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VIBRATIONS AND STABILITY OF A GEOMETRICALLY NONLINEAR WEIGHTY DRILL STRING FOR DRILLING OIL AND GAS WELLS

Abstract. Heavy weight drill pipe (HWDP) in wells are hollow, weighty rods with stepwise changing physical properties (for example, stiffness), and each link of the string can deform according to geometrically nonlinear laws. They are the most critical part in the drilling process, transmitting power from the drilling rig to the rock failing tool, and are in hydrodynamic and contact interaction with the borehole walls, and are always curved. This occurs due to the curvature of the well itself, and under the action of its own weight, contact forces, as well as centrifugal forces in the case of rotation of the pipe. In this case, the curvature of the HWDP axis can be significantly influenced by the geometric nonlinearity of the deformation of its pipes.

A review of this issue revealed a number of poorly studied problems, which include accounting for both physically and geometrically nonlinear problems, accompanied by various types of complications (loss of stability HDWP, pipe breaks, etc.), as well as other processes in the elements of a dynamic drilling system (DDS).

In this paper, based on the use of modern methods for studying dynamic processes in mechanical systems, a method is proposed for studying longitudinal oscillations of a geometrically nonlinear HWDP of its stability under torsion, taking into account the physical nonlinearity in the process of its deformation. The dependences characterizing this process are found.

Key words: oil and gas wells, heavy weight drill pipes, longitudinal oscillations, stability, geometric nonlinearity, dynamic systems.

Introduction. The dynamics of the HWDP is reflected in analytical works [1-7]. Modern methods of dynamics analysis, in particular, the use of the finite element method (FEM) for the analysis of the dynamics of mechanical systems were considered in [8, 9]. The fundamental problems of the HWDP dynamics in a nonlinear formulation of the problem are originated in works [10-13]. At the same time, the problems of stability loss of rod systems were solved in work [13]. However, as stated above, these fundamental foundations of the dynamics and stability of rod systems were created with some assumptions.

It should be noted that modern works of Kazakhstani scientists are also devoted to analytical studies of drilling systems [14, 15]. They present the results aimed at studying the kinematics of the drilling process to determine the drilling scheme. The analysis of the principles of operation of drilling tools is performed.

Due to the large length of the HWDP in comparison with the transverse dimensions, it is often modeled with a long uniform thin rod, which is a rather rough approximation, since the components of the HWDP are connected by locks, equipped with centralizers and other devices that significantly change the dynamics of the drill pipe. Therefore, theoretically, the column should be considered as a nonlinear mechanical system with an infinite number of degrees of freedom. But here a difficulty arises, associated with the impossibility of analytically studying the dynamics of the operation of such system, and, consequently, identifying its strength, stability, negative or, conversely, positive influence of oscillations and vibrations under dynamic loads during drilling.

The foregoing gives reason to believe that when developing methods for analyzing the oscillation and stability of HWDP, especially in the nonlinear formulation of problems, the results of applied research on the dynamics of drilling systems are also important. The dynamics of HWDP has been studied in the works of Russian researchers [16-25]. These works are undoubtedly sources for a more realistic modeling of the HWDP dynamics. However, these works mainly cover the development of a theory for controlling the dynamics of HWDP associated with increasing the efficiency of the process of drilling deep and directional wells by minimizing torsional and longitudinal low-frequency oscillations of the drilling tool [19, 21-23]. Many of them are devoted to rotational-longitudinal oscillations of the HWDP in order to create its bottom stabilizing assemblies (BSA), which is very important when drilling inclinedly directed and horizontal wells with downhole motors, etc.

Aims and objectives. From the above, it follows that the problem of studying the longitudinal oscillations of a geometrically nonlinear HWDP of its torsional stability, considering the physical nonlinearity in the process of its deformation, is an urgent problem and is of great scientific interest.

Results of theoretical research. In order to study the longitudinal oscillations of the drill pipe, considering the physical nonlinearity in the process of its deformation, a model was created where the HWDP is presented in the form of a multi-link long bar performing longitudinal oscillations. After accepting the origin of coordinates in the upper cross section of the pipe and the direction of the *x*-axis vertically downward, the potential and kinetic energies of a physically nonlinear rod were presented in the form [18]:

$$U = \frac{EF}{2}\int_0^l \left((\frac{\partial u}{\partial x})^2 (1 - a_3 (\frac{\partial u}{\partial x})^2 \right) dx,\ T = \rho F \int_0^l \left(\frac{\partial u}{\partial t} \right)^2 dx + \sum_{i=1}^{N} m_i \left(\frac{\partial u(t, l_i)}{\partial t} \right)^2 \quad (1)$$

where $u(x,t)$ is the longitudinal displacement of the rod; E, ρ is the Young's modulus and the density of the rod material; *F* and *l* are the area and length of the rod, respectively; $a_3 = -\frac{2}{9}\frac{3K}{3K+G}\frac{\gamma_2}{G}$, *K*, *G* are the moduli of volumetric compression and shear; γ_2 is the coefficient characterizing the geometric nonlinearity of deformation, determined experimentally; m_i is the mass of the lock joint (sleeve) located in the cross section $x = l_i$.

The following boundary value problem is considered:

$$\frac{\partial u}{\partial x} = -\frac{P_0}{EF} \text{ at } x = 0,\ u = u_0(t) \text{ at } x = l$$

where *E* is the Young's modulus, P_0 is the constant compressive axial force acting on the drill pipe, *l* is the total length of the drill pipe.

To solve the boundary value problem, the finite element method is applied. The HWDP length was divided into *n* finite elements (*n*+1 nodes) of the same length *a*. It is considered that the lengths of the sections of the elements are related to the value *a*. The concentrated masses are located at the nodal points, and in the first node there is no mass, and the lowest mass (bit) moves according to a given law $u_o(t)$. Denoting through $q_i(t)$ $(i = 2..n+1)$ $(q_{n+1} = u_0(t))$ displacements of concentrated masses, displacements of drill pipe cross sections (referred to the value *a*) within each element, is represented in the form of a system of equations:

$$\begin{aligned} u_{1,2} &= (1 - 4\xi^2)(p - q_2)/3 + N_2(\xi)p, \\ u_{2,3} &= N_1(\xi)q_2 + N_2(\xi)q_3, \\ u_{3,4} &= N_1(\xi)q_3 + N_2(\xi)q_4 \\ u_{i,i+1} &= N_1(\xi)q_i + N_2(\xi)q_{i+1} \\ u_{n,n+1} &= N_1(\xi)q_n + N_2 u_0 \quad (2) \end{aligned}$$

where $\xi = x/a$, $N_1 = 1 - 3\xi + 2\xi^2$, $N_2 = 2\xi^2 - \xi$, $p = P_0 a / EF$, $i = 2..n-1$

substituting $u_{i,j}(\xi, t)$ from (2) into (1) and obtaining expressions for the kinetic and potential energies:

$$U = \frac{EFa}{2}\sum_{i=2}^{n+1}\overline{U}_i\ ,\ T = \frac{F\rho a^3}{2}\sum_{i=2}^{n+1}\overline{T}_i \qquad 3)$$

taking the variables q_i $(i = 2..n)$ as generalized coordinates, the second kind Lagrange equation was formulated [10]:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_i}\right) - \frac{\partial T}{\partial q_i} = -\frac{\partial U}{\partial q_i} \qquad (4)$$

After formulating the expressions for the kinetic and potential energies from (3) to (4) and solving them, a system of nonlinear differential equations is obtained to determine the coordinates of the displacements of the added masses. In particular, in the case when $n = 3$, it is obtained:

$$27\rho a^2(27\ddot{q}_2 - \ddot{q}_3) = E\{2a_3[9037q_1^3 + q_2^2(837q_3 + 128p) + q_2(621p^2 + 23q_3^2) + (891q_3^3 - 28p^3)] - \\ - 378q_2 - 27q_3 + 12p\}\ , \qquad (5)$$

$$\rho a^2(8\ddot{q}_3 - \ddot{q}_2 - \ddot{q}_4) = 2E\{a_3[44q_2^3 + 92q_3q_2^2 + 132q_3^2(q_2 + q_4) + 488q_3^3 + 44q_4^3] - q_2 - q_4 - 14q_4\} \qquad (6)$$

$$5\rho a^2(8\ddot{q}_4 - \ddot{q}_3) = E\{15a_3(488q_4^3 + 132q_4^2(q_3 + u0) + 92(q_3^2 + u_0^2) + 44(q_3^3 + u_0^3)] - 50(q_3 + u_0) \\ - 700q_4 + 5\ddot{u}_0\} \qquad (7)$$

Figures 1 and 2 show the curves of the dependences of the displacements of concentrated masses q_2/a and q_4/a on the dimensionless time $\tau = ct / a$ ($c = \sqrt{E/\rho}$ is the speed of wave propagation in the links of the pipe) for geometric linear ($a_3 = 0$) and nonlinear ($a_3 = -0.4$) deformation.

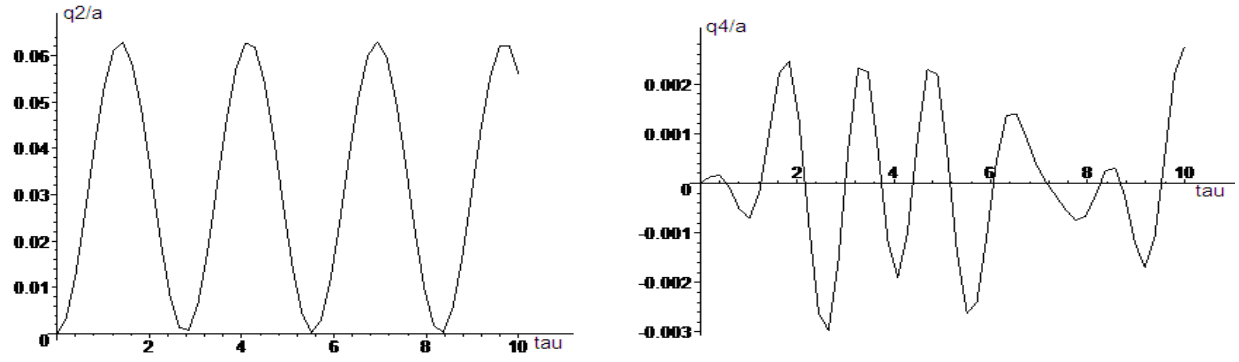

Figure 1 – Curves of dependences of displacements of concentrated masses q_2 / a and q_4 / a on dimensionless time $tau = \tau = ct / a$ at $a_3 = 0$

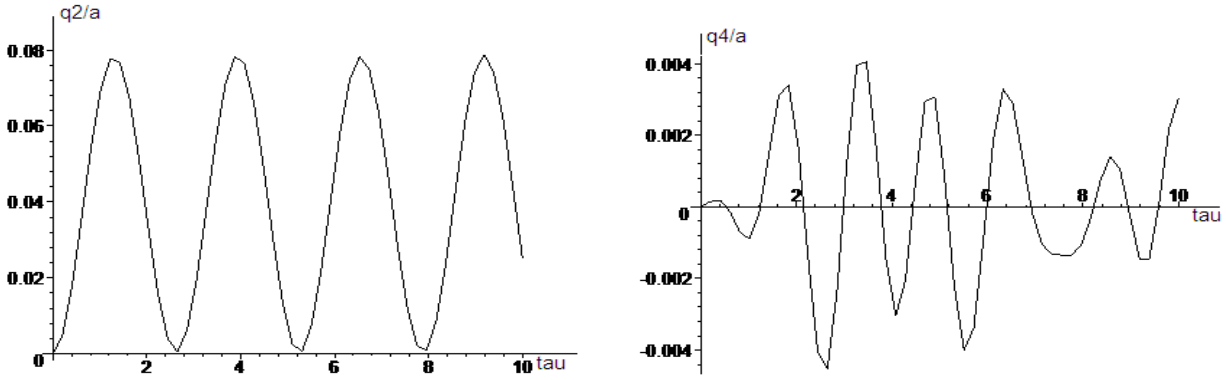

Figure 2 – Curves of dependences of displacements of concentrated masses q_2 / a and q_4 / a on dimensionless time $tau = \tau = ct / a$ at $a_3 = -0.4$

The lower end of the HWDP (bit) moves according to the law $u_0 = v_0 t - j_0 t^2 / 2$ (v_0 и j_0 and the initial velocity and acceleration of the bit deceleration) In calculations it is accepted: $v_0 = 2m/c$, $j_0 = 1m/c^2, c = 4000m/c$, $p = 1$.

From the analysis of the obtained curves, it follows that taking into account the geometric non-linearity leads to an increase in the displacements of the concentrated masses, this regularity is more noticeable for the displacement of the end of the string close to the bit.

Now let us study the torsional stability of a geometrically nonlinear HWDP. In the general case, the problem of the stability of rods under the action of torques is non-conservative, and they must be solved considering the complex deformed state of the rod caused by the action of axial, bending and torsional moments:

$$\left(\frac{M_k}{2EJ}\right)^2 + \frac{P}{EJ} = \frac{\pi^2}{l^2} \tag{8}$$

where M is the torque, P is the compressive force. As can be seen from expression (8), the compressive force leads to a decrease in the value of the critical moment. If the compressive force is known, then from (8) it is possible to determine the critical value of the torque

$$M_k = 2EJ\sqrt{\frac{\pi^2}{l^2} - \frac{P}{EJ}}\,.$$

If we denote by $\varphi(x,t)$ the angle of rotation of the section of the HWDP bar, then the expression of the torque taking into account the nonlinear shear deformation $\frac{\partial\varphi}{\partial x}$ can be expressed by the formula:

$$M = GJ_{p0}\left[1 + \gamma_2 \frac{J_{p2}}{J_{p0}}\left(\frac{\partial\varphi}{\partial x}\right)^2\right]\frac{\partial\varphi}{\partial x}\,, \tag{9}$$

where G is the shear modulus, $J_{po} = \frac{D_o^4 - D_i^4}{32}$ the polar moment of inertia of the bar sections, $J_{p2} = \frac{2}{9}\frac{D_o^6 - D_i^6}{64}$ and γ_2 is the coefficient characterizing the shear nonlinearity.

The total work of deformation is calculated by the formula:

$$U = \frac{\pi}{4} G \frac{D_н^4 - D_в^4}{16} \int_0^l \left(\frac{\partial\varphi}{\partial x}\right)^2 \left[1 + \frac{2\gamma_2}{3}\frac{D_н^2 - D_в^2}{4}\left(\frac{\partial\varphi}{\partial x}\right)^2\right] dx\,. \tag{10}$$

Kinetic Energy of the HWDP rod is equal to:

$$T = \frac{\pi m}{4}\frac{D_н^4 - D_в^4}{16}\int_0^l \left(\frac{\partial\varphi}{\partial t}\right)^2 dx\,, \tag{11}$$

where m is the linear mass of the rod material. A variable moment $\pm M_0(t)$ is applied in the sections $x = 0$ and $x = l$.

Angle of rotation of the rod is presented in the form of

$$\varphi = \frac{M_0 l}{GJ_{p0}\pi}\sin\frac{\pi x}{l} + q(t)\cos\frac{\pi x}{l}\,, \tag{12}$$

For potential and kinetic energy, we obtain the expressions

$$U = \frac{\pi^3}{128} G \frac{D_н^4 - D_в^4}{l} [\overline{M}_0^2 + q^2 + c(\overline{M}_0^4 + 2\overline{M}_0^2 q^2 + q^4)],$$

$$T = \frac{\pi m (D_н^2 - D_в^2) l}{128} \dot{q}^2$$

where $\overline{M}_0 = \frac{M_0 l}{G J_{p0} \pi}$, $c = \pi^2 \gamma_2 (D_н^2 - D_в^2)/8l^2$.

Taking $q(t)$ as the generalized coordinate, we compose the Lagrange equation of the second kind

$$\ddot{q} + b_1 q + b_2 q^3 = -\ddot{\overline{M}}_0, \tag{13}$$

where $b_1 = (1 + 2c\overline{M}_0^2)\omega^2$, $b_2 = 2c\omega^2$, $\omega = \frac{G(D_н^2 + D_в^2)\pi^2}{ml^2}$.

The quantity c in equation (13) characterizes the nonlinearity of the rod during torsion. The equation is integrated under the following initial conditions $q(0) = 0$, $\dot{q}(0) = 0$.

Figure 3 shows the graphs of the dependence of the angle of rotation of the bar sections $x = 0$ under the action of the moment $\overline{M}_0$ according to the law $\overline{M}_0 = 1 - \cos\omega_0 t$ for different values of the parameters c and ω_0.

It can be seen that the nonlinearity, depending on the frequency ω_0 of the torque, has a different effect on the torsional oscillations of the rod. At small values of ω_0, nonlinearity in the considered case decreases the oscillation amplitudes.

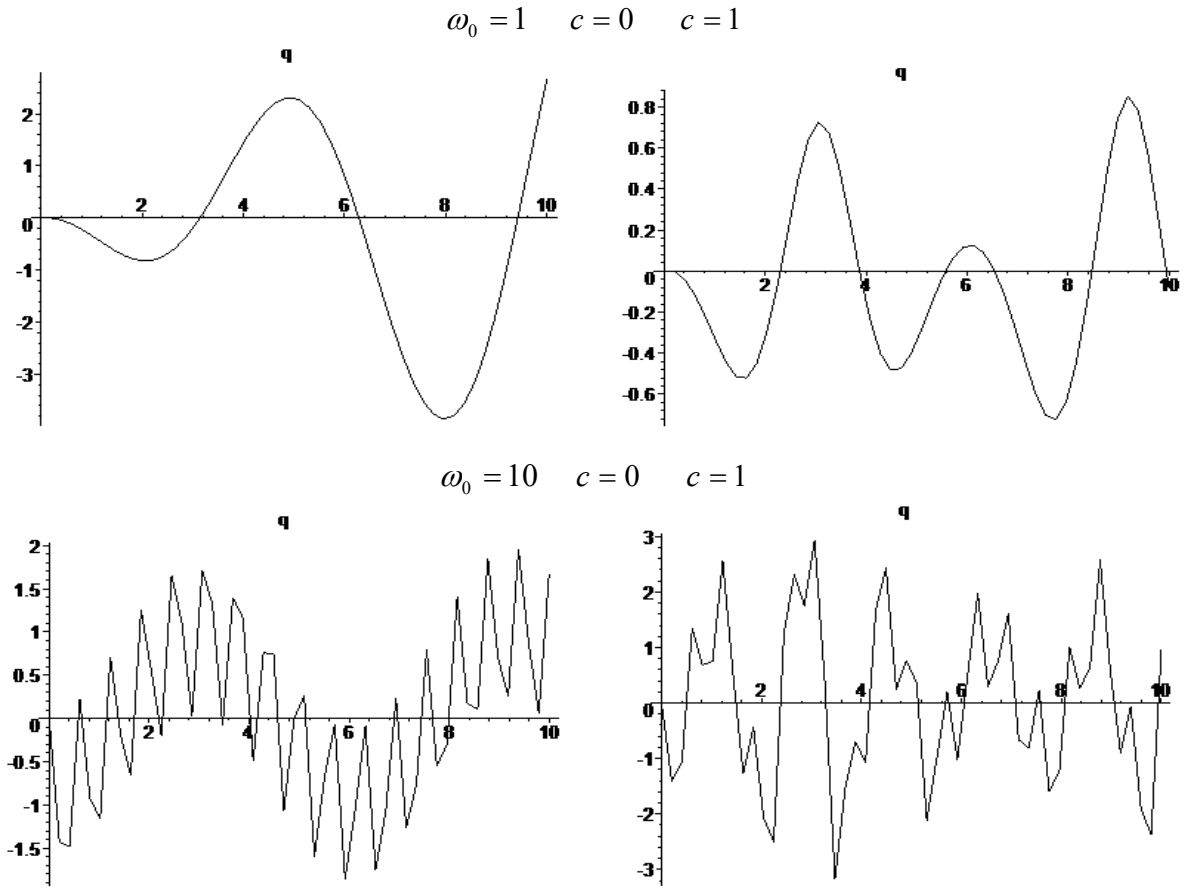

Figure 3 – Torsional vibrations of the rod at different values of the parameters c and ω_0

Now let the torsional movement of the HWDP rod occur under the action of a compressive force *P*, we assume that the rod performs transverse oscillations in the plane $y0z$ in two directions. We assume that the transverse motion of the cross-sections of the HWDP rod does not affect its torsional oscillations (figure 4).

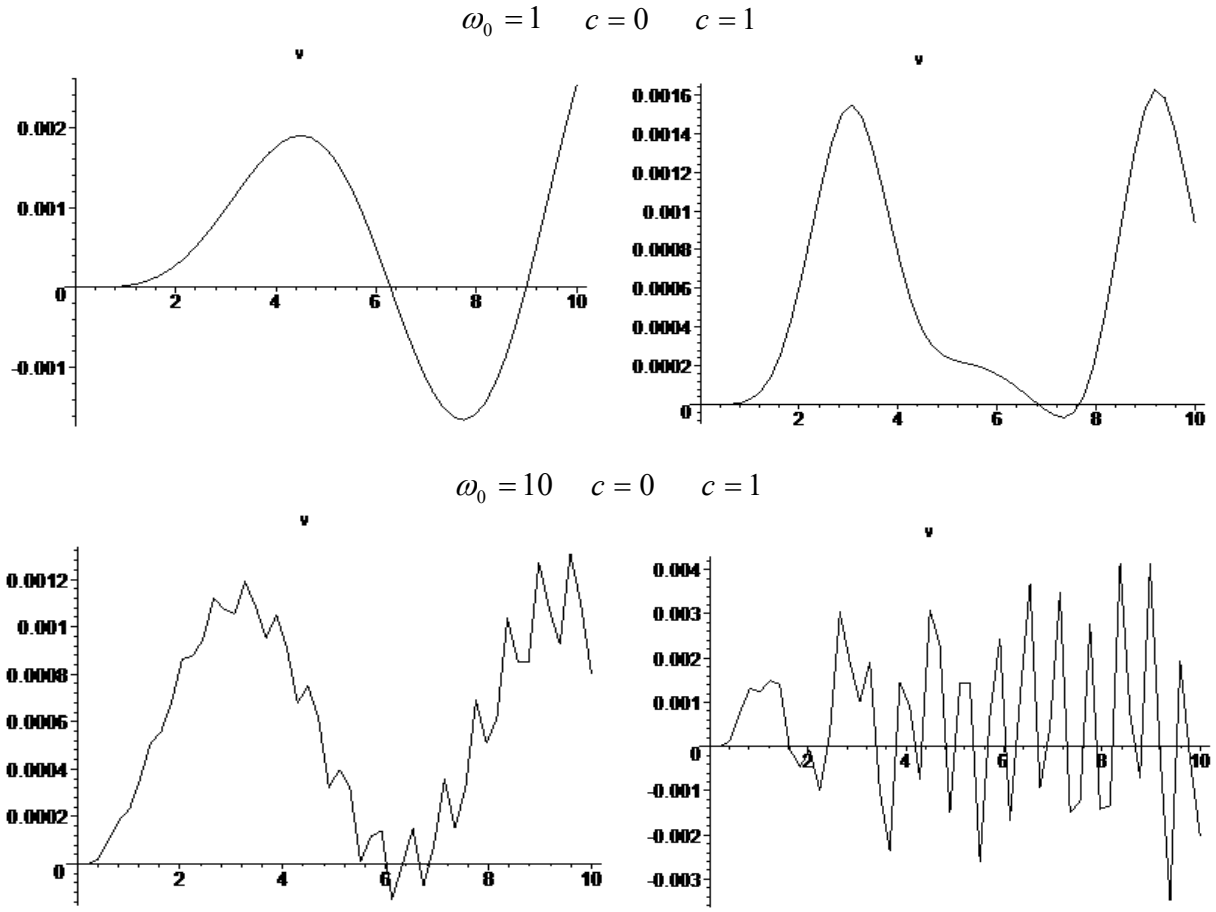

Figure 4 – Transverse oscillations of the rod at different values of the parameters *c* and ω_0

The equations of motion of the rod in the case of geometric linearity are written in the form [1]

$$m\frac{\partial^2 v}{\partial t^2} + EJ\frac{\partial^4 v}{\partial x^4} + Pz_0\frac{\partial^2 \varphi}{\partial x^2} = 0 \tag{14}$$

$$m\frac{\partial^2 w}{\partial t^2} + EJ\frac{\partial^4 w}{\partial x^4} - Pz_0\frac{\partial^2 \varphi}{\partial x^2} = 0 \tag{15}$$

where $v(x,t)$ and $w(x,t)$ are displacements of bar sections along the axes $0y$ and $0z$.

Equations (14) and (15) introducing dimensionless variables and quantities by the formulas $\tau = \frac{t}{l}\sqrt{\frac{EJ}{ml}}$, $\xi = x/l$, $\bar{z}_0 = z_0/l$, $\alpha = \frac{\pi^3 GJ_{p0}}{2EJ}$, $\overline{P} = \frac{Plz_0}{\pi GJ_{p0}}$, considering (12) and bringing to the form

$$\frac{\partial^2 \bar{v}}{\partial \tau^2} + \frac{\partial^4 \bar{v}}{\partial \xi^4} - \alpha\overline{P}[\overline{M}_0(\tau)\sin\pi\xi + q(\tau)\cos\pi\xi] = 0 \tag{16}$$

$$\frac{\partial^2 \overline{w}}{\partial \tau^2} + \frac{\partial^4 \overline{w}}{\partial \xi^4} + \alpha \overline{P}[\overline{M}_0(\tau)\sin \pi\xi + q(\tau)\cos \pi\xi] = 0 \qquad (17)$$

Equations (16) and (17) are integrated under the conditions $\overline{v} = 0$, $\overline{w} = 0$, $\frac{\partial \overline{v}}{\partial \tau} = 0$, $\frac{\partial \overline{w}}{\partial \tau} = 0$ at $\tau = 0$, $\overline{v} = 0$, $\overline{w} = 0$, $\frac{\partial^2 \overline{v}}{\partial \xi^2} = 0$, $\frac{\partial^2 \overline{w}}{\partial \xi^2} = 0$ at $\xi = 0$ и $\xi = 1$, the solution of which is obtained by the Fourier method $\overline{v} = \sum_{n=1}^{\infty} T_n \sin n\pi\xi$, $\overline{w} = -\sum_{n=1}^{\infty} T_n \sin n\pi\xi$ where

$$T_n = \frac{\alpha}{2n\pi} \int_0^{\tau} \overline{P} \sin[n^2\pi^2(\tau - \varsigma)][\overline{M}_0(\varsigma) + q(\varsigma)]d\varsigma .$$

As can be seen from the dependences of the displacement of the midpoint of the elastic line on the dimensionless time τ presented in Figure 4 under the action of the moment $\overline{M}_0$ according to the law $\overline{M}_0 = 1 - \cos \omega_0 t$ for various values of the parameters c and ω_0, consideration of the nonlinearity of the rod during torsion can lead to a decrease in the deflection of the rod at small values of the parameter ω_0. With an increase in this parameter, the rod performs high-frequency oscillations with large amplitudes. The calculations were made taking $\alpha = 0.01$, $\overline{P} = 0.005$.

Conclusion. The proposed method for studying longitudinal oscillations of a geometrically nonlinear HWDP of its torsional stability, considering the physical nonlinearity in the process of its deformation, makes it possible to improve the methods of ensuring the reliability and strength of HWDP at the stage of their design. The established dependences characterizing the stability parameters of HWDP demonstrate the ability to control them by varying their values. This makes it possible to evaluate the most optimal values of the DDS operating parameters for their stable operation, which subsequently ensures their operability during real case.

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МҰНАЙ-ГАЗ ҰҢҒЫМАЛАРЫН ТЕРЕҢДЕТКІШ САЛМАҚТЫ БҰРҒЫЛАУ ТІЗБЕГІНІҢ ГЕОМЕТРИЯЛЫҚ СЫЗЫҚТЫ ЕМЕС ТЕРБЕЛІСТЕРІ МЕН ТҰРАҚТЫЛЫҒЫ

Аннотация. Ұңғымалардағы бұрғылау тізбектері (БТ) – бұл физикалық қасиеттері біртіндеп өзгеретін қуыс салмақты өзектер (мысалы, қаттылығы), бұл жағдайда тізбектің әрбір бөлігі геометриялық сызықты емес заңдарға сәйкес деформациялануы мүмкін. Олар бұрғылау қондырғысынан тау жыныстарын талқандайтын құралға қуат беретін және бұрғылау қабырғаларымен гидродинамикалық, демек жанасу кезінде өзара әрекеттесетін бұрғылау үрдісінің ең маңызды бөлігі болып табылады және әрқашан қисық болады. Бұл ұңғыманың қисаюына байланысты да, өз салмағының, байланыс күштерінің, сондай-ақ тізбек айналған жағдайда ортадан тепкіш күштердің әсерінен болады. Бұл жағдайда тізбек осінің қисаюына тізбек құбырларының деформациясының геометриялық бейсызықтығы айтарлықтай әсер етуі мүмкін.

Бұл мәселені қарау кезінде физикалық және геометриялық сызықтық емес есептердің әр түрлі асқынулар түрлерімен (тізбектердің тұрақтылығының жоғалуы, құбырлардың үзілуі және т.б.), сонымен қатар динамикалық бұрғылау жүйесінің (ДБЖ) элементтеріндегі басқа процестерді есепке алуды қамтитын бірқатар аз зерттелген мәселелер анықталды.

Бұл жұмыста механикалық жүйелердегі динамикалық процестерді зерттеудің заманауи әдістерін қолдану негізінде деформация процесінде физикалық сызықты емес екенін ескере отырып, бұралу кезіндегі

оның тұрақтылығының геометриялық сызықты емес бұрғылаутізбегінің бойлық тербелістерін зерттеу әдісі ұсынылған. Бұл процесті сипаттайтын тәуелділіктер табылды.

Түйін сөздер: мұнай-газ ұңғымалары, бұрғылау тізбектері, бойлық тербелістер, тұрақтылық, геометриялық сызықтық емес, динамикалық жүйелер.

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КОЛЕБАНИЯ И УСТОЙЧИВОСТЬ ГЕОМЕТРИЧЕСКИ НЕЛИНЕЙНОЙ ВЕСОМОЙ БУРИЛЬНОЙ КОЛОННЫ ДЛЯ УГЛУБЛЕНИЯ НЕФТЕГАЗОВЫХ СКВАЖИН

Аннотация. Бурильные колонны (БК) в скважинах представляют собой полые весомые стержни со ступенчато изменяющимися физическими свойствами (например, жесткостью), при этом каждое звено колонны может деформироваться по геометрически нелинейным законам. Они являются наиболее ответственной частью в процессе бурения, передающим звеном мощности от буровой установки до породоразрушающего инструмента и находятся во взаимодействии со стенками скважины как гидродинамическом, так и контактном и всегда искривлены. Это происходит как за счет искривления самой скважины, так и под действием собственного веса, контактных сил, а также центробежных сил в случае вращения колонны. При этом на искривления оси колонны могут существенно влиять геометрическая нелинейность деформирования труб колонны.

Обзор данной проблемы выявил ряд малоизученных задач, к которым относятся вопросы учета как физически, так и геометрически нелинейных задач, сопровождаемых различными видами осложнений (потери устойчивости колонн, разрывы труб и др.), а также другие процессы в элементах бурильной динамической системы (БДС).

В данной работе на основе применения современных методов изучения динамических процессов в механических системах предложена методика исследования продольных колебаний геометрически нелинейной БК ее устойчивости при кручении с учетом физической нелинейности в процессе ее деформирования. Найдены зависимости, характеризующие данный процесс.

Ключевые слова: нефтегазовые скважины, бурильные колонны, продольные колебания, устойчивость, геометрическая нелинейность, динамические системы.

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MICROFACIES AND DEPOSITIONAL ENVIRONMENT OF TERTIARY LIMESTONE, GORONTALO PROVINCE, INDONESIA

Abstract. The research area is located in northern Limboto Lake in Gorontalo Province, which has complex geological characteristics. The geological complexities include stratigraphy and tectonics which influence the formation of the Limboto Basin. Limestone research in the Late Tertiary Limboto Basin is very intriguing to be done because of the lack of research in limestone. Gorontalo limestone outcrops, which become the focus of the research, have a total thickness of 30 meters. The research objective is to analyze facies, microfacies, and depositional environment of tertiary limestone. These two research objectives are attained by using two research methods, namely measurd section and petrography analysis. The research result exhibits that there are four Gorontalo limestones facies, including coralline rudstone intercalated with thin mudstone facies, sandy micrite intercession facies, coralline rudstone intercession facies and sandy allochem limestone intercession facies. According to the limestone microfacies standard, the depositional environment of Gorontalo limestone is platform interior restricted (facies zone 8).

Keywords: microfacies, depositional environment, tertiary limestone, Gorontalo.

Introduction. Sulawesi Island has tectonic and geological complexity. This complexity is influenced by the collision of three plates, namely the Eurasian Plate, the Indo-Australian Plate, and the Pacific Plate. The interaction of these three plates causes a striking change from the shape of the Sulawesi island, changing from an archipelago with a convex side towards the Pacific Ocean to the K shape as it is now. The collision of the moving Pacific plate pushes Sulawesi westward along 800 km [1, 2].

Sulawesi complexity makes this island, can be divided into several tectonic provinces including pluton and volcanic rocks composing the West Sulawesi arm, the metamorphic belt composing Central Sulawesi, ophiolites composing East Sulawesi and the continental micro blocks of Banggai-Sula and Buton-Tukang Besi [3, 4].

The north arm of Sulawesi, which is part of the West Sulawesi arm, is also composed of volcanic rock, which is estimated to be of late Paleogene and Neogene origin from the Maluku plate and Sulawesi Sea plate subduction zone [5]. The middle part of the Sulawesi North Arm lies the Limboto plain formed by Limboto Lake and several rivers. The constituent rocks in this basin are limestone. Quaternary limestone spread to the northwest of Lake Limboto with an area of 20 x 4 km2 of Pliocene-Pleistocene age and in the west and south an area of 37 x 4 km2 of Pleistocene age [6, 7].

The distribution of Quaternary age rocks is closely related to the various forms of morphology and basin shapes produced by the last tectonic process which developed since the time of the Late Miocene epoch, volcanic activity, and denudation processes. Quaternary rock distribution can be known from remote sensing imagery, both with aerial portraits, radar, and Landsat. The alluvial plateau and elevated coral limestone that spread out wide shows the stability of the bedrocks [7, 8].

Limestone research in Lake Limboto has been done by creating a regional geological map. Two limestone formations consist of Clastic Limestone Formation and Coral Limestone Formation. The Pliocene-Pleistocene Clastic Limestone Formation is located in the west of the lake comprising calcarenite, calcirudite and coral limestone with the thickness up to 200 meters. Coral Limestone Formation (Ql)

which is located in the south of the lake is estimated to be Holocene; this reef limestone is uplifted with the main component of coral [9].

Limestone research in Limboto Lake has only been carried out in general by producing regional geological maps. Two limestone formations are Clastic Limestone Formation and Reef Limestone Formation. The Clastic Limestone Formation located in the western lake is Pliocene-Pleistocene lake with calcarenite lithology, calcirudite and coral limestone with thickness up to 200 meters. The Reef Limestone Formation (Ql) found in the south of the lake is estimated to be Holocene in age; this reef limestone is elevated with coral as the main component [9].

Limestone research in the Yosonegoro area produces two facies and microfacies, namely coraline rudstone facies and wackestone-packestone intercession facies with a slope to toe of slope depositional environment [10]. Limestone research in the north of Lake Limboto is carried out due to a lack of research data on Gorontalo limestone. Hence, this research is carried out in detail by taking a more comprehensive approach from the geological aspect so that new findings will be generated. The research aims to analyze microfacies, depositional environments, relative age and paleobathymetry of Gorontalo limestone, which involves microfacies and biostratigraphy analysis methods.

Research Method. The location of the research is the West Limboto District of Gorontalo Regency in the North of Lake Limboto with the geographical location at coordinates (00º 39' 5"- 00º 39' 7.644" North) and (122º 55' 20.833"- 122º 55' 34" East) (figure 1). Materials and research supplies are limestone outcrops with a thickness of up to 30 meters. The research method consists of two stages. The first stage is doing a measured section (MS) using a 1.5 meter interval jacob's staff systematically from the oldest to the youngest rocks [10, 11, 12, 13].

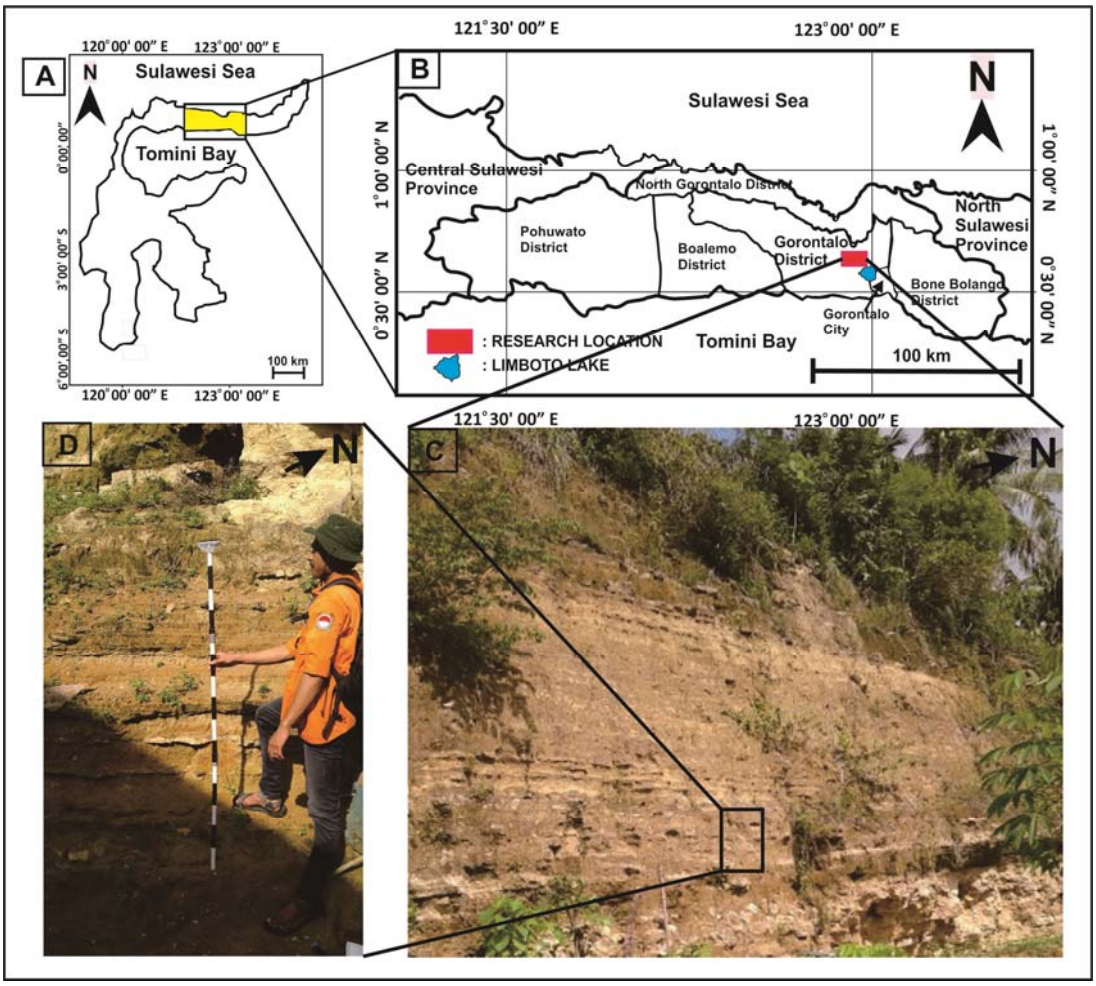

Figure 1 – Research location which is located on the north of Lake Limboto, West Limboto District, Gorontalo Regency. (A) the location of Gorontalo Province on the map of Sulawesi island, (B) the research location on the map of Gorontalo Province, (C) the measuring section location on research location, and (D) the measuring section (MS) uses a jacob's staff

This method is fundamental to know the facies in the study site, including measuring the exact thickness of the facies and taking appropriate samples for petrographic analysis. The next method is the petrographic analysis of a thin section using a 1053 polarization microscope equipped with a computer-connected camera. The petrographic analysis is beneficial in determining microfacies so that the depositional environment can be easily determined [14, 15].

