to the use of reflective devices, with the help of which the necessary irradiation of the object is achieved [1, 2]. To obtain a directed radiation flux, reflectors of various shapes are used: spherical, parabolic, hyperbolic, elliptical, etc. [3]. However, the difficulty of using such reflectors is caused by optical aberrations and the finiteness of the radiation bodies of real sources, each surface element of which is a source of a diffuse radiation flux. In work [4], a deep analysis of the research of domestic and foreign researchers in the field of IR heating and geometric modeling of heat transfer by radiation in infrared installations during heat treatment of food products was carried out, the regularities of modeling of IR radiation in absorbing gaseous media were investigated. However, the author has not solved the problem of determining the profile of the reflector for uniform irradiation of the convex receiver. In work [5], researchers describe a combined method of processing food products with IR radiation and microwave influence, but also did not consider the problem of dissipation of thermal energy during exposure. In work [6], the authors described the computer simulation of the temperature field using induction and radiation heating, however, the resulting dependences on the determination of the temperature of the inner layers of the processed material is not correct. The authors of [7] propose an innovative solution for the development of a device for low-temperature processing of meat products by infrared radiation. A feature of the device is the possibility of using secondary heat, and coming from the working space of the device, by absorbing it by an absorbing screen. But the problem of uneven irradiation of products of various shapes has not been resolved either.

Therefore, solving the problem of irregularity of radiation heat transfer during infrared roasting of food products and determining the profile of the reflector with the subsequent design of the device is an urgent scientific problem.

2. Material and methods

The heat engineering system (**Fig. 1**) consists of a tubular radiator 1, a cylindrical reflector 2, and a heat receiver with a convex cross-sectional shape 3. A Cartesian coordinate system is connected to the system so that the Oz axis passes along the radiator, and the Ox, Oy axes are located as follows, as this is shown in the **Fig. 1**.

The following designations are used: h – distance from the axis of the emitter to the center of the receiver, m; α – half of the angle in which the rays propagate, do not hit the reflector; θ_0 – half of the angle in which the rays propagate, falling on the receiver AB directly from the emitter.

As a heat receiver, a semi-ellipse was chosen with the lengths of the major and minor semi-axes a and b , respectively, which shape is closest to the section of a portioned meat semi-finished product (beefsteak and steak). The semi-ellipse equations are compiled in relative polar coordinates using the ratios of the absolute coordinates and dimensions of the heat engineering system to the semi-ellipse semi-major axis.

The beam has only one reflection from the reflector surface. When the point of reflection M moves along the surface of the reflector from N to P towards an increase in the polar angle φ , point K of the working medium, where the reflected beam hits, monotonously move its surface from A to B towards an increase in coordinate β (**Fig. 2**).

The direct flow from the emitter falls only on the CD section, limited by those attached to the ellipse (**Fig. 1**), and the AC and BD sections remain unheated by it – only the rays reflected from the reflector fall on them. Let's introduce into the calculations the direct irradiation function, which is proportional to the irradiation density.

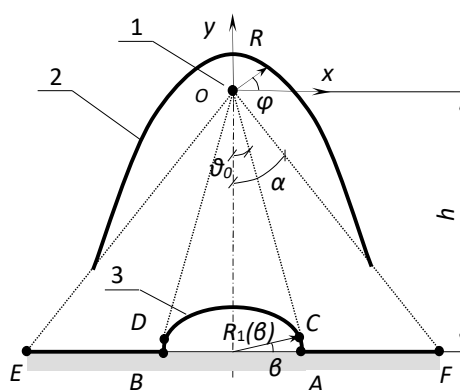


Fig. 1. Diagram of the heating system

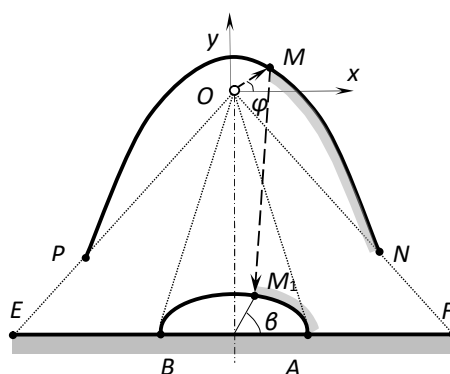


Fig. 2. Diagram of beam movement

The value of the relative density of direct irradiation is maximum on the plumb axis of the heating system, decreasing from it to points C and D , and is zero in the so-called “shadow” in sections AC and BD .

The value of the relative density of the reflected radiation is maximum in the so-called “shadow” of the heat receiver, where the direct radiation flux does not fall.

The total energy that the semi-ellipse will receive consists of the energy of the direct radiation and the energy reflected from the reflector. Taking into account the length of the semi-ellipse, this determines the equation of the relative density of the direct and reflected radiation.

Let's compose the energy balance by equating the amount of heat per second from a radiator of a given power with the required parameters of the reflector $R(\varphi)$ and φ to the relative density of the reflected radiation, integrated along the length of the semi-ellipse with the required parameters $R_1(\beta)$ and β . From the energy balance equation, let's obtain an equation for determining the angular coordinate of the reflector section φ .

Let's introduce into the calculation the relative radial coordinates of the reflector and the receiver, respectively, as the ratio of $R(\varphi)$ and $R_1(\beta)$ to a , and obtain a differential equation for determining the profile of the reflector, which describes the relationship between the relative radial coordinate of the reflector and the relative angular coordinate of the receiver. The differential equation obtained in the research is solved using the Mathcad computer algebra system by the universal hybrid Adams-BDF method, which also calculates and constructs a family of reflector profiles, one of which is subject to structural implementation in accordance with the selected process of IR-roasting of meat portioned semi-finished products.

2. 2. Experimental infrared roasting device

The aim of the experimental study was to evaluate the efficiency of using a profiled reflector by physical modeling and comparing the results with computer verification of the created technique.

The experimental device implements a heat engineering system, the diagram of which is shown in **Fig. 3**. It consists of a linear radiator 1, a cylindrical reflector 2 and a heat receiver 3.

The experimental device uses one quartz emitter with a supply voltage of 220 V, a power of 720 W, and the emitter length is 250 mm. The heat wavelength is $1.2 \mu\text{m}$, so the angles of incidence of heat rays on the reflector are equal to the angles of reflection.

The reflector is made of letter-polished aluminum, providing a reflectivity of about 90 %. Note that the size of the sheet is $275 \times 214 \text{ mm}$ and the profile of the reflector is determined by the section of semi-finished meat products and calculation in Mathcad in accordance with the created method.

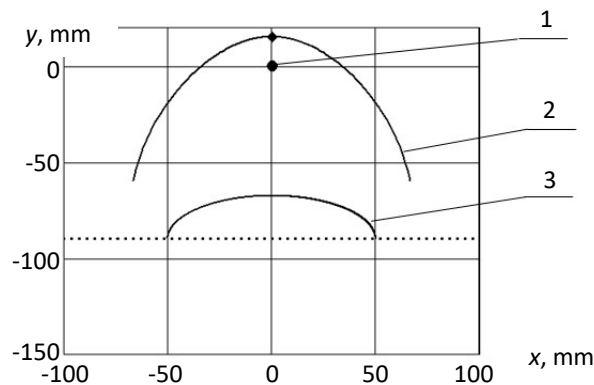


Fig. 3. Heat engineering system: 1 – emitter; 2 – reflector; 3 – receiver

A semi-ellipse with a width of 100 mm and a height of 20 ... 25 mm (for computer modeling – 22.5 mm) and a length of 200 mm is chosen as a receiver, which corresponded to the usual size and mass of steaks and splint. The distance between the centers of the emitter and the receiver is 90 mm. There should be a distance of 100 mm from the center of the product to the edge of the wire rack where it is located (**Fig. 3**).

The temperature in the working chamber is determined using nine sensors with chromel-alumel TCA thermocouples (measurement at 1100°C), which are installed on a flat frame.

2. 3. Methods of computer simulation of exposure

Existing computer programs (COSMOSWorks, TracePro, SolidWorks, etc.) fundamentally solve exclusively direct problems of irradiation, that is, determine the heat density on the surface of the receiver with a known reflector profile. In addition, the required number of beams is determined experimentally, by approximating the results to theoretical conclusions, and an incorrect number of beams can lead to significant errors.

To obtain a numerical Solution in TracePro, set the amount of heat rays emanating from the source. The computer program randomly selects points on the emitters and the direction of movement of the rays emanating from them, and automatically calculates their trajectories, but first it is necessary to set the profile of the cylindrical reflector.

The spatial distribution of the radiation flux density is modeled by calculating the trajectories of individual random rays, and the decoupling accuracy corresponds to their number. To obtain a realistic picture of the distribution of the radiant flux, it is necessary to take the number of rays at least a million.

3. Results

Let's determine the shape of the fragmented reflector of the heat engineering system for all-round uniform irradiation of the semi-elliptical receiver (with different values of the radiant flux density on the upper and lower surfaces).

Let's consider a heat engineering system (**Fig. 4**), which consists of a tubular radiator 1, a cylindrical reflector 2, and a heat receiver with a semi-elliptical shape of the upper surface and a flat lower surface 3. Let's associate the Cartesian coordinate system with the system so that the Oz axis passes along the radiator and the Ox axis, Oy positioned as shown in the **Fig. 4**.

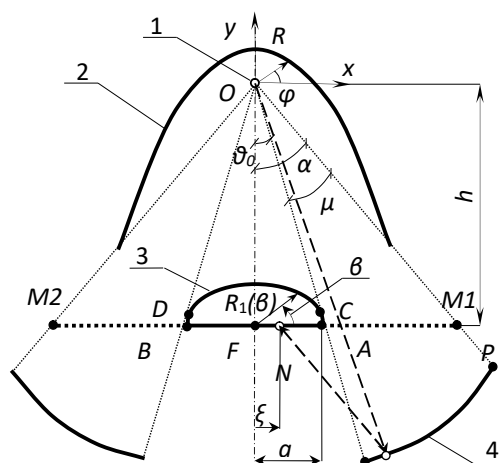


Fig. 4. Diagram of the heating system

Let's use the following notation: h – distance from the axis of the emitter to the bottom surface of the receiver, m; α – half of the angle in which the rays propagate, do not hit the reflector; θ_0 – half of the angle in which the rays propagate, falling on the receiver AB directly from the emitter.

To designate the polar coordinates of the reflector section surface, let's use the symbols $R(\mu)$ and φ , for the coordinates of the upper surface of the receiver – $R_1(\beta)$ (m) and β , and at the bottom – Cartesian coordinates x and y .

The technique for determining the profile of reflector 2 was presented. Therefore, let's focus on determining the profiles of reflectors 4 (Fig. 4), that is, exactly those that will ensure uniform heating of the working fluid 3 from below. To do this, let's use a heat flux that did not fall on the receiver either directly or from the reflector. This approach to the design of heating plants will allow the processing of food from all sides with a simultaneous reduction in energy consumption.

Obviously, the heat flux density on the upper surface will be several times higher than the density on the lower one, but this ratio can be adjusted by changing the geometric parameters of the working chamber (angles α , θ_0).

Let's assume that when the point of reflection of the heat ray along the surface of the reflector moves from N to P in the direction of increasing the polar angle φ , the point where the reflected ray hits will move by its lower surface from F to A in the direction of increasing coordinate ξ (Fig. 4).

Let's design the device in such a way that the heat flux propagating in any of the corners $\mu = \alpha - \theta_0$ (Fig. 4) is reflected only from one of the fragments of the reflector and uniformly illuminates the nearest half of the lower plane of the receiver.

Let's denote by the Q the energy from one meter of the source (W/m). All the heat that falls on one linear meter of the lower half of the surface in one second is equal to

$$Q_z = \frac{Q}{2\pi} \mu. \quad (1)$$

This heat is evenly distributed with a density (W/m²)

$$q_z(\xi) = \frac{Q_z}{a} = \frac{Q}{2\pi a} \mu. \quad (2)$$

Thus, the relative density of irradiation in the absence of direct irradiation is provided by the rays reflected from below:

$$p_z(\xi) = \frac{q_z(\xi) a}{Q} = \frac{1}{2\pi} \mu. \quad (3)$$

The product section of length ξ receives the following reflected energy (W/m):

$$\int_0^{\xi} q_z(\xi) a \, d\xi = \int_0^{\xi} Q p_z(\xi) \, d\xi = Q \int_0^{\xi} p_z(\xi) \, d\xi. \quad (4)$$

This energy comes after reflection in the corner $\phi + \frac{\pi}{2} - \theta_0$ and is equal $\frac{Q}{2\pi} \left(\phi + \frac{\pi}{2} - \theta_0 \right)$. Equating it to dependence (4), let's obtain

$$\frac{Q}{2\pi} \left(\phi + \frac{\pi}{2} - \theta_0 \right) = Q \int_0^{\xi} p_z(\xi) \, d\xi. \quad (5)$$

Taking into account (3), let's obtain

$$\phi = \theta_0 - \frac{\pi}{2} + 2\pi \int_0^{\xi} p_z(\xi) \, d\xi = \theta_0 - \frac{\pi}{2} + \int_0^{\xi} \mu \, d\xi. \quad (6)$$

To determine the shape of the reflector, there is the following differential equation:

$$\frac{d\rho}{d\xi} = -\rho \frac{(\rho_1 - \rho) \cos \phi + \xi}{(\rho_1 + \rho) \sin \phi - \eta} \frac{d\phi}{d\xi}, \quad (7)$$

where $\eta = -\chi$, $\phi = \phi(\xi)$, $\rho_1 = \sqrt{(\rho \cos \phi - \xi_z)^2 + (\rho \sin \phi - \eta)^2}$, $\rho = R/a$.