Research Results and Discussion.

A. Facies and Microfacies. MS measurements are carried out in detail by distinguishing one facies unit to another facies. The reference to differentiate these facies is done by doing field descriptions and petrology based on texture, structure, and composition. Determination of standard microfacies (SMF) in addition to the initial data distribution of facies and sedimentary structures found in the field as well as the detailed composition of petrographic analysis. MS results at the research site contain four facies, namely facies A, B, C, and D (figure 2). Descriptions of the four facies are as follows:

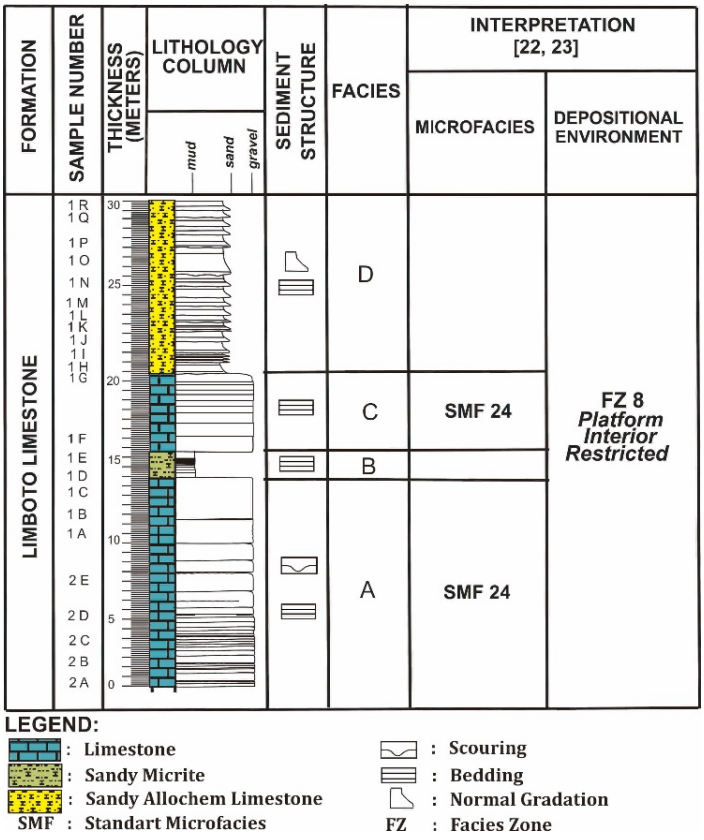

Figure 2 – Lithostratigraphic distribution chart which divides Gorontalo limestone into four facies

Facies A is interpreted as coralline rudstone intercalated with thin mudstone facies [16]. The coralline rudstone intercalated with thin mudstone facies are at the bottom of the lithostratigraphic column. The position of this facies is at intervals of 0-13 meters. This facies is described as brownish-white, grain size> 2 mm, poor sorting, rough fragmental bioclastic texture, open packaging, the connection between grain is floating in the matrix. The bedding structure is thickining upward and the scouring structure is at the top of the contact with the mudstone. The rock composition is composed of coral fragments, micrite, and opaque minerals. The composition of these facies based on petrographic analysis consists of red algae (7%), foraminifera (8%), corals (10%), brachiopods (4%), bryozoa (2%), mollusks (1%), echinoids (1%)), and non-skeletal shells in the form of peloids (15%). Granules are embedded in the matrix in the form of carbonate mud (5%) with cementation (30%) in the form of microspar-pseudospar. Found a cavity of vuggy (3%), intercrystalline (10%), intercrystalline (0.5%), and cracks (0.5%); replacement is characterized by the presence of clay minerals (3%) (figure 3).

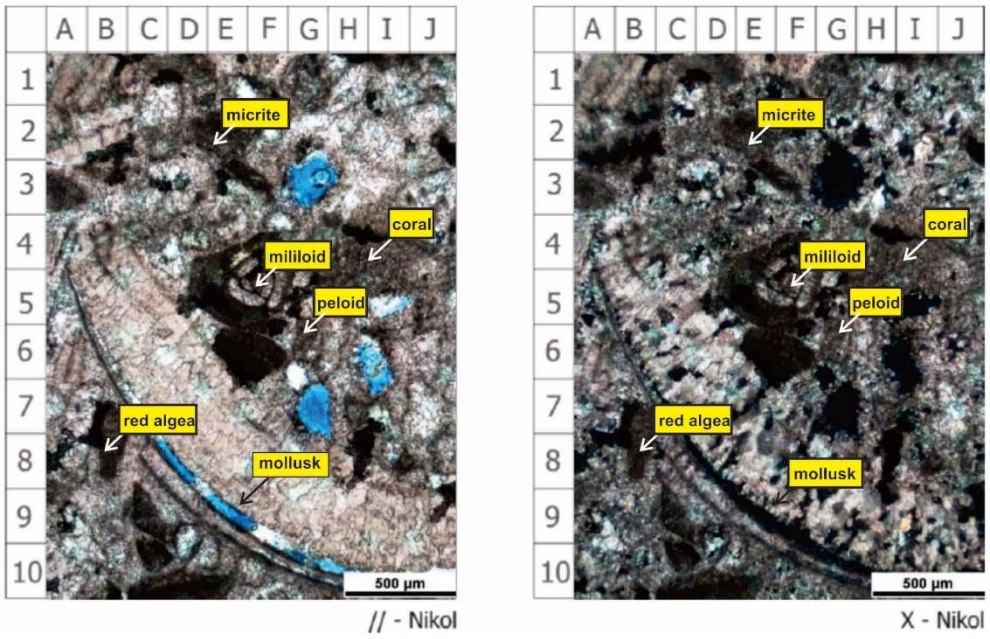

Figure 3 – Petrographic analysis of coralline rudstone samples [16], which is Facies A

Based on the composition of these facies, the type of microfacies is SMF 24 [17, 18]. The reason is that these microfacies are composed of coarse bioclasts and are influenced by slope or imbrication with sparse matrices. The depositional environment for microfacies based on the type of SMF 24 is the restricted interior platform (FZ 8) (figure 4).

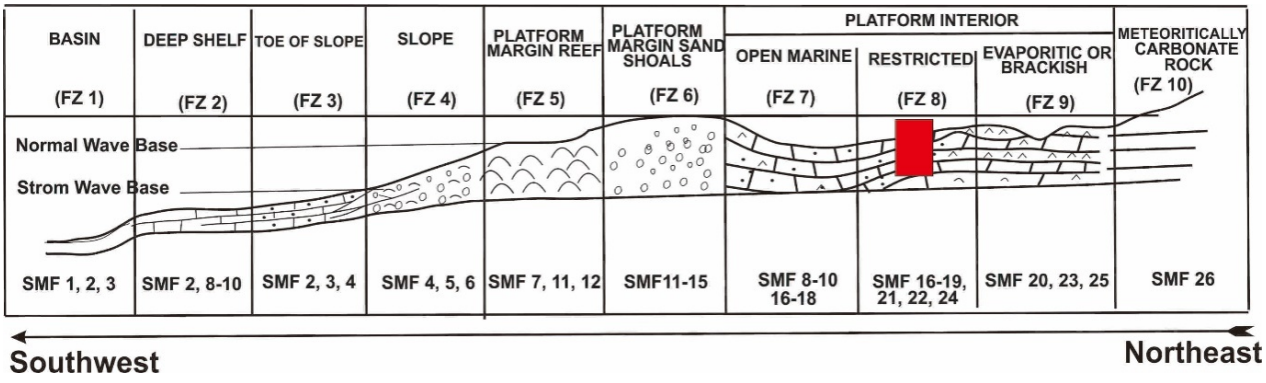

Figure 4 – Gorontalo limestone depositional environment,
which is a platform interior restricted (FZ 8) [17, 18]

Facies B is interpreted as sandy micrite intercession facies [19]. This facies is above the coralline rudstone intercalated with thin mudstone facies of the lithostratigraphic column. The position of these facies is at intervals of 13-15 meters. Further, this facies is described as brown, grain-size silt (1/256-1/16 mm), good sorting, closed packaging, composition: micrite and quartz with some rock fragments. The structure of this facies is bedding (thinning upward). The interpretation of depositional energy is high.

The composition of these facies is based on petrographic analysis consisting of small foraminifera (1%), and non-skeletal granules in the form of plagioclase (2%), quartz (3%), hornblende (1%), carbon (7%), opaque minerals (5%), and rock fragments (1%) embedded in the matrix (40%) with cementation (25%) of the cavity in the form of vuggy (5%). Substitution is characterized by the presence of clay minerals (10%) (figure. 5).

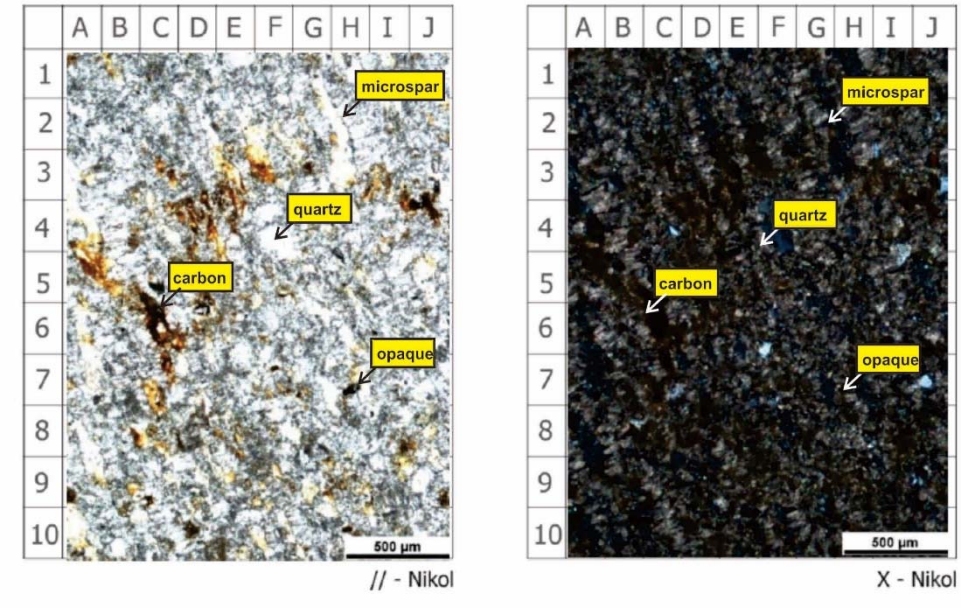

Figure 5 – Petrographic analysis of sandy micrite samples [19], which is Facies B

Facies C is interpreted as coralline rudstone intercession facies [16]. The coralline-rudstone intercession facies are above the sandy micrite intercession facies of the lithostratigraphic column. The position of these facies is at intervals of 15-20.5 meters. This facies description is brownish-white, grain size > 2 mm, poor sorting, rough fragmental bioclastic texture, open packaging, the connection between grains is floating in the matrix. The structure is bedding (thinning upward).

Based on the composition of these facies, the type of microfacies is SMF 24 [17, 18]. The reason is that these microfacies are composed of coarse bioclasts and are influenced by slope or imbrication with sparse matrices. The depositional environment for microfacies based on the type of SMF 24 is the restricted interior platform (FZ 8) (figure 4).

Facies D is interpreted as sandy allochem limestone intercession facies [19]. This facies are above the coralline rudstone intercession facies from the lithostratigraphic column. The position of this facies is at intervals of 20.5-30 meters. This facies description is a light brown, fine-sized grain (1/8-1/4 mm), good sorting, and closed packaging. Further, the structure is bedding (thickining upward) and normal gradation

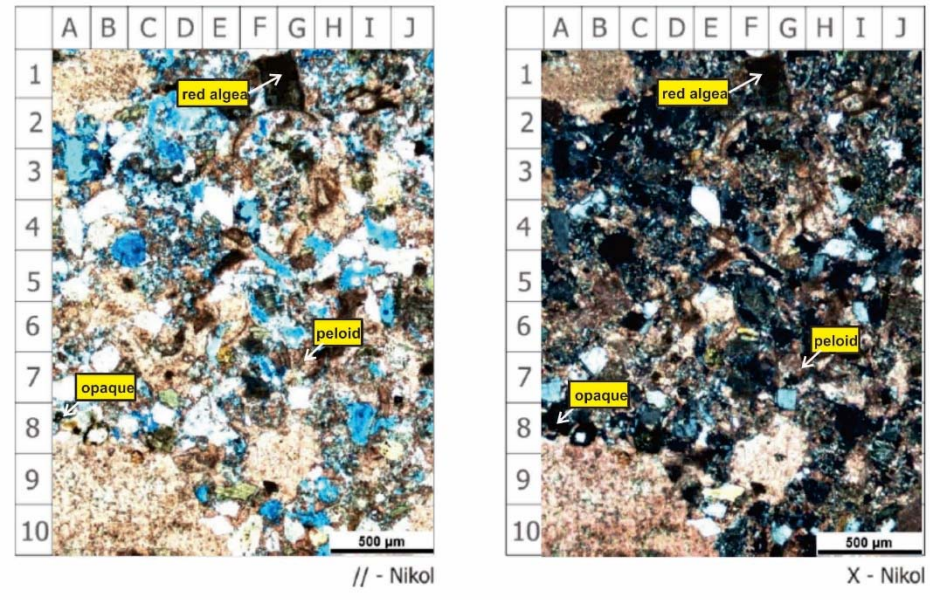

Figure 6 – Petrographic analysis of sandy allochem limestone samples [19], which are Facies D

with the composition of the micrite, quartz, and feldspar. The interpretation of formation energy based on grain size is high.

Moreover, the composition of these facies is based on petrographic analysis consisting of small foraminifera (8%), red algae (2%), echinoids (3%), bryozoa (5%), corals (5%), and large foraminifera (5%). Meanwhile, non-skeletal granules consist of opaque minerals (1%), hornblende (1%), plagioclase (2%), quartz (10%), rock fragments (3%), peloids (7%), carbon (1%), actinolite (1%) embedded in the matrix (13%) in the form of a small amount of carbonate mud and cementation (7%) in the form of calcite spines and clay minerals (2%). Porosity (25%) is vuggy and moldic (figure 6).

Conclusion. The research of microfacies and depositional environments of tertiary limestone, Gorontalo Province, Indonesia yielded several essential points which become the conclusions, including:

1. The facies analysis of tertiary limestone consists of four types of facies, namely coralline rudstone intercalated with thin mudstone facies, sandy micrite intercession facies, coralline rudstone intercession facies and sandy allochem limestone intercession facies.

2. The depositional environment for microfacies based on the type of SMF 24 is the restricted interior platform (FZ 8).

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МИКРОФАЦИАЛЬНАЯ И ОСАДОЧНАЯ СРЕДА ТРЕТИЧНОГО ИЗВЕСТНЯКА, ПРОВИНЦИЯ ГОРОНТАЛО, ИНДОНЕЗИЯ

Аннотация. Район исследований расположен в северном озере Лимбото в провинции Горонтало, которое имеет сложные геологические характеристики. Геологические сложности включают стратиграфию и тектонику, которые влияют на формирование бассейна Лимбото. Исследования известняка в позднетретичном бассейне Лимбото очень интересны из-за отсутствия до сих пор исследований по известняку. Горонтальские известняковые обнажения, ставшие объектом исследования, имеют общую толщину 30 метров. Цель исследования – анализ фациальной, микрофациальной и осадочной среды третичных известняков. Эти две цели исследования достигаются с помощью двух методов исследования, а именно измерительного разреза и петрографического анализа. Результаты исследований показывают, что существует четыре фации горонтало-известняков, в том числе коралловый рудный камень, интеркалированный тонкими аргиллитными фациями, песчаная микритная покровная фация, коралловая рудная покровная фация и песчаная аллохимическая известняковая покровная фация. Согласно стандарту микрофаций известняка, осадочная среда горонтальского известняка ограничена внутри платформы (фациальная зона 8).

Ключевые слова: микрофации, осадочная среда, третичный известняк, Горонтало.

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TOPONYMS OF CRETACEOUS DEPOSITS IN WESTERN KAZAKHSTAN TERRITORY (in the context of Aktobe region)

Abstract. The article deals with the occurrence of Cretaceous deposits in the territory of Aktobe region and geographical ground of their reflection in local toponyms. Aktobe region is characterized by the complexity of the terrain in West Kazakhstan. Terrain features are influenced by its geological structure and terrain-forming factors. The map presents a selection of toponyms including the words *ak, bor, saz, kum, shagyl* which correspond to the formations of lower Cretaceous and upper Cretaceous deposits widespread in the western part of the region. The percent of oronyms, hydronyms and oikonyms in the toponyms of 141 names selected in the study area was analyzed with subsequent representation on the diagram. The analysis of the names of *Aktolagay, Akshatau, Belogorka, Aktau, Akzhar*, etc., indicating the reflection in toponyms of such physical properties of rocks as composition, color and the rate of their frequency is carried out, the results are presented in a table. The map shows the position of geographical features corresponding to the outcropping Cretaceous beds and photos of the area are provided.

Key words: Cretaceous deposits, geological properties, Aktobe region, toponyms.

Introduction. Onomastic stratigraphy is understood as the relative chronology of onomastic systems, processes and phenomena. Onomastics of a single chronological period in the study of onomastic stratigraphy of the region is considered a synchronous cross-section. The terms synchronous cross-section and stratigraphy are borrowed from archaeology and geology but today both the method of synchronous cross-section and stratigraphic analysis are parts of the traditional set of research techniques of onomastics [1, 203-215]. The first term helps to study the onomastic state, i.e. the state of the name system of the territory in a certain geological period, the second term - the onomastic process – the regular change of onomastic states of this territory in chronological order.

Toponymy in combination with stratigraphy gives us a new section of toponymy - geostratonymy the purpose of which is determined as the study of the origin, development, current state, etymology of the set of names of the Earth's geological layers - stratons. The object of geostratonymy is a separate name of a geological straton - geostratonym and the subject is its history of origin, etymology and diachronic transformation. The proposed terms are derived from the Greek stems geo - earth, onyma - name, and Latin stratum - formation, layer, - literally "names of the layers of the Earth", i.e. they are based on the principle of internationality of toponymic terminology, and, at the same time, reflect the field of their use, the subject and object of research [2].

Cretaceous deposits in Kazakhstan are widely developed in the western part of the country - these are marine sediments of the Paleocaspian sea that covered the entire area of West Kazakhstan. The Paleocaspian waters were rich with foraminifera and planktonic Golden microalgae – coccolithophorids - whose skeletons in huge quantities sedimented on the bottom and formed Cretaceous deposits.

In this article we will focus on the history of the study of only those Cretaceous deposits development areas in Western Kazakhstan that we are directly interested in, namely: the Embensky district (Zhem), Mugalzhar, Shoshkakol anticline, and the North Aral sea region. The Lower Cretaceous deposits within the Embensky region were first established by N. N. Tikhonovich and A. N. Zamyatin [3]. After that brief descriptions or references to the participation of Lower Cretaceous deposits in the geology of individual structures or small areas appeared in dozens of different articles and essays concerning the Embensky district.

Cretaceous deposits of the Western Kazakhstan territories. During the Cretaceous period marine conditions had relatively stable development only in the South-West of the Republic of Kazakhstan. The sea here did not represent a permanent basin, and more than once left the territory of the Kazakhstan's western outskirts. The sea was most widespread in the Upper Cretaceous, when the entire western part of Kazakhstan up to the western edge of the Kazakh Upland was covered by the waters of a vast Upper Cretaceous transgression. This vast basin was connected through the Turgai basin to the Cretaceous basin that covered the West Siberian lowland. The Lower Cretaceous deposits in the Caspian lowlands are predominantly marine, while the Upper Cretaceous deposits are exclusively marine. The characteristic sediments of the Upper Cretaceous are presented by white writing chalk stone. Cretaceous deposits of western Primugodzharie have a similar section. In the eastern Primugodzharie sediments of Early Cretaceous period are represented by continental facies sometimes bauxitebearing ones [4].

Considering the works which provide coverage of the structure of West Kazakhstan Cretaceous deposits we see that the marine formations of this age are the most well-studied and, first of all, the Cretaceous deposits of the Emba basin (Zhem). However, the nature of the transition of marine sediments to continental sediments in the direction from the central parts of the Emba basin to its eastern margin, to the Mugalzhar and Shoshkakol anticline, remained unclear. It was not clear which Cretaceous system stages represented in the Emba basin by marine sediments correspond to the continental deposits of the Shoshkakol anticline and the western slope of the Mugalzhar. The details of the change in the section of Lower Cretaceous sediments within the Emba basin itself in the direction to the East were not known, in particular, the nature of the transition of the Lower and Middle Albian marine sediments to the same-age sediments of continental origin was not clarified, though the existence of such transition was supposed by a number of authors [5].

The study of the Cretaceous deposits of the Zhem (Emba), Sagiz, and Uil river basins is of particular importance for our work as just here we encounter the most complete section of sediments of this age, represented almost exclusively by marine sediments. The thickness of marine sediments decreases in the direction of the migration area located in the east and the north-east, there is a sharp depletion of their fauna and partial replacement by continental formations. This pattern allows for the estimating the age of particular formations of continental origin developed within the upper reaches of the Emba and even further east - in the Shoshkakol anticline and the Mugalzhar by tracing the gradual transition of marine faunistically characterized deposits to continental ones.

The entire complex of Lower Cretaceous sediments of the Emba, Sagiz, Uil and Ilek river basins represents sediments basically of a single transgressive cycle. Commencing in Valangian the transgression developed with some fluctuations in Hauterivian-Barremian and reached the maximum in Aptian. Then a regression began and in the upper Albian marine sediment deposition occurred only within the southern Emba, giving the way to the accumulation of thick continental strata in the rest of the territory [6].

In the West, in the area of the Emba river (Zhem) lower and middle reaches the Cretaceous deposits are almost entirely represented by marine sediments among which almost all the layers and sometimes particular zones of this system could be distinguished and faunistically characterized. To the East, in the upper reaches of the Emba river, in the area of the Shoshkakol anticline and in the North Aral sea region, marine sediments are represented only by Upper Cretaceous deposits. At the same time in most sections only Senonian deposits are expressed in marine facies, and the underlying deposits, which cover by age the Lower Cretaceous and the foot of the upper Cretaceous, are continental formations.

The study of the gradual replacement of sea sediments in the eastern direction by continental formations allowed to find out which marine sediments of a given stage of the Cretaceous system correspond to particular formations of continental sediments containing plant remains or devoid of them [7].

Continental Cretaceous deposits of the Shoshkakol anticline to the north off Zhaman-Tau transfer to the same-age formations of the southern Mugalzhar. However, the extremely poor exposure of both slopes, the southern Mugalzhar and the transgressive occurrence of the Paleogene, which in some places is located proper on the protruding Paleozoic and Precambrian rocks, does not allow to trace the continuation of the selected formations to the north and establish their direct relationship with the Mesozoic deposits of more northern regions.

The continental Mesozoic deposits of the Mugalzhar were studied in detail by P. L. Bezrukov and A. L. Yanshin (1937), who attributed a significant part of them to the Jurassic. But in the light of further research it turned out that the continental Mesozoic deposits of the southern Mugalzhar are more correctly to attribute in whole to the Lower Cretaceous, and within the northern Mugalzhar there are both Jurassic and Lower Cretaceous deposits.

Research methods and study materials of research. The object of the study is the compilation of toponyms in the area of Cretaceous deposits in the territory of Aktobe region. Layers of Cretaceous deposits occupy the western part of the region. This feature has caused the functioning of many toponymic terms in the region's toponymy.

The study used a descriptive method for a comprehensive disclosure of the topic, as well as a set of complementary methods: information search, analysis and systematization of scientific publications on the object and subject of research, comparative method, cartographic method. The basic research tools used were system analysis, qualitative and quantitative methods of collecting and processing information.

The reflection of environmental features in toponyms was analyzed in the research works of many foreign and Kazakh scientists. Among them the research was held on the geological and geographical features of the area as a factor of formation of toponyms [8], toponymic directions in geological studies [9], the specific character of toponyms formed in connection with physical and geographical features of the terrain [10], and the importance of toponymic research in landscape changes [11, 12, 13]. Living in a certain area people expressed the natural features of this area in the names, therefore researching the interconnection between names and named places reveals much information about the way people perceived, understood, and adapted the natural environment to their needs [14].

Result and Discussion.

The reflection of the Cretaceous deposits in the names. Toponyms that characterize the features of the geological structure of the territory can convey the information about the composition of geological rocks both directly and indirectly. Such toponyms can be considered as names that reflect the composition of geological rocks, reflect the color and are associated with mineral resources. These features can be identified by means of *words - terms* in the composition of toponyms.

On the whole territory of the region located to the west of the line running from Orsk along the foot of the Mugalzhar ridge and to the north-west off the Zhem river basin the Upper Cretaceous deposits are well exposed in the valleys of many rivers and streams, and even in watershed spaces. In the coastal zone of the Late Cretaceous sea, especially in the beginning, sandy and dust-like (silty) sediments were deposited, farther on from the coast - clay and calcareous silts were deposited. Now at the foot of the Mugalzhar and on the Or-Ileksky hill first are greenish-gray glauconite-quartz sands and sandstones, and even often with a layer of gravel and pebbles at the bottom, and above are silt and clay, and higher are already white marls and even writing chalk stone [15, 64]. Such features of the territory are reflected in toponyms with the words *bor (chalk), ak (white), kum (sand)*, etc.(figure 1).

On the territory, corresponding to the ancient Eastern European platform, toponyms with the word *ak (white)* predominate in the composition of toponyms characterizing the geological features of rocks. The meaning of the word *ak(white)* in toponyms has various meanings, for example, in the names of hydrographic items, in addition to indicating the color of water, it was used in the name of snow-fed water bodies. Among the Kazakh names of rivers most often you can find words beginning with the words "*ak*"*(white)* and "kara"(black). It is widely believed that almost half of geographical network of Kazakhstan and adjacent regions of the Russian Federation consist of "white "("ak") and" black "("kara") rivers, streams, gullies, lakes. But it is quite definite that this name does not explain the local properties of geographical features. Therefore the name needs not only the translation but also the explanation of its origin [16, 47].

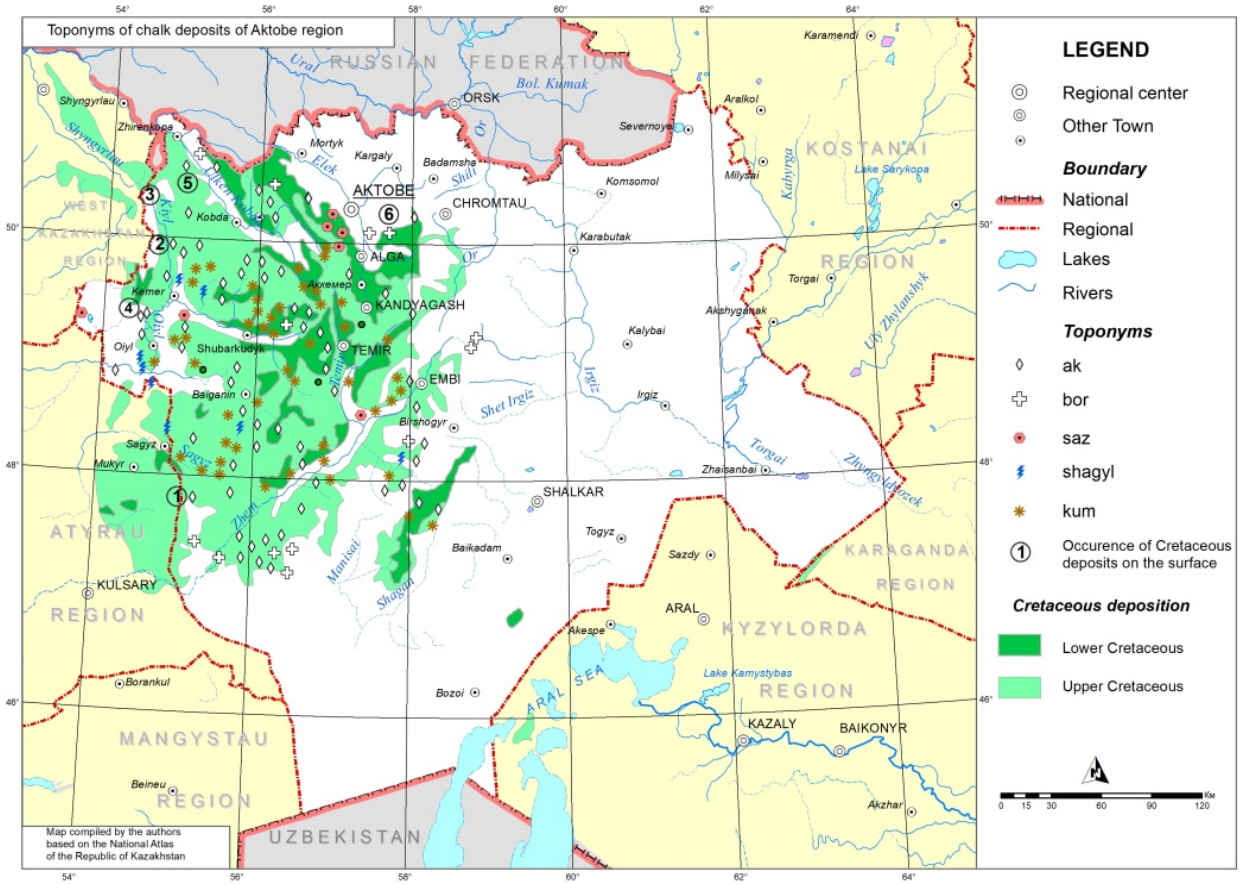

Figure 1 – Toponyms of chalk deposits of Aktobe region

Photos of areas as per marks on the map

Figure 1 –
South Aktolagai (*photo by the author*)

Figure 2 –
Akshatau (near Kiyl) (*photo by the author*)

Figure 3 –
Kobda (near the river Kiyl) (*photo by the author*)

Figure 4 –
Akshatau (Oiyl) (*photo by the author*)

Figure 5 –
Ushkaragantau (*photo by Smelyanov*)

Figure 6 –
Belogorka (quarry)

In our research, the word *ak (white)* as part of oronyms was used to describe the lithological specific nature of orographic objects, the color of rocks such as limestone and chalk. Some toponyms directly or indirectly define the composition of rocks, names with the word *ak* are found in other areas of Kazakhstan in the form of complex names *Aktau (South-Eastern Kazakhstan*) [17], *Akshoky, Aktas*, where veins of limestone, gypsum, marl, white marble, monoquartzite, barite and quartz occur. Such toponyms include the names of the fields *Aktasty* and *Akzhar* in Aktobe region. Aktasty is a limestone field, it was discovered in 1964 in the Khromtau district of Aktobe region and is located 27 kilometers off the city of Aktobe and Akzhar, located 16 kilometers northeast off the city of Aktobe and 4 kilometers north off the village of Akzhar, is a field where limestone is being produced [18]. Similar toponyms *Akshatau (mountain)*, *Aktasty (mountain), Aktau (mountain, hill)*, *Akshoky (mountain, depression in ground), Akkum (hill), Aktas (hill), Aktobe (mountain)* indicate a lithological feature of orographic objects, i.e. the presence of limestone, chalk deposits or gypsum rocks. It also proves that the *Aktolagay* mountains (located on the border of the Bayganinsky district and Atyrau region), *Akshatau* (Uilsky district) in the south-western area of Aktobe region, where the sea and the subsequent transgression of the Caspian sea took place during the geological Mesozoic, are named because of the color of their constituent rocks. *The Aktolagay plateau* is located in the Bayganinsky district of Aktobe region, near its border with Atyrau region, 440 km south-southwest off the city of Aktobe, 250 km east off the city of Atyrau, 9-10 km wide, stretches from North to South up to 50 km. From the point of view of its origin and morphology, Aktolagay is an original plateau, which is however smaller compared to the famous Ustyurt plateau. The surface plain of Aktolagay is bounded at its western end by a steep falling ledge, the depth of which sometimes reaches 140 m. A

reference section of the upper Cretaceous-Neogene structures for the entire Ural–Zhem oil region was studied on this bench. Geological strata in the gorges of the bench were formed at the bottom of the sea which extended to present-day Hungary. Snow-white chalk and limestone strata of Cretaceous origin are formed by the fossils of billions of very small ancient organisms. Here you can find quite large fossils, such as teeth of Cretaceous sharks, belemnites, as well as fossils of ammonites, marine animals, corals, sea lilies, sea urchins, etc. The hills surrounding the plateau are made up of gypsified clays, and also contain a large number of paleontological remains, and they are very impressive, as they are covered with placers of gypsum crystals that reflect in the sun [19]. Concerning the etymology of the name Aktolagay, the word "ak" *(white)* is associated with the description of the color of the object and the word" Tolagay" is synonymous with the word *tolgoi* in the Mongol-Buryat language, but having undergone phonetic changes, it has adapted to the Kazakh language and means "Top, hill, high mountain". Such names are common in Eastern Kazakhstan. For example: Tolagay Mountain (985m, 926m) (in Kokpekty and Zaisan districts). R. A. Segedin reports that the formation of the name *Aktolagay* is associated with carbonate remains of marl and white chalk [15].

Toponyms such as *Borly, Borzher, Melovoy,* made up by the term *bor (chalk)*, which we consider together with the word *white*, provide the information about the concentration of rocks such as limestone, chalk, marl. A. A. Chibilev showed that the toponyms Burtya, Burlya, Burlin, Borly - *chalky* indicate the meaning of the word *chalk* [20]. We suppose that the toponym Borte, which is found on the territory of the region, must also come from the word *borly (chalky)*.

Based on the state catalog of geographical names of Aktobe region and the topographic map of 1:500 000 scale 141 toponyms were selected with the terms *ak, bor, saz, kum, shagyl*, corresponding to the areas of Cretaceous deposits occurence, which are classified in accordance with the types of oronyms, hydronyms, oikonyms, etc. (figure 3).

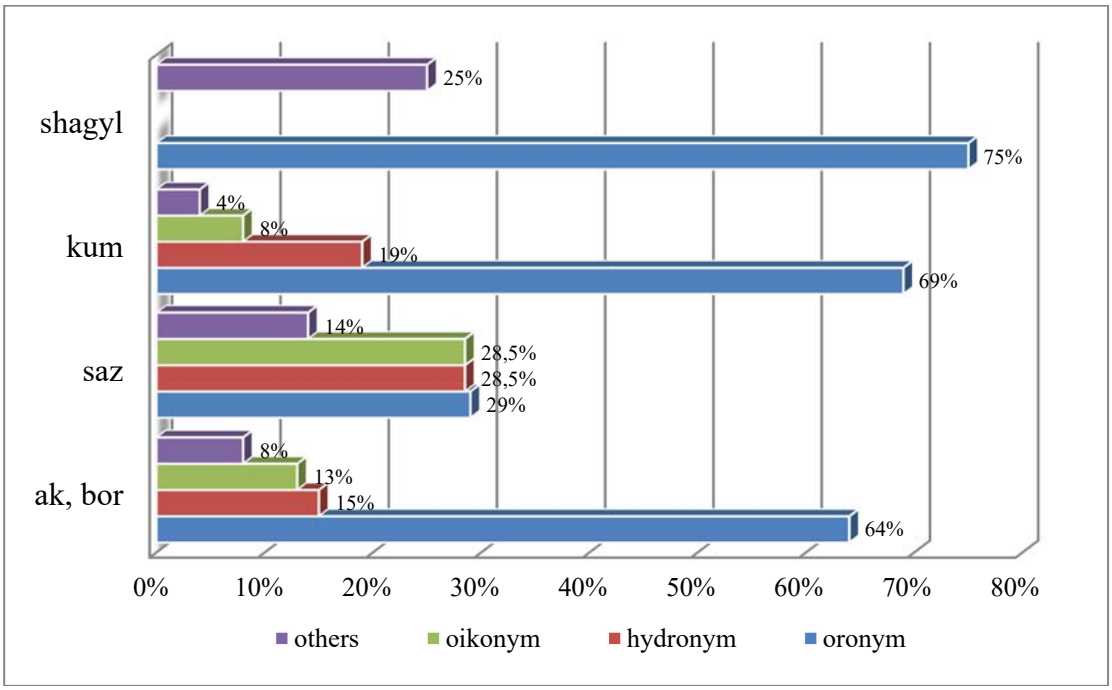

Figure 3 – The proportion of terms in toponyms

The analysis of the toponyms in the study area, as shown in figure 3, shows that the share of these terms is 65% in oronyms, 16% - in hydronyms, and 11% - in oikonyms.

Among toponyms there are also names that are repeated several times. Their concentration as per the type of orographic forms was summarized in table below.

The concentration of toponyms in the orographic units

Toponyms	Repetition rate	Division of names by orographic units				Others
		Names of mountains	Names of hills	Names of depressions	Names of settlements	
Akzhar	6			4		2
Akkebek	1	1				
Akkemer	2					2
Aksai	6	1		3		2
Aktas	2	1				1
Aktau	5		3		2	
Aktolagai	1	1				
Aktortkil	1	1				
Aktumsyk	1		1			
Akungir	3			1		2
Akshat	5		2	2	1	
Akshatau	3	2				1
Akshukyr	1					1
Belogorka	7	2	3		1	1
Borzher	3				3	
Borly	4		1			3
Zhalgyzshagyl	3					3
Kumzhargan	5			1	1	3
Kumsai	15			12		3
Melovoi	3		1		2	
Sazdy	5		1			4
Kumbauyroba	1	1				
Kumdy	2					2

The table is based on the state catalog of geographical names of Aktobe region [21].

It was found that the names of *Akzhar, Aksai, Aktau, Akshat, Borly, Belogorka, Kumsay* and *Kumzhargan* are more common in the names concentrated in oronyms. In addition more than 60% of the given toponyms correspond to the names of orographic items, such as a mountain, a hill, depressions and a settlement.

Conclusion. The following factors are the most important in the formation of geographical names in the study area: related to the color of chalk rocks (55%), geological - geomorphological (40%) and lithological features of the relief (5%). Among the toponyms the frequently repeated names Akzhar, Aktau, Akshat, Belogorka, Borly mainly correspond to exposed (exposed) parts of Cretaceous deposits. The past processes on the territory of Aktobe region during geological periods, especially in the Cenozoic, impacted the formation of the modern relief of the region. Names related to the color, composition and to water erosion of rocks are concentrated in areas where traces of ancient flooding of the East European platform and the Turan plate are covered by Paleogene deposits, where traces of Mesozoic floods and Cretaceous deposits protruding to the surface are preserved.

There are many examples of toponyms of Cretaceous deposits on the territory of Aktobe region, and it does not contribute to the effectiveness and ease of knowledge and understanding of its geological structure. Therefore the use of the toponymic method in the study of the etymology of the names of formations in the future opens the way to create a register of these names, clear up the history of their separation, authors and to some extent solve the problem of toponyms for future new geostratonyms. Thus, the practical significance of applying the toponymic approach to the study of stratigraphic nomenclature is primarily seen in the systematization of the nomenclature aspect of stratigraphy by introducing modern methods for collecting, processing, storing and updating geostratonymic information through the mechanism of GIS technologies – electronic banks and databases. The problems of geostratonymy open up a wide range of applying the toponymic approach in stratigraphy of any scale at the territorial level, primarily at the local and regional levels. It requires the organization and centralization of comprehensive research in this area.

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БАТЫС ҚАЗАҚСТАНДАҒЫ БОР ШӨГІНДІЛЕРІНІҢ ТОПОНИМДЕРІ (Ақтөбе облысы мысалында)

Аннотация. Мақалада Ақтөбе облысы аумағындағы бор шөгінділерінің таралуы және олардың жергілікті топонимдердегі бейнелену ерекшеліктерінің географиялық негіздері қарастырылды. Ақтөбе облысы Батыс Қазақстандағы жер бедерінің күрделілігімен сипатталады. Рельефтің ерекшеліктері оның геологиялық құрылымына және рельефті құрайтын факторларға байланысты.

Облыстың батыс бөлігінде таралған төменгі және жоғарғы бор шөгінділері қабаттарымен сәйкес келетін *ақ, бор, саз, құм, шағыл* сөздерімен жасалған топонимдер топтамасы картада көрсетілді. Зерттеу аумағындағы таңдап алынған 141 атаудың топонимдер құрамындағы ороним, гидроним, ойконимдер үлесі талданып, диаграмма жүзінде бейнеленді. Тау жыныстарының құрамы, түсі сияқты физикалық қасиеттерінің топонимдердегі көрінісін дәлелдейтін *Ақтолағай, Ақшатау, Белогорка, Ақтау, Ақжар* т.б. атауларға талдау жасалды және олардың қайталану жиілігі анықталып, нәтижесі кесте түрінде көрсетілді. Жалаңаштанған бор шөгінділері қабаттарына сәйкес келетін географиялық нысандардың орны картада белгіленіп, фотосуреттері берілген.

Түйін сөздер: бор шөгінділері, геологиялық ерекшелік, Ақтөбе облысы, топонимдер.

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ТОПОНИМЫ МЕЛОВЫХ ОТЛОЖЕНИЙ ТЕРРИТОРИИ ЗАПАДНОГО КАЗАХСТАН (на примере Актюбинской области)

Аннотация. В статье рассматриваются вопросы залегания меловых отложений на территории Актюбинской области и географические основания их отражения в местных топонимах. Актюбинская область характеризуется сложностью рельефа в Западном Казахстане. Особенности рельефа зависят от его геологического строения и рельефообразующих факторов.

На карте была представлена группа топонимов со словами *ақ, бор, саз, құм, шағыл*, совпадающие со слоями нижнемеловых и верхнемеловых отложений, распространенных в западной части области. Проанализирована и отражена на диаграмме доля оронимов, гидронимов, ойконимов в составе топонимов 141 избранных наименований в области исследования. Проведен анализ наименований *Актолагай, Акшатау, Белогорка, Актау, Акжар* и др., свидетельствующие о проявлении в топонимах таких физических свойств горных пород, как состав, цвет и определена частота их повторения, результаты представлены в виде таблицы. На карте обозначено положение географических объектов, соответствующих слоям обнаженных меловых отложений, даны фотографии.

Ключевые слова: меловые отложения, геологические особенности, Актюбинская область, топонимы.

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APPLICATION OF LINEAR ASYNCHRONOUS MOTORS FOR HIGH-SPEED GROUND TRANSPORT

Abstract. Magnetic suspension in high-speed ground transport systems is an alternative to the rail wheel. The successful solution to the development of high-speed ground transport is largely determined by the creation of operationally efficient linear motors, the main task of which is to convert electrical energy into mechanical energy and create tractive force to ensure the movement of the crew according to a given program in the range of operating speeds.

The article investigates linear asynchronous motors with longitudinal closure of magnetic flux of single-ended design. As a result of investigation of physical processes in linear motors caused by edge problems it was found that the cause of the transverse edge effect is the finite width dimensions of the reactive bus, the change of which causes closure of eddy currents within the active area of inductor, leads to weakening of magnetic field in the central zone and to reduction of tractive force.

The discrepancy between the calculated and experimental indicators of physical processes in linear asynchronous motors due to significant idealization of mathematical models led to the development of a three-dimensional theory, brought to the calculation programs. The developed calculation program of electromechanical characteristics of linear induction motors with inductor and reactive bus layout, as well as their geometrical and physical parameters allows to determine the necessary integral motor characteristics in the form of a levitation function.

Key words: high-speed ground transport, linear induction motor, reactive bus, edge effects, inductor, traction drive.

The most investigated are linear asynchronous motors with unilateral action and double-sided stators - linear asynchronous motors with longitudinal closure of magnetic flux in unilateral and double-sided version. The methods of calculation of electromechanical characteristics in traction and braking modes, ventilation and thermal calculations were developed with respect to them. Experiments were conducted on models of linear induction motors at power supply of thyristor frequency converters.

Conducted researches [1-3] showed that for the nearest perspective the most rational for high-speed ground transport is application of one-way linear induction motor, located on the crew. Developments of linear motor with superconducting excitation winding and active track structure are also known. The one-way induction motor has a number of positive features:

- flat track structure, convenient for cleaning from ice and snow;
- possibility of relatively simple and reliable mounting of the superconducting excitation winding on the crew;
- small sensitivity to crew vibrations due to a large air gap.

Powerful electromagnetic field created by a superconducting electromagnet gives linear motors the following advantages: absence of iron components in the anchor winding; possibility of operation with air gap an order of magnitude greater than similar arrangements; operation of superconducting electromagnet in "frozen flow" mode allows to solve current collector problem; high value of energy factor 0,5-0,8. The disadvantages of linear motors include: the need to cool the superconducting electromagnet to the

temperature of liquid helium and related equipment; the complexity of the control system; the problem of transition by the crew of the joints of the powered sections and shielding of the passenger compartment. For the theoretical analysis of linear motors with a superconducting excitation winding, preference is given to the energy approach, which allows for high calculation accuracy, maximum approximation to the real design of linear motors, analysis of their operation in steady-state and transient modes.

Principle construction of linear motors with superconducting excitation winding consists of three-phase anchor winding located on track structure, sectioned and powered by static frequency converter, which allows to regulate voltage *U* and frequency *f*. Superconducting electromagnets of the excitation system are located on the crew.

Structurally, linear induction motors consist of the following units: inductor core and winding, housing, auxiliary devices and the secondary part. The inductor core is assembled from varnish-insulated electrotechnical steel plates of thickness 0,3-0,5 mm with chiseled grooves, as a rule, of rectangular shape [4]. The teeth in the upper part have a notch for mounting wedges, fixing the winding. Assembly of the inductor package is performed with insulated studs, passing through the grooves of the same shape on the outer surface of the package.

The study of electromagnetic forces and technical and energy performance on the basis of energy approach shows that the energy of two interconnected circuits of superconducting, located on the crew, and traction - on the track, assuming that currents in the first I_c, in the second I_a are constant in time and determined by the ratio:

$$W_M = \frac{1}{2}[L_c(I_c)^2 + 2M_i I_c I_a + L_T(I_a)^2], \quad (1)$$

where L_c and $L_т$ are the inductances, respectively, of the superconducting and traction circuits; M_i is the mutual induction coefficient between the superconducting conductor and the *i*-th circuit of the complete anchor winding.

The total force acting on the superconducting field winding is given as:

$$\bar{F}_{x,y,z}(x) = \sum_{m=1}^{3} k_c I_c i_m grad M_i(x), \quad (2)$$

where k_c – number of superconducting electromagnets; i_m – the current in *m*-th phase of the armature winding.

With the sinusoidal form of current in the armature winding of the linear motor forces are determined by the higher harmonics of the derivatives from M_i, which can be minimized by the methods known from the theory of rotating machines. According to expression (2) the derivatives from $M_i(x)$ were determined and after some transformations for the first harmonics the total force is represented in projections as

$$\left.\begin{aligned} F_x &= \frac{3}{\sqrt{2}} N k_c I_c I_т \frac{\partial M_{ст}}{\partial x} sin\theta_м \\ F_z &= \frac{3}{\sqrt{2}} N k_c I_c I_т \frac{\partial M_{ст}}{\partial z} cos\theta_м \\ F_y &= \frac{3}{\sqrt{2}} N k_c I_c I_т \frac{\partial M_{ст}}{\partial y} cos\theta_м \end{aligned}\right\}, \quad (3)$$

where N is the number of crews; $I_т$ is the effective value of the anchor winding current; $\theta_м$ is the angle between the axes of the magnetic flux of the superconducting circuit and the resulting flux of the anchor winding.

The primary boundary effect is characterized by the appearance in the active zone, in addition to the main running wave of induction, of its components that are stationary in space and pulsating in time. The secondary longitudinal marginal effect is caused by successive entry and then exit of the reactive bus elements, respectively, into and out of the zone of the running magnetic field of the inductor, which leads to deformation of the machine magnetic field, its removal beyond the running edge of the inductor, occurrence of forces in the synchronous speed mode, and additional power losses in the reactive bus [5]. The transverse edge effect is caused by the finite width dimensions of the reactive busbar, due to which the eddy currents are short-circuited within the active zone of the inductor, resulting in a weakening of the magnetic field in the central zone and a decrease in the tractive force at low slip.

The existing methods for calculating rotating induction motors do not take into account the edge effect and are not suitable for the calculation of high-speed linear induction motors. In this connection it is offered to use special methods, based on analytical or numerical solution of Maxwell equations system for different zones of the machine and allowing to make calculation of integral electromechanical characteristics of linear induction motors with sufficient for practice degree of accuracy [6]. The complexity of real physical processes in high-speed linear induction motors initially predetermined a significant idealization of calculated mathematical models, but because of the discrepancy between the calculated and experimental indicators, we then had to move to more complex models. At the first stage of research, one-dimensional theories of linear induction motors were used, which were developed over time to three-dimensional ones [3]. In this publication three-dimensional theory was developed and brought to computational computer programs for linear induction motors of various designs with an arbitrary number of poles, with or without additional three-phase compensation winding, with two- or one-sided inductor and return magnetic core made of roasted or solid steel, as well as with layered reactive bus bar.

In formulating the problem and constructing the calculation model (figure 1), the following assumptions have been made:

(a) The area of existence of the magnetic field is bounded by two infinite perfectly stratified ferromagnetic surfaces, with magnetic constant $\mu_c = \infty$ and conductive material density $\gamma_c = 0$;

b) the inductor windings are fed by three-phase symmetrical current systems and produce sinusoidal running waves - m.e.f. in the form $F_M f(y) \exp j(\omega t - \frac{\pi}{\tau} x)$;

c) the change of m.p.s. in transverse direction with period 2L is given by function *f(y)* in the core: at $|y| \le a \cdot f(y) = 1{,}0$; at $|y| > a \cdot f(y) = 0{,}83 exp((c-y)/\Delta)$; and $a = c + (2\delta + d) ln 0.83$;

d) the components I_{1z}, I_{2z}, I_{3z} of current densities and A_{1z}, A_{2z}, A_{3z} of vector magnetic potential in the primary and reactive bus bars are negligibly small;

e) the model is periodized in the longitudinal direction with period $l = L_S + L_L$.

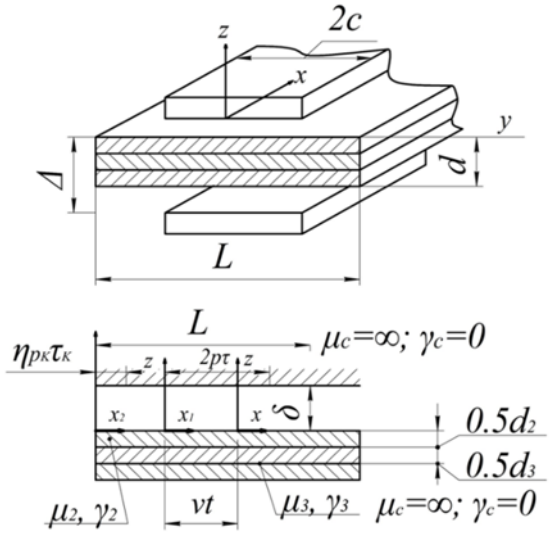

Figure 1 – Model of a linear induction motor

In order to obtain the calculated relations of a linear induction motor for a given type of M.P.H., the system for the vector magnetic potential is solved by the Fourier method:

$$\overline{\nabla}^2 \bar{A}_\delta = 0;\ div \bar{A}_\delta = 0, \tag{4}$$

$$\overline{\nabla}^2 A_{2(3)} = \gamma_{2(3)} \mu_{2(3)} \frac{\partial A_{2(3)}}{dt}, div A_{2(3)} = 0, \tag{5}$$

and by the known $A_{x(\delta,2,3)}$ and $A_{y(\delta,2,3)}$ the corresponding components of induction $B_{(x,y,z)}$magnetic $H_{(x,y,z)}$ and electric $E_{(x,y,z)}$ field strengths, and reactive bus current densities $I_{(x,y)}$ are determined. The total electromagnetic power $S_{\text{ЭМ}}$, found through the Poynting vector, as well as the thrust and normal

forces (F_x, F_z) of the linear induction motor, for the finding of which the Maxwell stress tensor was used, are defined by the following expressions:

$$S_{\text{ЭМ}} = j\frac{\omega_1 C_{20}^2 l^3}{16\pi^2\mu_0}\sum_n^{n_M}\sum_\nu^{\nu_M} z_\Pi^2 \lambda G_{n\nu}\left|k_{\nu_0}\right|\frac{ch\lambda\delta + c_{12}sh\lambda\delta}{ch\lambda\delta + c_{12}\lambda\delta}; \quad (6)$$

$$F_x = -\frac{l^2 L c_{20}^2}{8\pi\mu_0}\sum_n^{n_M}\sum_\nu^{\nu_M} z_\Pi^2 \frac{\nu\lambda\delta n\nu\left|k_{\nu_0}\right|^2 Im(c_{12})}{|sh\lambda\delta + c_{12}ch\lambda\delta|^2}; \quad (7)$$

$$F_y = \frac{Ll^3 c_{20}^2}{32\pi^2\mu_0}\sum_n^{n_M}\sum_0^{\nu_M} z_\Pi^2 \lambda^2 G_{n\nu}\left|k_{\nu_0}\right|^2; \quad (8)$$

where

$$Z_n = \frac{1}{n}\frac{1}{1+\left(\frac{\pi n\Delta}{L}\right)^2}\left[sin\left(\frac{\pi na}{L}\right) + \frac{\pi n\Delta}{L}cos\left(\frac{\pi na}{L}\right) + 0{,}83\left(\frac{\pi n\Delta}{L}\right)^2 sin\left(\frac{\pi n}{2}\right)exp\frac{2c-L}{2\Delta}\right];$$

$$\omega_c = \frac{1}{n}\frac{1}{1+\left(\frac{\pi n\Delta^1}{L}\right)^2}\left[sin\frac{\pi na}{L} + \frac{\pi n\Delta^1}{L}cos\frac{\pi na}{L} + 0{,}83\left(\frac{\pi n\Delta^1}{L}\right)sin\frac{\pi n}{2}exp\frac{2c-L}{2\Delta}\right];$$

$c_{20} = \mu_0\frac{16\sqrt{2}\tau^2 A k_{o\delta 1}}{\pi^2 l^2}$; $\lambda = \sqrt{\left(\frac{\pi n}{L}\right)^2 + \left(\frac{2\pi\nu}{l}\right)^2}$; $G_{n\nu} = \frac{sin\left(\frac{\pi n}{n_M+1}\right)}{\pi n/(n_M+1)}\cdot\frac{sin\left(\frac{\pi\nu}{\nu_M+1}\right)}{\pi n/(\nu_M+1)}$ - Lantzsch sigma-multipliers; A - linear current load; c_{12} and k_{ν_0}, respectively, integration constant and winding factor [7].

The program for calculating the electromechanical characteristics of linear induction motors assumes the known layout of inductor and reactive bus, their basic geometrical and physical parameters, winding data and allows to determine the necessary integral motor characteristics as a slip function: total electromagnetic power S_EM and its components $P_{\text{эм}}, Q_{\text{эм}}$, traction and normal forces F_x, F_z, $cos\varphi_1$, voltage U_1, at $I_1 = const$, as well as distribution of the normal component of induction along the inductor length.

The electromechanical characteristics of the one-way motor, calculated according to the three-dimensional theory with a reversed magnet wire, are shown in figure 2.

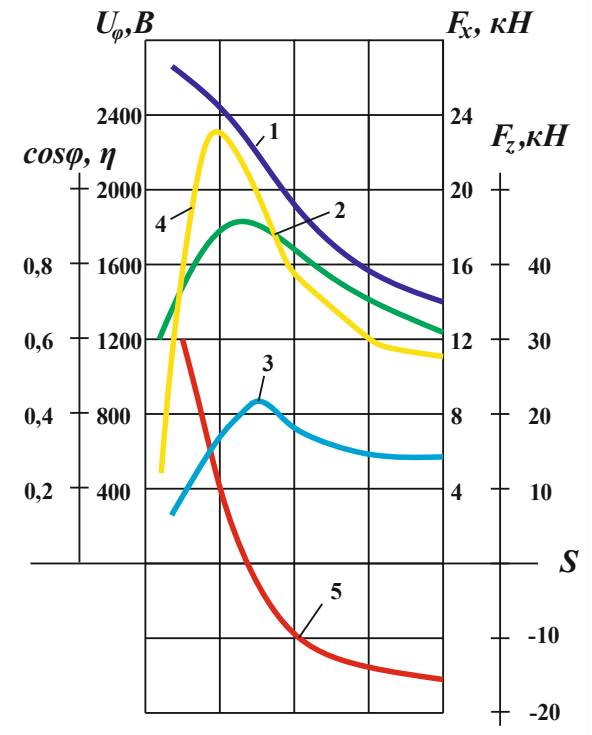

Figure 2 –
Electromechanical characteristics
of the calculated linear asynchronous motor
as a function of slip *S*:
1 – phase voltage U_φ; 2 – efficiency η;
3 – power factor $cos\varphi$; 4 – thrust force F_x;
5 – normal force *F*

To reduce the heating of linear induction motor elements and to improve its mass-size and energy performance, intensive forced cooling is used. With liquid cooling the current density in the inductor winding should be increased to 15-25A/mm^2. In this case, the liquid supplied by the pump circulates through hollow conductors, takes the heat and transfers it to the cooler. Despite the need for additional equipment, design and technological complexity, it provides a gain in size and mass of the linear motor about 20% in comparison with air cooling with a decrease in the motor efficiency by about 8-10% [8].

The secondary part of a linear induction motor is a T-shaped reactive bus made of aluminum alloys. To increase F_x, alloys with small electrical conductivity are used or made in the form of a hollow section. The reactive bus consists of a non-magnetic pad, made of aluminum alloys and a ferromagnetic solid magnetic core.

According to experimental and calculated data, in order to obtain high traction and energy indices, it is advisable to make the reverse magnetic core fully charged [9].

Conclusions. Structural solution on installation of additional equipment, change of design and material of reactive bus for creation of continuous magnetic wire in motor secondary winding allows to increase levitation indices of linear induction motor, which is confirmed by preliminary calculations.

According to data of Japan, the USA, Germany, China and Russia the main indices of linear induction motors are on the average level: specific thrust $F_x < 12$ kN/m^2; $cos\varphi_1 \leq 0{,}6, \eta \leq 0{,}87$; ratio of mass of linear motor movable elements to effective power $M/P_2 > 1{,}0$ kg/kW.

As a development of perspective direction and radical improvement of linear motors performance it is reasonable to apply a phase design of the secondary element with inclusion of capacitors in the secondary winding. The proposed design in combination with intensification of inductor cooling opens up possibilities of improvement of specific traction force F_x up to 40-60 kN/m^2 and can be put in a basis of the priority decision of a problem of creation of the traction drive of the crew for a high-speed land transport.

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ЖОҒАРЫ ЖЫЛДАМДЫҚТЫ ЖЕР ҮСТІ КӨЛІГІ ҮШІН ЖЕЛІЛІК АСИНХРОНДЫ ҚОЗҒАЛТҚЫШТАРДЫ ҚОЛДАНУ

Аннотация. Жоғары жылдамдықты жердегі көлік жүйелеріндегі магниттік суспензия рельсті көлік доңғалағына балама болып табылады. Жоғары жылдамдықты жер үсті көлігін дамытудың сәтті шешімі көбінесе тиімді жұмыс істейтін желілік қозғалтқыштарды құрумен анықталады, олардың негізгі міндеті электр энергиясын механикалық энергияға айналдыру және экипаждың берілген бағдарлама бойынша жұмыс жылдамдығының диапазонында қозғалысын қамтамасыз ететін Тарту күшін құру болып табылады.

Мақалада бір жақты магнит ағынының бойлық тұйықталуы бар сызықты асинхронды қозғалтқыштар зерттеледі. Шекаралық міндеттерге байланысты сызықтық қозғалтқыштардағы физикалық процестерді зерттеу нәтижесінде көлденең жиек әсерінің себебі ені бойынша реактивті шинаның соңғы өлшемдері болып табылады, олардың өзгеруі индуктордың белсенді аймағында құйынды токтардың жабылуына әкеліп соғады, орталық аймақтағы магнит өрісінің әлсіреуіне және тартылыс күшінің төмендеуіне әкеледі.

Математикалық модельдердің едәуір идеализациясына байланысты сызықтық асинхронды қозғалтқыштардағы физикалық процестердің есептік және эксперименттік көрсеткіштерінің сәйкессіздігі есептеу бағдарламаларына келтірілген үш өлшемді теорияның дамуына әкелді. Индуктор мен реактивті автобустың орналасуы бар сызықтық асинхронды қозғалтқыштардың электромеханикалық сипаттамаларының, сондай-ақ олардың геометриялық және физикалық параметрлерінің жобаланған бағдарламасы левитация функциясы түрінде қозғалтқыштың қажетті интегралды сипаттамаларын анықтауға мүмкіндік береді.

Түйін сөздер: жоғары жылдамдықты жер үсті көлігі, сызықты асинхронды қозғалтқыш, реактивті автобус, шекті эффектілер, индуктор, тартқыш.

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ПРИМЕНЕНИЕ ЛИНЕЙНЫХ АСИНХРОННЫХ ДВИГАТЕЛЕЙ ДЛЯ ВЫСОКОСКОРОСТНОГО НАЗЕМНОГО ТРАНСПОРТА

Аннотация. Магнитное подвешивание в системах высокоскоростного наземного транспорта является альтернативой колеса рельсового транспорта. Успешное решение развития высокоскоростного наземного транспорта в значительной мере определяется созданием эффективных в эксплуатации линейных двигателей, основной задачей которых является преобразование электрической энергии в механическую и создание силы тяги, обеспечивающей движение экипажа по заданной программе в диапазоне эксплуатационных скоростей.

В статье исследуются линейные асинхронные двигатели с продольным замыканием магнитного потока одностороннего исполнения. В результате исследования физических процессов в линейных двигателях, обусловленных краевыми задачами, установлено, что причиной поперечного краевого эффекта является конечные размеры реактивной шины по ширине, изменение которых вызывает замыкание вихревых токов в пределах активной зоны индуктора, приводит к ослаблению магнитного поля в центральной зоне и уменьшению тягового усилия.

Несоответствие расчётных и экспериментальных показателей физических процессов в линейных асинхронных двигателях из-за значительной идеализации математических моделей привело к разработке трехмерной теории, доведенной до расчётных программ. Разработанная расчетная программа электромеханических характеристик линейных асинхронных двигателей с компоновкой индуктора и реактивной шины, а также их геометрических и физических параметров позволяет определить необходимые интегральные характеристики двигателя в виде функции левитации.

Ключевые слова: высокоскоростной наземный транспорт, линейный асинхронный двигатель, реактивная шина, краевые эффекты, индуктор, тяговый привод.

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DISPOSAL OF LEAD PRODUCTION WASTES BY EXTRACTION OF LEAD AND ZINC OXIDES

Abstract. Information is given about the need to dispose of waste from the Shymkent lead plant in the form of slags, which have accumulated about 2 million tons. It is proved that lead production slags contain a large number of toxic compounds, such as lead, zinc, osmium, and cadmium, which are dangerous sources of environmental pollution.

According to the results of X-ray diffractometric analysis and DTA, it was found that the slag of lead production contains a fairly high number of non-ferrous metal compounds: the content of lead oxide up to 2 %, zinc oxide up to 17% and copper oxide up to 1.25% of the total weight of the sample. The qualitative composition and content of non-ferrous metals of lead slags makes it possible to make the process of recycling toxic waste from lead production technically and economically feasible.

The results of preliminary tests allow us to select a technology for more complete and selective extraction of lead and zinc oxides from the slag waste of lead production. When using a selective method for extracting non-ferrous metals, it is expected to improve the ecological state of the environment and reduce the negative impact on human health due to the disposal of toxic slags from lead production. At the same time, a significant contribution is made to the development of the system of rational use of natural and secondary resources.

Keywords: waste, lead waste, toxic compounds, lead and zinc compounds, environmental pollution, toxic waste processing, waste disposal

Introduction. On the territory of South Kazakhstan region (now Turkestan region), in the city of Shymkent during the 30s of the last century, a lead plant for the production of lead operated. Even after its closure, the plant is environmentally unsafe. The technologies used at the plant were inferior in efficiency to modern analogues. The mined ore had a high lead concentration, which allowed the plant to neglect the residual metals in the slags due to their relatively low concentration. As a result of the activity of the enterprise, about 2 million tons of wastes in the form of lead slags have been accumulated [1-3]. Due to the open storage of slags, the environmental expertise revealed a huge excess of the maximum permissible concentration (MPC) of lead in the soil near the former lead plant: currently, the MPC near the plant is more than 3000 mg/kg in the soil, and according to the standards it should be 3.2 mg/kg. According to the analyzes carried out in all plant samples, the norm was exceeded from 1.83 to 8.13 times [4-5].

Lead production slags also contain a certain amount of potentially harmful elements, such as lead, zinc, osmium, cadmium, which are possible environmental pollution sources. The environmental damage of long-term storage of slag is seriously dangerous when the slag is in an acidic environment (soil pH < 4). Shymkent soil cover contamination with lead compounds of waste slags leads to the ingress of metal into the human body. Lead compounds negatively affect the human nervous system, which leads to a decrease in intellect, causes changes in physical activity, coordination of hearing, affects the cardiovascular system, leading to heart disease [6].

Lead occupies the first place among professional intoxications, and there is a tendency to its increase. Among workers affected by lead exposure, about 40% are women. Lead is particularly dangerous for women as this element has the ability to penetrate through the placenta and accumulate in breast milk. As a rule, the highest lead concentration in the atmospheric air is observed in winter, which is associated with additional emissions of fuel combustion products into the atmosphere. Unfavorable meteorological conditions during this period of the year also contribute to the lead accumulation in the lower atmosphere layers. Lead enters the body through the gastrointestinal tract or the respiratory system and is then carried by the blood throughout the body. Moreover, the inhalation of lead dust is much more dangerous than the presence of lead in food. Lead compounds also accumulate in bones, partially replacing calcium in phosphate. Entering in soft tissues – muscles, liver, kidneys, brain, lymph nodes, lead causes a disease – plumbism. Like many other heavy metals, lead (in the form of ions) blocks the activity of certain enzymes. The authors established that their activity decreases 100 times with an increase in the lead concentration in the blood 10 times – from 10 to 100 micrograms per 100 ml of blood. At the same time, anemia develops, the hematopoietic system, kidneys and brain are affected, and intellect decreases. This has a negative impact on the health of the population, and especially children, who are most susceptible to lead poisoning [7-8].

Lead can easily enter the body with drinking water if it comes into contact with metal: in the presence of carbon dioxide, soluble bicarbonate slowly passes into the solution. It is enough that there is only one milligram of lead in a liter of water – and drinking such water becomes very dangerous. The lead accumulation is intensively carried out by fungi, mosses and lichens and bring its concentration to 64.76 ppm, respectively. The more familiar oats and clover, already at a lead concentration of 50 ppm, begin to slow down growth and yield declines. Lead comes from the atmosphere into the soil most often in the form of oxides, where it gradually dissolves, turning into hydroxides, carbonates or the form of cations [9]. The main source from which lead enters the human body is food, along with this, inhaled air plays an important role, and in children also the lead dust they ingest. Inhaled dust is retained in the lungs by about 30-50%, its significant part is absorbed by the blood stream. Absorption in the gastrointestinal tract is generally 5-10%, in children – 50%. Calcium and vitamin D deficiency enhances the lead absorption in the gastrointestinal tract. On average, the human body absorbs 26-42 μg of lead per day. This ratio may vary. About 90% of the total amount of lead in the human body is found in bones, in children – 60-70%. In addition to lead, lead production slags contain zinc compounds, which also adversely affect the environment: wastewater containing zinc is not suitable for irrigation of fields, and the negative zinc effect on microorganisms and soil microfauna significantly reduces soil fertility. Many manifestations of zinc intoxication are based on the competitive relationship between zinc and a number of other metals. Residents of nearby areas showed a significant decrease in total serum calcium levels [10-12].

Excessive zinc ingress into the body of animals was accompanied by a drop in the calcium content not only in the blood, but also in the bones, while the absorption of phosphorus was disrupted; as a result, osteoporosis developed. The toxicity of zinc oxide is explained by its catalytic activity. Zinc can be mutagenic and oncogenic. Thus, due to the great harm to the health of the population of neighboring regions, the problem of lead production slags disposal is urgent [13-15].

At the same time, the lead plant slags are an important raw material containing various non-ferrous metals, and at present non-ferrous metals obtained from secondary raw materials play an important role in the overall balance of production and consumption of non-ferrous metals in the Republic of Kazakhstan: their share in relation to the total production volume of non-ferrous metals is about 25%. For example, lead has a high economic value and the applications of lead have changed in recent years, and now approximately 80% of world consumption fall at the electric battery production sector. The flexibility, density and anti-corrosion properties of lead are still actively used in the construction of tanks for storage of caustic liquors and as protection against X-rays and radiation. Lead is used in the manufacture of paints and pigments and other chemical compounds [16].

Other major consumer of lead is IT sector, where the metal is used as solders and additives. Due to its unique physical and chemical properties, lead has found a place in the production of various engineering products, such as protective coatings for buildings and structures. High corrosion resistance of the metal, durability and ease of use are the main advantages when using it, as well as for use in medical devices for

protection against gamma radiation, in the production of X-ray and spectrographic equipment. Lead is included in bronzes, brasses, babbits, printing alloys [17-18].

Zinc is another non-ferrous metal offered for extraction in the lead production slag disposal process. Zinc is also used for zincing metal products in order to give them anti-corrosion properties. Zinc is widely used in the production of alloys (brass, cupronickel), printing materials, rolled products and zinc oxide [19]. The demand for zinc remains strong due to the explosive growth in the production of anti-corrosion coatings. Zinc compounds are also used in the manufacture of pigments for paints, rubber, glass and glazes. Another important area of application is in neutralizing cosmetic pastes and pharmaceuticals. After extraction of non-ferrous metals from slags, they can be used in the production of cement, building materials, since the lead production slags contain FeO, CaO, SiO_2 in an amount of about 75-85% [20-21].

Problem statement. The research object is lead-containing slag dumps from the lead plant, which are production costs. To determine the methods of disposal and processing of lead slags for extraction of zinc oxide, lead oxide, there is a number of scientific works based on the need to determine the chemical composition and quantitative content of non-ferrous metals and other compounds. The main goal of the research is to create a highly efficient technology for processing the lead production slags, which allows to involve the lead production slag wastes in processing as secondary resources. This, in turn, will allow to rationally use natural resources and reduce the area occupied by the wastes.

Preliminary data on the lead production slag obtained in the production cycle showed that the lead production wastes are smelter slags. The particles of lead-containing slags are in the form of irregular granules, the material density in the loose body is 2 t/m^3, the angle of repose is approximately 35°, the particle size mainly ranges from 2-6 mm, and there is a small number of particles of about 10 mm [2]. The lead production dry slag components are shown in table 1.

Table 1 – Components of slag of lead-zinc production in a dry state

Element	Pb	Zn	Cu	Fe	SiO_2	CaO	K_2O	S	O	Other	Total
Numerical value	2,38	9,81	0,97	25,31	24,62	16,21	1,42	1,35	10,16	7,32	100
Note: The numerical value of a sample is the average of a randomly selected sample.											

To determine the chemical composition of the lead production slags, we performed spectral, X-ray phase, thermal and chemical analyzes. The studies were carried out at Institute of Metallurgy and Ore Beneficiation of the National Academy of Sciences of the Republic of Kazakhstan, Almaty, and at K.I. Satpayev Institute of Geological Sciences.

The study of the material composition was carried out on bulk slag material, externally black, with the particle size of 2 to 6 mm. A heavy fraction was isolated from the sample, according to which artificial polished sections (briquettes) were made. The polished sections were examined under LEICA DM 2500P microscope. Along with this, the sample was studied under a microscope in immersion liquids, and as a result, samples were selected for further research.

X-ray diffractometric analysis of the slag samples was carried out on DRON-4 diffractometer with Cu-radiation, graphite monochromator. Conditions for recording diffraction patterns: U = 35 kV; I = 20 mA; scale: 2000 imp; time constant 2s; shooting theta – 2 theta; detector 2 deg/min. Semiquantitative analysis was carried out on the basis of diffraction patterns of the powder sample using the method of equal weights and artificial mixtures. The quantitative ratios of the crystalline phases were determined. The diffraction patterns were interpreted using ASTM Powder diffraction file and diffraction patterns of minerals free of impurities. The contents were calculated for the main phases. Possible impurities, the identification of which cannot be unambiguous due to low contents and the presence of only 1-2 diffraction reflections or poor crystallization, are indicated in table 2.

As follows from the data of X-ray diffractometric analysis presented in table 2, the slag samples are represented by amorphous phases of composition close to crystalline phases of natural origin, namely fayalite, wollastonite, zinc oxide and iron oxide. In an immersion preparation in transmitted light under a microscope, all these phases are externally black and amorphous, however no crystalline formations are observed. The identification of mineral phases according to the data of X-ray diffractometric analysis is shown in the diffractogram in figure 1.

Table 2 – The results of the semiquantitative atomic emission spectral analysis of the slag's technological sample

Elements	Content of elements, %	Elements	Content of elements, %
Gold	<0.0002	Silver	0.001
Silicon	>>1.0	Magnesium	>1.0
Aluminum	>1.0	Calcium	>1.0
Copper	0.3	Rhenium	<0.0003
Nickel	0.0025	Chromium	0.015
Antimony	<0.002	Cobalt	0.005
Arsenic	<0.01	Molybdenum	0.01
Iron	>>1.0	Strontium	0.1
Manganese	0.2	Tellurium	<0.003
Titanium	0.3	Lanthanum	0.002
Zinc	>1.0	Bismuth	0.0005
Potassium	<1.0	Beryllium	0.0003
Sodium	>1.0	Zircon	0.01
Tin	0.001	Ytterbium	0.0002
Barium	0.3	Yttrium	0.003
Scandium	0.0005	Antimony	0.07
Vanadium	0.007	Cerium	0.005
Wolfram	0.005	Gallium	0.002
Germanium	0.001	Thallium	<0.0005
Cadmium	<0.0005	Lead	0.1
Iridium	<0.001	Niobium	<0.001
Arsenic	<0.01	Mercury	<0,003
Platinum	<0.001	Palladium	<0.0002
Rhodium	<0.0005	Ruthenium	<0.001

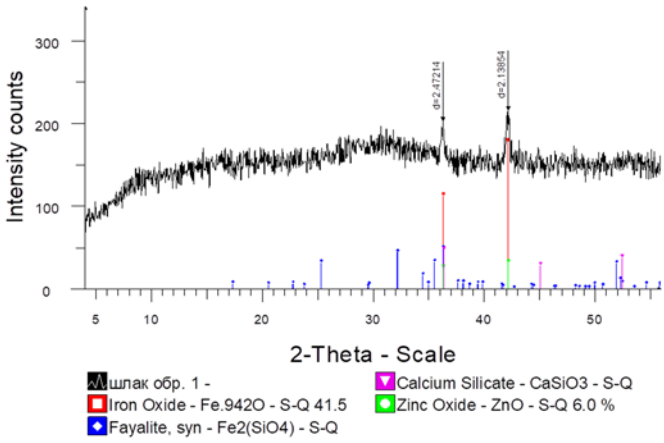

Figure 1 –
Diffractogram of the slag sample

The results of interplanar distances and phase composition of the slag sample are presented in table 3.

Table 3 – The interplanar distances and phase composition of the slag sample

Slag sample		
d, Å	I, %	Phase
2.47214	93.8	Iron Oxide, Fayalite, Zinc Oxide, Calcium Silicate
2.13854	100.0	Iron Oxide, Zinc Oxide

All presented diffraction peaks shown in Table 3 belong only to the above phases. The characteristic diffraction reflections are noted, which allow to identify the phases present.

The results of the semiquantitative X-ray phase analysis of the crystalline phases are shown in table 4.

Table 4 – The results of the semiquantitative X-ray phase analysis of the crystalline phases

Mineral phase	Chemical formula	Content, %
Iron Oxide	$Fe_{0.942}O$	41.5
Fayalite, syn	$Fe_2(SiO_4)$	35.4
Calcium Silicate	$CaSiO_3$	17.2
Zinc Oxide	ZnO	6.0

The analysis of table 3 shows that the slag sample is based on an amorphous substance with the listed crystalline phases with superimposed reflections.

When examining the sample in the polished briquette in the reflected light, shown in figure 1, it was revealed that the slag sample consists of an amorphous matrix with numerous inclusions of heterogeneous copper mineral phases, which externally resemble natural copper sulfide minerals such as chalcopyrite and even native copper. They often have a rounded isometric outline and a light yellow color, typical of chalcopyrite.

Thermal analysis of the slag samples was carried out according to DTA and TGA measurements. The thermal analysis of the powder slag sample was carried out on Q-1000/D derivatograph of F. Paulik, J. Paulik and L. Erdey systems of "MOM" company (Hungary, Budapest). The survey was carried out in the air, in the temperature range 20-1000°C, heating mode – dynamic (dT/dt = 10), reference substance – calcined Al_2O_3, sample weight – 500 mg with a valuable division of the sample weight change scale – 500 μV. The research revealed the following parameters: the sensitivity of the balance is 100 mg, the sensitivity of other measuring systems of the device: DTA = 250 μV, DTG = 500 μV, TG = 500 μV T = 500 μV.