To determine the shape of the lower part of the reflector, eq. (7) was solved using Mathcad by the universal hybrid Adams-BDF method for pivelips with the ratio of the minor axis to the major axis 0.5 and such initial values ρ_0 of the relative radial coordinate ρ beyond $\phi = \theta_0 - \frac{\pi}{2}$:

$\rho_{01} = 1.25\rho_{\text{MAX}}$, $\rho_{02} = 1.5\rho_{\text{MAX}}$, where ρ_{MAX} – the relative distance from point O to point M_1 . For other variables, the following values were taken: $\chi=4$, $M_1M_2/a=6$ (Fig. 4).

Based on these results, a number of fragmented reflectors were developed, shown in Fig. 5 (the coordinate grid corresponds to the relative dimensions of the heating system). They provide a uniform heat flow on the lower plane of the heat sink.

Fig. 6 (the coordinate grid corresponds to the relative dimensions of the heat engineering system) shows a fragmented reflector for all-round uniform irradiation of a heat receiver with semi-elliptical upper and flat lower surfaces. For the upper part of the reflector, the previously described technique was used for semi-ellipse with the ratio of the minor axis to the large axis of 0.5 and such initial values ρ_0 of the relative radial coordinate ρ at $\phi = \alpha - \frac{\pi}{2}$: $\rho_{01} = 0.5\rho_{\text{MAX}}$, $\rho_{02} = 0.75\rho_{\text{MAX}}$, $\rho_{03} = \rho_{\text{MAX}}$. For the lower part, a fragmentary reflector with Fig. 5 is taken closer.

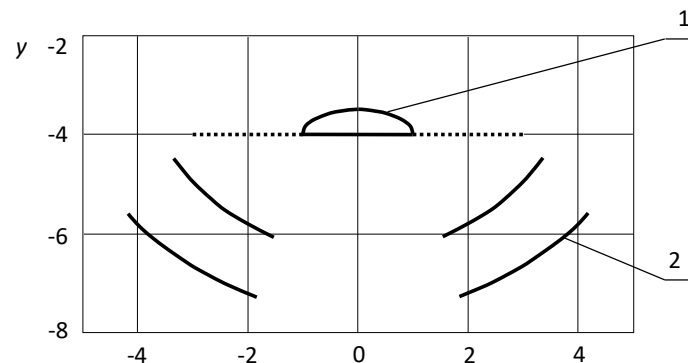


Fig. 5. Uniform irradiation of the lower plane of the semi-axis: 1 – receiver; 2 – reflector

To use the Trace Pro software package, let's take the following parameters: the emitter has a power of 720 W and a length of 1000 mm, the product has a cross-section in the form of a half ellipse 100 mm wide and 22.5 mm high, the product length is 1000 mm, which corresponds to the cross-section of a semi-finished product and the condition of considering a plane problem.

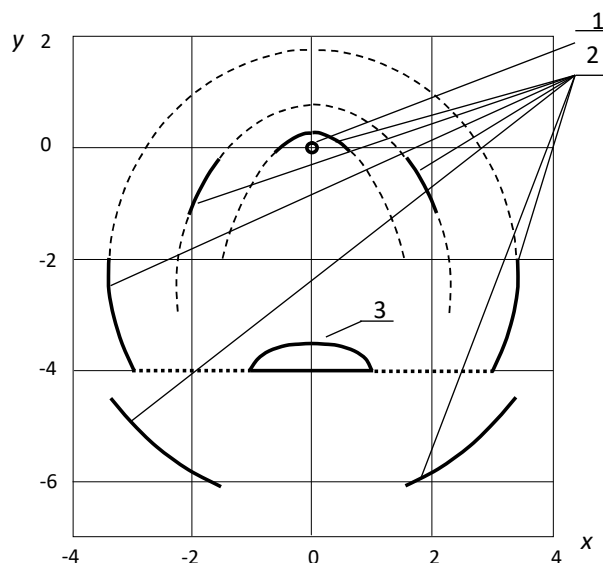


Fig. 6. All-round uniform irradiation of semi-ellipse: 1 – emitter; 2 – fragmented reflector; 3 – receiver

Let's take the shape of the reflector from previous studies. At first, 500 beams were received. The distribution of rays in the working chamber, obtained under such conditions, is shown in **Fig. 7**.

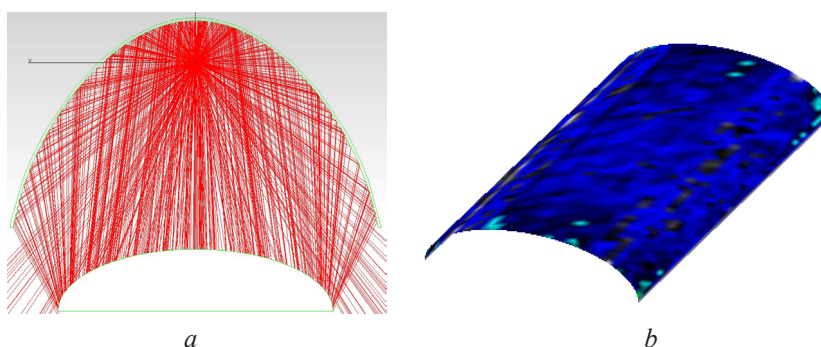


Fig. 7. Distribution of rays in the working chamber: *a* – axial projection; *b* – isometric projection

To obtain a realistic picture of the distribution of the radiant flux, it is necessary to take the number of rays at least a million. How the receiver irradiation looks like is shown in **Fig. 7, b**. A change in the irradiation intensity is presented as a change in the surface color, but even a monochrome image makes it possible to state that the heat flux density on the surface of the working fluid is a constant value (the presence of places with a slight color change in the figures is explained by the errors of the computer calculation method).

The general view of the developed device is shown in **Fig. 8**.

The uniform total irradiation of the product is provided by the polished reflector 3, the profile of which is determined by the developed method [8] and calculated for the use of the created software product in the Mathcad complex.

During roasting of semi-finished beef products in device without a reflector, the product was ready in 10 minutes, with a reflector – in 7 minutes. Roasting stopped after reaching a temperature of 75 °C inside the product was determined using a chromel-copel thermocouple.

The uniform total irradiation of the product is provided by a reflector, the profile of which, determined according to the developed method and calculated using the created software product in the Mathcad complex, is shown in **Fig. 9** (the grid is in mm).

In accordance with the dimensions of the working chamber and the selected cross-section of the product $\alpha = 0.838$; $\theta = 0.521$; $L = 118.017$ mm. For a radiator with a power of 1 kW and a length of 0.25 m, the radiant flux density is

$$q = \frac{1,000}{3.14 \cdot 118.017 \cdot 10^{-3} \cdot 1} (3.14 + 0.521 - 0.838) \times \frac{1}{0.25} \approx 30.48 \text{ kW/m}^2. \quad (8)$$

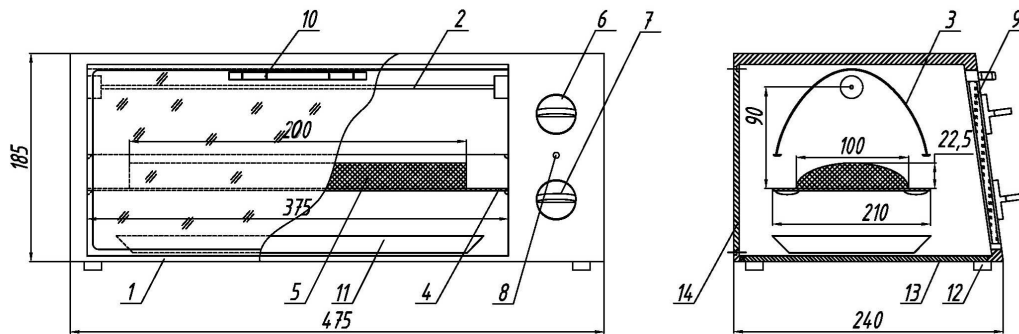


Fig. 8. General view of the ARZhM-0.07-1 device: 1 – body; 2 – emitter; 3 – reflector; 4 – lattice; 5 – product; 6 – power regulator; 7 – timer; 8 – indicator; 9 – glass doors; 10 – door handle; 11 – baking sheet; 12 – legs 13 – folding pallet; 14 – cover

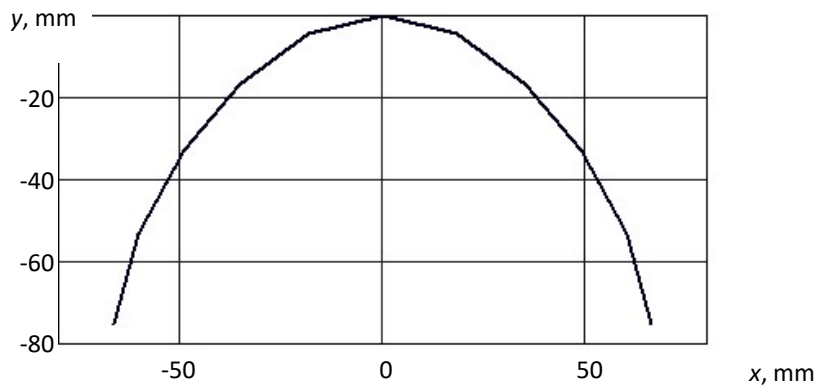


Fig. 9. Reflector profile

The analytical solution was obtained for a semi-elliptical product with a semi-major axis of 50 mm, and less – 22.5 mm, which was determined by the recommended values of a semi-finished meat product thickness of 20 ... 25 mm. That is, the ratio of the pivot axes of the receiver is $22.5/50=0.45$.

The experimental distribution of the irradiation density for a flat arrangement of thermocouples has a concave semi-elliptical character with a value in the middle of 29.83 kW/m^2 , and at the edges of 49.75 kW/m^2 . Thus, the ratio of the axes of the semi-elliptical distribution of the irradiation density is $(49.75-29.83)/50=19.92/50=0.4$. Taking into account the errors in the manufacture and installation of the reflector, this result can be considered acceptable.

Thus, comparison of the obtained results of physical and analytical modeling of infrared radiation of a convex product proves the effectiveness of the developed technique for determining the profile of the reflector of the ray flux. The device with a reflector for roasting semi-finished meat products ARZhM-0.07-1 provides on the surface of the product a uniform radiant flux density of about 30 kW/m^2 .

4. Discussion of research results

A heat engineering installation is considered, in which it is permissible to investigate the distribution of heat rays in accordance with the plane problem [9]. A technique has been created for determining the profiles of reflectors for uniform irradiation of a receiver with a convex section by solving the inverse problem of irradiation, that is, from the receiver to the shape of the reflector. The solution of the inverse problem allows to arrive at a rational form of the reflector. As a heat sink, a semi-ellipse was chosen with given lengths of semi-axes, which shape is closest to the section of a portioned meat semi-finished product (Fig. 3). As a result of analytical modeling, a differential equation was obtained to determine the shape of the reflector (formula 7). The

verification of the created technique for determining the profiles of reflectors was carried out by means of a computer experiment using the TracePro and Mathcad software systems, which proves its correctness [8, 10]. The developed technique for determining the profiles of reflectors was validated by a physical experiment on the use of an experimental IR roasting device (**Fig. 8**), which made it possible to evaluate the efficiency of using an analytically profiled reflector and compare the results with computer verification of the created technique, proves its acceptability for designing IR equipment for food production and restaurant facilities. When using the Mathcad software package, a software product was created to determine the shapes of reflectors, which will provide exactly the specified distribution of the radiant flux on the surface of the convex heat sink (**Fig. 7**). An industrial prototype of device with a reflector for roasting semi-finished meat products has been developed, which provides a uniform density of radiant flux on the surface of the product.

The limitation of this research is the geometry of the receiver, namely semi-ellipse, which is the closest to the shape of a semi-finished meat steak. The heat engineering system for modeling the reflector profile takes into account precisely the semi-ellipse geometry. That is, this technique is not general.

In this study, the shape of the receiver, namely the semi-ellipse, determined the profile of the simulated reflector. That is, further research involves the choice of a receiver of a different shape and, as a consequence, the calculation of a different geometry of the reflector profile.

5. Conclusions

A technique has been developed for determining the profile of a ray flux reflector during heat exchange by infrared radiation. Computer simulation of the propagation of heat rays in the working chambers of heat engineering systems using the TracePro software package proves that the obtained technique for profiling reflectors of heat engineering systems is correct.

The use of an experimental device with a radiant flux reflector for roasting semi-finished meat products proves that the obtained technique for profiling reflectors of heat engineering systems is acceptable for the design of infrared equipment for food production and restaurant facilities. The use of a profiled reflector in the device reduces the roasting period of natural portioned semi-finished beef products by 33 %. An industrial prototype of device with a reflector for infrared roasting of semi-finished meat products has been developed, which provides a uniform radiant flux density of about 30 kW/m² on the surface of the product.