The method used is based on the device registering changes in the thermochemical and physical parameters of a substance, which can be caused during its heating. The thermochemical state of the sample is described by the curves: T (temperature), DTA (differential thermoanalytical), TG (thermogravimetric) and DTG (differential thermogravimetric), the last curve is a derivative of the TG-function.

The optimal thermochemical parameters obtained during high-temperature processing of the test system allowed to reveal the nature of the destruction of thermally active components.

The powder sample composition was identified by the thermal curves morphologies and the obtained numerical values of the intensities of endo- and exothermic effects, using the thermogravimetric readings of the TG lines coupled with them [22].

The results of the analysis were compared with the data given in the atlases of the thermal curves of minerals and rocks and compared with the descriptions of the thermal behavior of monomineral samples set forth in other reference sources and accumulated in the data bank of the laboratory conducting these studies.

The slag sample in dynamic heating mode on (DTA-, DTG- and TG-) curves in different temperature ranges left a series of effects caused by endo- and exothermic reactions, as shown in figure 2 and their quantitative values in table 5.

Within the limits of low temperatures (20-200°C) in the system under study, the endothermic effect was noted with the weight loss Δm1 equal to 1.75% of the sample mass shown in figure 2, table 5. Many powder samples contain atmospheric water, which in the specified temperature range is carried out into the atmosphere. In this case, the main part of the evaporated molecular water can be attributed to the dehydration of particles of the powder slag adsorbed H_2O. After the sample dehydration process, the enthalpy of the system in the range of 200-280°C practically does not change, which is caused by the absence of weight loss in this temperature range. It should be noted that in the range of 280-930°C the thermogravimetric curve (TG) is steadily shifting upward – towards an increase in the sample mass, which is caused by the introduction of atmospheric oxygen into the system. The increase in mass is accompanied

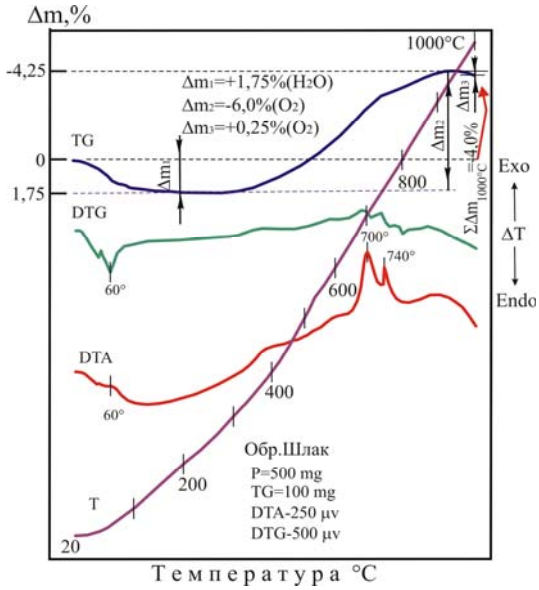

Figure 2 –
Derivatogram of the slag sample

Table 5 – The sequence of the quantitative values of the weight loss of volatile components

Sequence of the weight loss	Weight loss, %	Volatile components	Decomposition temperature range, °C
Δm_1	1.75	H_2O	20-200
Δm_2	-6.0	$-O_2$	280-930
Δm_3	0.25	O_2	930-1000
$\Delta m_{1000°C}$	4.0	H_2O, $-O_2$, O_2	20-1000
Note to figure 2 and to table 5: The minus sign (-) at the Δm2 value means the introduction of atmospheric oxygen into the system. This sign is the opposite of the sign applied to the weight loss parameter.			

by a rise in the DTA-curve line, which, in the range of 640-800°C, formed distinct exothermic peaks at 700 and 740°C. The processes that caused the introduction of heat into the system are associated with the oxidation of the ferrous components of the sample. Oxygen-enriched iron oxides are usually formed within the indicated temperature ranges. These high temperature peaks are caused by the transition of iron oxide from a lower acidity level to a higher level. At a higher temperature (930°C), the increase in sample mass reaches its limit (Δm2 = -6%). And further heating of the sample (up to 1000°C) leads to a decrease in its mass by 0.25% [23].

According to the results of the X-ray diffractometric analysis of the slag samples, the formation of the following useful components was revealed: copper in the form of sulfides, complex compounds of oxides of lead, zinc, iron and copper, which are in the form of inclusions in an amorphous host matrix of complex composition. The results of the laboratory studies of the lead production slag showed a sufficiently high content of non-ferrous metal compounds, which allows to evaluate the process technically and economically efficient when extracting them during the lead production toxic wastes' disposal.

Conclusion. Modern methods of analysis were used to determine the chemical composition of waste from the Shymkent lead plant (JSC Yuzhpolimetal). The results of X-ray diffractometric analysis and DTA showed that the slag of lead production contains a fairly high amount of non-ferrous metal compounds: the content of lead oxide up to 2 %, zinc oxide up to 17 % and copper oxide up to 1.25 % of the total weight of the sample. The qualitative composition and content of non-ferrous metals of lead slags makes it possible to make the process of disposal of toxic waste of lead production technically and economically feasible.

The results of preliminary tests allow us to choose a technology for more complete and selective extraction of lead and zinc oxides from the slag waste of lead production. When using a selective method of extracting non-ferrous metals, it is expected to improve the ecological state of the environment and reduce the negative impact on human health due to the disposal of toxic waste.

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ҚОРҒАСЫН ЖӘНЕ МЫРЫШ ОКСИДТЕРІН АЛУ АРҚЫЛЫ ҚОРҒАСЫН ӨНДІРІСІНІҢ ҚАЛДЫҚТАРЫН КӘДЕГЕ ЖАРАТУ

Аннотация. Шымкент қорғасын зауытының қалдықтарын 2 млн тоннаға жуық қож түрінде кәдеге жарату қажеттілігі туралы мәліметтер келтірілді. Қорғасын өндірісінің шлактарында экологиялық ластанудың қауіпті көзі болып табылатын қорғасын, мырыш, осмий, кадмий сияқты көптеген улы қосылыстар бар екендігі дәлелденді.

Рентгенодифрактометриялық талдау және ДТА нәтижелері бойынша қорғасын өндірісінің қожында түсті металдар қосылыстарының жеткілікті жоғары мөлшері бар екендігі анықталды: қорғасын оксидінің мөлшері 2%-ға дейін, мырыш оксиді 17%-ға дейін және мыс оксиді сынаманың жалпы салмағының 1,25%-на дейін. Қорғасын қождарының түсті металдардың сапалық құрамы мен қорғасын өндірісінің улы қалдықтарын кәдеге жарату процесін техникалық және экономикалық тұрғыдан орынды етуге мүмкіндік береді.

Алдын ала сынақтардың нәтижелері қорғасын өндірісінің қожды қалдықтарынан қорғасын және мырыш оксидтерін неғұрлым толық және селективті алу үшін технологияны таңдауға мүмкіндік береді. Түсті металдарды алудың селективті тәсілін қолданған кезде қорғасын өндірісінің уытты шлактарын кәдеге жарату есебінен қоршаған ортаның экологиялық жай-күйін жақсарту және адамдардың денсаулығына теріс әсерді азайту күтіледі. Бұл ретте табиғи және қайталама ресурстарды ұтымды пайдалану жүйесін дамытуға елеулі үлес қосылады.

Түйін сөздер: қалдықтар, қорғасын қалдықтары, улы қосылыстар, қорғасын және мырыш қосылыстары, экологиялық ластану, улы қалдықтарды қайта өңдеу, қалдықтарды кәдеге жарату.

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УТИЛИЗАЦИЯ ОТХОДОВ СВИНЦОВОГО ПРОИЗВОДСТВА ПУТЕМ ИЗВЛЕЧЕНИЯ ОКСИДОВ СВИНЦА И ЦИНКА

Аннотация. Приведены сведения о необходимости утилизации отходов Шымкентского свинцового завода в виде шлаков, которых накопилось около 2 млн тонн. Доказано, что шлаки свинцового производства содержат большое количество токсичных соединений, таких как свинец, цинк, осмий, кадмий, которые являются опасными источниками экологического загрязнения.

По результатам рентгенодифрактометрического анализа и ДТА выявлено, что в шлаке свинцового производства содержится достаточно высокое количество соединений цветных металлов: содержание оксида свинца до 2 %, оксида цинка до 17 % и оксида меди до 1,25 % от общего веса пробы. Качественный состав и содержание цветных металлов свинцовых шлаков позволяет сделать процесс утилизации токсичных отходов свинцового производства технически и экономически целесообразным.

Результаты предварительных испытаний позволяют выбрать технологию для более полного и селективного извлечения оксидов свинца и цинка из шлаковых отходов свинцового производства. При применении селективного способа извлечения цветных металлов ожидается улучшение экологического состояния окружающей среды и уменьшение отрицательного влияния на здоровье людей за счет утилизации токсичных шлаков свинцового производства. При этом вносится весомый вклад в развитие системы рационального использования природных и вторичных ресурсов.

Ключевые слова: отходы, отходы свинца, токсичные соединения, соединения свинца и цинка, экологическое загрязнение, переработка токсичных отходов, утилизация отходов.

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FORMATION OF ROCK SLOPES DURING WORK TO REDUCE THE EROSION ACTIVITY

Abstract. The formation of anti-erosion procedures is based primarily on achieving an equilibrium state that affects the state of the soil or constituent rocks of the slope. In this regard, the formation of a model that can demonstrate the processes of slope destruction, which can be represented not only by soil, but also by rocks or other formations, becomes relevant. In particular, it should be relevant for urban soils and technologically transformed landscapes. The novelty of the study is determined by the fact that all possible materials that form both slopes of natural origin and technological origin are considered as objects of potential erosion activity. The authors of the article are considering the possibility of applying reclamation measures that will reduce the maximum erosion activity within not only natural, but also urban landscapes. The article developed a model for analyzing the potential of erosion activity in combination with the physical parameters of the slopes and their mechanical composition. The practical significance of the study is determined by the fact that the proposed measures and the developed model for countering erosion activity can reduce technological costs for reclamation activities and thus increase the economic and technological efficiency of the project.

Key words: slope stability, destruction of rocks, rock mass, model of stability, erosion activity.

Introduction. The destruction of rocks is described in mechanics as the result of breaking of their structural bonds due to the application of external forces [1]. The study of this process is always done by analyzing the corresponding physical models. They include either structural models, which consider the object of study at the atomic-molecular level, or structureless model, in which a solid body is considered as a continuous homogeneous medium [2, 3]. Combined probabilistic-statistical models are also known, where the medium is presented in the form of a solid body consisting of randomly arranged elements with their own low-level microstructure [4, 5].

Theories of Strength are the most applicable in solving elastoplastic problems in geomechanics. Studies of rock fracture under severe load conditions made it possible to formulate a number of strength theories that take into account the heterogeneity of materials, which is exposed in the process of controlled fracture [6, 7]. The authors of strength theories proceeded from the assumption of an ideal structure that is solid, that is, has a homogeneous structure [8]. Real construction materials and rocks are far from being perfect. Consequently, strength theories do not always match laboratory test results. Particularly substantial discrepancies arise if the material under study contains sufficiently large defects – inclusions, pores that differ significantly in their physicomechanical properties. These materials with an imperfect structure include rocks.

For inhomogeneous solids, the deterministic model of continuous medium is insufficient [9, 10]. As the places of stress concentration are local and are observed mainly near inhomogeneities that are randomly placed in the material, the interpretation of rock strength taking into account probability-statistical models gains pronounced importance [11]. To describe the critical state of soils and soft rocks, such as clays and loams, the most commonly used criteria are the destruction of Mohr-Coulomb, Drucker-Prager, Hoeck-Brown, Cam-Clay, which are based on the classical concepts of natural destruction of solids [12, 13].

Since in soft rocks the main factors affecting the strength of the massif are porosity and moisture saturation of the massif, these criteria can describe the fracture process using a different set of initial data [14]. Thus, in the criterion for the destruction of Mora-Coulomb, based on determination of the conditions of stress-strain state and described by a curved tangent to the limit circles of the main stresses, there is an angle of internal friction and adhesion, as well as tensile strengths for uniaxial compression R_c and tension R_p.

The Drucker-Prager criterion was initially proposed to describe plastic deformations in soils and soft rocks, and later to assess the strength of polymers and other materials [15, 16]. The Hoeck-Brown criterion takes into account the physic mechanical properties of the intact and unharmed rock mass, which is subjected to external loads of both natural and technological origin [17].

Materials and methods. For brittle materials, the physical model was initially proposed, which shows the dependence of strength on the presence of microdefects. Failure criterion has the form:

$$(\delta_1 - \delta_3)^2 + 8R..(\delta_2 + \delta_1) = 0, when\ 3\delta, +\delta_1 > 0 \quad (1)$$

$$\sigma_3 = R_p, 3\sigma_3 + \sigma_1 < 0 \quad (2)$$

When $\sigma_3 = 0$ the expression (1) implies the relationship between the ultimate tensile strength on uniaxial compression R_c and the ultimate tensile strength on uniaxial tension R_p:

$$R_C = -8R_p \quad (3)$$

This is consistent with soft rock test results. In the coordinate system "$\tau - \sigma$", the basic equation can be expressed as follows:

$$4\tau^2 - 2R_c\sigma - 0.25R_c^2 \quad (4)$$

Based on other physical premises, a fracture criterion was proposed, the basic formula of which has the form (5) or (6):

$$4\tau^2 - 2\sigma(1-\psi)R_c - \psi R_c^2 = 0 \quad (5)$$

$$(\sigma_1 - \sigma_3)^2 - (1-\psi)R_c(\sigma_1 - \sigma_3) - R_c^2\psi = 0 \quad , \quad (6)$$

where $\psi = \frac{R_p}{R_c}$ – is the fragility coefficient, σ_1 and σ_3 are the largest and smallest values of the principal tensions.

To take into account the factor, which is shown in the form of falling section of the curve on the deformation graph, the so-called strength reduction function is usually introduced into the strength condition. Then the strength condition (5) can be described as follows:

$$F(\sigma_1, \sigma_2, \sigma_3) \leq k(x, y, z) \quad (7)$$

where $k(x, y, z)$ – is the strength criterion, the value of which is different at different points in the fracture area.

As a rule, in soils and soft rocks, a significant part of massif is represented by cavities filled with air or water. As a result, massif deformations are accompanied by significant and often irreversible volume changes. The main advantage of the classic and modified Cam-Clay models is the most suitable description of the volumetric changes in the massif. The critical state of the rock mass is characterized by three parameters: effective average tension p', deviation tension (shear tension) q', specific volume v. In conditions of widespread compression, the average tension p'can be calculated from the main tensions $\sigma_1, \sigma_2, \sigma_3$:

$$p' = \frac{1}{3}(\sigma_1, \sigma_2, \sigma_3) \quad (8)$$

A triaxial shear tension can be defined as:

$$q' = \frac{2}{\sqrt{2}}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2} \quad (9)$$

Therefore, the processes of destruction of solids, in particular rocks, are described by various phenomenological theories and criteria. The selection of the most appropriate criterion for rock destruction facilitates reliable analysis of the stability of geotechnical objects and engineering systems.

Results and discussion. Let us consider the Mohr-Coulomb criterion for a model of stability of soil slope. Adhesion C and angle of internal friction φ are the main parameters for assessing the strength and fracture of soft rocks using the Mohr-Coulomb criterion, which is most widely used in geotechnical practice. In generalized form, the criterion can be written like this:

$$\tau = c + \sigma_n tg\rho \quad (10)$$

where τ – is the shear tension, σ_n – is the normal tension. The soil model, which is usually used in the study of slopes, consists of six parameters: calculated adhesion c', calculated angle of internal friction φ', dilution angle (expansion) ψ ', Young's modulus E', Poisson's ratio ν', specific weight γ. The destruction of the array can be expressed in terms of existing tensions:

$$F = \frac{\sigma_1' + \sigma_3'}{2} sin\,\varphi' - \frac{\sigma_1' - \sigma_3'}{2} - c'\,cos\,\varphi' \quad (11)$$

where σ_1', σ_3' – is the maximum and minimum effective tension.

The elastic modulus (Young's modulus) and Poisson's ratio characterizing the elastic characteristics of the material with respect to external stresses can be determined experimentally in odometers or by formula:

$$E' = \frac{(1+\nu')(1-2\nu')}{m_\nu(1-\nu')} \quad (12)$$

where m_ν – is the compression coefficient.

The value of Poisson's ratio for non-irrigated soils lies in the range $\nu' = 0{,}2 \ldots 0{,}35$. The most important parameters for analysis of slope stability using the finite element method (FEM), as in traditional methods of limiting equilibrium, are specific weight γ, shear resistance characteristics $c'$and φ', and geometric parameters of the slope [18, 19].

Safety factor (SF) of the slope is a value on which we should divide the output parameters of soft rock shear resistance for the phenomenon of destruction to take place. This definition of SF is similar to traditional methods of limiting equilibrium, characterized by the ratio of the moments of holding forces to the moments of forces causing a shift in the slope:

$$F = \frac{\text{Resistance of the material (rock,soil) to shear}}{\text{Resistance of the shear that is necessary for the balance}} = \frac{t}{t^*} \quad (13)$$

the same for the traditional analysis of limit equilibrium. The characteristics of shear strength $c_f'$and φ_f'can be written as:

$$c_f' = \frac{c'}{KZ};\ \varphi_f' = arctam\left(\frac{tan\varphi'}{KZ}\right) \quad (14)$$

RSR is used for calculations of SF, depending on the c_f' and φ_f'. With regard to assessing the stability of slopes, the method consists in phased calculation of the coefficient of reduction in shear resistance (CRSR), which is equivalent to CRSR for given soil strength characteristics.

RSR provides for the application of the Mohr-Coulomb criterion for the analysis of slope stability. A unique feature of this linear model is that it can be simply and explicitly expressed both in units of principal stresses $(\sigma_1 - \sigma_3)$and in the form of the mutual dependence of tangential and normal stresses $(\tau - \sigma_n)$. Factorized value of soil strength in terms of reduction of resistance to shift criterion Mohr-Coulomb can be expressed as:

$$\frac{\tau}{F} = \frac{c'}{F} + \frac{tan\varphi'}{F} \quad (15)$$

This equation can be transformed to:

$$\frac{\tau}{F} = c^* + tan\varphi^* \quad (16)$$

where $c^* = \frac{c'}{F}$ and $\varphi^* = arctan\left(\frac{tan\varphi'}{F}\right)$ are factored parameters of shear resistance of Mora-Coulomb.

Let us consider the Hoeck-Brown criterion, which is the most suitable model for predicting rock failure to assess the stability of slopes. The generalized Hoek-Brown criterion expresses the strength of the massif through the principal stresses:

$$\sigma_1' = \sigma_3' + \sigma_{ci}\left(m_b \frac{\sigma_3'}{\sigma_{ci}} + s\right)^a, \quad (17)$$

where σ_1 and σ_3 are the maximum and minimum tensions in the array, m_b is a constant of Hoeck-Brown for rock mass, S and a are the constant values considering the genesis and the state (quality) of a rock mass, σ_{ci} is a tensile strength for uniaxial compression of rock mass intact.

The characteristics of the rock mass can be calculated by the formulas:

$$m_b = m_i exp\left(\frac{GSI-100}{28-14D}\right) \tag{18}$$

$$s = exp\left(\frac{GSI-100}{9-3D}\right) \tag{19}$$

$$a = \frac{1}{2} + \frac{1}{6}\left(e^{-GSI/15} - e^{-20/3}\right) \tag{20}$$

where GSI (Geological Strength Index) is the coefficient of geological strength, taking into account the geological features of the rock mass, in particular its structure and the presence of cracks (5≤GSI≤100); D is a parameter depending on the degree of disruption of the mass due to blasting and the effect of stress relaxation varies from 0 (for intact) to 1 (for severely disrupted) rock mass. Normal and shear stresses relate to principal stresses in accordance with these equations:

$$\tau = (\sigma_1' - \sigma_3')\frac{k}{k^2+1} \tag{21}$$

$$\sigma_n' = \frac{\sigma_1'+\sigma_3'}{2} - \frac{\sigma_1'-\sigma_3'}{2}\frac{k^2-1}{k^2+1} \tag{22}$$

where

$$k^2 = \frac{d\sigma_1'}{d\sigma_3'} = 1 + am_b\left(\frac{m_b\sigma_3'}{\sigma_{ci}} + 1\right)^{a-1} \tag{23}$$

Using the equations for shear tensions (23), we can calculate the factorized strength indices as follows:

$$\frac{\tau'}{F} = (\sigma_1' - \sigma_3')\frac{\sqrt{1+am_b\left(m_b\frac{\sigma_3'}{\sigma_{ci}'}+s\right)^{a-1}}}{2+am_b\left(m_b\frac{\sigma_3'}{\sigma_{ci}'}+s\right)^{a-1}} \times \frac{1}{F} = (\sigma_1' - \sigma_3')\frac{\sqrt{1+am_b^*\left(m_b^*\frac{\sigma_3'}{\sigma_{ci}^*}+s^*\right)^{a-1}}}{2+am_b^*\left(m_b^*\frac{\sigma_3'}{\sigma_{ci}^*}+s^*\right)^{a-1}} \tag{24}$$

For the Hoeck-Brown and Mohr-Coulomb criteria most commonly used in engineering practice, a parallel can be drawn by constructing an envelope curve to display the destruction of the rocks. This approach lets us obtain equivalent parameter values and make a mutual transition between the criteria [20]. Thus, from the envelope of Mora's circles, one can determine not only the adhesion and the angle of internal friction, but also the equivalent parameters of the Hoeck-Brown criterion. The method also brings the straight line enveloping the Mohr-Coulomb circles to the curved Hoeck-Brown contour. Geometrically, it can be expressed in the equality of the sums of the positive regions above the Mohr-Coulomb line and the negative regions below the line. The final formulas for calculating the equivalent Mohr-Coulomb parameters are as follows:

$$\varphi' = sin^{-1}\left(\frac{6am_b\left(s+m_b\sigma_{3n}'^{|}\right)^{a-1}}{2(1+a)(2+a)+6am_b\left(s+m_b\sigma_{3n}'^{|}\right)^{a-1}}\right) \tag{25}$$

$$c' = \frac{\sigma_{ci}(1+2a)s+(1-a)m_b\sigma_{3n}'\left(s+m_b\sigma_{3n}'\right)^{a-1}}{(1+a)(2+a)\sqrt{\frac{1+\left(6am_b\left(s+m_b\sigma_{3n}'\right)^{a-1}\right)}{(1+a)(2+a)}}} \tag{26}$$

where $\sigma_{3n}' = \frac{\sigma_{3max}'}{\sigma_{ci}}$. The matching procedure takes place through a range of stresses from tensile strengths $\sigma_t$to maximum compressive stresses σ_{3max}'.

The maximum compression resistance can be calculated from the equation:

$$\sigma_{3max}' = 0.72\sigma_{cm}'\left(\frac{\sigma_{cm}'}{\gamma H}\right)^{0.91} \tag{27}$$

where γ is the specific weight of the rock,$H$is the slope height, σ'_{cm} is the rock strength coefficient. This coefficient is calculated by the formula:

$$\sigma'_{cm} = \sigma_{ci} \frac{(m_b+4s-a(m_b-8s))\left(\frac{m_b}{4}+s\right)^{a-1}}{2(1+a)(2+a)} \quad (28)$$

Let us consider a slope composed of homogeneous rock with the following geometric characteristics: height H = 30 m, angle of inclination $\alpha = 37^{\circ}$. To comply with the boundary conditions, we set the following parameters: 60 m from the lower edge and 60 m from the upper edge to the horizontal boundaries of the model; distance from the top edge to the lower border of the model is 80 m.

The force of gravity acts on the slope. The initial physical and mechanical characteristics of the rock mass, as well as the calculated equivalent parameters are provided in table 1. We use the RocLab engineering program (from Rocscience Inc.), which implements the capacity to convert the parameters of the Hoeck-Brown criterion to the equivalent parameters of the Mohr-Coulomb criterion. As a result, we obtain equivalent values of adhesion C = 0.011 MPa and the angle of internal friction $\varphi = 9{,}45^{\circ}$. Further, according to the obtained parameters of equivalent strength by Mohr-Coulomb we can calculate SF in Phase2 software.

Table 1 – Physical and mechanical characteristics of rocks

Properties	Values	Properties	Values
Young's E modulus, MPa	20	Parameter m_b	0.5
Poisson's ratio ν, dimensionless.	0.3	Parameter s	8e-5
Specific gravity γ, MN / m^3	0.01764	Parameter a	0.6
Uniaxial compressive strength σ_{ci}, MPa	0.8	Dilation angle ψ, Degrees	0
Geological Strength Factor, GSI	15	Adherence C, MPa	0.03
Intact breed parameter m_i	10	Angle of internal friction φ, degrees	17.3
Massif intact Factor	0		

Rocks of various genesis stay in a state of unequal comprehensive compression. Their destruction under these conditions proceeds, both as for brittle for rocky materials and plastic for soft sedimentary rocks. In addition, the massif, depending on genesis, has a certain texture, and is broken by systems of randomly oriented cracks of the appropriate degree of disclosure, different parts of it have an excellent degree of flooding, inclusion, emptiness, etc. These circumstances result in that the characteristics of the rock strength in the sample and massif have a substantial difference, which is estimated by coefficient structural weakening – k_c, which is numerically equal to the relative values of the specific carrier characteristics in the massif R_m to its value obtained by testing samples of standard linear dimensions M (R):

$$k_c = \frac{R_m}{M(R)} \quad (29)$$

As this characteristic is associated with level limiting stresses and elastic parameters of the rock mass state, then setting the value of the objective structural weakening coefficient is a complex task involving both rational design geotechnical structures, and evaluating stability of natural and man-made slope. The structural attenuation coefficient for a rock mass weakened by a system of cracks depends on the average distance between cracks, the size of standard rock sample, and coefficient of variation of the test results of rock samples.

For a perfectly homogeneous environment $\eta_0 = 0$ and $k_c = 1$. As the heterogeneity increases, the value k_c tends to a value 0.4. Accounting for irregularities and planes of weakness in the rock mass is an important research step for quantifying the scale effect in massive statistically inhomogeneous medium.

The approaches to estimation of the scale effect make it possible to evaluate the strength of rock and semi-rock massif taking into account the coefficient of structural attenuation k_c and, accordingly, calculate the slope stability. In this case, the most significant factors are the strength of the rock mass genesis, lithology of rocks, the presence of weakening and fracture surfaces.

There is suggested and investigated probabilistic and statistical model of strength for monolithic undisturbed and cracked rock massifs. Such massifs are represented by various soft rocks of sedimentary genesis, in particular, loams, clays, and loamy soils. In such a rock mass strength is conditioned by adhesion forces that are primarily dependent on factors such as lithology, porosity and moisture saturation.

With regard to evaluating the stability of natural and artificial slopes, increasing of humidity in massif of argillaceous rocks and filling the pore space with water tends to reduce adhesion forces and the massif turns to viscoelastic state, which promotes such sliding processes as floods and landslides. The inverse process of loss of moisture in the mass due to opening of slopes and climatic influences causes development of fracturing in the surface layers of loams with subsequent destruction of the slopes.

Variations in the strength properties of the massif determine the natural heterogeneity of the structural elements and the variability of the physical and mechanical characteristics even within the same lithological difference. Thus, determining the strength of soft rocks by testing laboratory standard samples is a difficult engineering task. Due to the changing values of the adherence C and the angle of internal friction φ as the basic characteristics of the massif strength, tensile strength and testing process taking samples of random values constituting the statistical array. Due to the natural heterogeneity of the rock environment, the strength of structural elements is a random variable and follows one or another law of probability distribution with a distribution density $f(R)$.

Probabilistic and statistical studies of the model of strength of monolithic rock mass using the normal law distribution of adhesion and the angle of internal friction. Based on the algorithm, the strength of the massif should be estimated by value R_m, so that the strength of its structural elements with a given reliability is less than this value. Based on the normal distribution law, a formula is obtained for calculating the structural attenuation coefficient under the assumption that the strength of the structural elements of the massif is distributed according to the normal law:

$$k_c = \eta arg F_0(1 - P) + 1 \quad (30)$$

Therefore, the structural attenuation coefficient depends, firstly, on the relative variation η, which, in fact, characterizes the degree of heterogeneity of the medium; secondly, from the probability Pthat characterizes the level of significance of the object.

We completed analysis of the physicomechanical characteristics of light yellow loess and yellow-brown dense loams to assess the landslide in dangerous natural slopes. Hence, the values of the angle of internal friction for light yellow loesslike loams vary in the range of 13-18 °, for yellow-brown loams – 16-26 °, and the variation relative to the average is 34-36%. The value of adhesion for light yellow loess loams varies in the range of 14-31 kPa, for yellow-brown loams of 20-50 kPa, and spread of values relative to the average is 38.5–39.5%. Let us determine, for example, the calculated value of adhesion and the angle of internal friction in the massif of loams, taking into account the variation of values. From equation (30) it follows that:

$$R_{rozr} = R_m = \overline{R_c} k_c \quad (31)$$

We shell set the probability P=0.95, we determine the value of the argument t for normal function $F_0(t)$ with its value equal to 1-0.95=0.05. We establish, that the values of integral function $F_0(t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{t} e^{-\frac{t^2}{2}} dt$, that is equal $F_0(t) = 0{,}05$, it corresponds to the value of the argument $t = -1{,}64$, i.e. $F_0(0{,}05) = -1{,}64$. The calculated strength parameters and the structural attenuation coefficient k_s in the soft rock mass are summarized in table 2.

Table 2 – The calculated strength parameters in the massif of soft rocks

Class	Array Strength Characteristics	The average value in the sample $\bar{x}^*$	Relative variation η^*	Structural attenuation coefficient k_s	The calculated value in massif
Light yellow loess loam	Adhesion C	19.61	0.385	0.369	7.23
	Angle of internal friction φ	13.39	0.341	0.441	5.90
Yellow-brown loam	Adhesion C	29.58	0.395	0.352	10.42
	Angle of internal friction φ	18.24	0.364	0.403	7.35

Cohesive soils have a certain resistance to both compression and strain. The compressive $R_c$and tensile $R_p$strengths of soft rocks and soils are related to the angle of internal friction φ and adhesion C. Let's consider a separate element of the soil mass, which is affected by tensions σ_1 and σ_2. Under the condition of uniaxial compression ($\sigma_2 = 0, \sigma_1 > \sigma_2$). The tension σ_1 corresponding to the destruction of the element is defined as:

$$R_c = 2Ctg\left(45 + \frac{\varphi}{2}\right) \tag{32}$$

In case of equilibrium of tensile element ($\sigma_1 < \sigma_2$), we indicate the tensile strength R_p by:

$$R_p = -2Ctg\left(45 - \frac{\varphi}{2}\right) \tag{33}$$

From the above formulas it can be seen that on condition $C = 0$ for disintegrated loose soils $R_c = R_p = 0$. The ratio of the final resistance of cohesive soil to compression and tension is determined by the expression:

$$\frac{R_c}{R_p} = -\frac{tg\left(45+\frac{\varphi}{2}\right)}{tg\left(45-\frac{\varphi}{2}\right)} = -tg^2\left(45 + \frac{\varphi}{2}\right) \tag{34}$$

It should be mentioned that this ratio does not depend on the amount of adhesion, but only on the angle of internal friction. This relationship can be turned into the following:

$$\frac{R_c}{R_p} = -tg^2\left(45 + \frac{\varphi}{2}\right) = -\frac{1+sin\,\varphi}{1-sin\,\varphi} \tag{35}$$

where we get:

$$R_c(1 - sin\,\varphi) + R_p(1 + sin\,\varphi) = 0 \tag{36}$$

$$sin\,\varphi = \frac{R_c+R_p}{R_c-R_p} \tag{37}$$

If we assume, that the average value for the yellow-brown loams selected from the ravine-beam networks is R_c = 0.5 kgf / cm ^{2} (49 kPa) and R_p = 0.2 kgf / cm ^{2} (20 kPa), we get:

$$sin\,\varphi = \frac{0,5-0,2}{0,5+0,2} = \frac{0,3}{0,7} = 0,428 \tag{38}$$

$$\varphi = arc\,sin\,0,428 = 25,4^{\circ} \tag{39}$$

Adhesion can also be determined through $R_c$and R_p. Transforming the equations, we obtain

$$C = \frac{1}{2}R_c tg\left(45 + \frac{\varphi}{2}\right) \qquad C = -\frac{1}{2}R_p tg\left(45 - \frac{\varphi}{2}\right) \tag{40}$$

where we get:

$$C = \frac{1}{2}\sqrt{-R_c R_p} \tag{41}$$

For example, for the above values: R_c = 0.5 kgf/cm^2 (49 kPa) and R_p = 0.2 kgf/cm^2 (20 kPa) we have: C = 0.16 kgf/cm^2 (16 kPa). The above calculations of the angle of internal friction φ and adhesion C are not perfect, since they have certain error. In laboratory testing of soft rock landslide devices typically determine the physical and mechanical characteristics of the samples at different loadings to provide a family of Mohr circles and build tangent curve l_t on the received points that correspond to a certain moment stress-strain state. But the use of plausible values φ and C obtained in laboratory tests, depends on the way we build a line tangent to the Mora circles.

If Mora circles are being used, starting from the first circle that corresponds to the value R_c, then there is a possibility of obtaining overestimated values of adhesion C_{max} at the intersection of straight line l_{max} with the axis of tangential tensions τ. If the calculation scheme to include a circle, which corresponds to the limit in the tensile strength R_p, the result of drawing the line l_{min} tangent to the circles R_c and R_p provides the minimum value of the adhesion C_{min} at the intersection with the axis of the shear stresses τ. We also offer a different approach to determination of calculated values φ^* and C^* analytically:

$$\varphi^* = \frac{1-\psi}{\sqrt[2]{\psi+2(1-\psi)\frac{\gamma H}{R_c k_c}}} \tag{42}$$

$$C^* = R_c k_c \frac{1-\sin\varphi^*}{2\cos\varphi^*} \tag{43}$$

where $\psi = R_p/R_c$ is the fragility coefficient; k_c is the coefficient of structural attenuation. Consequently, the Mohr-Coulomb criterion can be rewritten in modified form:

$$\tau = C(W_0) + \sigma_n tg\varphi(W_0) = R_c k_c \frac{1-\sin\varphi(W_0)}{2\cos\varphi(W_0)} + \sigma_n tg\left(\frac{1-\psi}{\sqrt[2]{\psi+2(1-\psi)\frac{\gamma H}{R_c k_c}}}\right) \tag{44}$$

The above equations indicate the element of uncertainty during laboratory tests that require using probabilistic statistic methods for determining strength properties of soft materials and their application in geotechnical calculations. Having the calculated indicators of the physicomechanical properties of rocks $tg\varphi_p, C_p, \gamma_p$, we can calculate the potential erosion activity of the slope, if its geometric parameters (height $H$and angle of slope α) are given:

$$\begin{gathered} F_s = f\left(tg\varphi_p, C_p, \gamma_p, \alpha, H\right) \\ H = f\left(tg\varphi_p, C_p, \gamma_p, \alpha\right) \\ \alpha = f\left(tg\varphi_p, C_p, \gamma_p\right) \end{gathered} \tag{45}$$

The degree of reliability of the final calculation results and the error of the functions presented above (45) are suggested to be estimated using the well-known error theory formula:

$$\sigma_{F_s}^2 = \left(\frac{\partial F_s}{\partial\varphi}\right)^2 \sigma_\varphi^2 + \left(\frac{\partial F_s}{\partial C}\right)^2 \sigma_c^2 + \left(\frac{\partial F_s}{\partial\gamma}\right)^2 \sigma_\gamma^2 \tag{46}$$

where $\sigma_{F_c}^2, \sigma_\varphi^2, \sigma_C^2, \sigma_\gamma^2$ are dispersions, respectively, of the safety factor of the slope, the angle of internal friction, adhesion and density of rocks.

Nevertheless, this approach is appropriate only for independent random variables, while the values of the random φ and C are correlated. We suggest using a probabilistic-statistical approach with respect to estimating the limiting parameters of the slope, based on the theory of linear regression. Using the diagram of the shear resistance for normal pressure $\tau = f(P)$ in laboratory test samples have shown that the maximum verisimilitude obtained line represents the locus of points corresponding to the average values of the random variables $\bar{\tau}(P)$distributed according to the normal law. That is, the expression of the linear regression equation $\bar{\tau} = a_0 + a_1 P$ is the equation of "random" line on the plane, and the average value is provided by the "true" line $\tau = a_0 + a_1 P$. The random line may deviate from the mean, depending on the deviations of the point (a_0, a_1) and the average $(\bar{a}_0, \bar{a}_1)$. Confidence boundaries form a band that, with a given probability, refers to the graph of unknown true dependence $\tau = f(P)$.

Accepting the confidence probability, we can also calculate the limiting parameters of the slope height H and its angle of inclination α, i.e., the slope with a safety factor $Fs = 1{,}0$, the value of which corresponds to the lower boundary of the confidence interval. Variability is an inherent property of rocks and effect caused by various factors in the formation and transformation of rocks, which have separate effect on their mechanical properties and characteristics. To solve the variability of input parameters in calculating the slope stability in various engineering analysis programs, for example in Phase2 (RocScience Inc.), statistical tools based on probabilistic method of point estimates (MPE) are used.

MPE principle consists in calculating the final function of SF in the range of two different values of physico-mechanical characteristics of rocks in changing conditions. To optimize the effort to reduce erosion activity, accurate calculations were carried out to determine the optimal geometric parameters of the slope in changing mining and geological conditions. Covering rocks are represented by layers of greenish-gray clay, Quaternary red-brown clay and forest light yellow loams with total thickness of 60...65 m. Excavation slope as a model consists of two layers: the upper layer of light yellow loesslike loams and the lower layer of red brown clay. A geomechanical assessment of stability of the slope is performed with two probabilistic input variables, namely, adhesion and angle of internal friction.

The calculation results demonstrate that the use of fixed values of the physical and mechanical characteristics of the rocks gives deterministic values of the safety factor. In changing geological

conditions, the adhesion indicators and the angle of internal friction, that are parts of Mohr-Coulomb strength condition, vary within wide range depending on the humidity of soft soils.

Conclusion. The analyzed probabilistic-statistical model of strength of structurally heterogeneous undisturbed rock mass with crack systems has demonstrated that it is necessary to develop formulas for the coefficient of structural attenuation, which allow us to estimate the strength of a statistically heterogeneous rock mass. A comparative analysis of the deterministic and probabilistic approaches to determine the stability and limit parameters of slopes was performed, which helps to make more reliable assessment and prediction of stability of natural slopes and man-made slopes for optimal engineering decisions to reduce erosion activity.

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ФОРМИРОВАНИЕ ОТКОСОВ ПОРОД ПРИ ПРОВЕДЕНИИ РАБОТ ПО СНИЖЕНИЮ ЭРОЗИОННОЙ АКТИВНОСТИ

Аннотация. Формирование противоэрозионных мероприятий основывается прежде всего на достижении равновесного состояния, которое затрагивает состояние почвы или слагающих пород склона. В этой связи актуальным является формирование модели, которая может выявить процессы разрушения склонов, которые представлены не только почвой, но и горными породами или иными образованиями. В частности, это становится актуальным для урбоземов и техногенно трансформированных ландшафтов. Новизна исследования определяется тем, что в качестве объектов потенциально эрозионной активности рассматриваются все возможные материалы, которые формируют не только склоны природного происхождения, но также и техногенного генеза. Авторы статьи рассматривают возможность проведения рекультивационных мероприятий, которые позволят снизить максимально эрозионную активность в пределах не только природных, но и урболандшафтов. В статье разработана модель анализа потенциала эрозионной активности в сочетании с физическими параметрами склонов и механическим составом. Практическая значимость исследования определяется тем, что предлагаемые мероприятия и разработанная модель противодействия эрозионной активности позволяет снизить технологические издержки от проведения рекультивационных мероприятий и тем самым повысить экономическую и технологическую эффективность проекта.

Ключевые слова: устойчивость откосов, разрушение горных пород, породной массив, модель устойчивости, эрозионная активность.

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ЭРОЗИЯЛЫҚ БЕЛСЕНДІЛІКТІ ТӨМЕНДЕТУ БОЙЫНША ЖҰМЫСТАРДЫ ЖҮРГІЗУ КЕЗІНДЕ ЖЫНЫСТАРДЫҢ ЕҢІСТЕРІН ҚАЛЫПТАСТЫРУ

Аннотация. Эрозияға қарсы шаралардың қалыптасуы, ең алдымен, топырақтың күйіне немесе көлбеу тау жыныстарының құрамына әсер ететін тепе-теңдік күйіне жетуге негізделген. Осыған байланысты тек топырақпен ғана емес, сонымен қатар тау жыныстарымен немесе басқа түзілімдермен ұсынылған еңістердің бұзылу үдерістерін анықтай алатын модельдің қалыптасуы өзекті болып табылады. Атап айтқанда, бұл қалалық топырақтар мен техногендік түрлендірілген ландшафттар үшін өзекті болады. Зерттеудің жаңалығы ықтимал эрозиялық белсенділік объектілері ретінде тек табиғи беткейлерді ғана емес, сонымен қатар техногендік генезді де құрайтын барлық мүмкін материалдар қарастырылатындығымен анықталады. Мақала авторлары тек табиғи ғана емес, сонымен қатар урболандшафт шегінде ең жоғары эрозиялық белсенділікті төмендетуге мүмкіндік беретін рекультивациялық іс-шараларды өткізу мүмкіндігін қарастырады. Мақалада беткейлердің физикалық параметрлерін және механикалық құрамымен бірге, эрозия белсенділігінің әлеуетін талдау моделі жасалды. Зерттеудің практикалық маңыздылығы ұсынылған іс-шаралар мен эрозиялық белсенділікке қарсы іс-қимылдың әзірленген моделін қалпына келтіру, технологиялық шығындарды азайтуға және сол арқылы жобаның экономикалық және технологиялық тиімділігін арттыруға мүмкіндік беретіндігімен анықталады.

Түйін сөздер: еңістердің тұрақтылығы, тау жыныстарының күйреуі, жыныстық массиві, тұрақтылық моделі, эрозиялық белсенділік.

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DETERMINING LIMIT DISPLACEMENTS IN SPACER PROPPING SINGLE BOLTING

Abstract. Using the existing engineering methodology of designing bolt joints taking up shear loads of dimension chains with gap elements according to N. N. Streletski and other authors' methodology give similar results, both for the analysis of single bolt joints accuracy and for that of multi-bolt joints. In this article there is considered the affect of gap elements number on the accuracy of multi-bolt joints. There is established the character of the intrinsic errors distribution functions interaction, particularly, limit displacements occurring when mounting single bolt joints, and errors distribution functions determining the accuracy of multi-bolt joints elements mutual orientation. There are considered theoretical schemes of forming setting errors for basic elements in the plane of formed joints for a more complicated case, when shearing forces cause element displacements not obligatory reaching limit values. An analysis of the revealed theoretical schemes for the formation of displacements of the installed elements in the plane of the formed bolted joints shows that the parameters of the displacement distribution are significantly different from the same parameters obtained when calculating dimensional chains with gap units.

Key words: dowel, self-anchoring bolt, spacer propping, "bolt-hole" coupling, linear and angular displacement, multi-bolt joint, setting error.

Introduction. In the conditions of permanently increasing level of building technology industrialization, when manufacturing buildings and structures parts is in the increasing degree transferred to plant conditions, there changes the structure of working on the site. Operations on assembly acquire the growing significance, the main of them being quality coupling and bolting. Lately among the main requirements there are setting fastening elements with the least labor content, reducing the work executing and achieving high bearing capacity of the joint on the whole. Besides, setting simplicity and aesthetics of the joint structures themselves are an integral requirement. Studying the now used traditional methods of the equipment fastening to the buildings bearing structures (embedded parts, special consoles, metal buckles, coupling rods, bolts and pins) showed that they do not satisfy the present day requirements to them. High labor intensity of the work executing is combined with significant metal consumption for making coupling strcxutures. Studying bolt joints taking up shear loads is dealt with in the works by N.S. Streletski [1], G.A. Shapiro [2], N.N. Streletski [3], A.F. Knyazhev [4] and other authors [5,6,7,8]. In these works it is shown that the bolt joints bearing capacity and deformability (including the ones taking up vibration loads) are affected by the whole number of factors, the main of which can be divided into four groups: C_1 – a group of parameters including technological factors of bolt joints manufacturing; C_2 – a group of parameters defining the joint friction effect characteristics; C_3 – a group of parameters including geometrical characteristics and mechanical properties of couples elements and bolts materials; C_4 – a group of parameters affecting the irregularity of force distribution between multi-bolt joint bolts. There was noted

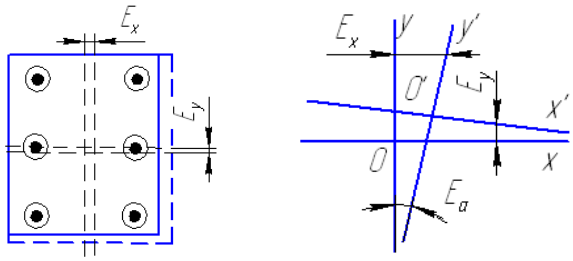
that deformability was the main criterion of rational selecting a joint type and defining breaking stress that can be taken up by the joint working on shear. However, the question was considered in a general conception, and there were not considered the main displacements and deformations of multi-bolt joints. The joint shear complete displacement S_{full} is the sum of displacements and deformations consisting of the following components:

$$S_{full} = S_{s.d} + S_s + S + S_{d.b} + S_y\,, \tag{1}$$

where S_c is the joint general shear displacement whose value depends on the accuracy of making holes and the difference between the hole diameter and the bolt body; S_s is shear and bending deformation of the bolt body; S is crushing deformation of the coupled elements; $S_{d.b}$ is crushing deformation of the bolt body; S_y is longitudinal elongation (shortening) deformation of the coupled elements sections between the bolts.

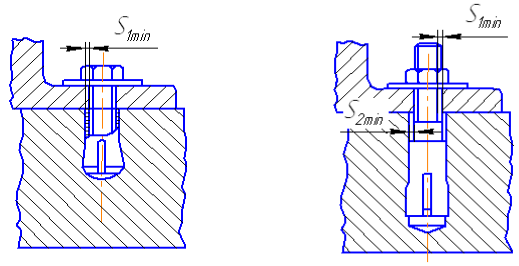
For bolt joint shear operation there is characteristic developing significant displacements – S_{full} (5-8 mm) opposite to which the sum of deformations $S_{d.b}$ and S_y (0,03-0,1 mm) is small and negligible.

The accuracy of setting basic elements in the plane of the formed couplings with the bearing structure surfaces is quantitatively characterized by the values of the set elements displacements from the nominal position. The setting processes performed by the way of aligning the holes in the basic elements with the set in the structure mass anchors (dowels) refer to partially regulated processes, for which error occurring is related to the presence of gaps in the "bolt-hole" couplings (figure 1a). Due to the mentioned gaps the set elements have three degrees of freedom in the plane of the formed couplings with the building bearing surfaces. In Figure 1b it is shown that occurring in setting basic elements deflections from the nominal position present linear displacements E_x and E_y of $0'X'$ and $0'Y'$ axes, as well as their angular displacements E_α relative to the specified coordinate system X_0Y.



a) b)

Figure 1 – Presence of gaps in "bolt-hole" couplings: a) set elements with gaps; b) linear and angular displacements in couplings



a) b)

Figure 2 – Coupling with dowels: a) holes for passing bolts are designed only in the basic elements; b) gaps are both in the basic elements and in anchor unit elements

The analysis of coupling basic elements and buildings bearing structures with dowels permitted to separate two most characteristic types of bolt joints. In figure 2 there are presented variants of dowel joints.

Their constructional difference is defined by characteristic features of dowel coupling with basic element holes and anchor unit elements. In the joints in figure 2a (A-type) holes for bolt passing are designed only in the basic element, and dowel-bushes themselves are placed in the concrete body without gaps. In the joints in figure 2b (B-type) the holes for bolt passing and gaps, respectively, are both in the basic elements and in anchor unit elements. It is obvious that in case of forming the second type joints orientation of the elements placed in the bearing structure planes, will be performed within the limits of the total gap. Taking into account constructional characteristic features of anchor bolts coupling, the formulae to determine minimal guaranteed gap and designing limit linear displacements of the set elements have the following form:

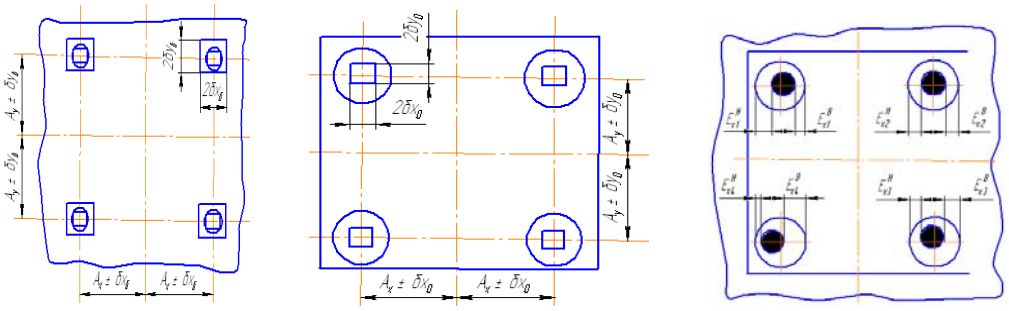
$$S_{min} = \frac{2\sqrt{(\delta_{X0} + \delta_{X\delta})^2 + (\delta_{Y0} + \delta_{Y\delta})^2}}{K}, \tag{2}$$

$$E_{X(Y)} = \pm(0{,}5 \times S + \sqrt{\delta_{X(Y)_0}{}^2 + \delta_{X(Y)_\delta}{}^2 + \delta_S{}^2}), \tag{3}$$

where $\delta_{X(Y)_0}$ is an admissible deflection of the hole axes in the basic element from the nominal position; $\delta_{X(Y)_\delta}$ is an admissible deflection of anchor dowels axes from the nominal position; $б_{x0}$, $б_{y0}$, $б_{x\delta}$, $б_{y\delta}$ are admissible deflections; $S_{min}= S_{min1}$, $\delta_S = \delta_{S1}$ for A-type couplings; $S_{min}= S_{min1}+S_{min2}$, $\delta_S = \sqrt{\delta_{S1}{}^2 + \delta_{S2}{}^2}$ for B-type couplings.

When analyzing present day methods of ensuring the accuracy of assembling bolt joints, it was established that the designing relations in N.S. Streletski's work do not take into account the affect of the "bolt-hole" couplings number on the value of limit displacements. That is using the existing engineering methodology of designing dimension chains with gap elements gives the same results both for the analysis of single bolt assembling accuracy and for multi-bolt couplings [9,10,11,12,13].

Research part. Let's consider in general the affect of the couplings number with gaps on the accuracy of multi-bolt joints assembling. Here we'll try to establish the character of interaction of intrinsic errors distribution functions, particularly, limit displacements occurring when assembling single bolt joints, and errors distribution functions defining the accuracy of the coupled elements mutual orientation in multi-bolt joints [14,15,16,17]. To solve the problem posed let's consider the schemes shown in figure 3. The first one shows clearly the location of the set dowels deflection axes from the nominal position specified by the coordinating dimensions A_x and A_y. Deflection fields are shown in figure 3a as shaded squares. Similarly there are shown the holes deflection fields in the basic elements (figure 3b).



a) b) c)

Figure 3 – Layout chart: a) admissible deflection fields of anchor bolts;
b) admissible deflection fields of hole in the support; c) bolts and holes when setting a basic element

In the neat scheme there is presented a set basic element with the complete alignment of its axes with the specified axes, i.e. the element setting errors in the joint plane are equal to zero. Besides, the holes in the element have random deflections within the admissible allowances, and anchor units axes are randomly oriented within the limits of allowances for setting anchor units. That's why in the scheme (figure 3c) the side gaps between the hole walls and dowel bodies have different values presenting a part of the diametrical gap S complete value. It is obvious that with the basic element displacement from the nominal position the value of the limit displacement will be restricted in the considered direction by the minimal of all the side gaps. As for the case shown in Figure 3c, the limit displacements in the positive $E_{xв}$ and negative $E_{xн}$ directions of X-axis will be equal respectively to the side gaps in the first and the fourth "bolt-hole" couplings. Let's note that for real assembly processes occurring the set element displacements described by relations (2) and (3), is connected with the conditions of the basic element aiming to the anchor bolts. It is clear that in the considered case the aiming error is no less than the value of "bolt-hole" coupling gap.

Let's consider theoretical layouts of forming basic elements setting errors in the plane of the formed joints for a more complicated case, when shearing forces cause displacing elements nor obligatory reaching the limit values. This case corresponds to real assembly processes with a more accurate that in the abovementioned example basic element aiming to the dowels. Besides, the set element is randomly oriented in the limit values range. Let's suppose that we know the law of limit values g(Ex) distribution and that there has been established the law of the set element distribution within the limits of gaps in the direction of X-axis. Then the theoretical law of displacements distribution accounting a random factor of

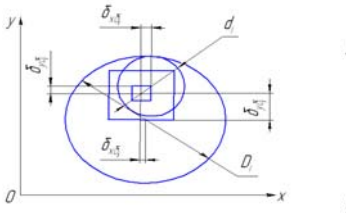
limit values will correspond to the layout of unconditional and conditional distributions which can be presented in the general form as follows:

$$g(x) = \int_{\psi(E_X)}^{\infty} g(x)g_0(x)d(E_x), \tag{4}$$

where $\psi(E_x)$ is the function describing the dependence of integration limit value on E_x changes.

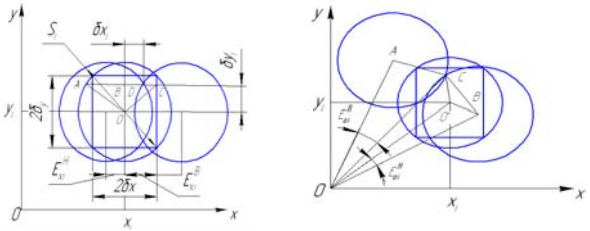
The character of E_x displacements distribution is true for displacements E_y, E_α.

The analysis of the revealed theoretical schemes of forming displacements of the set elements in the plane of the formed bolt joints shows that parameters of the displacements distribution differ significantly from the similar parameters obtained in designing dimensions chains with gap elements [18,19,20]. Besides, changing the parameters of element displacements distribution is oriented to the side of increasing the accuracy of these elements setting which proves the presence of accuracy reserves and reducing assembly processes labor intensity. To derive the relations permitting to define limit displacements of the set element in the plane of the formed bolt joint depending on the real values of geometrical characteristics of the i-th coupling with a gap, let's consider the schemes presented in Figure 4. In the schemes there is shown the mutual location of bolts and holes axes of the i-th coupling with a gap when aligning the axes of the set element with the specified axes and forming A-type couplings (figure 4a) and B-type (figure 4b). The holes and bolts are shown with deflections from the nominal position specified by X_i, Y_i dimensions within the limits of δ_{x0}, δ_{y0}, $\delta_{x\delta}$, $\delta_{y\delta}$ allowances. The holes and bolts are schematically shown by the circles whose diameters are designated D_{1i}, D_{2i}, d_i.



a) b)

Figure 4 – Mutual location of the bolts and holes of the i-th coupling with a gap: a) A-type coupling; b) B-type coupling



a) b)

Figure 5 – Layout for limit displacements designing: a) in the direction of X-axis; b) with the basic element turning

With the aim of simplifying the further computation, let's reduce the number of geometrical characteristics considered by means of introducing indicators in less detail. Starting from geometrical relations, we'll move from the holes and dowels diametrical dimensions to the gaps values and from the holes and dowels axes location deflections to their mutual location values: S_i is a diametrical gap (total); $S_i = D_{1i} - d_i$ for A-type joints; $S_i = D_{1i} + D_{2i} - 2_{di}$ for B-type joints; δ_{xi}; δ_{yi} are deflections of the holes and dowels axes mutual location ($\delta_{xi} = \delta_x\delta_i - \delta_{x0i}$; $\delta_{yi} = \delta_y\delta_i - \delta_{y0i}$). In Figure 5 using the designations there are presented the set element nominal and limit position with displacement in the direction of X-axis (figure 5a) and with the element turning (figure 5b). As shown in Figure 5a, limit displacement values E_{xi}^{B} и E_{xi}^{H} are defined by the lengths of AD and DC sections. It is easily seen that AD section is equal to the sum of AB and BD sections, and СД section is equal to the difference of BD and BC sections (AB).

Taking into account that ВД section is equal to δ_{xi} deflection, AB section is the leg of the right-angle triangle AOB, whose hypotenuse AO is equal to half-diameter gap $AO = 0{,}5S_i$, and leg OB is equal to δ_{yi} deflection, from geometrical relations we'll obtain:

$$E_{Xi}^{B(H)} = \delta x_i \pm \sqrt{0{,}25S_i^2 - \delta_Y^2} \tag{5}$$

When opening the introduced designations δ_{xi} and δ_{yi}, let's write down expression (5) in the form:

$$E_{Xi}^{B(H)} = (\delta x_{\delta i} - \delta x_{0i}) \pm \sqrt{0{,}25S_i^2 - (\delta y_{\delta i} - \delta y_{0i})^2} \tag{6}$$

In order to determine limit angular displacements $E_{\alpha i}^{B}$ and $E_{\alpha i}^{H}$, let's consider figure 5b.

Considering positive the basic element turn counterclockwise, let's designate angle $AOO^{/}$ as equal to angular displacement E_{α}, respectively, $O^{/}OB=E$. Taking into account that angles AOC and COB are equal, as AO = OB = x + y, and OC is the common side of triangles ACO and BCO, we'll obtain:

$$E_{\alpha i}^{B} = \angle O^{/}OC + \angle AOC, \qquad E_{\alpha i}^{H} = \angle O^{/}OC - \angle AOC \tag{7}$$

In figure 5b it is seen that OOC is equal to the difference of inclination angle of OC and OO lines to OX-axis which can be expressed by the relation:

$$\angle O^{/}OC = \operatorname{arctg}\frac{y_i + \delta_{yi}}{x_i + \delta_{xi}} - \operatorname{arctg}\frac{y_i}{x_i} \tag{8}$$

In its turn, angle AOC at the known values of sides AO, OC and AC of triangle AOC is determined from geometrical relations as follows:

$$\angle AOC = \arccos\frac{\sqrt{(AO)^2 + (OC)^2 - (AC)^2}}{2 \times AO \times OC} \tag{9}$$

Let's substitute in this relation the values of sections $AO = \sqrt{x_i^2 + y_i^2}$, $OC = \sqrt{(x_i + \delta_i)^2 + (y_i + \delta_{yi})^2}$, $AC = 0{,}5S_i$, and obtain:

$$\angle AOC = \arccos\frac{4(x_i + \delta_{xi})^2 + 4(y_i + \delta_{yi})^2 + 4(x_i^2 + y_i^2) - S_i^2}{8\sqrt{(x_i + \delta_{xi})^2 + (y_i + \delta_{yi})^2} \times \sqrt{x_i^2 + y_i^2}} \tag{10}$$

Based on relation (7), taking into consideration formulae (9) and (10), limit angular displacements $E_{\alpha I}^{B(H)}$ should be determined as follows:

$$E_{\alpha 1}^{B(H)} = \operatorname{arctg}\frac{y_i + \delta_{yi}}{x_i + \delta_{xi}} - \operatorname{arctg}\frac{y_i}{x_i} \pm Q \tag{11}$$

$$Q = \arccos\frac{4(x_i + \delta_{xi})^2 + 4(y_i + \delta_{yi})^2 + 4(x_i^2 + y_i^2) - S_i^2}{8\sqrt{(x_i + \delta_{xi})^2 + (y_i + \delta_{yi})^2} \times \sqrt{x_i^2 + y_i^2}} \tag{12}$$

The obtained relations for determining limit linear and angular displacements depending on the real values of geometrical characteristics of a single coupling with a gap will permit, using relation (4) to calculate basic elements setting errors in the plane of the formed joints with bearing surfaces, as well as using probabilistic statistical studying methods to establish parameters of these errors scattering. For the probabilistic-statistical analysis of setting errors it is necessary to establish preliminary the laws and parameters of intrinsic errors distribution.

Conclusions:

1. For real assembly processes the set element displacements described by relations (2) and (3) are related to the conditions of the basic element aiming to anchor bolts. Therefore the aiming error is no less than the value of gaps in "bolt-hole" couplings.

2. The analysis of the revealed theoretical layouts of the set element displacements in the plane of the formed bolt joints shows that parameters of displacements distribution differ significantly from the similar parameters obtained when designing dimension chains with gap elements. Besides, changing parameters of the element displacement distribution is oriented to the side of increasing these elements setting accuracy which proves the presence of accuracy reserves and reducing assembly processes labor intensity.

3. The obtained relations for determining limit linear and angular displacements depending on the real values of geometrical characteristics of a single coupling with a gap will permit, using relation (4) to design the basic elements setting errors in the plane of the forms joints with bearing surfaces.

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КЕРГІШ БЕКІТПЕЛЕРДІҢ БІР БОЛТТЫ ҚОСЫЛЫСТАРЫНДАҒЫ ШЕКТІ ЫҒЫСУЛАРДЫ АНЫҚТАУ

Аннотация. Н. Н. Стрелецкий әдістемесі бойынша зазор – буындары бар өлшем тізбектерінің жылжу жүктемелерін қабылдайтын болтты қосылыстарды есептеудің қазіргі инженерлік әдістемесін және басқа авторларды қолдану бір болтты қосылыстарды құрастыру дәлдігін талдау үшін де, көпболтты қосылыстар үшін де бірдей.

Мақалада саңылаумен жанасу санының көп болтты қосылыстарды құрастыру дәлдігіне әсері қарастырылған. Бастапқы қателіктерді, атап айтқанда бір бұрандамамен қосылыстарды құрастыру кезінде туындайтын шекті ығысу және көп болтты қосылыстардың жиналатын элементтерінің өзара бағдарлануының дәлдігін анықтайтын қателіктерді үлестіру функциясының өзара байланысының сипаты белгіленген. Ығысу күштері міндетті түрде шекті мәндерге жете бермейтін элементтердің ығысуын тудыратын неғұрлым күрделі жағдай үшін түзілген қосылыстардың жазықтығында негізгі элементтерді орнату қателіктерінің пайда болуының теориялық схемалары қарастырылады. Құрылған болт қосылыстарының жазықтығында орнатылған элементтердің ығысуының пайда болуының анықталған теориялық сызбаларын талдау, ығысудың таралу параметрлері байланыс-саңылаулары бар өлшемді тізбектерді есептеу кезінде алынған ұқсас параметрлерден айтарлықтай ерекшеленетінін көрсетеді.

Түйін сөздер: субель, өзінен анкерленетін болт, кергіш бекіткіш, "болт-тесік" түйіндемесі, сызықтық және бұрыштық ығысу, көпболттық қосылыс, қондырғының қателігі.

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ОПРЕДЕЛЕНИЕ ПРЕДЕЛЬНЫХ СМЕЩЕНИЙ В ОДНОБОЛТОВЫХ СОЕДИНЕНИЯХ РАСПОРНЫХ КРЕПЛЕНИЙ

Аннотация. Использование существующей инженерной методики проектирования болтовых соединений, воспринимающих сдвиговые нагрузки размерных цепей с зазорными элементами по методике Н. Н. Стрелецкого и других авторов, дает сходные результаты как для анализа точности одиночных болтовых соединений, так и для анализа точности многоболтовых соединений.

В статье рассмотрено влияние количества сопряжений с зазором на точность сборки многоболтовых соединений. Установлен характер взаимосвязи функций распределения исходных погрешностей, а именно предельных смещений, возникающих при сборке соединений с одним болтом, и функциями распределения погрешностей, определяющих точность взаимной ориентации собираемых элементов многоболтовых соединений. Рассмотрены теоретические схемы образования погрешностей установки базовых элементов в плоскости образуемых соединений для более сложного случая, когда сдвигающие силы вызывают смещения элементов не обязательно достигающих предельных значений. Анализ выявленных теоретических схем образования смещений устанавливаемых элементов в плоскости образуемых болтовых соединений показывает, что параметры распределения смещений существенно отличаются от аналогичных параметров, получаемых при расчете размерных цепей с звеньями-зазорами.

Ключевые слова: дюбель, самоанкерующийся болт, распорный крепеж, сопряжения «болт-отверстие», линейные и угловые смещения, многоболтовое соединение, погрешность установки.

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ANALYSIS OF METEOROLOGICAL CONDITIONS SIGNIFICANT FOR SMALL AVIATION AND TRAINING FLIGHTS AT THE AIRFIELD "BALKHASH" FOR PLANNING AND FLIGHT SAFETY PURPOSES

Abstract. Cloudiness and range of visibility are the most significant flight conditions for aircraft. The impact of clouds and visibility on the safety of aircraft flights, especially small aircraft, cannot be overestimated. According to the Interstate Air Committee, Kazakhstan ranks second in the number of aviation disasters. The average age of a third of Kazakhstan's small aircraft is more than 30 years. Over the past few years, 14 air accidents have occurred in the Republic of Kazakhstan, 11 of them with small aircraft.

In this work, we investigate long-term data on cloudiness and visibility at the most weather-favorable airfield in Balkhash, for the possibility of safe and economical flights of small aircraft and planning training flights.

Key words: analysis, planning, flight safety, weather conditions.

Induction. Cloudiness, its height and shape are one of the main characteristics of atmospheric processes and an essential factor in the radiation balance of the Earth – atmosphere system.

The average long-term cloudiness regime is formed under the influence of circulation processes that determine the prevailing direction of air masses and their moisture content, as well as under the influence of the underlying surface. Under the influence of local factors, the annual variation of all cloud characteristics is formed. The nature of cloudiness in the analysis area is rather peculiar. The reason for its appearance in the airfield area is the sharply continental conditions of the territory, the extremely low moisture content of the air masses participating in atmospheric circulation in the aerodrome area in summer and the proximity to the Asian maximum of atmospheric pressure in winter.

We investigated the number of cases with cloudiness less than 450 m. In winter, there is a general decrease in the lower limit of clouds.

Figure 1 shows the percentage ratio of cases with base of clouds (ceiling) less than 450 meters from January to December. The maximum of clear days falls on the summer months of July and August. Most often cloudy weather is observed in, from January to April and from September to December. From the analysis of the charts in figures 1 and 2, it can be concluded that low clouds have a well-defined annual course. The greatest recurrence of clouds below 450 m is observed in the cold season (January to April), the minimum in the warm (July, August).

Maximum cloudiness recurrence below 450 m is noted in winter during the night and morning hours. Minimum repeatability occurs in daytime for 15-17 hours. The evening and night repeatability minima of VNGO below 450 m are explained by the influence of breeze circulation, while the minimum in the middle of the day is associated with daytime warming and increased turbulent exchange.

Analysis of the various cloud forms recurrence reveals some characteristic features of the temporal distribution of different cloud forms.

The most repeatable are cirrus (Ci) and cumulus (Cu, As,) clouds, the maximum of which falls in the summer, when intense convection is most pronounced.

The least recurrence of cirrus clouds is observed in winter.

Cirrocumulus cloud (CC) has negligible repeatability (up to 2%) and it is not possible to identify any regularity of the intra-annual distribution.

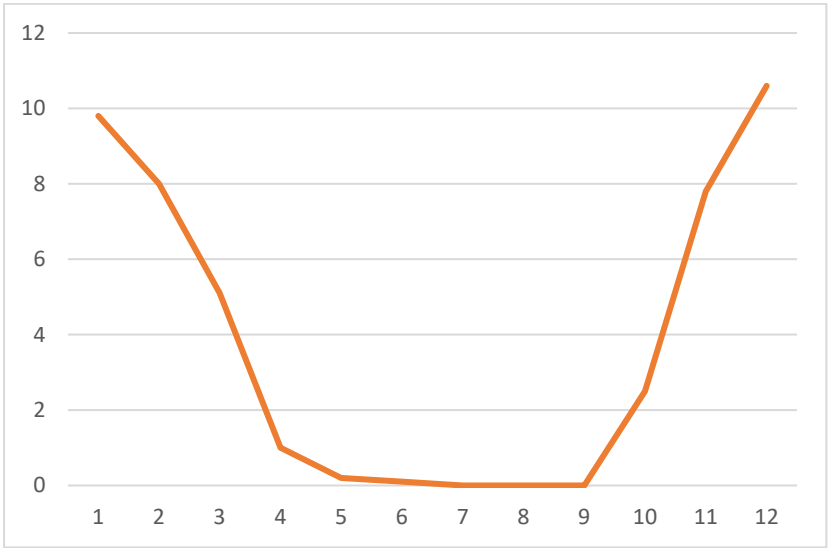

Figure 1 – Annual recurrence (%) of cloudiness less than 450 m, the amount of 5-8 octants at the Balkhash airfield

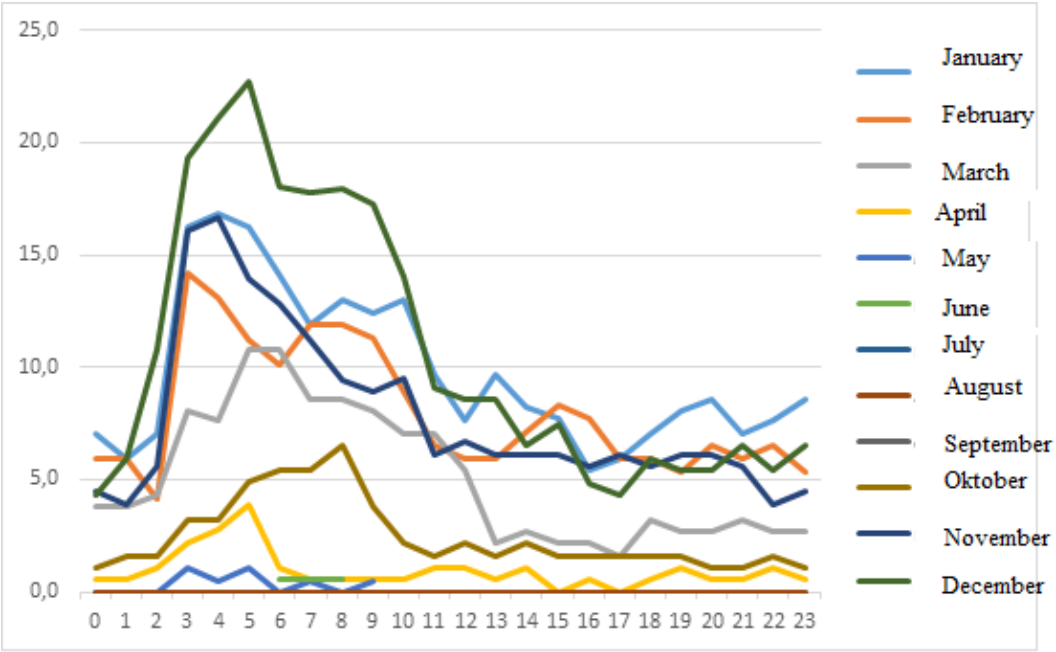

Figure 2 – Recurrence of cloudiness of 5-8 octants at Balkhash airfield in personal time of day by months

Cirrostratus cloudiness (Cs) has a well-defined annual variation with maximum repeatability in February and March (10-15%) and minimum in July and August (5-10%).

Very often observed high-cumulus clouds (Ac) are associated with both general circulation and convective processes. The maximum recurrence of high-cumulus clouds is in Summer period and in September-October. At this time, the recurrence of As on average reaches 25-30%. The least recurrence of high-cumulus clouds is observed in January, February when it decreases to 5-20%.

The annual variation of high-layered cloud (As) reflects the repetition of cyclones and associated fronts, which are usually preceded by this form of cloud. Most often, this form is observed in winter (10-25%) when cyclonic activity is more actively developed. In summer, the repeatability of highly layered clouds decreases to 5-15% in the north of the territory and to 1-10 in the south.

Cumulus (Cu) is almost not observed in winter. It usually develops in April, and has a well-defined summer maximum when its repeatability reaches 15-25%.

Cumulonimbus (Cb) has the same intra-annual distribution as cumulus, but its repeatability is less. Winter cumulus-rain is extremely rare, its repeatability mainly does not exceed 1%.

The recurrence of Stratus (St) is most often observed in winter (January, February).

Least often, Stratus clouds are observed in Spring, when their recurrence does not exceed 1%.

Stratus (Sc) is rare, this is due to the fact that its formation is associated both with the processes of destruction of the clouds of cumulus forms and with the advection of air masses. Maximum recurrence in autumn (6-10%).

Nimbostratus (Ns), has a well-defined annual variation. Its maximum recurrence is observed in winter.

Fracto-nimbus cloudiness are rare. Its highest recurrence is observed in Spring and Autumn (3-13%).

Along with the annual variation of the main cloud forms, their diurnal variation is well traced. Cirrus clouds have maximum recurrence, as a rule, during the daytime, and in the summer-time in the evening, during the spread of powerful cumulonimbus.

High cumulus has a pronounced diurnal variation. In winter, its maximum recurrence is less often observed at night and more often in the daytime, in spring-autumn periods, in the morning, in summer, high-cumulus clouds are observed at night. Altostratus with its intra-diurnal distribution repeats alto-cumulus, but the diurnal variation is smoother. Cumulus cloudiness has a maximum recurrence everywhere at 13:00, at the moment of the maximum development of convective cloudiness; in the rest of the observation periods, especially at night, its recurrence percentage is insignificant.

The maximum recurrence of cumulonimbus shifts to 19:00, although at 13:00 its recurrence is also significant, and the minimum, as a rule, falls in the morning. Stratus is more often observed in the morning and at night, less often during the day. The daily maximum of the recurrence of stratocumulus clouds is observed in Winter in the mornings, at a minimum temperature, in Summer, in the evening hours, when convective clouds spread.

Nimbostratus is observed more often in the morning and less often in the afternoon and evening. Fracto nimbus has insignificant recurrence. Most often it is observed together with nimbostratus, therefore, its daily variation resembles the nimbostratus variation, but less pronounced.

Visibility of less than 1000 m and less than 3000 m has an almost identical variation with highs in February, December and a slight shift in July. The minimum number of low visibility cases is observed in May and September.

Maximum visibility recurrence less than 3000m is observed in winter; between May and September, it is very small and does not exceed 1%.

From April to October, visibility less than 3000 m does not exceed 1% of cases.

Figure 4 shows the daily variation of gradations of visibility range less than 1000 m and less than 3000 m. From the analysis of graphs it follows that horizontal visibility has a well-defined daily course, which has several highs (1-3 hours of the night, 7 hours and from 14-19 hours).

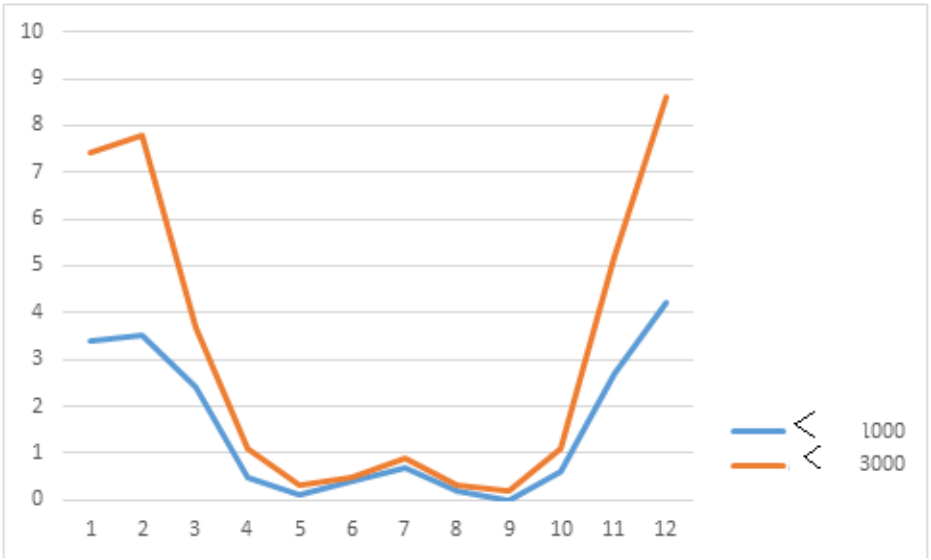

Figure 3 – Annual repeatability% low visibility at Balkhash airfield

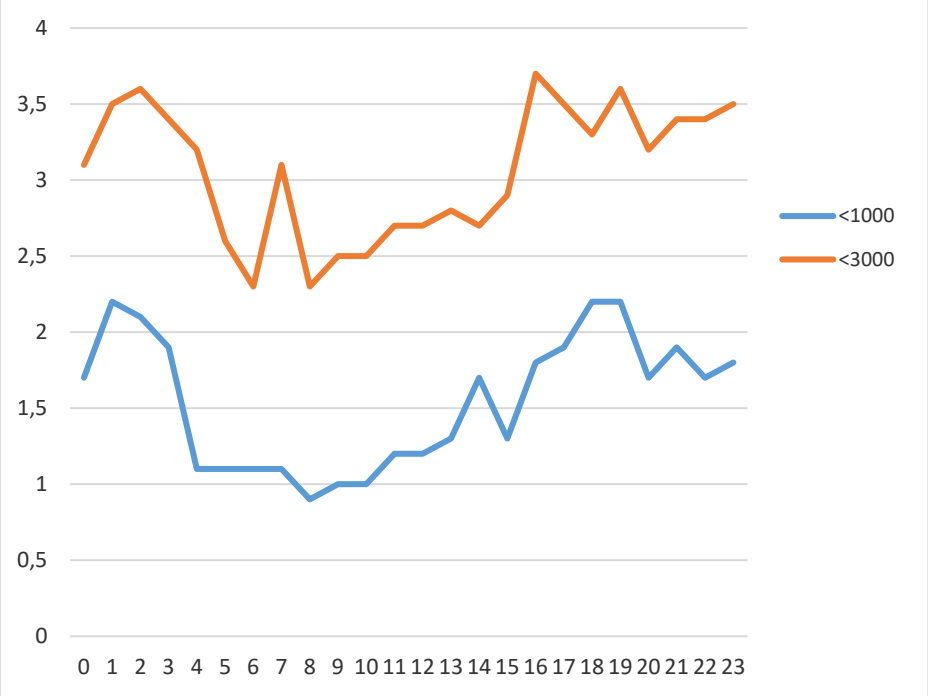

Figure 4 – Daily variation of % gradations of visibility range less than 1000 m and less than 3000 m

It is also interesting to consider the recurrence of observation of the range of visibility and/or the height of the lower edge of the clouds of the lowest layer with a significant and continuous cover of the sky cloud below the value of 3000/300 m in order to plan training flights. To do this, we built the following graphs presented in figure 5.