References

- [1] Ramazanov, S. K., Skripnik, V. O., Molchanova, N. Iu. (2015). Modeling of dynamics of heat conductivity in the process of double-sided frying of meat on the basis of nonlinear optimization. *Technology audit and production reserves*, 3 (3), 41–47. doi: <http://doi.org/10.15587/2312-8372.2015.44167>
- [2] Tormosov, Yu. M. (2004). *Heometrychne modeliuvannia ta optymizatsiia protsesu teplovoi promenevoi obrobky kharchovykh produktiv*. Kyiv, 270.
- [3] Sereda, N. I. (1999). *Heometrychne modeliuvannia perebihu promeniv v eliptychnykh ta parabolichnykh vidbyvalnykh systemakh*. Kyiv: KNUBA, 174.
- [4] Tormosov, Yu. M., Saienko, S. Yu. (2018). *Heometrychne modeliuvannia reflektoriv infrachervonykh aparativ kharchovoi promyslovosti*. Kharkiv, 123.
- [5] Aboud, S. A., Altemimi, A. B., R. S. Al-Hilphy, A., Yi-Chen, L., & Cacciola, F. (2019). A Comprehensive Review on Infrared Heating Applications in Food Processing. *Molecules*, 24 (22), 4125. doi: <http://doi.org/10.3390/molecules24224125>
- [6] Dutka, V. A. (2013). *Kompiuterne modeliuvannia temperaturnoho polia v protsesi spikannia karbidnykh kompozytiv pry vykorystanni induktsiinoho ta promenevoho nahrivannia*. *Sverkhтверде материалы*, 1, 40–55.
- [7] Zahorulko, A., Zagorulko, A., Yancheva, M., Serik, M., Sabadash, S., Savchenko-Pererva, M. (2019). Development of the plant for low-temperature treatment of meat products using ir-radiation. *Eastern-European Journal of Enterprise Technologies*, 1 (11 (97)), 17–22. doi: <http://doi.org/10.15587/1729-4061.2019.154950>
- [8] Plevako, V. P., Kostenko, S. M., Pedorych, I. P. (2013). Check of the methodology for determination of profile of reflector of beam stream. *Eastern-European Journal of Enterprise Technologies*, 6 (5 (66)), 42–45. Available at: <http://journals.uran.ua/eejet/article/view/18735>
- [9] Plevako, V. P., Saienko, S. Yu. (2008). Dovedennia dotsilnosti rozrakhunku teplotekhnichnykh system u plaskii postanovtsi. *Heometrychne ta kompiuterne modeliuvannia*, 21, 20–29.
- [10] Saienko, S. Yu., Plevako, V. P. (2009). *Modeliuvannia rozpovsiudzhennia teplovykh promeniv u ICh-aparatakh kharchovoi promyslovosti zasobamy TracePro*. *Heometrychne ta kompiuterne modeliuvannia*, 25, 57–62.

EVALUATION OF FETAL REACTIVITY IN A TEST WITH ACOUSTIC STIMULATION IN WOMEN WITH A HISTORY OF CESAREAN SECTION

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ARTICLE INFO

Article history:

Received date 22.09.2020

Accepted date 26.10.2020

Published date 30.10.2020

Section:

Practical medicine

DOI

10.21303/2313-8416.2020.001482

KEY WORDS

cesarean section
scarred uterus
fetal condition
antenatal assessment
perinatal pathology

ABSTRACT

Object of study: pregnancy in women with a history of cesarean section, perinatal period.

The problem to be solved: clarification of the perinatal significance of the factor “scarred uterus”, substantiation of the clinical significance of the test with acoustic stimulation of the fetus as a method for predicting early neonatal adaptation.

Main scientific results: it was found that pregnancy in women with a history of cesarean section is characterized by an increased perinatal risk and is associated with psychoemotional stress of the mother, which affects the reactivity of fetal cerebral hemodynamics. It has been shown that the test with acoustic stimulation of fetus allows one to gain an idea of the fetus’s perception of stressful influences, which should be taken into account when drawing up a delivery plan.

The area of practical use of research results: obstetric departments of maternity hospitals and multidisciplinary hospitals.

An innovative technological product: technology for assessing the state of the fetus in full-term pregnancy, which allows predicting complications of early neonatal adaptation based on the susceptibility of the fetus in the test with acoustic stimulation.

Scope of application of an innovative technological product: obstetric clinical practice, perinatal medicine.

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1. Introduction

1.1. Object of study

Pregnancy in women with a history of cesarean section, perinatal period.

1.2. Description of the problem

Delivery by caesarean section (CS) is recognized worldwide as the most effective way to overcome the risks of perinatal losses, as a guarantee of reducing maternal morbidity and mortality [1]. However, this does not hide the obvious problems associated with the increase in CS levels throughout the world [2].

In the modern reproductive population, the number of women with uterine scar after CS has increased significantly. Many of them are planning a new pregnancy in the future. The postponed surgical intervention leaves negative consequences: pain and discomfort in the area of the scar, inflammatory changes in the pelvic organs, disorders of the immune and endocrine systems, sexual dysfunction [3]. These factors serve as prerequisites for the development of a number of complications during subsequent pregnancy.

Traditionally, the greatest importance is attached to the reliability of the scar during labor. At the same time, an equally important aspect is perinatal, which is not given enough attention in clinical practice. The scarred uterus, which has experienced trauma and reparative process, theo-

retically is no longer an ideal host, which inevitably affects the conditions for development of the fetus. This aspect remains poorly understood.

1.3. Suggested way to solve the problem

Psychophysiological disorders are a particular problem in women with a CS in anamnesis [4]. Patients with negative experience of previous childbirth have a higher risk of stress, a complex of neuropsychiatric disorders [5].

Maternal stress, regardless of its causes, is a risk factor for perinatal pathology [6], associated with physiological [7], neurological, psychological consequences in offspring [8, 9].

All of the above substantiates the relevance of assessing the adaptive potential of the fetus when planning the method of delivery – choosing a repeated CS or vaginal delivery. The solution to this problem is possible under the conditions of carrying out functional tests [10, 11]. One of the promising options for testing resistance to stress is the test with acoustic stimulation (TAS) of the fetus [12, 13]. Sound is a stressful stimulus, the target of which is brain [14, 15]. Acoustic stimulation is one of the factors of direct action on the fetus, with the ability to directly assess its sensory response [16, 17].

The aim of this work is to assess the prognostic value of the fetal acoustic stimulation test by assessing changes in fetal cerebral blood flow during full-term pregnancy in women with CS in anamnesis, in comparison with indicators characterizing the psycho-emotional status of a woman.

2. Materials and research methods

The studies were carried out in 128 multiparous women with singleton pregnancies in the period of 37–39 weeks during 2017–2019 on the basis of the municipal non-profit enterprise “City Clinical Maternity Hospital No. 6” of the Kharkiv City Council. According to the criterion “presence of scarred uterus”, two clinical groups were formed, selected according to the “case-control” (“copy-pair”) principle. The first group included 64 pregnant women with one history of CS, with an intergenetic interval of 2–7 years. The indications for CS in the past were obstructive labor (in 28), fetal compromise (in 21), premature placental abruption (6), breech presentation (5), severe preeclampsia (4). The only significant perinatal risk factor was the uterine scar. The second (control) group consisted of 64 multiparous women with an intact uterus, with an intergenetic interval of 2–15 years.

Exclusion criteria were fetal malformations, abnormalities and tumors of the uterus, somatic diseases, and neurological disorders.

The age of women in group 1 was on average 32.1 ± 3.8 years (from 26 to 39), in group 2 – 30.2 ± 5.1 years (from 25 to 40).

The state of the feto-placental complex was assessed according to the data of fetometry, placentography, dopplerometry of the uteroplacental-fetal vascular circuit, with measurement of blood flow in the middle cerebral artery (MCA), with the determination of vascular resistance indicators.

To achieve the goal, a test with acoustic stimulation was chosen, known as “prenatal hearing screening” M. Sovilj, A. Ljubic [12]. The studies were carried out on a Mindray DC-T6 apparatus (China) with a convex transabdominal sensor with a radiation frequency of 3.5 MHz, with a color marking of blood flows, during periods of absence of respiratory and motor activity in the fetus. Qualitative analysis of Doppler images included the definition of vascular resistance indicators: systolic-diastolic ratio (SDR), pulsation index (PI), resistance index (RI).

The test procedure with acoustic stimulation (TAS) included, in particular, the use of antiphones on the ears of a pregnant woman in order to avoid the influence of sound stimulation through the mother’s auditory system, recording the baseline Doppler curve MCA, the delivery of sound stimulus (intensity 90 dB, frequency 1500–4500 Hz, duration 0.2 sec.) on the area of the fetal auricle at a right angle at a distance of 5 cm from the abdomen of the pregnant woman, recording the Doppler curve MCA.

To assess the response of fetal cerebral blood flow, we used the coefficient of vascular reactivity (CVR) – the ratio of the initial SDR MCA to the SDR of the same vessel after the acoustic signal is applied: $CVR = \frac{SDR_{initial}}{SDR_{after\ the\ acoustic\ signal}}$. When interpreting the changes occurring in each observation, it was taken into account that $CVR > 1$ reflects a decrease in the vascular resis-

tance of the MCA, respectively, a dilatation of the vessel. With $CVR < 1$ – an increase in vascular resistance, vasospasm.

Psycho-diagnostic examination was carried out in the following volume: multifactorial personality questionnaire FPI “Freiburg Personality Inventory”, test questionnaire for measuring levels of anxiety by J. Taylor, adapted by T. A. Nemchinov, self-assessment of the level of reactive and personal anxiety by Ch. D. Spielberger and Yu. L. Khanin, express diagnostics of anxiety in the Luscher color choices test.

The primary endpoint was development of fetal compromise during labor, birth of a baby with a low Apgar score, need for neonatal care and intensive care.

The study design was reviewed by the Ethics Commission of the “City Clinical Maternity Hospital No. 6” KCC, approved by the Ethics Committee of the KhMAPE, recognized as consistent with the principles of the Declaration of Helsinki of the General Assembly of the World Medical Association (1964–2000), the Council of Europe Convention on Human Rights and Bio-medicine (1997), the international code of medical ethics and the rights of Ukraine. All patients provided informed consent for additional examinations on a conscientious basis.

The results were statistically processed using the STATISTICA-7 software package. Qualitative data were presented as a percentage; quantitative data were presented as mean and standard error ($M \pm m$). To compare quantitative indicators in independent samples, the Student’s t-test was used. The critical significance level for testing statistical hypotheses in the study was taken equal to 0.05.

3. Results

In all cases in both groups, the Doppler images had a typical biphasic form, consisting of an acceleration phase (ascending part), reflecting an increase in blood flow velocity corresponding to the heart systole, and a deceleration phase (descending branch), reflecting a diastolic decrease in blood flow.

The average baseline indicators of fetal cerebral blood flow resistance (**Table 1**) did not reveal differences in the groups. As you can see, all three indices are identical to each other. At the same time, it can be noted that for real clinical practice, it is the SDR that is most acceptable for quick, simple calculations, since it has a slightly larger range due to integers. At the same time, PI and RI, in contrast to SDR, have values that differ in the decimal order. This justified our choice of SDR to assess the dynamics of cerebral blood flow in the TAS and calculate the CVR.

The study of the psycho-emotional sphere of pregnant women was carried out before performing the TAS.

A general survey of women in group 1 showed that 48.4 % had a distinct negative psychological attitude towards vaginal delivery and a belief in the inevitability of repeated CS. In group 2, 4.7 % of women had no alternative attitude towards CS due to negative experience of the first birth. In group 1, 35.9 % of women were hospitalized during pregnancy due to the threat of miscarriage or for prophylactic purposes.

Table 1

Indicators of vascular resistance in the middle cerebral artery of the fetus in the groups of multiparous women with scarred (1) and intact uterus (2)

Group	Systole-diastolic ratio	Pulse index	Resistance index
1	4.99±0.133	1.52±0.05	0.78±0.05
2	4.63±0.123	1.5±0.04	0.82±0.05

Evaluating the response of fetal cerebral blood flow to an acoustic stimulus, we identified several options. First of all, depending on the presence/absence of SDR changes by more than 5 % from the baseline CVR value, the results were divided into reactive and non-reactive TAS categories.

The areactive test – the absence of changes in the SDR indices in the MCA after an acoustic stimulus by more than 5 % from the initial one – in group 1 we stated in 19 cases (29.7 %), in group 2 in 10 (15.6 %). In both groups, areactive fetal TAS is associated with negative individual characteristics of women. They were distinguished by a high level of neuroticism, emotional lability, susceptibility, with mood swings, expressive emotional reactions, as well as weakened self-control and higher personal anxiety.

In group 2, 8 out of 10 women with areactive fetal TAS gave birth to children with an Apgar score of 5–7 points due to various clinical situations during childbirth (12.5 % of the number of women in the group). In group 1, all women with areactive TAS underwent CS, including in 15 cases elective planned repeated at the request of the woman, in 4 – emergency due to the development of fetal compromise in the latent phase of labor.