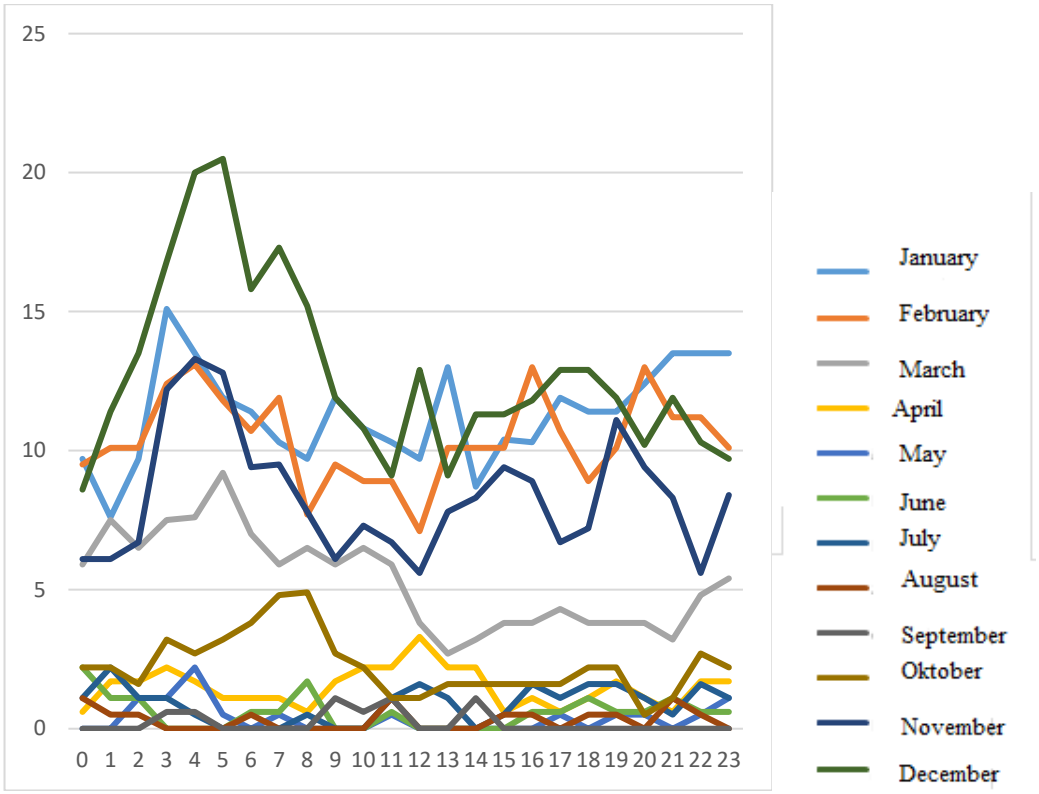

Figure 5 – Recurrence of cases of observation of visibility range and/or height of the lower boundary of clouds of the lowest layer with significant and continuous cover of the sky of cloud below the value of 3000/300 m

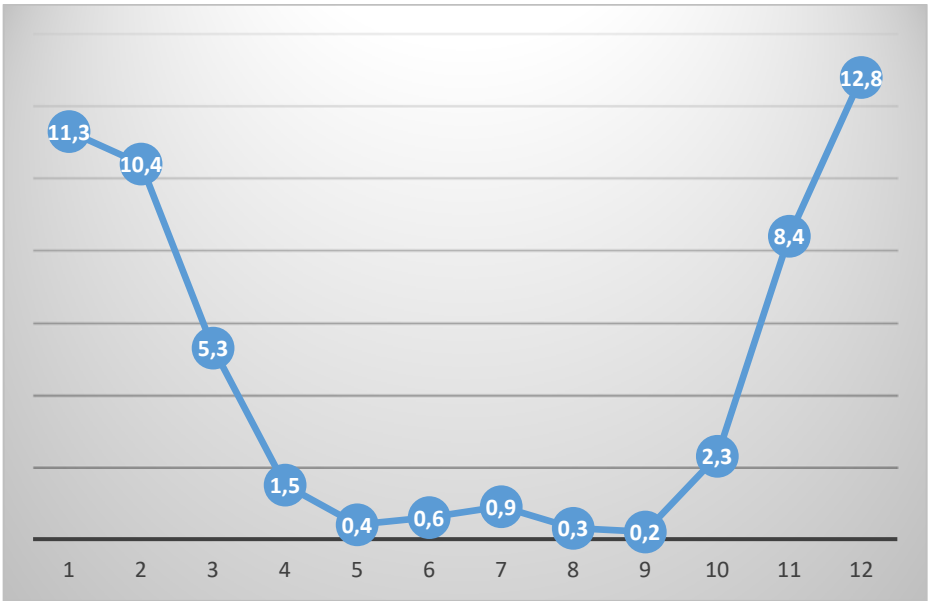

Figure 6 – Average repeatability, %, of visibility range and/or lower cloud height observations of the lowest cloud layer BKN or OVC below 3000/300 m

An analysis of the schedules suggests that the most favorable period for flights is from April to September. The most difficult flight conditions are noted in January and December. During the day, the most favorable hours for flights in the daytime from 4.00 to 13.00.

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ҰШУДЫ ЖОСПАРЛАУ ЖӘНЕ ҚАУІПСІЗДІК МАҚСАТТАРЫ ҮШІН «БАЛХАШ» ӘУЕАЙЛАҒЫНДАҒЫ ШАҒЫН АВИАЦИЯ ЖӘНЕ ОҚУ-ЖАТТЫҒУ ҰШУЛАРЫ ҮШІН МАҢЫЗДЫ МЕТЕОРОЛОГИЯЛЫҚ ЖАҒДАЙЛАРДЫ ТАЛДАУ

Аннотация. Бұлттылық пен көріну – бұл әуе кемелерінің ұшуының маңызды шарттары. Бұлттылық пен көрінудің әуе кемелерінің, әсіресе шағын ұшақтардың қауіпсіздігіне әсерін асыра бағалау қиын. Мемлекетаралық авиация комитетінің бағалауы бойынша, Қазақстан авиациялық апаттар саны бойынша екінші орында. Kazakhstan шағын ұшақтарының үштен бірінің орташа жасы 30 жастан асады. Соңғы бірнеше жылда Қазақстан Республикасында 14 авиациялық апат болды, оның 11-і шағын авиациямен. Бұл жұмыста біз ауа-райы жағынан ең қолайлы аэродромдағы бұлттылық пен көріну туралы ұзақ мерзімді деректерді зерттейміз. Балқаш қаласы, шағын ұшақтардың қауіпсіз, үнемді ұшуы және оқу рейстерін жоспарлау мүмкіндігі үшін.

Бұлттылық, оның биіктігі мен формасы атмосфералық процестердің негізгі сипаттамаларының бірі және Жер - атмосфера жүйесінің радиациялық балансының маңызды факторы болып табылады.

Түйін сөздер: талдау, жоспарлау, ұшу қауіпсіздігі, ауа райы жағдайлары.

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АНАЛИЗ ЗНАЧИМЫХ ДЛЯ МАЛОЙ АВИАЦИИ И УЧЕБНЫХ ПОЛЕТОВ МЕТЕОРОЛОГИЧЕСКИХ УСЛОВИЙ НА АЭРОДРОМЕ «БАЛХАШ» ДЛЯ ЦЕЛЕЙ ПЛАНИРОВАНИЯ И БЕЗОПАСНОСТИ ПОЛЕТОВ

Аннотация. Облачность и дальность видимости являются наиболее значимыми условиями полета воздушных судов. Влияние облачности и видимости на безопасность полетов воздушных судов, особенно малой авиации, трудно переоценить. По данным Межгосударственного авиакомитета, по числу авиационных катастроф Казахстан занимает второе место. Средний возраст трети воздушных судов малой авиации

Казахстана составляет более 30 лет. За последние несколько лет в Республике Казахстан произошло 14 авиационных происшествий, 11 из которых – с воздушными судами малой авиации.

В статье приведены результаты многолетних данных об облачности и видимости на наиболее благополучном с точки зрения погоды аэродроме г. Балхаш для возможности безопасных и экономичных полетов малой авиации и планирования учебных полетов.

Облачность, ее высота и форма являются одной из основных характеристик атмосферных процессов и существенным фактором радиационного баланса системы Земля – атмосфера.

Ключевые слова: анализ, планирование, безопасность полетов, погодные условия.

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MODELING OF THE COMBUSTION PROCESS IN A DIESEL ENGINE

Abstract. The issues of combustion processes and the organization of the combustion workflow in diesel engines are relevant in view of the tightening of economic and environmental requirements for them. The problem of saving liquid fuels remains one of the most acute in the provision of fuel and energy resources. The development of highly efficient methods for organizing work processes when burning natural gas in a compressed or cryogenic state in the cylinders of internal combustion piston engines and determining ways to further reduce toxic emissions, increase fuel efficiency and reliability in promising gas engines is an urgent task. Mathematical modeling of liquid fuel combustion is a complex task, since it requires taking into account a large number of complex interrelated processes and phenomena. The article presents a simple 3-D model of cylinder diesel tractor engine D 144, the results of numerical simulation of combustion of liquid and gaseous fuel in the cylinder of the diesel engine D-144. The article presents the results of modeling, including graphs of the dependence of nitrogen oxides, particles in outgoing gases, depending on the consumption of gaseous fuel in the form of pure methane. Additionally, temperature and velocity contours are shown. The corresponding conclusions are made.

Key words: internal combustion engine, simulation, nitrogen oxides, liquid fuel.

Introduction. At the moment, a lot of work is underway to develop efficient internal combustion engines with high environmental performance. It is obvious that internal combustion engines, like all heat engines, are sources of both heat, sound and, most importantly, environmental pollution, since there is no alternative to burning fossil fuels. On the other hand, it is difficult to imagine a serious alternative to internal combustion engines at the moment, since modern electric vehicles do not have a sufficiently high reliability and economy.

At the moment, there are quite a lot of studies in the field of reducing harmful emissions of internal combustion engines, these include mixing hydrogen fuel [1, 3, 10, 12], using modern water injection control systems [2], swirling the flow [4], diluting various types of fuel with liquefied gas [5] or methane [6], diesel [7], catalysis [8], gas recirculation [9], "poor" burning [11].

From the point of view of the efficiency of the hydrogen fuel of course there has pros, this high flame temperature and the flammability limit low. However, hydrogen fuel is quite dangerous and more stringent safety conditions are required when using it. Water injection is a fairly widely used technology, but it has its drawbacks in the form of the possibility of formation of corrosion debugs, flame attenuation with uneven distribution. Water can also affect the formation of carbon monoxide, which can be formed in the event of a sharp "cooling" in the cold parts of the cylinder.

Twisting is a fairly effective technology, but it cannot radically solve the problems of toxic substances formation. The most appropriate way to reduce the formation of toxic substances can be considered the use of various fuels together with the main fuel.

In the article [12], such additives as methanol, ethanol, and n-butanol were used. The results showed that dilution of the main fuel with alkaloids leads to a decrease in the formation of CO and aerosol particles, which are integral products of combustion. However, the addition of alkaloids increased the formation of nitrogen oxides. The use of oxygen as an additive to the oxidizer [14, 16, 17, 18] in the combustion of methanol has shown greater efficiency in terms of carbon monoxide. At the maximum oxygen concentration, the CO content decreased from 48.59 to 30.9%. However, the concentration of nitrogen oxides has increased significantly from 38.7% to 112.2%. Adding nanoparticles in the form of oxides of titanium and zinc [15] have led to a decrease in hydrocarbon concentrations from 37 to 26%, the content of carbon monoxide from 36 to 26% and reduce the concentration of nitrogen oxides from 19 to 15%.

All of the above shows that the method of diluting the main fuel is quite a promising technology. On this basis the authors performed a numerical simulation of the combustion processes when adding to the fuel of natural gas.

The combustion process is a rather complex process that includes both chemical processes of fuel oxidation and physical processes of mixing of high-temperature gases in the combustion zone. To improve work efficiency the internal combustion engine, in particular the combustion process, a clear understanding of the processes that occur during the combustion of fuel.

From an economic point of view, the most suitable method is numerical modeling of combustion processes [3, 8, 11]. There are difficulties in the form of the influence of the temperature of the cylinder walls and the process of heat transfer from the walls to the gases, so an important aspect is to take into account heat exchange. Unfortunately, at the moment it is not possible to obtain a sufficiently accurate model in the form of the factors described above, but it is advisable to use models for approximate calculations.

Model. A simple 3-D model of the D 144 diesel tractor engine cylinder was used in the simulation (figure 1). The dimensions of the cylinder are 105x120 mm. Fuel was supplied from point 1, and an oxidizer in the form of air was supplied from point 2. When modeling, it was assumed that there is no swirl of the current. The initial modeling conditions are shown in table.

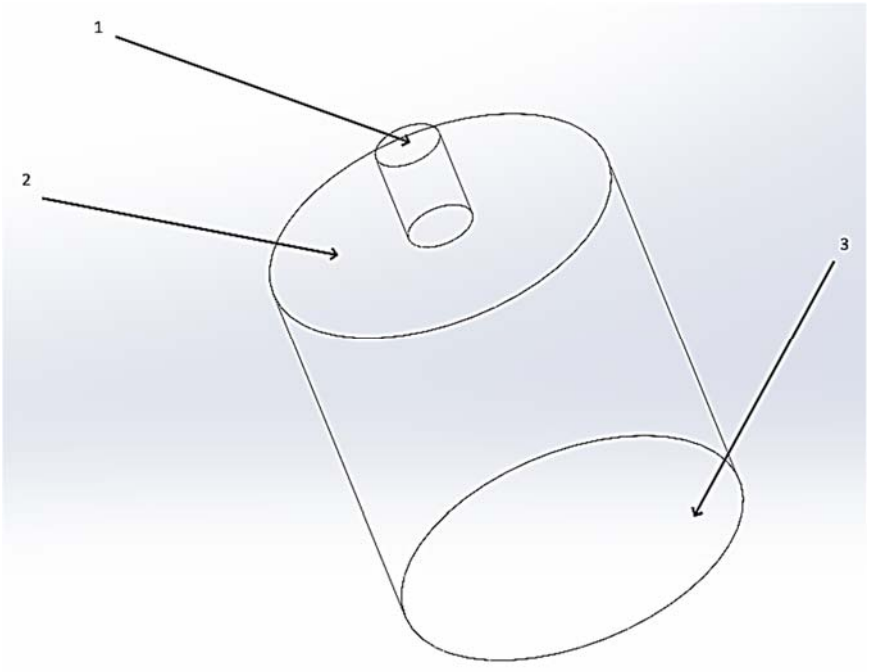

Figure 1 – Iisometric view of the burner device:
1 – fuel inlet nozzle; 2 – air inlet; 3 – outlet

During the simulation, it was assumed that the air flow rate was constant and equal to 20 m/s, and the flow rate of gaseous fuel varied in the range of 0-15 m/s. N-pentane (c5h16) was used as the main liquid fuel.

Initial parameters

Option No.	Gas fuel consumption, kg/hour	Air speed, m/s	Initial temperature of the oxidizer (air)/fuel, K	Number of tetrahedral elements in the simulated area
1	0	20	300	200 000
2	19.152			
3	38.16			
4	54			

To study the effect of liquid droplet flow, the injection function was used. The fuel consumption was 0.001 kg/s, the flow rate was 20 m / s, and the drop diameter was 0.0001 m. The k-ε turbulent model was used to model combustion processes.Gorenje The standard k-ε model is a model based on model transport equations for the kinetic energy of turbulence and its dissipation rate (ε) [6].

Results. Figure 2 shows the temperature contours at different speeds of the gaseous fuel. As can be seen from the figures, when the gas flow rate increases, the high-temperature zone moves lower to the cylinder. Moreover, the temperature contours do not change their structure.

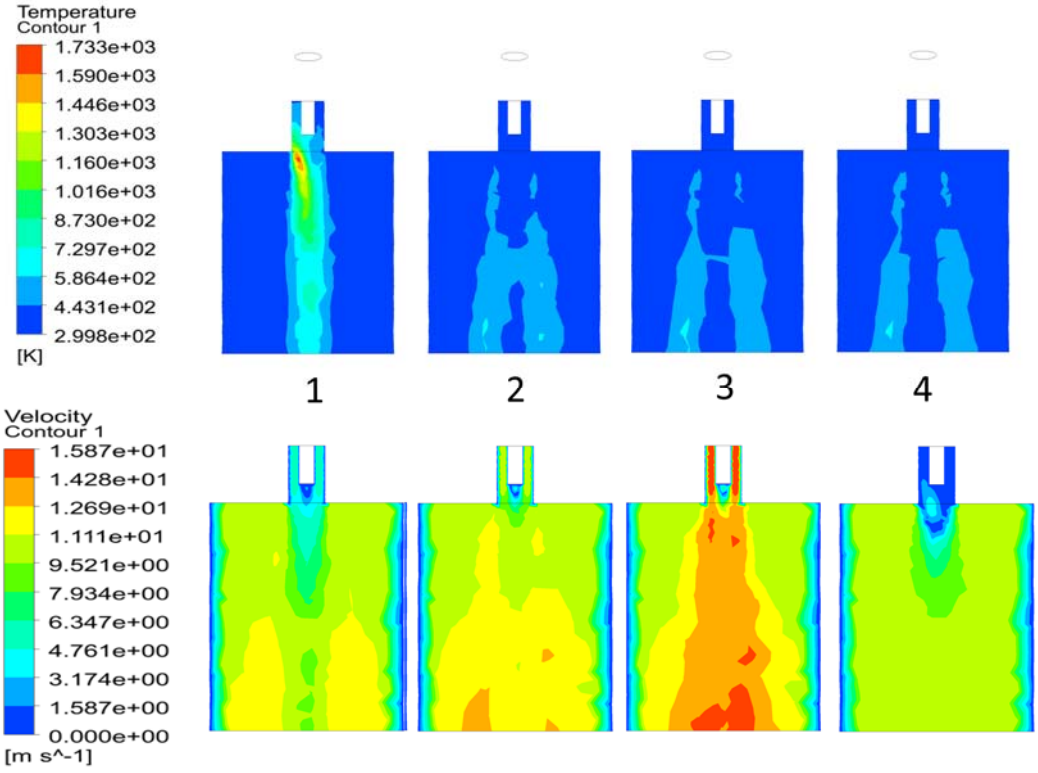

Figure 2 – Temperature and speed contours at different fuel consumption

Nitrogen oxide. Figure 3 shows the dependence of the concentration of nitrogen oxides on the consumption of organic fuel. As can be seen from the figure, the maximum concentrations of oxides are observed when pure liquid fuel is supplied. When the gas flow rate increases, the concentration of nitrogen oxides decreases, but after a certain value, the concentrations increase. This is because when a certain concentration increases, the temperature in the combustion zone increases, and the completeness of combustion increases accordingly, which leads to an increase in the concentration of nitrogen oxides [17, 18].

Figure 4 shows the dependence of the particle concentration in the outgoing gases on the flow rate of the gaseous fuel. This graph shows that as gas consumption increases, the number of particles with underburned increases.

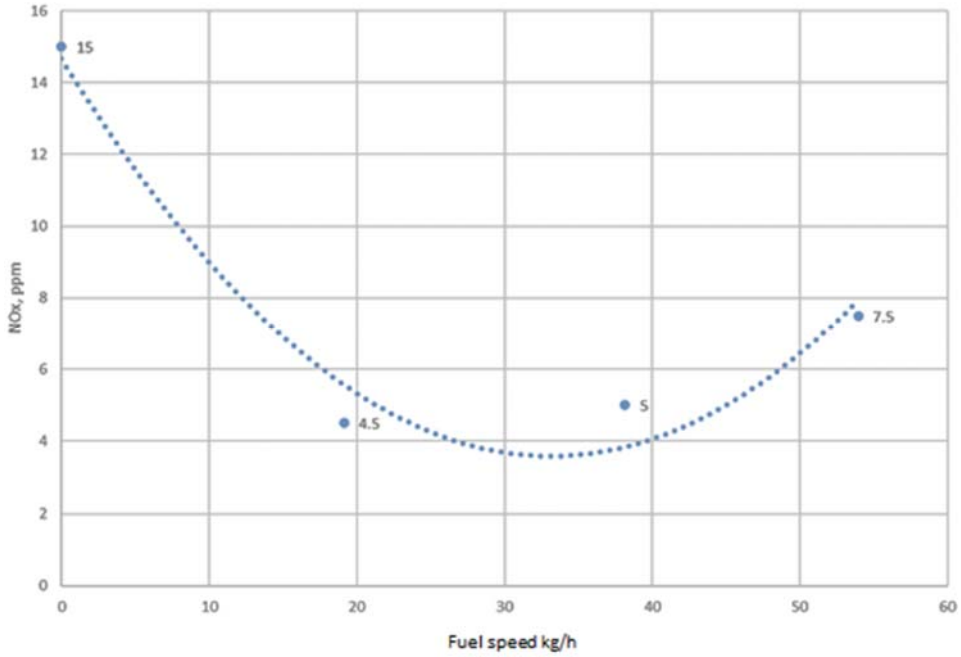

Figure 3 – Dependence of nitrogen oxide concentrations on fuel consumption

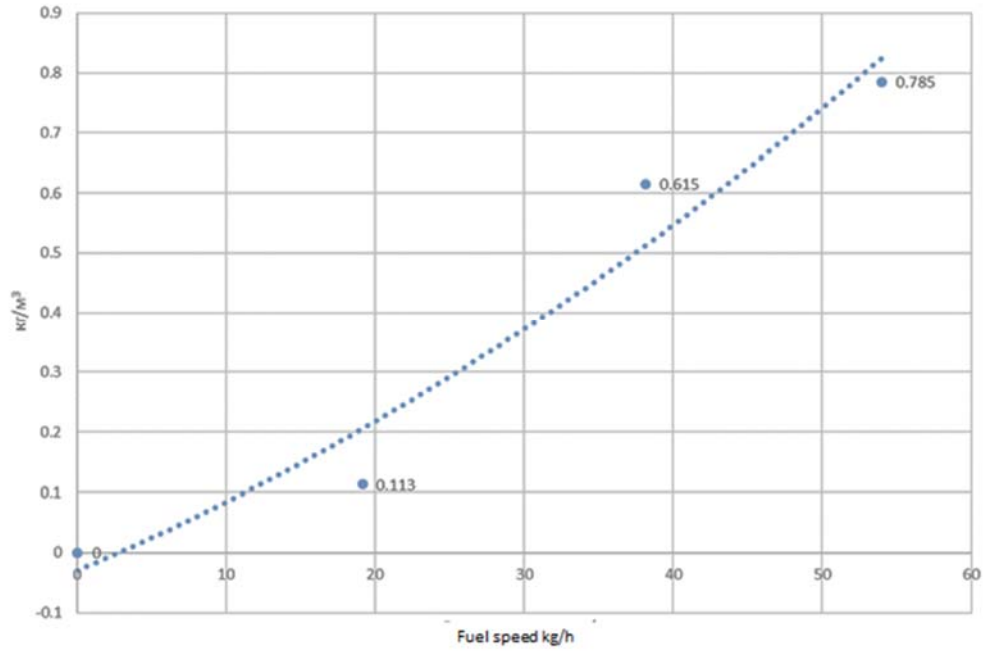

Figure 4 – Concentration particle in exhaust gases depending on fuel consumption

Conclusion. The article presents the results of modeling the combustion of liquid fuel with dilution with gaseous fuel (methane). From the presented results, we can say that the most optimal flow rate is 20 kg/s. This flow rate is optimal from the point of view of nitrogen oxides, as well as from the point of view of the concentration of particles at the exit of the cylinder.

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ДИЗЕЛЬДІ ҚОЗҒАЛТҚЫШТАҒЫ ЖАНУ ПРОЦЕСІН МОДЕЛЬДЕУ

Аннотация. Дизельді қозғалтқыштардағы жану процестерінің және жұмыс процесін ұйымдастырудың мәселелері оларға қойылатын экономикалық және экологиялық талаптарды қатаңдату тұрғысынан өзекті болып табылады. Сұйық отынды үнемдеу проблемасы отын-энергетикалық ресурстармен қамтамасыз етудегі ең өткір мәселелердің бірі болып қалуда. Сығылған немесе криогендік күйдегі табиғи газды ішкі жану қозғалтқыштарының цилиндрлерінде жағу кезінде жұмыс процестерін ұйымдастырудың жоғары тиімді әдістерін жасау және улы шығарындыларды одан әрі азайту, перспективалық газ қозғалтқыштарында отын тиімділігі мен сенімділігін арттыру жолдарын анықтау өзекті мәселе болып табылады. Сұйық отынның жануын математикалық модельдеу қиын міндет, өйткені ол көптеген күрделі өзара байланысты процестер мен құбылыстарды ескеруді қажет етеді.

Мақалада модельдеу нәтижелері, соның ішінде таза метан түріндегі газ тәрізді отынның шығынына байланысты азот оксидтерінің, шығатын газдардағы бөлшектердің тәуелділік графигі келтірілген. Сонымен қатар, температура мен жылдамдықтың контурлары келтірілген. Тиісті қорытындылар жасалды.

Түйін сөздер: ішкі жану қозғалтқышы, модельдеу, азот оксиді, сұйық отын.

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МОДЕЛИРОВАНИЕ ПРОЦЕССА СГОРАНИЯ В ДИЗЕЛЬНОМ ДВИГАТЕЛЕ

Аннотация. Вопросы процессов горения и организации рабочего процесса горения в дизельных двигателях являются актуальными в виду ужесточения экономических и экологических требований к ним. Проблема экономии жидких топлив остается одной из самых острых в обеспечении топливно-энергетическими ресурсами. Разработка высокоэффективных способов организации рабочих процессов при сжигании природного газа, находящегося в сжатом или криогенном состоянии, в цилиндрах поршневых двигателей внутреннего сгорания и определение путей дальнейшего уменьшения токсичных выбросов, повышения топливной экономичности и надежности в перспективных газовых двигателях является актуальной задачей.

Математическое моделирование горения жидких топлив является сложной задачей, так как требует учета большого количества сложных взаимосвязанных процессов и явлений.

В статье представлены результаты моделирования горения жидкого топлива с разбавлением газообразным топливом (метан), в том числе графики зависимости оксидов азота, частиц в уходящих газах в зависимости от расхода газообразного топлива в виде чистого метана. Кроме того, показаны контуры температуры и скорости. Сделаны соответствующие выводы.

Ключевые слова: двигатель внутреннего сгорания, моделирование, оксид азота, жидкое топливо.

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DETERMINATION OF THE RUNOFF CHARACTERISTICS OF THE YESIL RIVER BASIN BASED ON GIS TECHNOLOGIES

Abstract. The article examines the effectiveness of GIS-technologies in Kazakhstan for determining and clarifying hydrographic characteristics (e.g. catchment area, river length, location, lakes and reservoirs), the analysis of hydrological processes and phenomena, as well as the creation of a cartographic and attributive database of water bodies. Yesil River, the main waterway of the central and northern part of Kazakhstan, is one of the least hydrologically studied catchments in the region. To address this research and information gap data was obtained from remote sensing and runoff depth based on the Kazhydromet network for the period 1945 to 2016. A topographic and river network map (1:1,000,000) of the Yesil River basin, including locations of gauging stations as well as depth and runoff coefficient maps were created using ArcGIS software. These maps provide a very useful tool for water resource management and economic policy decision making.

Keywords: ArcGIS, hydrological modelling, Yesil river, water resource management.

Introduction. Currently, the geographical sciences are adopting and developing a range of new geoinformation technologies (GIS-technologies), which have enormous capabilities to represent, analyze and model geographic objects and phenomena compared to traditional methods.

Now it is possible to use modern information technologies in the creation of cartographic and thematic databases, especially through the development and implementation of geographic information systems (GIS) with different hierarchical level and territorial coverage. [1]. The cartographic method has been used in hydrology since the first half of the last century, and is based on creating and using maps that reflect the spatial characteristics of hydrological data. However, this method has not been widely used in Kazakhstan due to the complexity and time consuming nature of manual cartographic analysis. The cartographic method has again become more widely adopted in hydrology for spatial data processing as the result of the development of new computer technologies [2].

GIS is a powerful tool in the study of water resources, including watershed delineation and morphometric analysis [3]. Digital elevation models (DEMs) are widely used to determine topographic characteristics, which are among the key requirements for obtaining hydrological, river network and terrain attributes. Also, the hydrological characteristics of arid basins and drainage systems can be modelled using DEM. In hydrological studies, DEM is often used to determine river network, catchment area and the morphometric characteristics of a drainage basin [4]. Morphometric analysis of a drainage basin is a quantitative description of a basin and an important aspect to know the character of the basin [5]. The Shuttle Radar Topographic Mission (SRTM), because of its global coverage of the Earth's surface with acceptable accuracy supports DEM, is widely used for watershed delineation distribution and hydrological studies [6].

To be found in the works aimed at the possibility of GIS technology application in hydrology and the fundamental hydrological characteristics of the Yesil River basin [7,8,9,10,11,12], etc., and most of these works address the issues of GIS technology application in case of insufficient hydrological data, determination of hydrological characteristics of reservoirs, graphic and cartographic display of hydrological information.

Justification of the topic choice. Aims and objectives. Defining and specifying the hydrological characteristics of a river basin using a GIS has significant advantages, including data processing capabilities, new versions are available for online download, and it is publicly available.

This study explores the use of GIS-technology for cartographic representation of hydrological data of the Yesil River basin. The Yesil River, Kazakhstan, is located at 50°38′05" N, 73°11′41″ E and 55°23′15" N, 69°21'46" E. The length of the river is 2450 km, the catchment area is 177 000 km^2, including the active basin area of 141 000 km^2[13]. The Yesil River, which is the main waterway of the central and northern part of Kazakhstan, belongs to a hydrologically understudied area.

Literature review and methodology of scientific research. Using GIS-technologies in hydrological studies begins with the choice of the cartographic base of the investigated area. Base map of the area can be obtained from the following pages: https://earthexplorer.usgs.gov/, https://earthdata.nasa.gov/, http://www.sasgis.org/sasplaneta/. In the process of work, https://earthexplorer.usgs.gov was selected from the above pages. To download a base map, click on the link provided and mark the desired area on a geographical map of the Earth's surface. To select and download digital elevation properties, the GMTED2010 digital map was chosen from the Digital Elevation parameter of the Data Sets function and all images displayed in the Results function were downloaded.

The ArcGIS software was chosen as the software tool, which has all the main advantages of any instrumental GIS. These include input and editing of graphic information, automatic generalization, spatial and practical analysis using overlay operations, use of a different scale of information material, creation and manipulation of thematic databases with the possibility of spatial reference to geographical objects, creation of thematic maps and in the end obtaining a finished cartographic product. GIS technologies allows the determination of the hydrographic characteristics of water bodies, such as catchment area, river length, number of tributaries, the order of their location, the area of lake and reservoirs, as well as mapping of water bodies and their basins at a given scale quickly and with maximum accuracy.

In ArcGIS, the images are combined when the selected area includes several images and other territories and then study area is clipped. The images are added to ArcMap and transferred from the Data Management Tools in the ArcToolbox to the Raster Dataset of Raster tools. The Raster Dataset is an organized array of pixels that can be one or several bands. This tool group offers tools to copy, add and create raster data. The Mosaic to New Raster tool can combine several raster datasets into a new raster dataset. The Raster Processing toolset in the Raster tool group facilitates data manipulation, one of which is clipping. This Clip tool cuts out a portion of a raster dataset, mosaic dataset, or image service layer (figure 1).

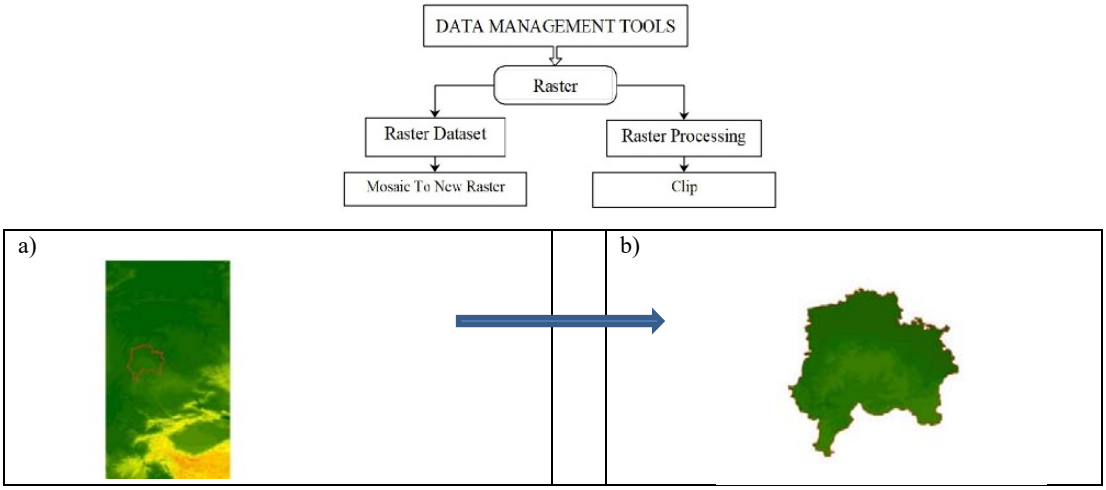


Figure 1 – (a) Data Management Tools model; (b) A cropped image of the Yesil River water basin

Research results and discussion. The ArcGIS program has produced a map at scale 1: 1000000, including the location of gauging stations that provide information on the physical, geographical and statistical hydrological characteristics of the Yesil River Basin (figure 2), as well as digital maps of the middle depth and flow module (figure 4).

During the production of the map, the watershed of the Yesil River catchment, as well as lakes and reservoirs were presented in polygon format. The objects created in this way allow the display of the shape and size of the basin, and the rapid calculation of areas. The layer of rivers is represented as a linear object and is optimal for determining the length of the river and the number of tributaries. It was carried out using two methods: traditional and computer technology. The gauging stations were specified as a point object and enables the relative distance between stations, the distance from the river mouth or the source to be calculated.

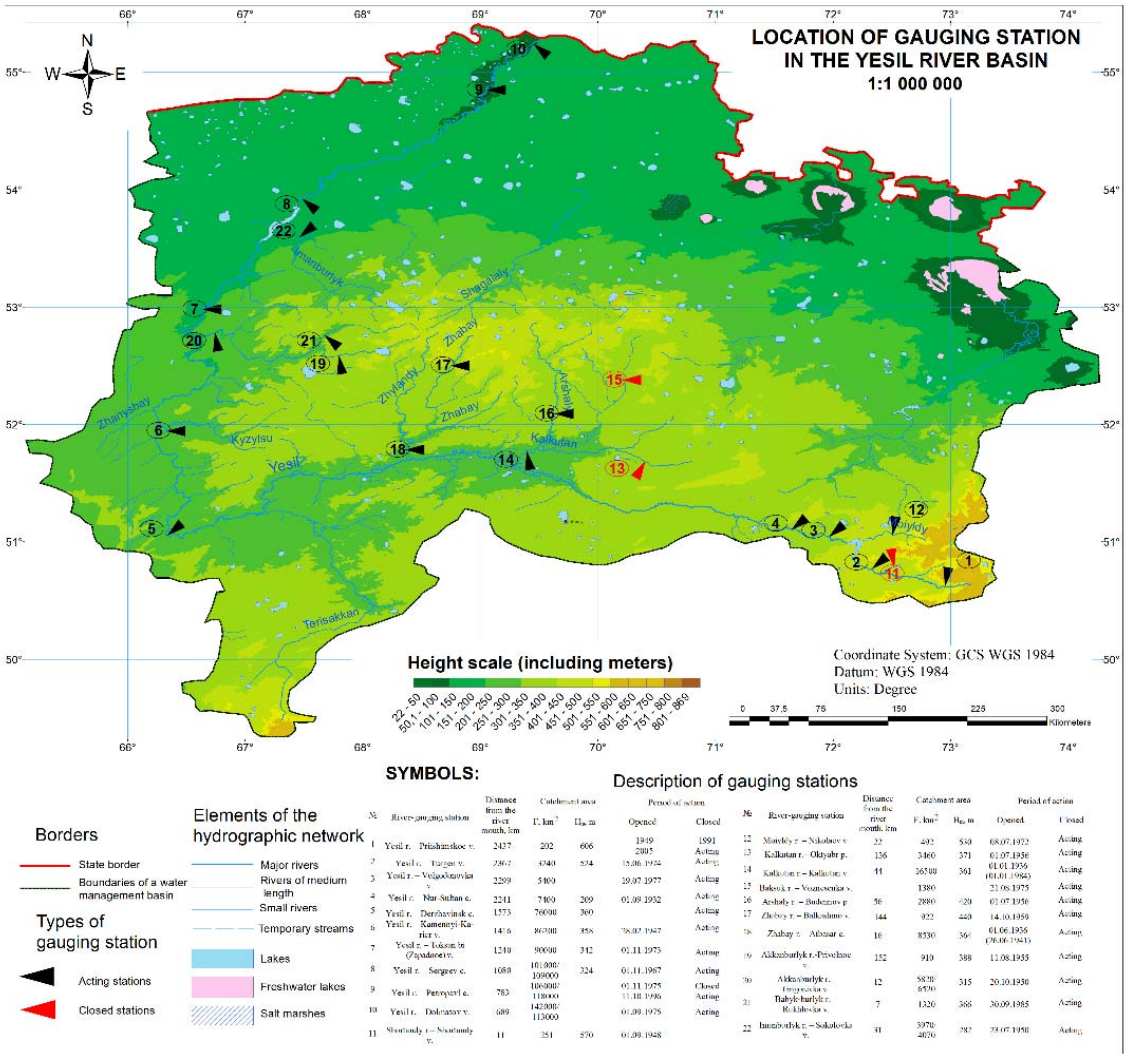


Figure 2 – Physiographic and hydrological map of the Yesil River basin

The hydrological series of runoff from the Yesil River basin has been compiled from publications of the Kazhydromet network 1945 to 2016 (Surface water resources of virgin and fallow lands areas. Akmola region of the Kazakh SSR. - Hydrometeoizdat, 1959; The main hydrological characteristics. Basin of the Yesil River. - 1963-1980; State Water Cadastre of the Republic of Kazakhstan. Long–Term Data on the Regime and Resources of the Land Surface Waters. Part 1. Rivers and Canals. Issue 1. Basins of the rivers Irtysh, Ishim, Tobyl (upstream) - Almaty, 2004; State Water Cadastre of the Republic of Kazakhstan. Annual Data on the Regime and Resources of the Land Surface Waters. Rivers and canals. - 2000-2016).

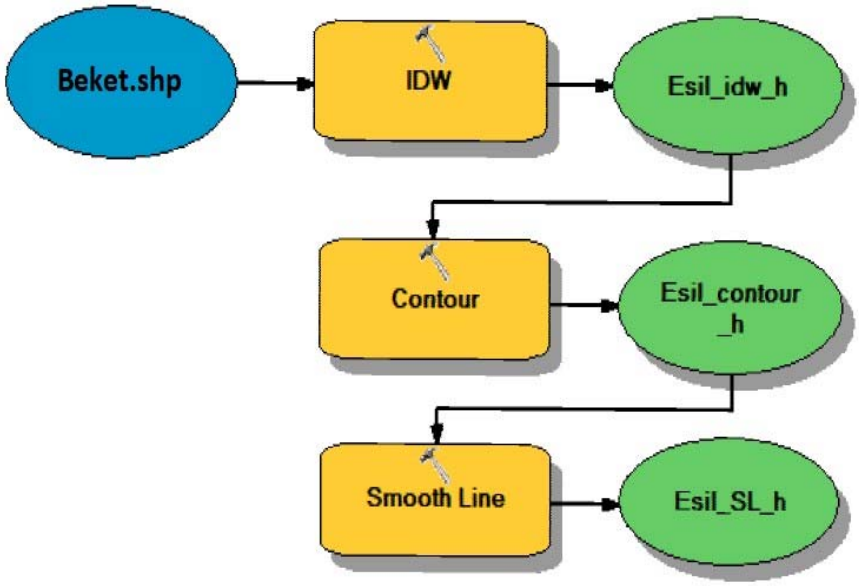


Figure 3 – Diagram of the geo-processing model created in the additional program ModelBuilder

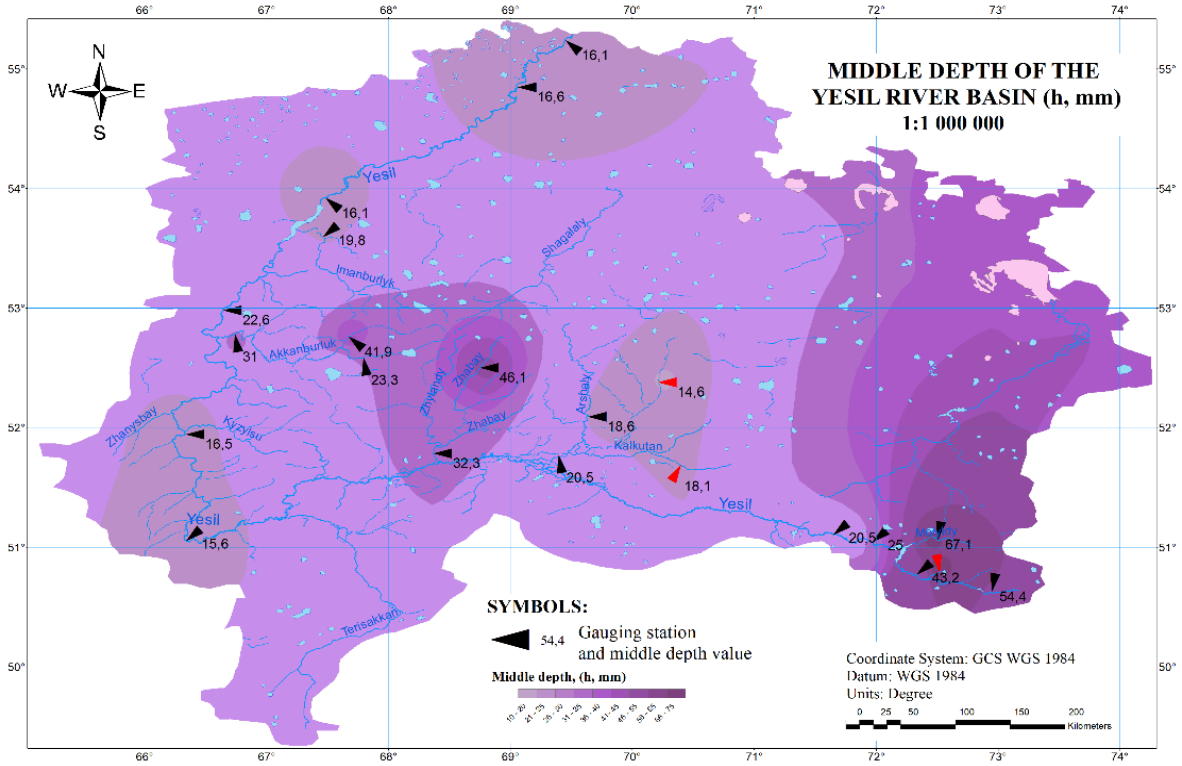
Measurement of hydrological parameter values using traditional methods for objects and phenomena observed at each point of the study object is time consuming and extremely difficult. However, using new information methods, it is possible to predict values that can be assigned to all territories.

A digital map of the distribution of the runoff and the flow module of the Yesil River basin was produced using GIS technology. The map was created with the assistance of ModelBuilder application, which allows creating a geo-processing model in the ArcGIS system. A group of Interpolation tools was selected from Spatial Analyst Tools. It creates a continuous (or predicted) raster surface from values measured at reference points. A raster surface from points is interpolated using an inverse distance weighted (IDW) technique. This IDW tool is used for visualization and numerical expression of terrain forms. To create a class of contour objects on the raster surface from the Surface tool group, select the Contour tool. To improve visual and cartographic quality of lines and smooth corners Smooth Line tools from Generalization tool group of Cartography tools was used (figure 3).

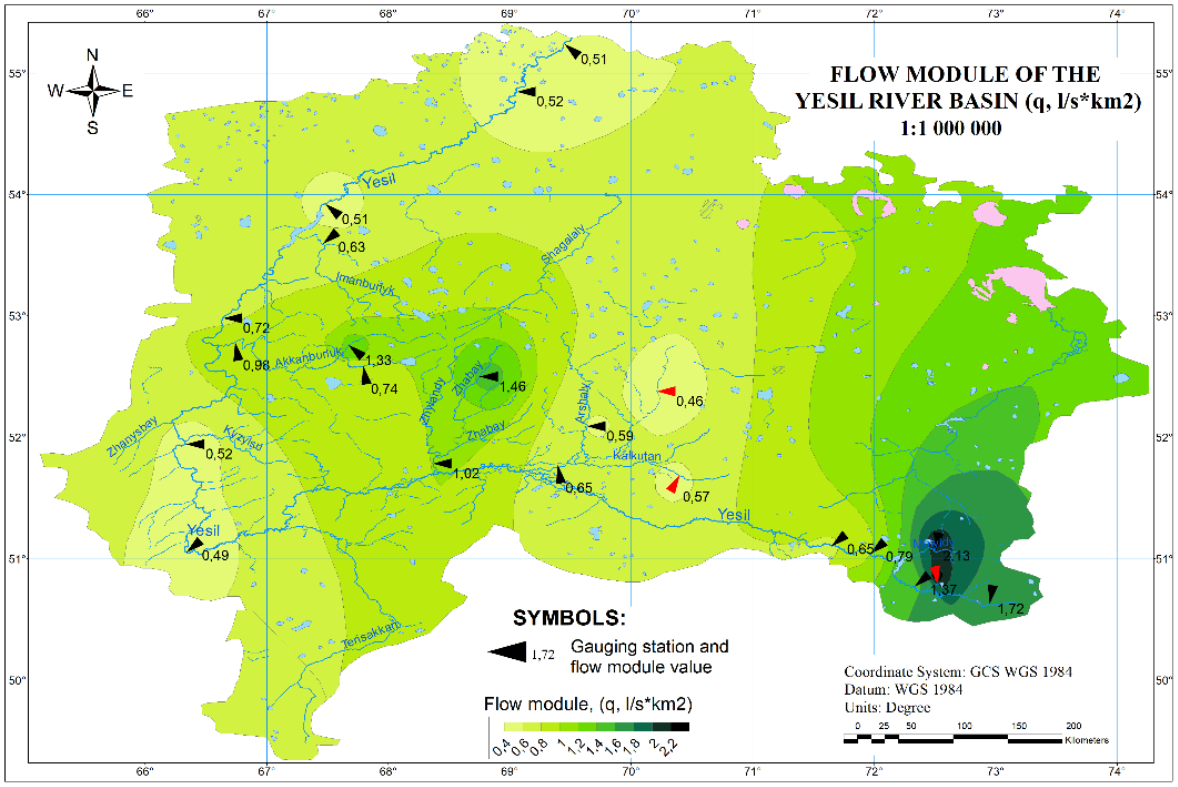
One of the capabilities of GIS-technologies in hydrological research is to create a predicted map of possible hydrological characteristics at all points (territories) of the investigated area using observation data at hydrological stations. In ArcGIS program, by clicking the Identify button at any point (area) of the forecast map, within a very short time in the Identify window it can see the value of the expected middle depth at this point. The water regime map clearly shows the quantitative runoff characteristics and their distribution of the space.

The values of middle depth and flow module at 22 hydrological stations in the Yesil River basin were taken as a hydrological characteristic in the research (figure 4). It should be noted that using statistical methods in hydrology, the values of insufficient series of observation data H, mm were reconstructed using annual average runoff data [14]. This is because the density of the relationship between the mean annual runoff data and the middle depth was high, and proof of this is also stated in [15]. As a result, using the formula [16] of the middle depth data, a multi-year flow module of the Yesil River basin gauging stations (1945-2016) was calculated.

The change in the values of the river basin's middle depth in recent years was compared with previous research works (table). Published data for the 1960s and given for the reporting period 1945-2016 as a result of the comparison revealed that the deviation of the middle depth values (h, mm) in the river basin ranged from +6.02 to -12.1%. In general, it is noted that the values of the middle depth have increased in recent years. At the same time, one can notice that the variability of the coefficient of variation has decreased from -6.59 to -32.9%.



A)



B)

Figure 4 – (A) digital map of the distribution of the middle depth and the (B) flow module of the Yesil River basin

The Yesil River runoff depth parameters' (of calculation period 1945-2016) comparison with the data [17,18,19]

No.	River-gauging station	Data [17,18,19]		Calculation period , 1945-2016		Deviations of parameters of the reporting period (1945-2016) from data [17,18,19], %	
		h, mm	C_v	h, mm	C_v	h, mm	C_v
1	Yesil r. – Udarnoe v.	49,3	0,99	54,4	0,81	+9,37	-22,2
2	Yesil r. – Nur-Sultan c.	23,0	0,97	20,5	0,91	-12,1	-6,59
3	Yesil r. – Kamennyi-Karier v.	13,5	1,13	16,5	0,85	+18,1	-32,9
4	Yesil r. – Petropavl c.	15,6	1,09	16,6	0,83	+6,02	-31,3
5	Kalkutan r.– Kalkutan v.	10,6	1,08	20,5	1,08	+97,7	–
6	Zhabay r. – Atbasar c.	19,7	0,92	32,3	0,76	+39,0	-21,0
7	Akkanburlyk r.–Vozvyshenka (Grigorevka) v.	17,0	–	31,0	0,68	+45,1	–
8	Imanburlyk r. – Sokolovka v.	15,6	1,02	19,8	0,90	+21,2	-11,7

In figure 4, the middle depth and flow module of the Yesil River basin are not evenly distributed. It shows that the middle depth values (h) are within the range 15.6-73.1 mm, the flow module (q) is within the range of 0.46-2.13 l/s·km^2. And this is explained by two main characteristics - physical and geographical features of the area of the study with an uneven distribution of the middle depth and flow module.

Conclusion. Utilization of geo-information technologies in hydrology is ideal for identifying, gathering and analyzing many hydrographic characteristics, modeling hydrological processes and phenomena, as well as for solving many applied tasks. By using these capabilities, water bodies can be rapidly studied and quantified, as demonstrated in this study through the modelling catchment surface runoff.

The hydrological assessment of the Yesil River basin with the assistance of GIS-technologies can be used in water management and planning, as well as by water industry practioners for flood risk assessment and the design of hydraulic structures.

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ГАЖ ТЕХНОЛОГИЯЛАРЫ НЕГІЗІНДЕ ЕСІЛ ӨЗЕНІ АЛАБЫНЫҢ АҒЫНДЫСЫНЫҢ СИПАТТАМАЛАРЫН АНЫҚТАУ

Аннотация. Мақалада гидрографиялық сипаттамаларды (су жинау алабы, өзендердің ұзындығы, олардың орналасу реті, көлдері мен су қоймалары және т.б.) анықтау және нақтылау, гидрологиялық процестер мен құбылыстарды талдау, сондай-ақ әртүрлі гидрологиялық ақпаратты қамтитын су нысандары мен олардың алаптарының картографиялық және атрибутивтік деректер базасын құру үшін ГАЖ-технологияларын қолданудың тиімділігі қарастырылған. Қазақстан Республикасының орталық және солтүстік бөлігінің негізгі су артериясы болып табылатын Есіл өзені гидрологиялық тұрғыдан аз зерттелген аймаққа жатады. Осы ғылыми-ақпараттық олқылықты жою үшін қазгидромет желісі негізінде 1945-2016 жылдар аралығында қашықтықтан зондтау және ағынның тереңдігі деректері алынды.

Нәтижесінде бағдарламалық құрал "ArcGIS" негізінде масштабы 1:1 000 000 болатын Есіл өзені алабының физикалық-географиялық және бекеттердің орналасу картасы, сонымен қатар алаптың ағынды қабаты мен ағынды модулінің карталары жасалды. Бұл карталар су ресурстарын басқару және экономикалық саясат саласында шешім қабылдау үшін өте пайдалы құрал болып табылады.

Түйін сөздер: ArcGIS, гидрологиялық үлгілеу, Есіл өзені, су ресурстарын басқару.

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ОПРЕДЕЛЕНИЕ ХАРАКТЕРИСТИК СТОКА БАССЕЙНА РЕКИ ЕСИЛЬ НА ОСНОВЕ ГИС-ТЕХНОЛОГИЙ

Аннотация. В статье рассматривается эффективность применения ГИС-технологий в Казахстане для определения и уточнения гидрографических характеристик (например, площади водосбора, длины рек, местоположения озер и водохранилищ), анализа гидрологических процессов и явлений, а также создания картографической и атрибутивной базы данных водных объектов. Река Есиль, главная водная артерия центральной и северной части Казахстана, является одним из наименее гидрологически изученных водосборов региона. Для устранения этого научно-информационного пробела были получены данные дистанционного зондирования и глубины стока на основе сети Казгидромета за период с 1945 по 2016 год. С помощью программного обеспечения ArcGIS была создана топографическая и речная сетевая карта бассейна реки Есиль (1:1 000 000), включающая расположение гидрометрических станций, а также карты глубин и коэффициентов стока. Эти карты являются очень полезным инструментом для управления водными ресурсами и принятия решений в области экономической политики.

Ключевые слова: ArcGIS, гидрологическое моделирование, река Есиль, управление водными ресурсами.

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CONDITIONS FOR THE FORMATION OF CLINOFORMS IN THE MIDDLE AND SOUTH CASPIAN MEGABASIN

Abstract. The paper considers sedimentation process and objects of lateral development in deep-water uncompensated and shallow-water – epicontinental paleobasins developed at various evolution stages of South-Caspian and Middle-Caspian basins. The South Caspian megabasin is a great tectonic crustal element and a highly prospective sedimentary basin in the central segment of the Alpine-Himalayan mobile belt. The role of boundary structures of Scythian-Turan platform in the Middle Caspian (such as South-Caspian land and Karaboghaz arc) and avalanche sedimentation on the continental shelf in development of sedimentation units and specific shape objects of lateral development in many kilometers long sedimentary cover of South-Caspian basin has been shown. According to interpretation of seismo-stratigraphic data the inflow of paleodeltaic, avandelatic and turbidite objects of lateral development for infill of the Early Pliocene basin has been proved. Seismo-stratigraphic analysis, using other analyses (e.g. study of morphostructure of palaeorelief and thicknesses of the units and formations) and GSW, enabled the genesis of deposits in the underlying PS formations to be clarified from a new perspective and the favourable zones of formation of large lithological and stratigraphic traps for oil and gas accumulations to be identified.

Key words: sedimentary basins, South Caspian basin, clinoform, Miocene, Early Pliocene, Absheron, Quaternary deposits.

Introduction. Analysis of regional seismic stratigraphy data acquired from the South Caspian and Middle Caspian basins display that at the various phases of their evolution the uncompensated sedimentation mode is common for this area. It must be noted that 50% of sediments in the south part of Middle Caspian basin and sediments in South Caspian basin consist of uncompensated laterally accumulating objects in deep water basins, which further form clinoform type sedimentary sequences. These objects and sequences were accumulated during the periods of sharp sea level drop and intensification of activity of paleoriver, underwater flows and channels and in areas of erosion of wide shelf zones. River deltas were generating progradation type sedimentary objects in coastal zones and shelfs while the output cones of underwater channels generated the same on the continental slopes and abyssals. Layers making up these sequences are characterized by inclined sigmoidal and clinoform type layer boundaries (figure 1). Layers thickness does not characterise syncronous vertical tectonic motions. In this respect, techniques such as “thickness analysis” and “hidden thicknesses restoration”, as well as some other tools, such as borders extrapolation and intrapolation techniques could not be applied for paleotectonic restoration of uncompensated basins. Seismic stratigraphy analysis of regional lines shows that at the all stages of basin evolution the uncompensated mode was dominating.

Geodynamic, tectonic and seismic stratigraphy studies performed for the last 2-3 decades evidenced that South Caspian basin is the relict of marginal (behind the arc) sea (Caucasus-Caspian – Kopetdag marginal sea) recovered in Middle Jurassic across the northern active flank of Meso-Tethys and developed over the oceanic crust. It has been identified that the platform cover was evoluted on shelfs and slopes of embracing continental areas in Mesozoic and Paleogene of Middle Caspian, while in Neogene the epicontinental – forebasins was developing (including North Absheron basin) [1,2].

Interpretation of data acquired in the South and Middle Caspian by use of 16-20 sec. ultra-deep seismic Common Depth Point technique displays consolidated crust of South Caspian basin as thin and oceanic type (~6 - 10 km) and its subduction below the Scythian-Turanian platform to the north-east [3,4]. Based on seismic stratigraphy studies 10 seismic stratigraphy units – sedimentation sequences are outlined in sedimentary cover of high thickness (>25 – 27 km) limited by seismic horizons and uncomformity surfaces [5].

Geodynamic processes, tectonic motions and sea level fluctuations in the region generated various types of tectonic and morphological sedimentary basins. Seismic stratigraphy outlines two types of morphological sedimentary basins: deep water (uncompensated) basins and shallow epicontinental basins [6-9] (figure 1).

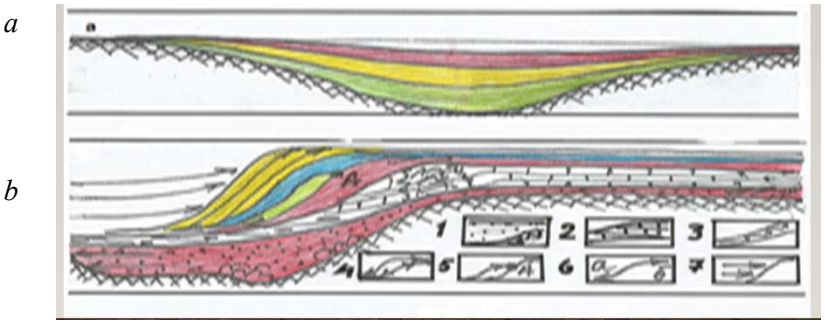

Figure 1 – Morphological types of sedimentary basins:
a – shallow consedimentation epicontinental basin; *b* – deep-water uncompensated basin:
1 – laterally filled (reverse) clinoform; 2 – carbonate (direct) clinoform; 3 – depression sediments;
4 – progradation clinoform; 5 –layers onlapping the steep slope; 6-laying over the foot (a) and top (b); 7 – onlapping the foot

The former are the basins recovered as a result of riftogenesis (horizontal stress and vertical sedimentation) and developed over the oceanic crust. In some cases they are named as “sedimentation traps” or “topodepression”. The latter are the basins developed over the platform or in intermountain areas [10-14]. Great Caucasus – South Caspian marginal sea outcropped as a result of riftogenesis in Jurassic extended and deepened to Oligocene and was not compensated by sediments. Despite subduction and tension started from Oligocene the marginal sea and its relict- the South Caspian Basin were an areas of constant subduction. Presence of terrigeneous laterally accumulating sedimentary objects in the northern part of South Caspian basin and fore-platform transition zones on continental slopes, as well as presence of carbonate clinoforms on shelf margins are evidencing deep water nature of this basin. Seismic stratigraphy makes it possible to outline lateral sedimentation (reverse clinoform), carbonate (direct) clinoform, progradation clinoform and depression sediments attributed to deep water seas existed in the South Caspian basin at various time periods. (figure 2).

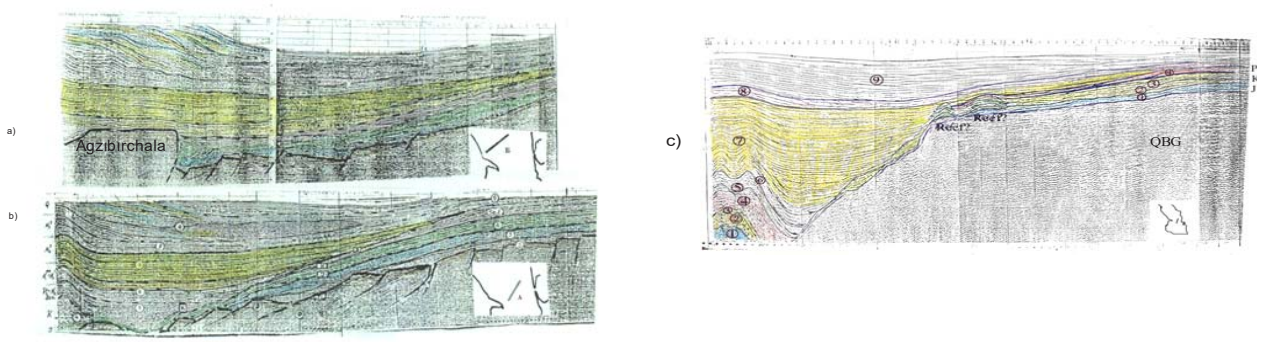

Figure 2 – Image of laterally accumulated terrigeneous and carbonate objects (sequences) in regional profiles

Lateral sedimentation is generated by terrigeneous material incoming from shelf, covering the bottom and relatively gentle slope (<10^0) creating reverse clinoform. This sequence consists of gently-sloping parallel layers onlapping the slope foot.

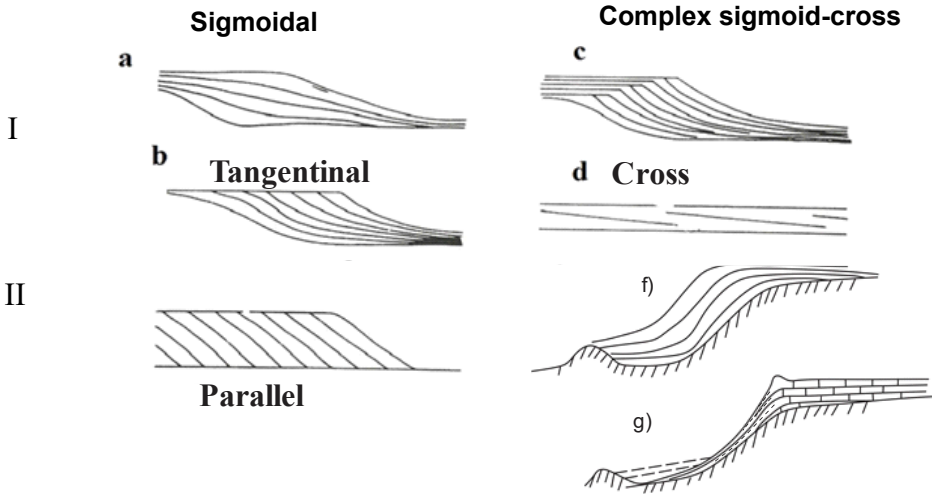

Figure 3 – Image of laterally accumulated sedimantary objects in seismic time sections:
I – scheme of laterally accumulated sedimentary objects;
II – progradation terrigeneous clinoform (f), carbonate clinoform (g) and elements of deltaic sequence

Carbonate clinoform is generated in areas with no erosion on passiv shelfs and far distance of sedimentation sources and replaced by depression facies at the foot of the slope. In case of abnormal amount of brought detritus the sedimentary sequence accumulated laterally on the gentle slopes creates terrigeneous clinoform (figure 3). On relatively steep ($>15^0$ - 20^0) slopes sediments brought from shelf serve as a transit along the slope and laterally cover foot of the slope. Progradation type clinoforms are observed also in areas far from avandelta and gentle slopes.

Applying backstripping analysis for reconstruction of the South Caspian basin subduction to the large depths [8] and seismic stratigraphy analysis it has been derived that the South Caspian basin always was a deep-water basin. At the divergence (extension) stage the depth was 3-5 km, at the convergence (compression) stage the depth was 2 - 1 km. In both cases the basin was not fully compensated.

It must be noted that even in the Early Pliocene basin considered as a shallow-water the deep-water lake existed in fore-Elbrus trough and deltaic and avandeltaic sediments were accumulating on its shelf and slopes due to sediments brought by large rivers (Paleo-Volga, Paleo-Uzboy, Paleo-Kur) and tens of small rivers. As a result, the lake was extended, however not fully compensated. Identification of seismo-facies units laterally accumulated and onlapping the slopes in Late Pliocene and Pleistoceine in the central part of South Caspian are the pivotal indicators of the deep-water basin presence in this area through all time periods.

Clinoforms are generated by joint impact of sea level fluctuations and sedimentation rate, while they have poor relation with tectonics. Studies of laterally accumulated sedimentary objects makes it possible to derive comprehension of paleotectonic and paleogeographic sedimentation environment in the basin. Paleotectonically these objects display uncompensated sedimentation mode of negative (subsided) relief. Paleogeographically these units by their form, configuration and dip of reflection surfaces allow to derive denudation areas locations, erosion direction, erosion basis and sedimentation areas. Finally, from oil and gas exploration point of view the clinoforms deserve the interest for prediction of coarse detrital and sand lenses presence [15-16].

Seismic stratigraphy makes it possible to outline and map paleogeographic zones playing a major role in generation of sedimentation cover in ancient continental margins in Caspian section of Scythian-Turanian platform during Mesozoic and Cenozoic.

In highly informative seismic time sections of Middle Caspian the wide continental shelfs (100-120 km) of Mesozoic –Paleogene basins the gentle ($<1^0$ - 5^0) and relatively steep (>20°) slopes are reflected (Figure 4). These shelfs and slopes for a long period of time (from Late Jurassic to the Middle Miocene) were morphological and structural units of regional scale on continental margins of Meso-Tethys (Neo-Tethys) marginal sea. In transition zone from the southern flank of Scythian-Turanian platform to the Alpian active zone several sedimentation units developed under the environment of sea

level fluctuations and tectonic processes, they were limited by layer boundaries and unconformity surfaces: vertically developing (aggradation), laterally developing (progradation), accumulative, massive, sediments filling exogenic relief and faults. In the South Caspian basin the clinoform type clastic sedimentary sequenc are widely distributed. These evidences lateral infill by sediments brought from continental margin of deep-water basin. On seismic sections of sedimentary sequences of various age in Middle Caspian and South Caspian basins the laterally developing units can be clearly seen (figure 4). In these basins the laterally developing and clinoform sequences were identified in Paleogene (Oligocene, in particular), Miocene, Early Pliocene, Absheron and Quaternary deposits.

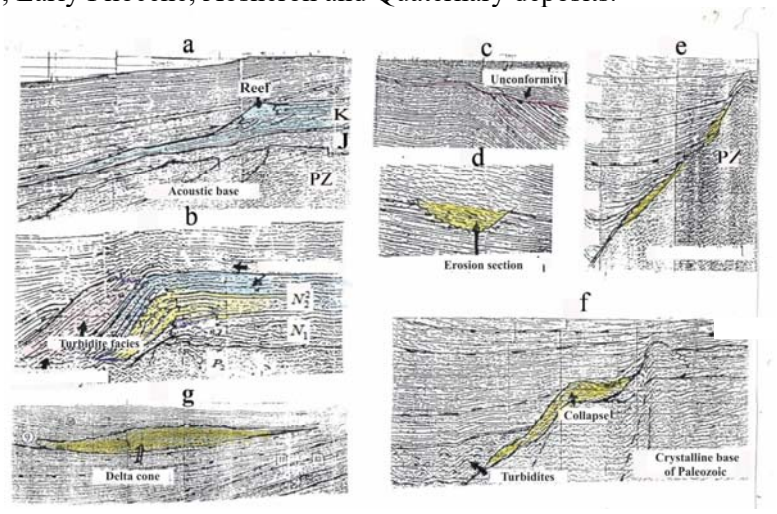

Figure 4 – Fragments of time sections dispalying lateral objects covered shelfs (b, c, g), gentle slopes (a) and steep slopes (e, f) and filled up the erosion sections (d)

The real mechanism of terrigeneous sedimentogenesis on continental margins is clearly displayed by flow-type sedimentation concept [17-18]. Modern concepts on eustatic and relative fluctuations of sea level gives us the logical explanation of huge amount of sediments in these zones. According to flow-type sedimentation concept while the low sea level the sediments are moved to the slope foot from deltas and shelfs by water flow and dense flow (gravities). Deltas, shelfs and slope foot are the major places where laterally accumulating sedimentation masses are developed. Seismic stratigraphy shows that in some cases the gentle continental slopes are areas favorable for generation of laterally accumulating objects.

Analysis of morphological features of northern near-flank structures of Mesozoic-Paleogene paleobasins in transition zone reflect that the zone corresponds to the classical model of continental margins of marginal seas in modern oceans. Here the specific features of transition from continent (platform) to deep-water marginal sea (the South Caspian basin as its relict after the Miocene) are the major indicators of the South Caspian basin being of marginal sea origin. Thus, transition structures of Epi-Paleozoic platform in the Middle Caspian play an exceptional role in generation of sedimentary units of various age and laterally developing objects of specific shape in sedimentary cover of South Caspian basin.

One of the major results of paleogeographical and facies analysis is the conclusion that sedimentary cover of high thickness (>20 – 25 km) was formed due to detrital and erosion materials brought mainly from the north – Scythian -Turanian platform and neighboring mountain ridges by river flows, mudflows and underwater flows.

Sediments of high thickness (>27 – 30 km) were accumulated on the northern flank of South Caspian basin – at the threshhold of Absheron-Balkhanyani (after closure of Great Caucasus and Kopetdagh segments of marginal sea in Miocene). On seismic sections they are mostly were traced in the northern flank of South Caspian basin - at the threshold of Absheron-Balkhanyani and adjacent areas. Mesozoic-Paleogene deposits of high thickness (~10 – 15 km) were uplifted and currently they can be identified at 1.0 – 3 km depths in some structures of North Absheron uplift zone (Absheron kupasi, Shargi Gilavar, etc.). A huge amount of sediment accumulation in the northern flank of South Caspian basin and uplifting of ancient (Mesozoic – Paleogene) deposits was previously supposed as related to geosynclinal processes in the region.

However, for the last years, based on interpretation of ultra-deep seismic data it became obvious that in the northern part of South Caspian basin the major reason of complicated folding, high thickness and uplifting of Mesozoic-Paleogene deposits is cutting and deformation of sediments during subduction of oceanic type of crust in the basin and development of overthrust type structure within its accretionary wedge. Seismic stratigraphic analysis of acquired data provides accurate data on laterally developing objects and tectonic and morphological elements in fluvial-deltaic zones of Middle and South Caspian, ancient continental shelfs, slopes and slope foot. To study laterally developing objects in these paleogeographic zones the known diagnostic techniques of seismic stratigraphy are applied [19-20].

The role of fluvial-deltaic sequences was significant in evulotion of sedimentary sequences on the northern continental border of marginal sea – in the southern flank of Scythian-Turanian platform. During the periods of low sea level the sediments were eroded from continental shelfs and slopes by underwater flows and dense mudflows down to the slope foot where they created huge cone outcrops.

In the South Caspian the origin of the major hydrocarbon bearing target – Productive Series of Early Pliocene is related mainly to three large rivers (Paleo-Volga, Paleo-Uzboy and Paleo-Kur) and paleodelta of several small rivers. At the end of Pontian during regional "Messinian Salinity Crisis" (5.1 mln. years ago) the sharp decrease (700 m) of erosion basis led to transportation of a huge amount of fluvial-deltaic, sandy-clay (detrital) sediments into the small lake on the south of the Caspian through Paleo-Volga and other rivers (figure 5), riverbeds, channels, ravines and underwater valleys.

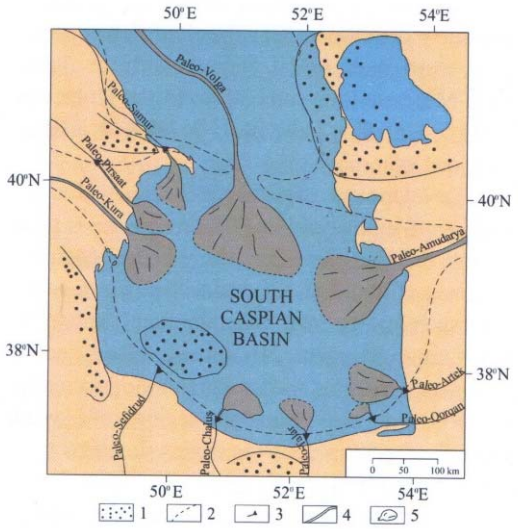

Figure 5 – Riverbeds and deltaic systems in the Early Pliocene basin:
1 – relative uplifts; 2 – basin limits; 3 – riverbeds; 4 – large riverbeds and underwater ravines; 5 – deltas

Deltaic and avandeltaic units of Paleo-Volga and Paleo-Uzboy were mentioned in many papers. The huge deltaic system of Paleo-Volga was developing from the end of Miocene to the south for 150 - 200 km (to the center of South Caspian basin) and moved for 200 km to the north (to the center of Middle Caspian) during basin transgression at the end of Early Pliocene (figure 6). The wide deltaic system of Paleo-Volga developed in the Early Pliocene in transition zone from Middle Caspian to the South Caspian, around the Absheron threshold in particular, has played a crucial role in development of oil and gas bearing Productive Series. Avandeltaic clinoforms of Paleo-Uzboy can be clearly traced in Early Pliocene section in the north-east of South Caspian basin (figure 6). These clinoforms were developing through the whole paracycle (apprpximately 500 thousand years) of relative sea level fluctuations in the narrow area (50 - 60 km). Stacked clinoforms consist of initial clinoforms (a), the cover made of conformable layers (b) and cross bedding (c). According to seismic sections the I – stacked clinoforms cover by 15-20 km laterally and by 100-200 m vertically the initial topographic trough. As a result, new sedimentary slope was developed, which after a long period of hiatus (approximately 300 thousand years) was covered by a new – II clinoform (figure 6). This clinoform covered new slope laterally by 30-40 km and vertically by 300 m. Currently this clinoform is buried at 4.5 – 7 km depths.

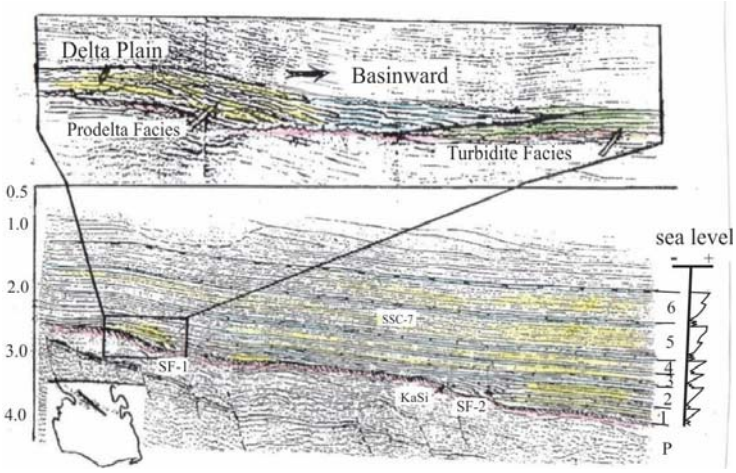

Figure 6 – Delta and avandelta systems of large rivers in the Early Pliocene
and delta-avandelta systems and turbidites in pinching out zones of Gala suite

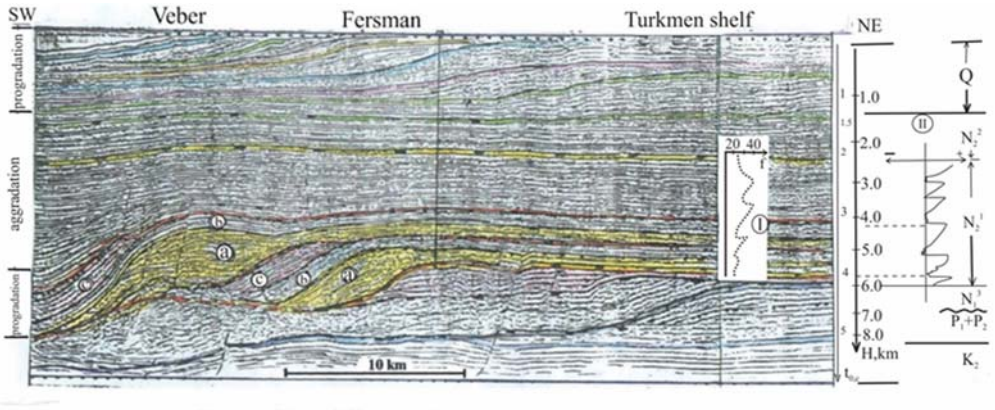

Figure 7 – Chronostraigraphic section displaying relative sea level fluctuations
and hiatus in accumulation of Paleo-Uzboy avandeltaic sequence in the South Caspian basin

The special attention should be paid to turbidites in deep-water basin of Early Pliocene across the South Caspian basin. In the USA large hydrocarbon accumulations have been discovered namely in such deposit types (turbidites). From the Ventura field only 120 mln.t of oil and 60 mln.m^3 meters of gas were produced from turbidite deposits. In the Mexican gulf also the oil and gas bearing sequence with alternation of high quality reservoirs and pelagic deposits has been attributed to turbidites [21-22]. They have been accumulated in areas far from frontal parts of deltas and avandeltas and in underwater cones. In the central portion of South Caspian several large structures (Umid, Babek, Inam, etc.) have been discovered by seismic survey. These are mainly located in the areas of turbidites accumulations in underwater cones of frontal parts of large and small rivers deltaic systems (Paleo-Kur, Paleo-Volga, Paleo-Uzboy, etc.) in the Early Pliocene basin (figure 7).