The condition of children born to women of group 1, in whom the fetus showed areactive TAS, was satisfactory at birth, 8–9 points on the Apgar scale. However, in the further course of the neonatal period, 9 cases developed CNS excitation syndrome, a disorder of early neonatal adaptation.

The reactive test consisted of obtaining a response in the form of a change in the SDR in the MCA. In this case, an increase in vascular resistance, reflecting vasospasm, which causes a decrease in the intensity of blood flow in relation to the initial (baseline) level, we consider as a negative reaction. At the same time, we interpreted a decrease in vascular resistance, which means dilatation of the vessel and an increase in blood flow, as a positive reaction.

In our observations, the systolic spectrum underwent changes in most cases, while the diastolic spectrum remained practically unchanged. Absent or reverse diastolic blood flow was not recorded in any case.

When repeating dopplerometry in the interval of 10–15 minutes after acoustic stimulation, we noted the reversible nature of the changes.

We observed reactive TAS in 99 cases (77.3 % of the total number of women). Comparative analysis of changes in blood flow resistance indicators in MCA in groups of multiparous women is presented in **Table 2**.

Table 2

Comparative analysis of vascular reactivity indicators of the middle cerebral artery of the fetus in the test with acoustic stimulation

Group	N	Systole-diastolic ratio (SDR)		CVR
		Baseline indicator	Response in TAS	
1	64	4.99±0.133	5.3±0.121	0.87±0.022*
			<i>p</i> >0.05	
2	64	4.63±0.123	4.7±0.11	1.04±0.021
			<i>p</i> >0.05	

Note: * – significance of differences at *p*<0.001 when comparing groups 1–2

The data given in **Table 2** demonstrate that for group 1 as a whole, changes in fetal cerebral hemodynamics are characteristic, corresponding to vasospasm. The absence of differences in the response to the acoustic stimulus in group 2 is a manifestation of the presence of opposite changes, which was reflected in the mean values. A slightly higher SDR in the response in group 1, despite the lack of significant differences, corresponds to the fact that in a greater number of observations there was spasm (ISR>1).

An individual analysis of clinical observations allowed us to note that the TAS response towards a maximum increase in SDR, respectively, a decrease in CVR up to 20 % coincides with impairments in early neonatal adaptation in newborn children. They had a syndrome of excitement or, on the contrary, depression of the central nervous system, retention of fetal fluid in the alveoli, pathological weight loss and delayed weight recovery, and transient tachypnea was observed. In four such cases, there were meconium-stained amniotic fluid (2 in each group) without complications from the fetus, in 2 cases meconium-stained amniotic fluid resulted in aspiration.

4. Discussion

The fact that the mean baseline values of fetal cerebral blood flow resistance did not reveal differences in the groups confirms the existing opinion about the low value of the isolated determination of blood flow in MCA [18].

The higher hospitalization rate during pregnancy in group 1 patients appears to be a factor with a negative impact on the fetus. Probably, against the background of treatment of a woman in a hospital, psycho-emotional stress developed or worsened. This fact can be considered a kind of

stress-generating factor contributing to the formation of somatoform disorders against the background of a “special disease” – a scar on the uterus [4, 5].

The observed dynamics of MCA reactivity under the influence of an acoustic stimulus reflects the gradient of changes in the velocity of blood movement in systole and diastole. The more the difference between the systolic and diastolic, as well as the average, increases, the more the resistance indices increase. The presence of a reaction in the TAS reflects the susceptibility of the fetus to stress.

In our observations, the systolic spectrum underwent changes in most cases, while the diastolic spectrum remained practically unchanged. Absent or reverse diastolic blood flow was not recorded in any case. The reversible nature of the changes and the absence of signs of critical shifts in fetal cerebral hemodynamics suggests that the supplied acoustic signal does not belong to the number of traumatic factors, does not pose a danger and does not affect the development of the child, but is a signal that the fetus “copes” with, demonstrating its ability perception of stress. The lack of response can be explained by the fact that the study was carried out in the sleep phase, which is not always possible to take into account based on the subjective feelings of the woman. It is also possible the influence of some technical aspects of the test, as well as the woman’s characteristics, for example, excess subcutaneous tissue, the amount of amniotic fluid, since the amniotic environment and adipose tissue play the role of a filter in the perception of external sound stimuli [19].

The average data obtained in the presented study demonstrated a general pattern, which consists in an increase in the vascular resistance of the cerebral vessels of the fetus in the group of women with an scarred uterus, in contrast to multiparous women with an intact uterus. In general terms, this fact reflects a trend towards increased perinatal risk in women with a history of CS. The ability to predict disorders of neonatal adaptation with the help of TAS, in the development of which the state of the nervous system of newborns is important, contributes to the decision of the choice of the optimal model of delivery.

In addition to the perinatal significance of the functional test under consideration, it is also necessary to take into account that the areactive TAS provides a basis for including a particular intrauterine patient in the risk group for speech and hearing impairment [20].

Study limitations. The present study was carried out in a homogeneous limited clinical group and does not cover other types of obstetric and perinatal pathology and women with other perinatal risk factors (breech presentation of the fetus, overweight women, with anemia, preeclampsia), which at this stage does not allow us to judge the specific or the universal nature of the identified changes.

Prospects for further research. Investigation of changes in fetal cerebral hemodynamics in the test with acoustic stimulation of the fetus in other clinical groups (for example, in breech presentation of the fetus, in overweight women, with anemia, preeclampsia). To study the influence of perinatal communications in the mother-fetus dyad as a possible way to optimize the course of the neonatal adaptation period in groups, based on the use of a test with acoustic stimulation of the fetus.

5. Conclusions

1. A non-invasive method for assessing the reactivity of the fetus to external sound effects – a test with acoustic stimulation with an assessment of changes in fetal cerebral hemodynamics – allows you to clarify the stability of the fetus under stress conditions that are inevitable during delivery.

2. The response in the form of spasm of the middle cerebral artery or unresponsiveness allows predicting impairments in early neonatal adaptation, which should be taken into account in the management of childbirth, giving priority to the safety of the fetus.

3. Pregnancy in women with an scarred uterus should be considered from the standpoint of increased perinatal risk associated with psycho-emotional stress of the mother, which affects the reactivity of fetal cerebral hemodynamics.

Conflict of interests

The authors declare that they have no conflicts of interest.

References

- [1] WHO recommendations on non-clinical interventions to reduce unnecessary caesarean sections (2018). World Health Organization, 79. Available at: <https://www.who.int/reproductivehealth/publications/non-clinical-interventions-to-reduce-cs/en/>
- [2] Dubrova, L. Y. (2013). The improvement of medical support and delivery of women with a previous cesarean section. Kyiv.

- [3] Vdovichenko, Y. P., Gurzhenko, O. Y. (2015). Algorithm of diagnostics, prophylaxis and treatment of sexual dysfunctions in women after caesarian section. *Zdorovye zhenshiny*, 5 (101), 66–68.
- [4] Orovou, E., Dagla, M., Iatrakis, G., Lykeridou, A., Tzavara, C., Antoniou, E. (2020). Correlation between Kind of Cesarean Section and Posttraumatic Stress Disorder in Greek Women. *International Journal of Environmental Research and Public Health*, 17 (5), 1592. doi: <http://doi.org/10.3390/ijerph17051592>
- [5] Garthus-Niegel, S., von Soest, T., Knoph, C., Simonsen, T. B., Torgersen, L., Eberhard-Gran, M. (2014). The influence of women's preferences and actual mode of delivery on post-traumatic stress symptoms following childbirth: a population-based, longitudinal study. *BMC Pregnancy and Childbirth*, 14 (1). doi: <http://doi.org/10.1186/1471-2393-14-191>
- [6] Garcia-Flores, V., Romero, R., Furcron, A.-E., Levenson, D., Galaz, J., Zou, C. et. al. (2020). Prenatal Maternal Stress Causes Preterm Birth and Affects Neonatal Adaptive Immunity in Mice. *Frontiers in Immunology*, 11. doi: <http://doi.org/10.3389/fimmu.2020.00254>
- [7] McCreary, J. K., Truica, L. S., Friesen, B., Yao, Y., Olson, D. M., Kovalchuk, I. et. al. (2016). Altered brain morphology and functional connectivity reflect a vulnerable affective state after cumulative multigenerational stress in rats. *Neuroscience*, 330, 79–89. doi: <http://doi.org/10.1016/j.neuroscience.2016.05.046>
- [8] Zakharova, L. A. (2015). Perinatal stress in brain programming and in the pathogenesis of neuropsychiatric diseases. *Bulletin of the Russian Academy of Sciences. Biological series*, 1, 17–26. doi: <http://doi.org/10.7868/s0002332915010130>
- [9] Entringer, S., Buss, C., Wadhwa, P. D. (2015). Prenatal stress, development, health and disease risk: A psychobiological perspective – 2015 Curt Richter Award Paper. *Psychoneuroendocrinology*, 62, 366–375. doi: <http://doi.org/10.1016/j.psyneuen.2015.08.019>
- [10] Tan, K. H., Smyth, R. M., Wei, X. (2013). Fetal vibroacoustic stimulation for facilitation of tests of fetal wellbeing. *Cochrane Database of Systematic Reviews*. doi: <http://doi.org/10.1002/14651858.cd002963.pub2>
- [11] Umana, O. D., Siccardi, M. A. (2020). Prenatal Non-stress Test. Available at: <https://www.ncbi.nlm.nih.gov/books/NBK537123/>
- [12] Sovili, M., Ljubic, A. (1992). Possibilities of Prenatal Examination of Reaction to Sound in fetuses with Congenital Infections. *Journal of Perinatal Medicine section, Serbian Medical Society*, 17–18.
- [13] Jardri, R., Houfflin-Debarge, V., Delion, P., Pruvo, J., Thomas, P., Pins, D. (2011). Assessing fetal response to maternal speech using a noninvasive functional brain imaging technique. *International Journal of Developmental Neuroscience*, 30 (2), 159–161. doi: <http://doi.org/10.1016/j.ijdevneu.2011.11.002>
- [14] Selander, J., Rylander, L., Albin, M., Rosenhall, U., Lewné, M., Gustavsson, P. (2019). Full-time exposure to occupational noise during pregnancy was associated with reduced birth weight in a nationwide cohort study of Swedish women. *Science of The Total Environment*, 651, 1137–1143. doi: <http://doi.org/10.1016/j.scitotenv.2018.09.212>
- [15] Dumov, E. L., Nöcker-Ribaupierre, M., Andrushchenko, N. V., Iova, A. S. (2014). Acoustic stress in premature neonates: causes of appearance and methods of correction. *Bulletin of the North-Western State Medical University named after I.I. Mechnikov*, 6 (2), 101–109.
- [16] Gélat, P., David, A. L., Haqhenas, S. R., Henriques, J., Thibaut de Maisieres, A., White, T., Jauniaux, E. (2019). Evaluation of fetal exposure to external loud noise using a sheep model: quantification of in utero acoustic transmission across the human audio range. *American Journal of Obstetrics and Gynecology*, 221 (4), 343. doi: <http://doi.org/10.1016/j.ajog.2019.05.036>
- [17] Sood, A. K., Singh, S. (2011). Vibroacoustic stimulation and modified fetal biophysical profile for early intrapartum fetal assessment. *The Journal of Obstetrics and Gynecology of India*, 61 (3), 291–295. doi: <http://doi.org/10.1007/s13224-011-0044-5>
- [18] Safonova, I. N. (2016). Antenatal ultrasound monitoring and perinatal results in antepartum fetal distress. *Eksperimentalnaya i klinicheskaya medicina*, 1 (70), 131–138.
- [19] Antonets, V. A., Kazakov, V. V. (2014). On noninvasive assessment of acoustic fields acting on the fetus. *Acoustic magazine*, 60 (3), 320–326. doi: <http://doi.org/10.7868/s0320791914030022>
- [20] Đorđević, V., Panić, M., Stanojević, N. (2019). Risk Factors at Birth and their Impact on Prelingual and Early Lingual Development in Prematurus. 7-th International Conference on Fundamental and Applied Aspects of Speech and Language, 377–384. Available at: [http://iefpg.org.rs/Conference/2019/S %26L2019_Program_and_Abtracts.pdf](http://iefpg.org.rs/Conference/2019/S%2026L2019_Program_and_Abtracts.pdf)

DUAL-USE MATERIALS SCIENCE TECHNOLOGIES TRANSFER IN UKRAINE: PREMISES AND PRESENT CATCH-22

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ARTICLE INFO

Article history:

Received date 25.09.2020

Accepted date 26.10.2020

Published date 30.10.2020

Section:

Technology transfer

DOI

10.21303/2313-8416.2020.001477

KEY WORDS

advanced materials
 materials science
 dual use technology
 technology transfer
 export control

ABSTRACT

The object of effort is to assess the underpin premises of transfer of dual use materials science technologies appeared in Ukraine after the Independence and those developed until nowadays. It is also to shed a light on this issue and evaluate historical, technical, political, and mental barriers between technology supplier/recipient and future prospects and successful steps to be made to overcome those.

The work **puts a problem** to scrutinize today's and future materials science dual use technology transfer control regulations and all premises associated and leaving an imprint on the realities existing in Ukraine. First of all, it is important to study technology transfer issues and a vital role of those premises appeared in Ukraine otherwise one may chase a ghost while trying to understand how to put it correct in a right legal and political way to successfully resolve this matter since in this case none turnkey solutions ever exist. For example, central to a control regime debate is to discuss an evolution, or lack of the existing transparent legislation covering dual-use technologies, and a discussion on its orientation and scope. Does this really work and sound in practice, and if "yes" then to what extent? Second, at a time of fundamental change in nature and order of international relations, the wisdom of ad hoc control regimes must not escape scrutiny. Although experts are very much aware of these problems, future of control regulations remains still blurred and uncertain, so what are their potential implications for international state's security?

The research revealed that a reassessment of the problems surrounding dual use materials science technologies and today's control regulations should be made – both in terms of their potential improvement and/or possible new universal multilateral agreements and transparency among states involved in technology transfer. This further argues a need for new international mechanisms to ensure the transfer of dual-use materials science technologies, while not powering proliferation opportunities for weapon systems.

The results of this endeavor make a ground floor for further debates in terms of politics and export control in the field of transfer of intangible technologies.

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1. Introduction

By definition a dual-use technology is a technology having its potential commercial (civil) and military and/or defense applications, has been always a controversial subject in Ukraine and rest of the world. Since 1990 a lot of defense technologies in Ukraine has been unclassified and legalized for its further civil and commercial applications and/or transfer of those thanks to the conversion program announced by the government, however the actual transfer of these technologies is still dimmed and stymied and needs further loop of evolution. Undoubtedly that a certain impact and influence on international security is caused by transfer of rather sensitive dual-use materials science technologies and this proves the rationale of the present thesis. Today, a relationship between a supplier and a recipient of dual use technologies is based on rigorous control regulations which, in many instances, provide a certain background and to some extent provoke conflicting political situations. Basically, control regulations were established to effectively constrain a development of nuclear and chemical weapons, means of its delivery, military reconnaissance satellites, and other weapon systems. The argument could also be made, however, that economic considerations have also stimulated these control regulations. If to put the polemics aside, the problems caused by these regulations are that there is an urgent need to rethink and reconsider the ways of implementation of dual use technologies into a common life, added to which is the fact that control regulations have also hindered, both directly and indirectly, the development of certain civil materials science programs.

1. 1. The object of research

In view of the need to evaluate and clarify historical, political, technical, mental and other implications for the impact of transfer of dual use materials science technologies, this effort is to rate and clarify some of ramifications which are often discussed in the context of non-proliferation debate of military technologies and national security.

1. 2. Materials and Methodology

The intricate nature of dual-use technologies and their potential for enhancing Ukrainian and other economies make 'em fundamental to both R&D and political debates. It should be mentioned that there has never been a clearly defined line between defense and civil research and this border is still strongly blurred. Found in an increasing number of industrial sectors ranging from nuclear and materials science, electronics, etc., intangible technologies must have an increased attention from developers, policy, and law makers. The blurring of civilian and defense industrial bases and the increase in issues with uncertain dual-use features make distinguishing between civilian and military products and platforms more difficult and complicate the issues of export control and technology transfer.

Mechanisms for actual *viz.* commercial transfer of production technologies of advanced materials of dual-use virtually does not exist and there are strong political, economic, security and legal reasons for this. Nevertheless, despite the above the transfer of intangible technologies and conditions associated with it have continued to ignite a huge interest in the last decade. The process of technology transfer as a whole is neither simple nor systematic and far from being that perfect, especially when it comes to dual-use technologies and at present reduced to a short relationship between supplier/recipient only.

Thus, this endeavor makes an attempt to analyze and scrutinize historical, technical, political, and mental barriers between technology supplier/recipient and future prospects and real steps forward. The work also undertakes an attempt to examine today's and future materials science dual use technology transfer control regulations. The study employs qualitative methodology and is under the umbrella of a descriptive research design to agree on historical, technical, political, and mental implications for a transfer of intangible technologies and state's security. Political, and legal analysis are conducted in relation to these technologies, actions and questions popped up nowadays associated with 'em. This descriptive research portrays a rather accurate profile of current situation happened around the dual use technologies in Ukraine. This design offers a profile of described relevant aspects of the problem of interest from author's individual perspective.

1. 3. Problem description

In former Soviet Union, Ukraine was a recognized leader in development of advanced materials with a high level of required performance and an employment of those under extreme conditions. Notably, that the main center of materials science in a face of Frantsevich Institute for Problems in Materials Science at that times was established in Kiev (1952). Although, most know that in those days it was more likely an exception to the rule since the rest R&D headquarters were situated preferably in Moscow. The USSR brought a significant state investments to science intensive materials science technologies and training of an appropriate scientific and engineering personnel to become of a high qualification. Scientific schools were established all over the USSR and those intensively developed this branch of science which allowed its quick possessing the leading position in the world scientific community. Needless to say, that, the main and only customers, and consumers of this kind of applied R&D results were defense, aviation, space and shipbuilding industries. After the USSR fallen apart, Ukraine could not simply "*digest*" (mostly due to financial reasons) the amount of knowledge that the scientific schools and institutions had created, since a dramatic fall of military and industrial sectors. All this finally brought to state's conversion program announced in early 1990. Many defense and dual-use technologies were unclassified, modified and afterwards used for civil applications. Nevertheless, it does not matter that the conversion program has negative impact on national security as a special governmental commission was established in that times and the commission after a careful study, decided which technology has to be unclassified or it should still remain state's secret. The procedure stayed aside from cutting-edge technologies as the technologies of tomorrow are as untouchable stock or like a forbidden fruit for any developed country as they may significantly affect state's national security. Thus, the conversion program was a rather bold plan at that times, however, all this has a profound significance and made good odds in favor of materials science schools and teams to survive and participate in various international

competitions and R&D programs. This was only the first step made towards a transfer of materials science dual use technologies, meaning the transfer not to any particular company and/or state but to the world scientific and industrial communities. In other words, it was just the first attempt of sharing the formerly classified R&D results with the rest of the world, using such newly established organizations as for an example, Science & Technology Center in Ukraine [1]. Meanwhile, a solid, transparent and proven mechanisms for actual *viz* commercial transfer of production technologies of advanced materials virtually are not exist when strong political, technical, mental, security and legal reasons are still alive and add the fuel to the flame.

Thus, what's the catch? Historically, after the Soviet Union collapsed, a strong grows of a number of participants in foreign economic activity came to light. For many of them, commercial interests were much more attractive, important and understandable than the national, economic and political security of Ukraine. Under the umbrella of disappearance of many administrative mechanisms, this brought to elevation of physical volume of sales of strategic goods and advanced technologies abroad, which may pose a threat to national security, regional and global stability, and a competitiveness of domestic economy. Another reason for a catastrophic aggravation of the situation with critical exports could be associated with the fact that in Ukraine the export control system, at that times young and not that experienced, was developed simultaneously under the influence of the Western and Soviet models. Formally, the basis of the Western and Ukrainian models is the licensing procedure for the export of critical goods, which is included in one form or another, as soon as the goods leave the state's jurisdiction. The Soviet model of export control was designed to abort all transactions that did not meet the national interests even before they were concluded, based on complex and informal internal and interdepartmental procedures for coordination with the final stage of discussion of each significant contract at the highest level, up to the Politburo of the Communist Party. Thus after 1991, the situation drastically changed. The increasing decentralization of control led to the fact that not every transaction went through the existed and well developed channels of the Soviet era. The emerging Western model was far from being that perfect at that times in Ukraine, covering the most visible and least important sphere of control, from the point of view of criticality, – the export of strategic goods outside the customs during the transactions between independent counterparties. As a result, multiple “open windows” popped up, rushing at those whose goal was only the earliest possible and fast enrichment, and even more those windows appeared every year because of underfunding of the Ukrainian military-industrial complex and the National Academy of Science.

Nevertheless, despite the above a transfer of dual use technologies and conditions associated with it have continued to ignite a huge interest in the last decades. The process of technology transfer as a whole is neither simple nor systematic as it may seem at first blush and far from being that perfect, and it does not happen overnight, especially when it deals with dual-use technologies and at present reduced to a short relationship between supplier/recipient only. Meaning the short-term relationships between the scientific laboratories or between scientists as a result of which in terms of the contract or not eventually a technology transfer takes place. Nevertheless, the technology transfer, if legally and not done under the table, is a rather complicated, translucent, multi-level and multi-players process which follows several factors and conditions that determine its success or failure at the end.

In consequence, the following questions may then be raised therein: (1) what are dual-use materials science technologies, and (2) how can they be distinguished from single-use technologies? Are operational interactions and technical similarities the only criteria to differentiate dual- from single-use technologies? Or are there other more conceptual and less technical reasons?

The term dual is used in its generic sense to denote the mathematical number “two”. When used in relation to an operative verb such as use, “dual” means more than one, nature, or characteristic of a given object or method, or any other word it qualifies. More specifically, in the context of materials science technologies, dual use can be defined as being a usage which has both civil and military application, whether proven or potential. In a more general sense, dual use also embraces weapon technologies and their systems and sub-systems, in any of their different basing modes: ground or mobile, ship- and air-mounted, etc. However, while there are a great variety of weapon specific systems that could be associated with, it is the non-weapon technology that could be employed for military purposes which is the most difficult to define.

Dual-use issues in science are increasingly discussed in literature [2] and in policy-making, as well as in media and in public discourse. However, there presently exists no widely accepted definition of dual-use. While previously the term was used in relation to specific technology applications, latterly

research too has entered the debate on dual use. A clear definition is necessary to ensure adequate consideration of the ethical issues involved. This definition should be neither narrow, hence liable to rule out issues of genuine importance, nor wide, making oversight of dual-use science ungovernable. For example, if the definition of dual-use is limited to particular experiments in the life sciences [3] involving dangerous biological or chemical agents, then scientists or policymakers may fail to take into account other types of potentially dangerous R&D, such as research that could be used to play havoc with computer networks, jeopardize buildings or contaminate the food supply. If the definition of dual use is too wide in a scope, it may be applied to areas of science that are very unlikely to be used for malevolent purposes, place futile administrative burdens on scientists, and eventually boost innovation that might prove beneficial to society.

Thus, it has always been a controversial and disputable subject not only in Ukraine and the EU but all over the world as there is a very thin boundary between the applications. While having a legal access to Ukrainian dual-use technology, in practice in other countries the access has been restricted to civil application. As it was above said since 1990 a lot of defense technologies in Ukraine has been unclassified and legalized for its further civil and commercial applications and/or transfer of those thanks to the conversion program announced by the government, however the actual transfer of these technologies is still dimmed and stymied and needs further successful loop of evolution as mentioned above, it does not happen overnight and requires further and further elaboration.

Nevertheless, the development of materials science technologies continues in a quagmire of conflicting interests and technology transfer export control rationales. First, there are political-military considerations where a state's decision to develop weapon systems or related applications can be assessed not only as a function of perceived levels of threat to its security, but also as a need to respond and/or step forward to potential technological innovations; and second, the fundamental conceptual differences in appreciation among countries of the right to possess different advanced weapons systems for defensive or offensive purposes. This is not only a question limited to the dual-use issue. It has been always at the heart of all debates and all non-proliferation talks about materials science technologies employed by nuclear, chemical, and biological industries for decades. Third, there are certain economic implications, which impact is perhaps the least well-known and debated. Amid of these and other interests the transfer of dual use technologies is stuck somewhere in between severe control regulations on the one hand and the absence of a kind of universal agreement — of mutual interest signed between a potential supplier/recipient of a technology on the other. Transfer of dual-use technologies does not take place in *"a space"*. At present, it is being strongly affected by the echo of the USSR collapse and recent aggressive hybrid threat came from Russia and it is of a significant concern not only in Europe but all over the world. In conjunction with the above, a new era calls for a reassessment of national priorities related to international security which affects the way of global and regional geopolitical policies and the important to this concern is the transfer of dual-use materials science technologies. For the time being, discussions on intangible technologies, misuse of those and WMD proliferation threat lack creativity; political and diplomatic initiatives really came nowhere as well.

An influence of the political factor on transfer of dual use material science technologies can be tracked down from the experience of Frantsevich Institute of Problems in Materials Science, National Academy of Sciences of Ukraine (IPMS NASU), which, since the Soviet Union, has been one of the European leaders in the development of advanced materials for aerospace engineering and weapons systems. A certain part of export of R&D results at different stages of readiness (from directed fundamental research to pilot lab production of individual parts) was carried out through the STCU with an appropriate state export control procedure. The most striking examples of negative impact of the political factor on promoting institute's R&D results to the world market and material science community could be the following two. The first one is that in 2012, the institute was visited by a delegation of the US Navy top level experts. A seminar was set up at the highest level (with the presence of top level officials of Ukraine). IPMS presented 12 projects devoted to advanced materials science technologies. Six months took leading US experts to evaluate all projects and to select 4. They were approved and submitted to the US government for contracting through the STCU, as the United States is one of the co-founders of this organization.

Since the total amount of these contracts was significant (over \$ 30 million) and this was the first unprecedented case for Ukrainian R&D contracts, the issue was referred to the US Secretary of State. It was a period that there was some tension in political relations between the USA and Ukraine and the

issue of allocation of money was vetted by Hillary Clinton, who was at that time the Secretary of State. Later it became known that the issue was vetoed solely for political reasons as she said to her scientific advisors who prepared the package of documents.

A second good one is IPMS project with the National University of Singapore in 2015 to develop a technology for production of nanocomposites based on dichalcogenides for the advanced electronics. The results obtained in terms of this project were planned to be included in the BIG DATA database for a computer design of nanomaterials of tomorrow, which then was launched in Singapore. It was a director of the Big Data Center, who initiated and ordered this project.

At that time in Ukraine, a new government began to work, and for more than six months could not determine its attitude to the STCU and did not give a permission for this work covering its' reluctance with a debate about dual-use issues. When the political decision was made and the project was approved, the political factor came from Singapore's government. One day before signing the contract the government banned the financing of R&D projects performed abroad. This decision was motivated as the one belonging to a set of factors developed by the government to fight a corruption when using budgetary funds.

On the side, this kind of a decision (a total ban on the export of state budget funds for scientific research to be carried out abroad) was adopted in some other countries as well. Namely this one inhibits a civilized transfer of advanced materials science technology (which usually are of dual use) and encourages a development of ways of imperceptible transfers of these technologies. China, which pace of industrial development requires the most rapid introduction of modern technologies, was the first one to realize a futility of practice of imperceptible transfer and began to look for other ways.

Since the beginning of 2020, controlled export of budgetary funds was allowed in China's most important open economic zones to finance foreign R&D projects in priority areas of state's development and a development of new materials is one of the first priorities. The government delegation of Guangzhou province, where this kind of a free economic zone was already established in January 2020, visited IPMS NASU and signed a Cooperation Agreement in the field of development of advanced materials. The Agreement already contains the above discussed provision (budgetary support of R&D projects to be performed abroad). This political decision is a good step forward towards a new approach to civilized transfer of dual use materials science technologies.

A political attitude of the Ukrainian government on this initiative has yet to be worked out, nevertheless it should be mentioned that a similar one was taken for the Western countries at the interstate level through the establishment of the STCU (USA, Canada, Sweden with the accession of the European Union and Japan).

Thus, this set of factors that affect an efficient and proper functioning and optimization of the process of transfer of dual-use materials science technologies, is quite a challenge nowadays.

2. Historical and Other Premises

It is well known that any developed economy is based on a solid Science&Knowledge background. New production technologies of high-tech products are the main driving force of any state's progress, and a success of their implementation in basic industries allows increasing national welfare and taking a stable high place in the world rankings [4]. However, for the last 27 years of independence, a business in Ukraine should have become more civilized. Every year, a rather large number of students graduate from Ukrainian technical institutes and universities, but there are no longer those industrial R&D institutes and industrial enterprises that previously could employ this annual huge flow of young specialists and attract those to development of high technologies. All this leads to the enormous outflow of talented young people from a scientific community, industrial and engineering sector, as well as to the crisis in materials science itself, which results in a decrease of a level of high-tech industry based on advanced materials. Nevertheless, the highest scientific level of knowledge accumulated by Ukrainian material science experts, gives a hope and good odds to revive these enterprises by attracting both knowledge and investments. The more are specialists experienced in the field of technology transfer, and able to work with experienced and powerful investors, the easier would be to tackle the problem and enter the global Hi-Tech market. It is obvious that training of technology transfer office staff and creation of national system of advanced training of scientists in the field of technology transfer management and export control that meets international requirements, are a key task that need to be resolved in the near future if Ukraine is to move towards a market economy and wants to meet the international standards.

If to analyze a foreign experience gained in this area, one may observe that institutions involved in R&D results commercialization, so-called technology transfer offices (TTO), are established almost in every university or R&D institute [5]. Thus, it is natural, since the main scientific research in Europe, USA, Singapore, Japan, etc. are conducted namely by scientists in R&D institutes and universities labs, and a product for further commercialization is either a technology, and/or a material, or a specific responsible article. However, it should be highlighted that TTO mainly provides consulting, investment involvement, and conducts thematic trainings, seminars, training courses on industrial development of scientific research and trade control, especially when it comes to dual-use technologies and misuse of those. All this helps scientists to acquire the required knowledge for further successful steps and safe implementation of their inventions. Nevertheless, if those offices are not necessarily aware of trade control of strategic goods constraints that might raise the risks of misuse and proliferation.

For Ukraine, a history of advancement of scientific developments and technologies that implement those (especially dual-use products) [6] to a consumer market is almost zero. At the USSR epoch the state usually divided a financial support of science and transferring R&D results to industry. And if the financial issues, as a whole, had a consistently moderate and controllable level throughout the country, the financial support of technology transfer to industry had a significantly higher priority, nevertheless, was geographically (geopolitically) clustered in nature and concentrated mainly in the environs of Moscow and Leningrad. An exception was a development of new advanced materials for military complex, aerospace, electronics and other high-tech industries. The Academy of Sciences of Ukraine has been the recognized leader in this field however, this may not be referred to most researchers but was also of a clustered nature and singled out certain groups of scientists who carried out targeted research and development programs fixed by the government decrees with specially allocated funding. One of such programs was a development of new industry - Powder Metallurgy (PM). Scientists from Frantsevich Institute for Problems in Materials Science, National Academy of Sciences of Ukraine created this new industry – Powder Metallurgy and commissioned four plants and more than 50 workshops at the existing other plants.

After collapse of the Soviet Union, a governmental umbrella and patronage of transfer of R&D results to industry were almost curtailed for all countries of the former Soviet Union except Russia, since all specialized and innovative institutions remained on its territory and under the state's authority.

Thus, a paradoxical situation has appeared – the carriers of knowledge in development of new materials remained “homeless” in own country. From the one hand they possessed a great value in hands, but simply do not know how to offer it to the world market and had no experience how to resolve this serious and important issue. In case of dual-use technologies, a danger of violation of the Law on State Secret, which has not been never canceled [7], still exists.

Nowadays, the Ukrainian materials science institutes, recognizing and understanding the world level of their developments, understand that their developments (both current and those left from the Soviet times) may not be easily brought to a format perceived by the global market (experiencing technical problems – a problem of certification, etc.) and to bring those to this market without any efforts applied. Thus, the biggest problem here is that scientists simply do not know how to competently and professionally do this as it was not simply their mandate! In the era of the USSR, 1) none of them even cared and 2) nobody taught them a way it can be done, and even at present a well-developed system of education does not exist, despite being of extremely important. The educational activities on innovation, trade control and technology transfer, which are conducted by international foundations are ineffective and not that systematic. During the last decade only a few organizations [1] originating from its mission, tried to manage and bring those efforts to the Ukrainian and former CIS scientific community. To study this problem abroad for Ukrainians is a very problematic, both due to financial and language barriers. In addition, such training does not account for peculiarities of a mentality of scientists from former Soviet Union and national regulatory and control system.

As it was above highlighted, the problem of a technology transfer itself and specifically transfer of dual-use technologies is mainly associated with the fact that the dual use has always been a rather tricky subject [8]. For Ukraine, at present, all these problems should be considered accounting for the fact that this is the two-way road. On the one hand, Ukraine with its military conflict in the East, needs to modernize the existing weapon systems and influx of new dual-use technologies. On the other, having a “golden stock” of materials science developments, Ukraine is extremely interested in export of those to elevate a level of its economy and total welfare. Thus, due to the technical problems, first and

foremost, virtually every exported technology is not that new to the state which want to acquire it and it makes sense as it was above mentioned the developed countries do not transfer the cutting-edge technologies as not to create competitors and potential threats to state's security.

Successful overcoming of the existing problems is possible only in case of the implementation of an effective national policy for innovative development as a component of socio-economic policy. The most important issue in this area is to create an effective, transparent and healthy system of interaction and development of institutions heavily involved in state's regulation of innovative processes, stimulate the innovative activity, financial, industrial and technological, human and information support, generation and commercialization of innovative ideas in all sectors of national economy. By forming an effective innovation infrastructure in Ukraine, a synergistic effect can be achieved from interaction of various institutions, which contributes to the most effective communication between science, education, business and the state for a continuous implementation and sale of scientific developments as well as ensure the competitiveness of the domestic economy based on its involvement into the international transfer. The need for active participation of the state in this process is justified by the current market failures and gaps in formation of national demand for new technologies and innovative products in the face of low competitiveness and drastic degradation of the economy. A comparative analysis of macroeconomic elements in Ukraine emphasizes the need for government active intervention in innovation processes as a generator of incentives for innovations that cannot yet be ensured by a fragile market system and existing institutional environment due to their imperfections at the initial stage of development.

In Ukraine, according to the official data [9], the downward trend in innovation activity remains crucially constant, and a development of national economy is carried out by increasing the raw material and agricultural segments in Gross Domestic Product. This is a consequence of insufficient state funding of fundamental applied nature R&D, which is a solid background for the development of high-tech highly profitable technologies of top industries. Unlike the developed countries, which actually (first and foremost) provide an innovative development of their own economies, in Ukraine this process still remains only a declarative, since there is no modernization of the national economy on an innovative basis and there are no incentives and levers to revitalize this process. All this unfortunately prevents the active involvement of Ukraine in the international technology transfer [10]. Thus, Ukraine, possessing a significant innovative potential, especially in the field of advanced materials and technologies, has not yet elaborated the effective mechanisms for implementation and transfer of those at the level of real sector of its economy.

3. Result and Discussion

The question of whether there should be a better restructuring a dual-use technology transfer process would now appear to be irrelevant without a better understanding of present relationship between Ukraine and other countries on vital materials science sector of national security debate. The quest for improved relationships in respect of technology transfer and dual use must first start with an assessment of historical, mental, political, military, technical, economic and other implications of materials science technologies. Any such assessment must therefore consider the relevance that access to these technologies has for different geopolitical situations. Only by tight and trustful cooperation can the supplier/recipient relationship be established in a sound, durable and in an open manner. However, any such cooperation must be reinforced by solid and transparent agreements to ensure transparency and predictability on issues which directly affect the states' security, economy, and development.

The right of any state to develop materials science technologies is unquestionable and a conscious necessity is dictated by the generally accepted paradigm that *"a material is a heart of any article"*. In practice, problems arise when technology development approaches the very fine and sharp border between civil and military application, as most of the technologies can be used for dual purposes. This dichotomy raised a number of technical, political, military, and other concerns which crucially affect the transfer of materials science technologies, and particularly between established and emerging materials science competent of Ukraine and other countries, thus the technology transfer process is a hard way which do not have turnkey solutions and each transfer activity has to be treated as to be the first one and unique.

This argument is not just ideological. It could constitute the basis of a policy that could be implemented if certain specific initiatives are taken. To build confidence between supplier and recipient countries of intangible technologies, adhesion to bilateral agreements on materials science technologies, limitation agreements on weapons of mass destruction, and other measures would offer elevated and re-

quired transparency in development of materials science technologies of tomorrow. Of course, the roles of both supplier and recipient in unilateral, reciprocal measures would have to be carefully evaluated. Concession issues would need to be given the highest priority due to improve predictability and creation of mechanisms of crisis management and resolution. There should also be an agreement to establish a transparent dialogue between the supplier's and the recipient countries, to enable mutual political objectives to be complemented by compliance and enforcement procedures. Central to the debate is fundamental and practical questions associated with transfer of dual-use technologies and a lot of questions comes to light. For example: is it appropriate to undertake multilateral negotiations? Then if so, in what form and what type they should be? However, scrutinizing ways of creating new relationships between supplier and recipient in transfer of dual-use materials science technologies can easily be a zero-sum-game endeavor. The challenge is to initiate impartial and innovative thinking. Steps towards cooperation simply for the sake of ensuring the transfer of dual-use technologies are not the answer. Moreover, while international organizations have their role, they are not a panacea, as the comprehensive test ban treaty discussions have shown.

4. Conclusion

In conclusion, the question of whether there should be a better restructuring of dual-use technology transfer would now appear to be irrelevant without a better understanding of present relationship between Ukraine and other countries on vital materials science sector of national security debate. The quest for improved relationships in respect of technology transfer and dual use must first start with an assessment of political, military, technical, and economic implications of materials science technologies. Any such assessment must therefore consider the relevance that access to these technologies has for different geopolitical situations. Only by tight and trustful cooperation can the supplier/recipient relationship be established in a sound, durable and open manner. However, any such cooperation must be reinforced by solid and transparent agreements to ensure transparency and predictability on issues which directly affect the states' security and development.

Acknowledgements

This effort and the research behind it would not have been possible without the exceptional support of my supervisor, prof. dr. Quentin Michel. His enthusiasm, knowledge and exacting attention to detail have been an inspiration and kept my work on track from my first encounter with political science and legislation referred particularly to transfer of dual use technologies in the EU and Ukraine.

References

- [1] Science and Technology Center in Ukraine. STCU Mission statement. Available at: <http://www.stcu.int/weare/missionstatement/mission/index.php>
- [2] Evans, N. G., Commins, A. (2017). Defining dual-use research: When scientific advances can both help and hurt humanity. *The Conversation*. Available at: <http://theconversation.com/defining-dual-use-research-when-scientific-advances-can-both-help-and-hurt-humanity-70333>
- [3] Misuse potential and biosecurity in life sciences research A discussion basis for scientists on how to address the dual use dilemma of biological research (2017). *Swiss Academy Reports*, 12 (3), 20.
- [4] Terebova, S. V. (2010). Transfer of technologies as an element of innovation development of economy. *Problems of development of territory*, 4, 32–34.
- [5] Iliin, P. V. (2013). Foreign experience of technology transfer in Russia. *Economic and social changes: facts, tendencies, prognosis*, 1 (25), 208–210.
- [6] Grigoriev, A. (2014). Technologies of dual use: Concept and forms of transfer. *Istoricheskie, filosofskie, politicheskie i iuridicheskie nauki, kulturologiia i iskusstvovedenie. Voprosy teorii i praktiki*, 8 (46), 42–44. Available at: www.gramota.net/materials/3/2014/8-1/9.html
- [7] State Secret of Ukraine (1994). Law of Ukraine No. 3856-XII. 21.01.94. Information of the Verkhovna Rada of Ukraine, 16, 94.
- [8] Dual Use Technologies (2016). *Journal of Strategy*. Available at: <http://strategyjournal.ru/rossiya-i-mir/tehnologii-dvojno-go-primeneniya/>
- [9] Ukraine again loses its position in the competitiveness rating of the World Economic Forum (2019). *News Front Informational Agency*. Available at: <https://news-front.info/2019/10/09/ukraina-opyat-teryet-pozitsii-v-rejtinge-konkurentosposobnosti-vsemirnogo-ekonomicheskogo-foruma/>
- [10] Odotyuk, I. V., Fashchetskaya, O. M., Shchegel, S. M. (2015). Modern innovation policy of Ukraine: preconditions, main approaches and directions of reforming. *Bulletin of the National Academy of Sciences of Ukraine*, 7, 32–46.

SPECIFICITY OF PROOF IN CASES OF INFRINGEMENT OF INTELLECTUAL PROPERTY RIGHTS ON SITES ON THE INTERNET

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ARTICLE INFO

Article history:

Received date 11.09.2020

Accepted date 23.10.2020

Published date 30.10.2020

Section:

Law

DOI

10.21303/2313-8416.2020.001494

KEY WORDS

intellectual property
judicial protection of intellectual property rights
violations on sites on the Internet
electronic evidence

ABSTRACT

In recent years, the rapid development of both technical progress and activities on the Internet, including the economic one, could not but affect the improvement of existing and the emergence of new mechanisms for violating the rights of intellectual property subjects, gives rise to various disputes between participants in the relevant relations, and such disputes is no exception, since each category of court cases has its own peculiarities of consideration.

However, analyzing the judicial practice, a number of procedural problems related to evidence and proving in the field of intellectual property rights protection on Internet sites were identified.

Object of Research: What is the key of proof?

– Where? and Who? need to collect evidence?

– What is meant by belonging and admissibility of evidence?

– What are the ways of securing facts as means of proof on the Internet?

Investigated problem: to give a legal assessment not only to the norms of national and international legislation, but also to the practical experience of using the institution of proof in the protection of intellectual property rights raised on sites on the Internet.

The main scientific results: the procedural nuances of proving the violation of intellectual property rights on sites on the Internet are highlighted, problematic points are identified, and the proposed optimal ways to overcome them, both in pre-trial and in court.

The area of practical use of the research results: fixation, preservation of the evidence itself, their assessment, both in pre-trial and in court.

Innovative technological product: an algorithm (technical and legal) securing factual data from the Internet site for submitting them to court.

Scope of application of the innovative technological product: the application of the algorithm for securing factual data from the Internet site when protecting intellectual property rights should be carried out in accordance with the rules of the current Economic Procedure Code of Ukraine, namely Chapter 5 "Evidence" of Section 1.

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1. Introduction

1.1. The object of research

In recent years, the rapid development of both technical progress and activities on the Internet, including the economic one, could not but affect the improvement of existing and the emergence of new mechanisms for violating the rights of intellectual property subjects, giving rise to various disputes between the participants in the relevant relations.

However, analyzing the judicial practice, a number of procedural problems related to evidence and proof in the field of intellectual property rights protection on Internet sites were identified, and the following objects of research were identified:

- What is the key of the proof?
- Where? and Who? need to collect evidence?
- What is meant by belonging and admissibility of evidence?
- What are the ways of securing facts as means of proof on the Internet?

1.2. Problem description

Our society is developing rapidly through the creation of new information technologies in order to further simplify our lives. The emergence and development of the Internet has become the

most effective solution to the problems of our time, contains a lot of information on one platform and allows all users to save their time – to find certain information.

Today, the Internet has become a virtual repository for all the results of intellectual activity that require protection in case of violation, but the legislation does not clearly regulate the protection mechanism, the issue of proving violated rights is especially acute.

This problem arose due to the fact that each category of court cases has its own peculiarities of consideration, and cases on the protection of intellectual property rights are no exception.

So, the Civil Procedure Code of Ukraine, the Economic Procedure Code of Ukraine contains norms that are the same for all categories of court cases within the relevant type of legal proceedings and/or type of proceedings.

At the same time, cases on the protection of intellectual property rights have a certain specificity of their consideration, including the evidence and the process of proving.

However, in the current legislation of Ukraine, few legal norms are directly devoted to defining the features of judicial proceedings in cases of this category, and these norms are not without flaws.

There are problematic aspects of proving on the Internet:

- fixation;
- preservation of the most evidence;
- their assessment.

Since evidence on the Internet lies in the “transience” and modification of information at any given time, as a rule, in most cases, information that is disseminated on network sites can be deleted, modified or edited by both the site owner and its distributor.

1. 3. Suggested solution to the problem

In the scientific literature, there are no detailed studies on the procedural features of proof in cases of violation of intellectual property rights on sites on the Internet, but a lot of attention is paid to the substantive aspects of copyright protection.

The study of evidence and proof in procedural law aims to study the general positions of evidence and proof in the legal system. Scientifically, there is a wide range of views on the industry of evidence.

So, Ya. Farkhtdinov calls the institutions of evidence in the procedural branches the same, because all procedural legislation provides for a noticeable similarity in this procedure [1]. Yu. Osipov believes that the institution of evidence is general and intersectoral [2]. A similar position is defended by the Polish process theorist [3, 4].

In turn I. Reshetnikova develops the concept of proof as an intersectoral complex institution, substantiating it by the fact that proof is regulated by various branches of law. And also believes that, within the framework of procedural law, evidence is of a complex nature, due to the placement of norms both in the general and special parts of the procedural legislation of Ukraine and in substantive law [5].

Along with this, in science there is an opinion about the advisability of considering evidence and proof in criminal and civil proceedings within the framework of one generalized theory [6].

However, this is possible at the level of a methodological approach to the study of evidence. After all, evidence and proof, both in civil and in the economic process for the protection of violated intellectual property rights on sites on the Internet, should be clearly regulated, and especially the process and procedure for their protection.

The aim of research is to highlight the procedural nuances of proving the violation of intellectual property rights on sites on the Internet, identifying problematic points, and suggesting optimal ways to overcome them, both in pre-trial and in court.

2. Materials and methods

Research carried out in modern Ukrainian legal science does not create a holistic view of the procedural mechanisms for collecting and fixing evidence, especially the use of the institution of proof in the protection of intellectual property rights raised on Internet sites, but disclose only certain aspects of the institution of proof, and therefore the existing today the level of scientific development of this issue is not enough.

The empirical basis of the study was the materials of domestic and foreign judicial practice and legislation.

The methodological basis of the research is a complex of general scientific and special methods of cognition. *The dialectical method* of cognition was used, in particular, in the study of the process of collecting and fixing evidence. *The formal legal method* was applied to study the terminology used in the context of consideration of economic disputes in the field of intellectual property protection. During the study of the content and essence of the evidence, methods of analysis and synthesis were used. With the help of *the system-structural method*, the sources of evidence, the amount of evidence, the subject of proof, the limits of proof are determined. The use of the comparative legal method made it possible to carry out a comparative analysis of the mechanism for collecting, fixing, researching evidence in the pre-trial order and in court proceedings. With the help of *the scientific generalization method*, the general features of the means of proof are highlighted. As a result of the use of the legal hermeneutics method, the interpretation of certain norms of the current legislation governing the institution of proof was carried out.

3. Results

Procedural legislation (Code of Civil Procedure of Ukraine and Code of Commercial Procedure of Ukraine) contains requirements that each party is obliged to prove the validity of their claims and objections that is, it is about the obligation to prove.

Evidence is any factual data on the basis of which the court establishes the presence or absence of circumstances substantiating the claims and objections of the parties, and other circumstances relevant to the resolution of the case. Let's believe that the legislator's approach to defining the concept of proof is correct. Evidence is, first of all, factual data, on the basis of which the court, in the manner prescribed by law, establishes the presence or absence of circumstances on which the claims and objections of the parties are based, as well as other circumstances that are important for the correct resolution of an economic dispute (Article 76 of the Code of Civil Procedure of Ukraine, article 73 of the Code of Commercial Procedure of Ukraine) [7, 8].

In the scientific literature, the following signs of evidence (means of proof) are distinguished: the list of means of proof is exhaustive; the means of proof must be simultaneously considered in two aspects as the list is precisely defined in the legislation and their admissibility for proof in a particular case; evidence by elements of evidence, which can be of informational, material or mixed nature and must meet the admissibility requirements for evidence in a particular case and belonging to this case, and also be obtained in accordance with the requirements of procedural regulations [9, 10]. It is worth agreeing with such signs of evidence, since they reflect their main characteristics. Moreover, these signs of evidence should be taken into account when considering cases on the protection of intellectual property rights rose on sites on the Internet.

In addition, the court accepts only those evidences that are of great importance for the given case. The circumstances of the case, which, in accordance with the law, must be confirmed by certain means of proof and properly, can't be confirmed by other means of proof.

That is, in every copyright protection case, the ownership and admissibility of this evidence should be taken into account. This is emphasized in paragraph 2.5 of the Resolution of the Plenum of the Supreme Economic Court of Ukraine No. 12 "On some issues of the practice of resolving disputes related to the protection of intellectual property rights" dated October 17, 2012 [11] where it is stated that any evidence presented by the participants in the process (including, in particular, and regarding information on the Internet) are subject to assessment by the court for relevance and admissibility. When deciding on evidence, the courts must take into account the institution of admissibility of means of proof, according to which the circumstances of the case, in accordance with the law, must be confirmed by certain means of proof, can't be confirmed by other means of proof.

Also, the court accepts only that evidence that is relevant to the case. The circumstances of the case, which in accordance with the legislation must be confirmed by certain means of proof, can't be confirmed by other means of proof. That is, in each copyright protection case, the ownership and admissibility of evidence should be taken into account.

At the same time, the evidence presented can't be rejected by the court on the grounds that they are not provided for by the procedural law [11].

An example is the case for the protection of copyright, which is quite common, and consists in the fact that illegal copying and use of text without the author's permission and without attribution is a violation of its personal non-property and property rights. Therefore, this fact can be proved only thanks to properly executed and confirmed material evidence.

Although the procedural legislation contains the same norms for all categories of cases within the relevant type of court proceedings, however, cases on the protection of intellectual property rights have not only a certain specificity of their consideration, but also the process of proving.

The specifics of the process of proving in cases of infringement of intellectual property rights on sites on the Internet is not only part of the evidence in the procedural sense, but also has a close intersectoral connection with all material branches of law, since the correct solution of such a category of disputes is possible only when the subject of proof is clearly defined.

Based on the peculiarities of the law enforcement practice existing in European countries, as well as national, it is possible to single out problematic issues and difficulties arising in the process of collecting evidence that can confirm or deny the existence of a violation of intellectual property rights on sites on the Internet. It should be emphasized that the main problem lies not in proving the fact of the use of intellectual property rights, but in proving an action or inaction that entails violations or creates conditions for violation of intellectual property rights.

Thus, the Internet is based on three "pillars", which are: communication channels, IP addresses and the domain name system. In this case, it is necessary to take into account the fact that the parties to the disputes about the violation of intellectual property rights on the Internet sites are the plaintiff and the defendant, which have their own characteristics, in particular. The plaintiff is the owner of the intellectual property object, who must prove that it is the copyright holder of the intellectual property object located on the Internet; an object that was placed by the defendant and such actions were committed without proper legal basis; the defendant takes actions regarding the infringement of the plaintiff's intellectual property rights. The defendant must prove that: it is not involved in the illegal placement of the intellectual property object on the Internet and/or that the object was placed with the permission of the copyright holder or the user independently owns the property rights and its actions are within the legal framework.

Since this offense is committed on the Internet, which is not stable, and public information can be changed at any time, the person who has identified violations of its rights and is a plaintiff in this area has the right to take all permitted actions in order for these facts to become valid evidence in the case. It should be noted right away that the algorithms for protecting intellectual property rights are diverse.

In this connection, there are a number of practical methods of securing facts, as means of proof, on the Internet, in particular.

Firstly, the owner of whose rights have been violated must record the content of the website by video recording with the preparation of a properly executed protocol signed by at least three people who must be present during the video recording of this offense on the network, including an independent representative of the organization, specializes in servicing telecommunications computer systems that will be able to confirm the ownership of the evidence, and, if necessary, that this video evidence is targeted.

In this case, the recorded video evidence must indicate the time and date of the video filming, for the subsequent establishment of the primacy of the publication of authorship, as well as the corresponding domain address of the offender's website. If the opportunity to make video recording does not have the person, then the person can take a photograph (Web-screenshot) of the offense.

However, in accordance with clause 46 of the Resolution of the Plenum of the Supreme Economic Court of Ukraine No. 12 [11], printouts of Internet pages (web pages) in themselves can't serve as evidence in the case. These documents must be issued or certified by an institution or a specially authorized person within their competence in the prescribed form and affixed with an official seal on the territory of one of the member states of the Commonwealth of Independent States, in accordance with Article 6 of the Agreement on the procedure for resolving disputes related to the implementation of economic activities of March 20, 1992 have the evidentiary force of official documents on the territory of Ukraine [12].

Together with the specified fixing method, the method of instant fixing of web pages using private online services is used. This fixation fixes not only the visual display, but also the source

code, the URL of the web page, and the time of the fixation. A variation of the previous method is to capture a cached copy of a web page in search engines using private online services. However, on the ownership of this evidence, discussions are underway and the court may not always accept them as it should be in the form of evidence.

The second method is to use the InternetArchive service. WaybackMachine, which captures the content of individual web pages both offline and at the user's request. The specified service has the status of a library and is subject to US law. This method assumes the existence of certain technical limitations of such fixation of the content of the web page. As it turned out in practice, the use of this method of fixing entailed such consequences as storing objects larger than 10 MB, and pages with limited access are not saved.

In addition, at the request of the site owner, the data on this web archive is deleted, resulting in the loss of evidence.

The judicial practice of our state in disputes on infringement of intellectual property rights on the Internet testifies to the involvement of forensic materials as evidence, where the subject of research, in particular, is the mentioned service, and not as separate evidence.

So, in the decision of the Economic Court of the city of Kyiv in case No. 59/230 of September 24, 2012 [13], it was established that the plaintiff did not agree with the conclusion of the complex forensic commission in the field of intellectual property, since it believed that the information received by the expert on the materials of the site www.archive.org is inaccurate, unreliable and may not be accurate.

At the same time, the plaintiff did not provide the court with evidence to prove that the information about the defendant's website, according to the site www.archive.org, is untrue and unreliable.

Also noteworthy is the decision of the Economic Court of the city of Kyiv in case No. 910/11186/16 of October 17, 2016.

This decision states that according to the expert opinion, within the framework of which the content of the web pages of the Internet archive "The Wayback Machine", including the corresponding website, was investigated and recorded, and it was confirmed that by the time the infringement of the content on this site was not recorded [14].

That is, an expert study of telecommunication systems (equipment) and means was assessed, within the framework of which the content of the web pages of the Internet archive "The Wayback Machine" was investigated and recorded.

Today, the issue of obtaining notarization of web pages on the Internet remains debatable, since notaries of Ukraine only provide for the procedure for certifying the correctness of copies of documents and extracts from them.

However, a person whose rights have been violated has the right to apply to a notary or local government official to draw up a protocol of inspection site and receive notarized printouts of its pages [15, 16].

Such a protocol contains:

- date, time (hours, minutes) and location of the inspection;
- information about the person carrying out the review (its last name and initials, status (notary), name of the notary district);
- information about the persons present during the examination;
- content of the application of the person who applied for the notarial act, indicating the reasons due to which the presentation of evidence will subsequently become impossible or difficult;
- sequence of actions of the notary regarding the review of such information.

The protocol may also include images of information published on the pages of an information resource printed on paper, as well as images on paper, reflecting the sequence of actions taken by a notary to access this information. And if images of information printed on paper are involved in the protocol, the time (hours, minutes) when this information was printed is indicated in the protocol. A person who has applied to perform a notarial act of its own free will has the right to ask for the inclusion of an electronic version of the examined evidence in the inspection protocol.

Simultaneously with these actions, the person should apply to the Cyber Police Department of the National Police of Ukraine to record the corresponding offense on the Internet and enter the

information into the Unified Register of Pre-trial Investigations. These actions will help to fix violations in the network, and in the future to stop the illegal actions of the site owner.

After receiving the aforementioned evidence of violation, the person has the right to contact the owner of the host server (host server) on which the site is hosted, with the certification of the printout of the disputed web page. This can be done through a special network protocol based on the TCP (Transmission Control Protocol), that is, it is possible to ask the owners of the WHOIS site in order to determine the owner of the domain zone, IP address, or autonomous system number on the Internet and get domain zones of the offending site. In this case, it is possible to get a refusal to obtain evidence.

If the defendant in a copyright infringement case denies access to the necessary information or does not provide it within an acceptable timeframe, interferes with the implementation of judicial procedures, or in order to preserve the relevant evidence of the alleged offense, the court has the right to apply interim measures at the request of the applicant before filing a claim or before the start of the consideration of the case with the participation of the other party (the defendant) [17].

From the analysis of the above, it follows that a person whose rights have been violated, for a more effective result, can directly apply to the court with a properly substantiated statement of claim against the domain name owner and at the same time submit an application for securing evidence in this case and after five days receive a court decision on securing evidence. After issuing an order on securing evidence, the court directly sends a request to the provider for obtaining a certificate (log files), which may contain information about the actions of users regarding the placement of this information.

However, the content of such information may differ depending on the hosting settings. Moreover, such files only record the name of the file, not its content.

At the stage of preliminary court proceedings, the court also considers the ownership of evidence and in accordance with the provisions of Article 82 of the Economic Procedure Code of Ukraine [7], examination of material, written and electronic evidence that can't be delivered to the court is examined at its location. This consists in the fact that the court, on its own initiative or at the request of a participant in the case, can inspect a web page, other places of data storage on the Internet in order to establish and record their content, and, if necessary, involve a specialist. The protocol, which will be drawn up by the judge after the above actions have been performed, will automatically become evidence in the case.

A separate method of fixing is provided for in paragraph 7 of part 1 of article 20 of the Law of Ukraine "On the Bar and Advocacy" [18], which provides that a lawyer has the right to draw up a protocol on the inspection of the website, which, on the basis of its professional right to collect information about facts can be used as evidence.

The fourth step will be to order an expert study of intellectual property objects that are posted on the site, and also attention will be paid to the evidence of the violation and to the author's way of writing the text. These actions may not be performed by a person if a specialist is involved in the court and this evidence is sufficient for the internal conviction of the court.

Violation of intellectual property rights on the Internet is too widespread, but not all persons whose rights have been violated are ready to fight for their restoration, cessation of violations, or for compensation for losses and/or moral (non-property) harm.

This is due to the fact that the algorithm for establishing the relevance of evidence is too complicated for a simple Internet user, who does not have special knowledge of proof, but in general faced this problem for the first time.

At the same time, the procedure for securing evidence is not always effective, because this type should contain the ability of factual data on information regarding the circumstances included in the subject of proof, serve as arguments in the process of establishing objective truth, since the question of ownership of evidence is finally decided by the court.

Therefore, persons possess intellectual rights, in case of violation, they must adhere to the following algorithm of actions to collect evidence of such a violation, namely:

- 1) record the content of the website by video and photographic recording with the preparation of a properly executed protocol signed by at least three people who must be present during the video recording of this offense on the network, including an independent representative of an

organization specializing in the maintenance of telecommunication computer systems, which will be able to confirm the ownership of evidence;

2) duly recorded evidence should be notarized as soon as possible by an appropriate person who has the authority to do so in accordance with the legislation of the state, so that the given factual data become adequate evidence to convince the court;

3) the fact of violation must be reported to the Cyber Police Department of the National Police of Ukraine in order to properly record the corresponding violation on the Internet and enter information into the Unified Register of pre-trial investigations;

4) after performing these actions and obtaining proper evidence, the person must apply to the court with a properly substantiated statement of claim and at the same time submit an application for securing evidence in this case, to obtain help (log files), from the owner of the host server, includes information about the actions of users regarding the placement of this information;

5) order an expert study of intellectual property objects, which will properly confirm the fact of a real violation of the plaintiff's rights.

5. Conclusions

An in-depth study of the practice and resolution of disputes on infringement of intellectual property rights on sites on the Internet in order to develop scientific recommendations on the problems of proof in resolving this category of disputes is a primary task not only for judges, but also for the copyright sub-industry.

Until scientists have developed a comprehensive legal mechanism for collecting evidence in support of the violation of intellectual property rights on sites on the Internet, individuals believe that their rights have been violated, must adhere to the following algorithm of actions to collect evidence of such a violation, namely:

1) record the content of the website by video and photographic recording with the preparation of a properly executed protocol signed by at least three people who must be present during the video recording of this offense on the network, including an independent representative of an organization specializing in the maintenance of telecommunication computer systems, which will be able to confirm the ownership of evidence;

2) duly recorded evidence should be notarized as soon as possible by an appropriate person who has the authority to do so in accordance with the legislation of the state, so that the given factual data become adequate evidence to convince the court;

3) the fact of violation must be reported to the Cyber Police Department of the National Police of Ukraine in order to properly record the corresponding violation on the Internet and enter information into the Unified Register of pre-trial investigations;

4) after performing these actions and obtaining proper evidence, the person must apply to the court with a properly substantiated statement of claim and at the same time submit an application for securing evidence in this case, to obtain help (log files), from the owner of the host server, includes information about the actions of users regarding the placement of this information;

5) order an expert study of intellectual property objects, which will properly confirm the fact of a real violation of the plaintiff's rights.

References

- [1] Farkhtdinov, Ia. F. (2002). *Istochniki grazhdanskogo protsessualnogo prava Rossiiskoi Federatsii*. Ekaterinburg, 375.
- [2] Osipov, Iu. K. (1973). *Podvedomstvennost iuridicheskikh del*. Sverdlovsk: Izd-vo iurid. in-ta, 124.
- [3] Siedlecki, W. (1987). *Postepowanie cywilne: zarys wykladu*. Warszawa: Panst. Wydaw. Naukowe. Krak.
- [4] Siedlecki, W. (1953). *Rozklad ciezaru dowodu w polskim procesie cywilnem*. PiP, 7.
- [5] Reshetnikova, I. V. (2000). *Kurs dokazatelstvennogo prava v rossiiskom grazhdanskom sudoproizvodstve*. Moscow: Norma-INFRA-M, 288.
- [6] Kurylev, S. V. (1969). *Osnovy teorii dokazyvaniia v sovetskom pravosudii*. Minsk: Izd-vo BGU, 204.
- [7] *Hospodarskyi protsesualnyi kodeks Ukrainy* (1991). No. 1798-XII. 06.11.1991. *Vidomosti Verkhovnoi Rady Ukrainy*, 6, 33.
- [8] *Tsyvilnyi protsesualnyi kodeks Ukrainy* (2004). No. 1618-IV. 18.03.2004. *Vidomosti Verkhovnoi Rady Ukrainy*, 40–41, 42.
- [9] *Subiekty dokazuvannia ta otsinky dokaziv u tsyvilnomu protsesi* (2005). Kyiv, 20.

- [10] Filyk, N. V., Trotsiuk, N. V. (2012). Spetsyfika sudovoho zakhystu avtorskykh prav na obiekty, rozmishcheni v merezhi Internet: porivnialno-pravovyi analiz. Sudova apeliatsiia, 2, 47–54.
- [11] Pro deaki pytannia praktyky vyrishennia sporiv, poviazanykh iz zakhystom prav intelektualnoi vlasnosti (2012). Postanova Plenumu Vyschoho hospodarskoho sudu Ukrainy No. 12. 17.10.2012. Available at: <https://zakon.rada.gov.ua/laws/show/v0012600-12#Text>
- [12] Uhody pro poriadok vyrishennia sporiv, poviazanykh iz zdiisnenniam hospodarskoi diialnosti(1992). Ratyfikovano Postanovoiu VR No. 2889-XII. 19.12.1992. Available at: https://zakon.rada.gov.ua/laws/show/997_076#Text
- [13] Rishennia Hospodarskoho sudu mista Kyieva u spravi No. 59/230. 24.09.2012. Available at: <http://reyestr.court.gov.ua/Review/26264741>
- [14] Rishennia Hospodarskoho sudu mista Kyieva u spravi No. 910/11186/16. 17.10.2016. Available at: <http://reyestr.court.gov.ua/Review/62176099>
- [15] Pro notariat (1993). Zakon Ukrainy No. 3425-XII. 02.09.1993. Available at: <https://zakon.rada.gov.ua/laws/show/3425-12#Text>
- [16] Pro zatverdzhennia Poriadku vchynennia notarialnykh dii notariusamy Ukrainy (2012). Nakaz Ministerstva yustytisii Ukrainy No. 296/5. 22.02.2012. Available at: <https://zakon.rada.gov.ua/laws/show/z0282-12#Text>
- [17] Pro vykonannia rishen ta zastosuvannia praktyky. Yevropeiskoho sudu z prav liudyny (2006). Zakon Ukrainy No. 3477-IV. 23.02.2006. Available at: <https://zakon.rada.gov.ua/laws/show/3477-15#Text>
- [18] Pro advokaturu ta advokatsku diialnist (2012). Zakon Ukrainy No. 5076-VI. 05.07.2012. Available at: <https://zakon.rada.gov.ua/laws/show/5076-17#Text>