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ОРТА ЖӘНЕ ОҢТҮСТІК КАСПИЙ МЕГАБАЗИНІНДЕГІ СЫНА ПІШІНДЕРІН ҚАЛЫПТАСТЫРУ ШАРТТАРЫ

Аннотация. Мақалада тұнбаға түсу процесі және Оңтүстік-Каспий және Орта Каспий бассейндерінің эволюциясының әр түрлі кезеңдерінде пайда болған терең сулы компенсацияланбаған және таяз-эпикон-тинентальды палеобазиндердің бүйірлік өсу объектілері қарастырылған. Оңтүстік Каспий мегабазині – жер

қыртысының үлкен тектоникалық элементі және Альпі - Гималай жылжымалы белдеуінің орталық сегментіндегі болашағы зор шөгінді бассейн. Скиф - Тұран платформасының шекаралас құрылымдарының Орта Каспийдегі рөлі (Оңтүстік Каспий ойпаты және Қарабоғаз доғасы) және континентальды қайраңдағы қар көшкінінің тұнбалары шөгінді кешендермен көпқабатты жанама аккреция сандарының даму рөлі көрсетілген. Оңтүстік Каспий ойпатының шөгінді жабыны көрсетілген. Басқа талдау деректерін қолдана отырып сейсмостратиграфиялық талдау (мысалы, палеорельефтің морфоструктурасын және мүшелер мен түзілімдердің қалыңдығын зерттеу) және ұңғымаларды геофизикалық зерттеу жаңа қабаттардан өнімді қабаттардың төменгі қабаттарындағы шөгінділер генезисін жарықтандыруға мүмкіндік берді және мұнай мен газды жинақтауға арналған үлкен литологиялық-стратиграфиялық тұзақтарды қалыптастыру үшін қолайлы аймақтарды анықтау.

Түйін сөздер: шөгінді бассейндер, Оңтүстік Каспий бассейні, клиноформалар, миоцен, ерте плиоцен, абшерон, төрттік шөгінділер.

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УСЛОВИЯ ФОРМИРОВАНИЯ КЛИНОФОРМ В СРЕДНЕ- И ЮЖНО-КАСПИЙСКОМ МЕГАБАССЕЙНЕ

Аннотация. В статье рассмотрены процесс седиментации и объекты латерального наращивания в глубоководных некомпенсированных и мелководно-эпиконтинентальных палеобассейнах, сформировавшихся на различных стадиях эволюции Южно-Каспийского и Средне-Каспийского бассейнов. Южно-Каспийский мегабассейн – крупный тектонический элемент земной коры и высокоперспективный осадочный бассейн в центральном сегменте Альпийско-Гималайского подвижного пояса. Показана роль пограничных структур Скифо-Туранской платформы на Среднем Каспии (Южно-Каспийская впадина и Карабогазская дуга) и лавинной седиментации на континентальном шельфе в развитии осадочных комплексов и объектов специфической формы латерального наращивания в многокилометровом осадочном чехле Южно-Каспийской впадины. Согласно интерпретации сейсмостратиграфических данных доказано поступление палеодельтаовых, авандельтовых и турбидитных объектов латерального наращивания для заполнения раннепилиоценового бассейна. Сейсмостратиграфический анализ с использованием других данных анализа (например, изучения морфоструктуры палеорельефа и мощностей пачек и свит) и ГИС позволил осветить генезис отложений в подошвенных свитах ПТ с новых позиций и выявить благоприятные зоны формирования крупных литолого-стратиграфических ловушек для скопления нефти и газа.

Ключевые слова: осадочные бассейны, Южно-Каспийский бассейн, клиноформы, миоцен, ранний плиоцен, Абшерон, четвертичные отложения.

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PROSPECTS FOR APPLICATION OF MULTI-SPECTRAL EARTH SENSING DATA IN FORECASTING AND SEARCHING FOR RESERVOIR-INFILTRATION URANIUM DEPOSITS

Abstract. Reservoir-infiltration uranium deposits («sandstone» type) today are the main active source of uranium mineral raw materials in the world and the only one in Kazakhstan. Their main advantage in the form of better environmental friendliness, productivity and minimum production costs creates prospects for their further detection in various parts of the world. It is important to simplify and improve multi-stage, expensive and difficult geological exploration works for the purpose of forecasting and searching them with affordable innovative solutions. The available multispectral satellite imagery has opened up new opportunities for the study of uranium ore provinces. Mapping of uranium ore provinces based on multispectral satellite imagery allows them to be compared with certain key ore-controlling data from geological and geophysical studies. The near-surface visible nature of geotectonic structures, climatic conditions and zonal anomalies are more easily and efficiently visualized using modern space technologies and computer solutions. The explanation of the derived correlations with the geotectonic and climatic conditions allows the use of multispectral images in order to simplify and improve the quality of forecasting, prospecting and exploration of reservoir-infiltration uranium deposits. More advanced aerial and space remote sensing methods make it possible to detect surface anomalies associated with this type of ore. The scientific explanation of the nature of these anomalies and their role in the geological and genetic model of ore formation creates a solid theoretical basis for improving the exploration methodology. The convergence of the results obtained, their theoretical explanation, simplicity and convincingness of the results make it possible to make new predictions of promising areas of reservoir-infiltration uranium regions for several of the key ore-controlling factors and use this methodology in conjunction with other data from regional and local studies at all stages of exploration.

Key words: Uranium ores, reservoir-infiltration deposits, geological exploration, prospecting, forecasting, multispectral sounding, satellite imagery.

Introduction. Reservoir-infiltration uranium deposits («sandstone» «roll-front» type by IAEA classification) have distinctive geotechnological parameters, due to which today they are among the most environmentally acceptable, productive and economically viable sources of natural uranium in the world [1]. The discovery of such deposits in the world is complicated by the relatively small thickness of ore bodies (usually 5-20 m) and their high depth of occurrence under a thick sedimentary cover (usually from 100 to 700 m and more). In terms of plan, uranium ores look by relatively narrow (several hundred meters) and extended (tens and hundreds of kilometers) intermittent and winding ribbon-like stripes, which also significantly complicates their search and forecasting at all stages of geological exploration [2, 3]. Forecasting and prospecting of such deposits in the main scope of work is carried out by exploratory drilling of geological exploration and hydrogeological wells with a set of related studies. When drilling wells, a complex of geophysical studies, core sampling, radiometric sampling, sampling from core and water for analytical studies and other work is performed. This search method proved to be the most successful and is used to this day. All previous regional and local geological exploration data, terrain maps and advanced research data are used to select the optimal drilling network and depth. The aim

of this work is to improve and simplify the methodology for forecasting, prospecting and exploration of these types of mineralization by using a modern theoretical base, accumulated experience and innovative computer, air and space technologies, which will improve the possibility and profitability of expansion and replenishing the uranium mineral resource base of Kazakhstan and the world as a whole.

Methods and solutions. For the study, materials were initially collected on the main sources of mined natural uranium in the world in the person of the Shu-Sarysu and Syrdarya reservoir-infiltration uranium ore provinces located in the southern part of the Republic of Kazakhstan. Numerous materials have been accumulated due to previous direct participation in various types of geological exploration, cameral and research work in these uranium ore provinces for 13 years in the organization of Volkovgeology JSC and one year in the Institute of High Technologies LLP of NAC Kazatomprom JSC. The historical materials of the previous geological exploration works of the Volkovskaya and Krasnokholmskaya expeditions were mainly used, with the addition of previous fund and public regional and geophysical studies, as well as data from modern geological exploration and research. Based on the materials of many years of experience, collected and literature data, the main ore-controlling factors on a regional scale were investigated and their mapping was analyzed. Cartographic information was analyzed from 40 to 50 parallel of North latitude and from 60 to 78 meridian of East longitude, as well as adjacent territories. Further, using various modern computer solutions and multispectral space sensing data, maps of these uranium ore provinces were compiled and combined in formats associated with ore-controlling factors. For the set goals and objectives, a satellite map of the terrain was chosen in combination with a satellite map of visible RGB light, which displayed the near-surface geotectonic and climatic conditions precisely at the level of detail that is closely related to ore-controlling factors. When creating a terrain map, a number of different methods were tried on the basis of publicly available data such as ALOS AW3D, SRTM, etc., which were easily visualized in software solutions such as Global Mapper, Surfer and the like, but there were difficulties in choosing the optimal color system for displaying the elevation level , which took a significant amount of time. To significantly simplify this task and obtain a sufficient level of quality, a ready-made solution World Relief Map was used in the catalog of ArcGIS online maps, which was freely exported at a resolution of 5000x5000 pixels, which is quite enough for a small-scale regional study. When choosing data for satellite maps of visible RGB color, materials of numerous Internet services with space images such as Google, Bing, Yahoo, Nokia, Yandex, ArcGIS and others were examined. After a detailed comparison, publicly available ArcGIS Imagery and Google imagery were selected, which had readily available, more recent, better quality and already processed data for the surveyed area. When combined with a terrain map, the color gamut of Google maps more clearly matched the satellite terrain map, and therefore chose the data on Google images. SASPlanet software was used to create high-resolution satellite maps with coordinate reference, which made it possible to download and seamlessly paste several thousand satellite images of these services in a matter of minutes [4]. The created satellite maps were combined with 50% layer-by-layer transparency in the Mapinfo Professional program and supplemented with thematic data, as well as compared with thematic maps on the data of uranium ore provinces (figure 3). Based on the compared data, a detailed analysis was carried out for the convergence of the results with ready-made thematic maps and ore-controlling factors, their quality, and detail (figures 1, 2, 3). After a detailed comparison, a theoretical explanation of the relationship between the uranium-ore zoning and the obtained mapped data was proposed, which also explains the studied local anomalies by other methods of remote sensing by other authors.

Results and discussions. According to the infiltration model of ore formation, the hydrodynamic conditions of the region, the climatic conditions of the ore formation epoch and the geochemical type of ore-hosting rocks are identified as the main factors necessary for the formation of uranium deposits [5, 7]. For the formation of a favorable reservoir-infiltration system, it is necessary to lay down permeable deposits between impermeable strata, the formation exit to the area of surface water recharge and the area of its unloading, which allows the infiltration process to take place for a long time. The formation of such layers is primarily determined by the geotectonic regime of the area. The uplift of the earth's crust above sea level leads to its destruction by natural phenomena and the transfer of newly formed loose sediments. Sedimentation occurs in stages and is characterized by different facies in conditions of activation [6] and calm, as well as climatic and other changes. The formed formations are universally characterized by the alternation of various lithological-facies zones with different filtration and geochemical features. The

sedimentation process in many cases leads to the formation of strata of the syneclisous type, and the violation of this structure, as a rule, creates other areas of aquifer recharge and unloading. For this reason, continental mountainous areas, which are well observed on satellite images, almost always form infiltration artesian basins in the immediate vicinity, and their scale largely depends on their type. The humid climate is favorable for the formation of organic sorbents and uranium reducing agents, but thereby prevents its migration in the waters, and the arid climate is favorable for the penetration of formation waters carrying uranium over long distances and depths, but not favorable for the formation of a powerful reducing barrier that allows the formation of a rich and contrasting deposits [7]. Zonal and periodic

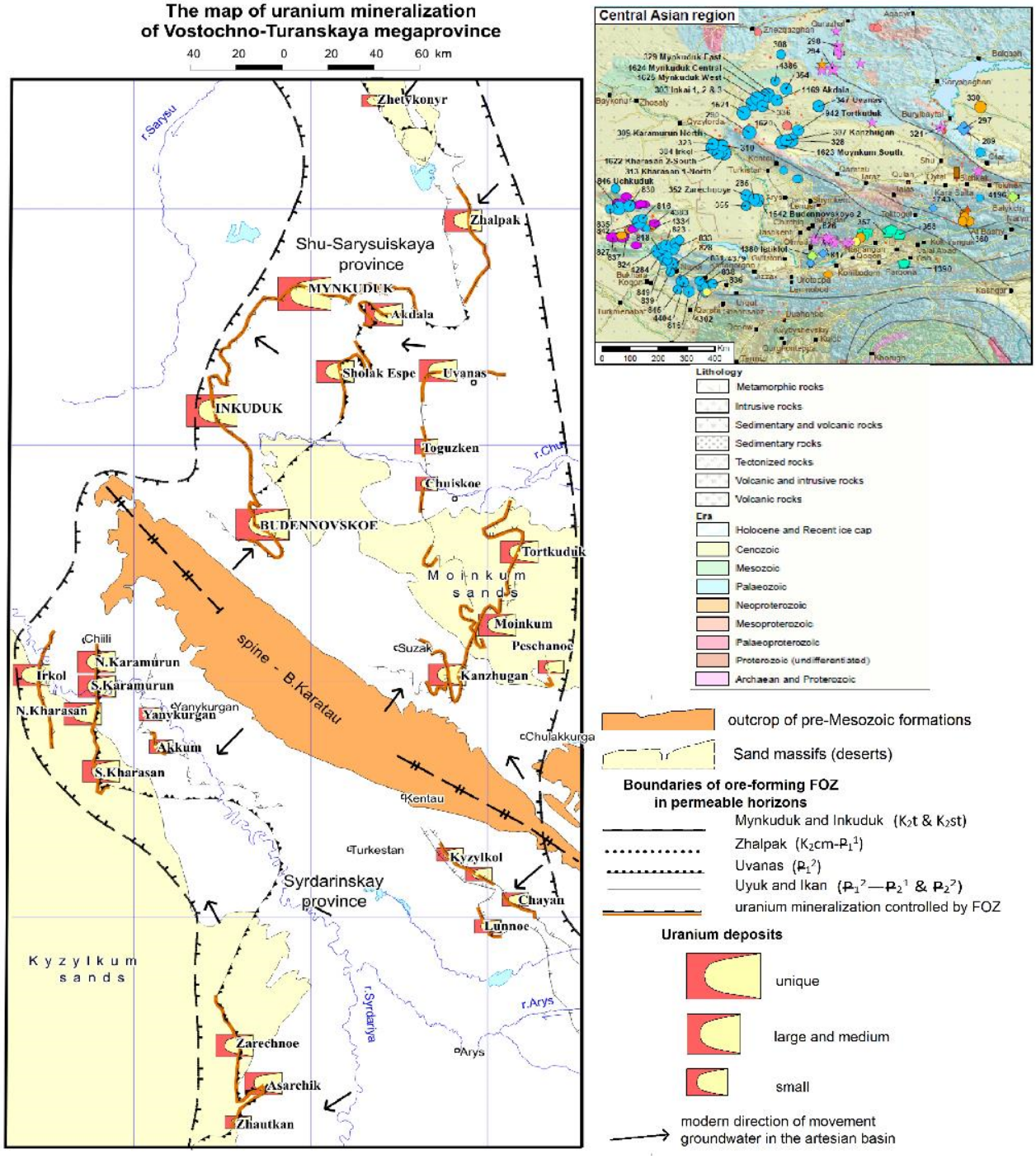

Figure 1 – Uranium mineralization of the East Turan province

climate changes from arid to humid and vice versa create geochemical boundaries with different oxidation-reduction potentials of sedimentary deposits favorable for the formation of uranium mineralization. But the formation of uranium mineralization is possible only during periods of a sufficiently long arid and subarid climates allowing uranium-dissolving surface waters to penetrate with a rich oxidizer over long distances and depths to transfer a significant amount of reservoir-infiltration ores to the reduction barrier [5]. Therefore, at the current time, the most promising for predicting potential reservoir-infiltration uranium provinces are desert and semi-desert zones in the vicinity of continental mountain ranges and uplifts, as well as adjacent areas. In such systems, extended zones of formation oxidation have formed, the fronts of pinching out which are the main ore-controlling factor in deposits of this type. The Shu-Sarysu and Syrdarya uranium ore provinces together represent the East Turan uranium ore megaprovince divided by the relatively young Karatau uplift. In a schematic form, the mineralization of these provinces according to the published data of Volkovgeology JSC and the IAEA [8] shown in figure 1. A more detailed display of them based on the data of deep geological mapping at a scale of 1: 1,000,000 [based on the base http://wms.vsegei.ru/] and the results of geological exploration for uranium are shown in figure 2. Near-surface geotectonic and climatic conditions are the most important factors necessary for the formation of a uranium ore province and its main ore-controlling factor. The creation of a combined satellite elevation map and the visible spectrum of colors with the overlay of thematic data allowed us to compare the convergence of the results (figure 3). The result surpassed all expectations, the resulting map, based on multispectral satellite images, perfectly displayed the near-surface geotectonic environment of the area, absolutely similar to the data of deep geological mapping at a scale of 1: 1,000,000, and displayed the

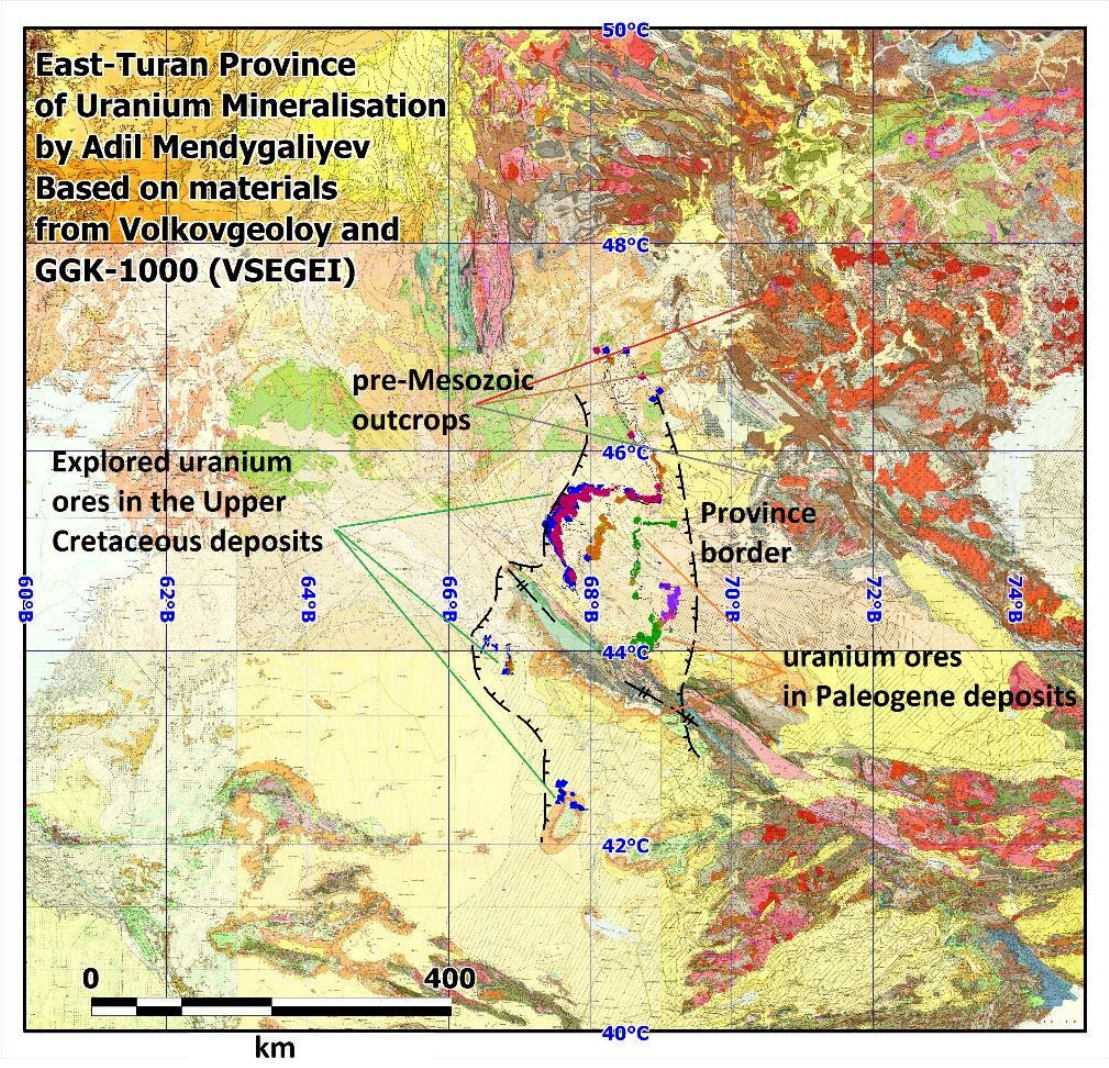

Figure 2 – East Turan uranium mineralization on map of deep geological mapping

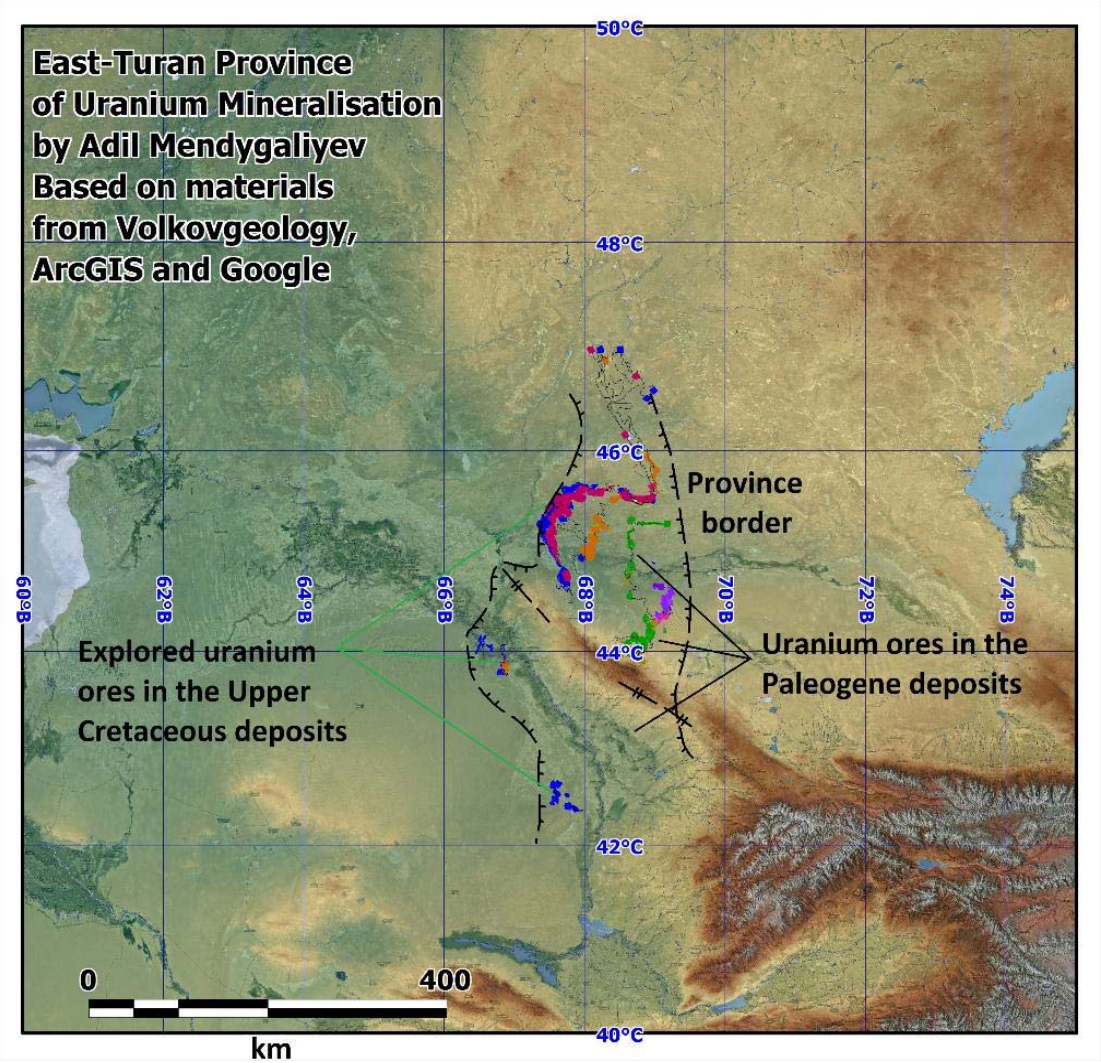

Figure 3 – East Turan uranium mineralization on map of multispectral satellite imagery

climatic situation of aquifer recharge area emerging to the surface in desert areas. The main source of sedimentation is the southern, southeastern and eastern continental uplifts from the side of the Tien Shan and the Kazakh shield towards the retreating Aral and Caspian seas. The East Turan province is divided into the Shu-Sarysu and Syrdarya by the younger Karatau uplift, the sharp uplift of which approximately occurred at the end of the Pliocene epoch [5]. The listed uplifts set the main directions of all ore-forming stratal water flows. Special attention should be paid to the Inkai-Mynkuduk ore arc (and its continuation) in the Upper Cretaceous deposits more than 100 km long, the shape of which exactly repeats the observed structure a few tens of kilometers north of the Sarysu-Teniz watershed, which directs the discharge area. To the east, in the area of the Zhalpak deposit, the ore strip unfolds by the uplift of the Kazakh shield. South of the Budennovskoe deposit, the ore strip is broken by the Karatau uplift and continues to the west of Karatau in the Syrdarya province (Karamurunskoe ore field, Zarechnoye, Asarchik, Zhautkan. [9]).

The nature of the ore zones in the Paleogene deposits is more complicated by the Karatau uplift, but otherwise practically repeats the character of the Cretaceous deposits, only a few hundred kilometers to the south-east, closer to the feeding zones near the Tien Shan zones. Continuing the topic of the use of multispectral data of remote sensing of the earth, more detailed specialized studies should be noted. On November 7, 2019 in Almaty at the IX International Scientific and Practical Conference "Actual Problems of the Uranium Industry" a report was presented (vol. 1, pp. 55-63) on the data obtained using the RMP method at the Mynkuduk Vostochny deposit [10]. In a discussion with colleagues, the method was perceived skeptically, since the high convergence of the results obtained with the explored ore strip was

left without theoretical explanations, and thermal anomalies could be caused by the result of operating enterprises. But personal attention was exacerbated by the predicted undiscovered ore strip, the prerequisites for which, by professional accident, were noticed earlier in some single wells of the neighboring area "Central Mynkuduk". Despite the fact that the ore strips themselves could not be detected by the infrared and color radiation used in the method due to the powerful (several hundred meters) roof sedimentary cover, this method could fix their inherent surface soil anomalies. In 2010, at the International Scientific and Practical Conference "Actual Problems of the Uranium Industry-2010", a joint report by the employees of JSC "Volkovgeology" I.A. Shishkov, T.Ya. Chesnokova and FSUE "VIMS" A.E.Bakhur, T.M. Ovsyannikova in which the obtained results of isotopic soil anomalies ^{210}Po and ^{210}Pb were presented at the surface of stratal-infiltration uranium deposits. Their theoretical explanation was given by means of an independent migration of elements upward through the zones of water exchange to the water surface and further penetration into the soil by capillary-diffuse rise, which was previously clearly explained in the thesis by A.E. Bakhur. [11]. In addition, at uranium deposits of this type, surface anomalies of methane, hydrogen and the amount of heavy hydrocarbons are everywhere noted [5].

The significance of the latter most likely explains the formation of sufficient recovery barriers directly above the oil and gas bearing areas (in spite of the assignment of the provinces to detritus), which is a topic for a separate discussion.

Conclusion. Modern computer solutions greatly simplify data processing, improve their quality and open up new opportunities. Space and airborne remote sensing technologies have provided geological services with highly justified public and commercial solutions for forecasting and prospecting for ores. The obtained convergence of the results is theoretically substantiated and the use of this method should bring forecasting and prospecting of reservoir-infiltration uranium deposits to a new level, simplifying and improving the quality of geological exploration at all stages. To carry out the first steps in predicting new uranium ore zones with the auxiliary use of this method, it was decided to build in this way and analyze the world map. According to the results obtained, the most promising were the territories of the Arabian Peninsula, the prospects of which are expected in the sediments of the Meso-Cenozoic artesian basins near the area located above the oil and gas bearing area of the Ghawar field. The visualized territories have large-scale areas for the formation of similar systems of penetration of ore-forming infiltration flows over long distances and depths, and the underlying oil and gas areas should create powerful recovery sources communicating with the overlying horizons to meet the infiltration flows, which can form large sandstone uranium deposits of the Kyzyl Kum and Australian types [12, 13].

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УРАННЫҢ ҚАБАТТЫҚ-ИНФИЛЬТРАЦИЯЛЫҚ КЕНОРЫНДАРЫН БОЛЖАУ ЖӘНЕ ІЗДЕУ КЕЗІНДЕ ЖЕРДІ МУЛЬТИСПЕКТРЛІ ЗОНДТАУ ДЕРЕКТЕРІН ҚОЛДАНУ ПЕРСПЕКТИВАЛАРЫ

Аннотация. Қабатты-инфильтрациялық уран кенорындары қазіргі кезде әлемдегі уран шикізатының негізгі және Қазақстанда жалғыз көзі болып табылады. Олардың экологиялық тазалығы, өнімділік және минималды өндірістік шығындар түріндегі басты артықшылығы оларды әлемнің әр түкпірінде одан әрі анықтауға мүмкіндік береді. Көп сатылы, қымбат және қиын геологиялық барлау жұмыстарын қол жетімді инновациялық шешімдермен болжау және іздеу мақсатында оңайлату және жетілдіру маңызды. Қол жетімді мультиспектралды ғарыштық суреттер уран кенді провинцияларын зерттеу үшін жаңа мүмкіндіктер ашты. Мультиспектральды ғарыштық түсірілім негізінде уран кенді провинцияларының карталарын жасау оларды геологиялық және геофизикалық зерттеулердің белгілі бір негізгі рудалық бақылау мәліметтерімен салыстыруға мүмкіндік береді. Геотектоникалық құрылымдардың, климаттық жағдайлардың және белдемдік ауытқулардың жер бетіне жақын көрінетін табиғаты заманауи ғарыштық технологиялар мен компьютерлік шешімдердің көмегімен оңай әрі сапалы түрде көрінеді. Геотектоникалық және климаттық жағдайлармен байланысты корреляцияны түсіндіру уран қабатты-инфильтрациялық кенорындарын болжау, іздеу және барлау сапасын жеңілдету және арттыру мақсатында мультиспектральды кескіндерді қолдануға мүмкіндік

береді. Әуе мен ғарышты қашықтықтан зондылаудың анағұрлым жетілдірілген әдістері кеннің осы түрімен байланысты жер бетіндегі ауытқуларды анықтауға мүмкіндік береді. Осы ауытқулардың табиғатын және олардың кен түзудің геологиялық-генетикалық моделіндегі рөлін ғылыми тұрғыдан түсіндіру геологиялық барлау әдістемесін жетілдіруге сенімді теориялық негіз жасайды. Алынған нәтижелердің жинақталуы, оларды теориялық тұрғыдан түсіндірілуі, нәтижелердің қарапайымдылығы мен сенімділігі уранның бақылау аймағының бірнеше негізгі факторлары үшін қабаттық-инфильтрациялық уранның аудандарына жаңа болжамдар жасауға және осы әдіснаманы геологиялық барлау жұмыстарының барлық кезеңдеріндегі аймақтық және жергілікті зерттеулерінің басқа да мәліметтермен бірге қолдануға мүмкіндік береді.

Түйін сөздер: уран кендері, қабатты-инфильтрациялық кен орындар, геологиялық барлау, іздеу, болжау, мультиспектральдық зондылау, ғарыштық суреттер.

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ПЕРСПЕКТИВЫ ПРИМЕНЕНИЯ ДАННЫХ МУЛЬТИСПЕКТРАЛЬНОГО ЗОНДИРОВАНИЯ ЗЕМЛИ ПРИ ПРОГНОЗИРОВАНИИ И ПОИСКАХ ПЛАСТОВО-ИНФИЛЬТРАЦИОННЫХ МЕСТОРОЖДЕНИЙ УРАНА

Аннотация. Пластово-инфильтрационные месторождения урана на сегодняшний день служат главным действующим источником уранового минерального сырья в мире и единственным в Казахстане. Главное их достоинство в виде лучшей экологичности, производительности и минимальной себестоимости добычи создаёт перспективы к их дальнейшему обнаружению в различных уголках планеты. Многостадийные, дорогостоящие и трудновыполнимые геологоразведочные работы с целью их прогнозирования и поисков позволяют актуально упрощать и улучшать в качестве доступными инновационными решениями. Доступные мультиспектральные космические снимки открыли новые возможности для исследования урановорудных провинций. Создание карт урановорудных провинций по данным мультиспектральных космоснимков позволяет сопоставить их с определенными ключевыми рудоконтролирующими данными геологических и геофизических исследований. Приповерхностный видимый характер геотектонических структур, климатические обстановки и зональные аномалии более легко и качественно визуализируются с помощью современных космических технологий и компьютерных решений. Объяснение выведенных корреляций с геотектонической и климатической обстановкой позволяет использовать мультиспектральные снимки с целью упрощения и повышения качества прогнозирования, поисков и разведки пластово-инфильтрационных месторождений урана. Более продвинутые аэро- и космо – методы дистанционного зондирования земли позволяют выявлять сопутствующие данному типу руд поверхностные аномалии. Научное объяснение природы данных аномалий и их роли в геолого-генетической модели образования руд создаёт прочную теоретическую основу для усовершенствования геологоразведочной методологии. Сходимость полученных результатов, их теоретическое объяснение, простота и убедительность результатов позволяют сделать новые прогнозы перспективных районов пластово-инфильтрационных урановых районов по нескольким из ключевых рудоконтролирующих факторов и использовать данную методологию в совокупности с другими данными региональных и локальных исследований на всех стадиях геологоразведочных работ.

Ключевые слова: урановые руды, пластово-инфильтрационные месторождения, геологоразведка, поиски, прогнозирование, мультиспектральное зондирование, космоснимки.

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APPLIED MODEL OF METHODS FOR RECLAMATION OF SALT LAND

Abstract. Based on the available achievements in the field of methodology, natural sciences and research in the field of environmental management, a method is proposed for constructing an applied model for the development of saline lands as "activity-natural objects" of the «Soils", including cognitive activities, transforming activities, transformations natural materials and materials formed as a result of anthropogenic activities, within the framework of which an applied model of methods for the reclamation of saline lands has been developed.

On the basis of an applied model transforming the activity of saline lands, a method for developing saline lands has been developed, including the preparation of temporary irrigation and drainage networks and checks, deep ameliorative loosening of the soil across the drains with alternating loosened strips with the same width with the subsequent supply of flushing water to the checks. The method differs in that the development of saline lands is carried out in two symmetrical and parallel-sequential actions in time in annual intervals, with desalinization of saline soils to a certain permissible level with the supply of a leaching rate, taking into account the environmental requirements of environmental management and classification of saline soils and salt tolerance of agricultural crops from very highly saline to highly saline, from highly saline to medium saline, from medium saline to slightly saline and from slightly saline to non-saline, with subsequent cultivation of the corresponding salt tolerant crops: very resistant – resistant – medium resistant – medium sensitive – sensitive.

Keywords: saline lands, reclamation, desalinization, method, applied model, technique, soil, system, object, activity, development, ecology, landscape.

Introduction. The problem of reclaiming saline lands has existed for several millennia and is becoming more and more acute in connection with the involvement of agricultural crops in their cultivation. The only radical way to solve the problem with the proven thousand-year experience of irrigated agriculture is leaching with removal outside the irrigated massif using drainage, taking into account the soil-hydrogeological conditions of the landscape or leaching accompanied by sown halophyte plants [1]. At the same time, it should be noted that the existing methods of reclamation of saline lands do not ensure sustainable leveling of reclaimed and background soils in terms of their productivity. The reason for this is the ascending currents of saline solutions of the upper soil layer during the growing season of the vegetation cover, as a result of which cyclical salinization occurs, which does not provide the ecological stability of the developed lands for the cultivation of agricultural crops [2; 3].

Purpose of the study. Development of an applied model of methods for the reclamation of saline lands for the cultivation of agricultural crops, which will allow removing salts from the soil to a certain level according to the degree of salinity in stages on a time scale in annual intervals with the supply of an appropriate leaching rate, followed by the cultivation of agricultural crops according to the salt tolerance, which constantly provide a decrease in the volume of collector-drainage water into natural water drainage facilities.

Materials and research methods. Scientific research is based on the classical doctrines of soil, soil-forming processes, soil fertility, salinization processes by V.V. Dokuchaev, V.I. Vernadsky, V.R. Williams, A.N. Kostyakova, V.A. Kovdy, B.G. Rozanova [4]; work on the development of degraded soils on the principles of ecological balance of irrigation, forest reclamation, agromeliorative and other impacts (B.M. Kizyaev, I.P. Kruzhilin, V.I. Petrov, K.N. Kulik, L.V. Kireicheva, V.V. Borodychev, E.B. Gabunshchina, Zh.S. Mustafaev, A.T. Kozykeeva and others) [5]; in terms of the desalting and desalting ability of plants (B.P. Strogonov, P.A. Genkel, G.V. Udovenko, P.P. Beguchev, B.A. Zimovets, Z.Sh. Shamsutdinov, O.A. Lachko, L. V. Rudnev) [6]; on the ecological and energy assessment of the efficiency of agriculture and the energy of soil-forming processes - A.N. Engelgard, K.A. Timiryazev, V.R. Volobuev, K.K. Gedroyts, V.M. Volodin, V.V. Korenets, Zh.S. Mustafaev and others [6].

To implement such a worldview when constructing an applied model of methods for the development of saline lands, it is advisable to use methods for constructing models of activity-natural objects (ANO), which are elements of activity-natural systems (ANS), which is a concept that includes elements of three categories: activity (A), natural material (M) and transformed material (TM) as a result of anthropogenic human activity [2].

For a correct understanding of the goals and objectives of the development of saline lands for agricultural production, determine the value system and designate the objects of influence, that is, at present, such values are a person and his habitat, and the objects of influence are soil, as the main component of the biosphere of the landscape as a whole and as the main means and object of labor in the conditions of anthropogenic human activity. At this level, the system «reclamation activity-soil» can be considered as «activity-natural objects» (ANO) of the «Soils», saturated with specific content, performing ecological and economic functions in the spheres of nature management and nature development.

Research results. The proposed new conceptual approach to the construction of an applied model for the development of saline lands lies in the orientation of the system "reclamation activity-soil" on the strict account of natural processes and their rhythmic fluctuations by felting changing climatic factors and consideration of nature as a single organism inherent in it cyclic movements of flows of substances in large and small cycles.

In the natural system, during the development of saline lands for the cultivation of agricultural lands, their objects of influence, that is, the soil and the soil-forming process as a whole, are ecologically unstable and therefore it is necessary to develop a set of control measures in order to optimize their functioning, that is, to transfer their regime to dynamically stable development with a set of corrective influences known by the method, method, intensity and time [2; 3].

The formation and functioning of the soil and vegetation cover in the desert and semi-desert is characterized by two parameters, that is, the soil cover is formed in the process of moisture and salt transfer, which characterize the evaporative features of the geochemical barrier, leading to the salinization process, and the vegetation cover - by biomass and species diversity on based on the law of genetic diversity.

Different types of plants in natural conditions do not grow in isolation from each other, but form certain combinations, characterized by special relationships with each other and with environmental conditions. Such a historically established stable set of species in a homogeneous area of the territory is called a plant community [7; 8; 9; 10].

Thus, on the basis of a natural-scientific approach to the doctrine of thinking and activity, the principles of constructing an applied model of methods for the development of saline lands as «activity-natural objects» of the «Soil» were formed, within the framework of cognitive activity, transforming activity, transformations of natural materials and formed materials as a result of anthropogenic activities.

The cognitive activity of the natural hydrogeochemical process is an active study of the surrounding reality, which begins with orientation and research activities, for the examination of the studied subject and in obtaining a variety of information about the degree of soil salinity and the distribution of biocenosis species necessary for transforming activities that increase their purchasing value.

At the same time, the stability of the vegetation cover of saline lands largely depends on the salt resistance of plants that determine the structure of the ecosystem, that is, the species diversity of the vegetation cover directly depends on the degree of soil salinity, which leads to a change in the balance and stability of natural landscapes (figure 1) which allowed us to build an applied model of those who know the activity of saline lands.

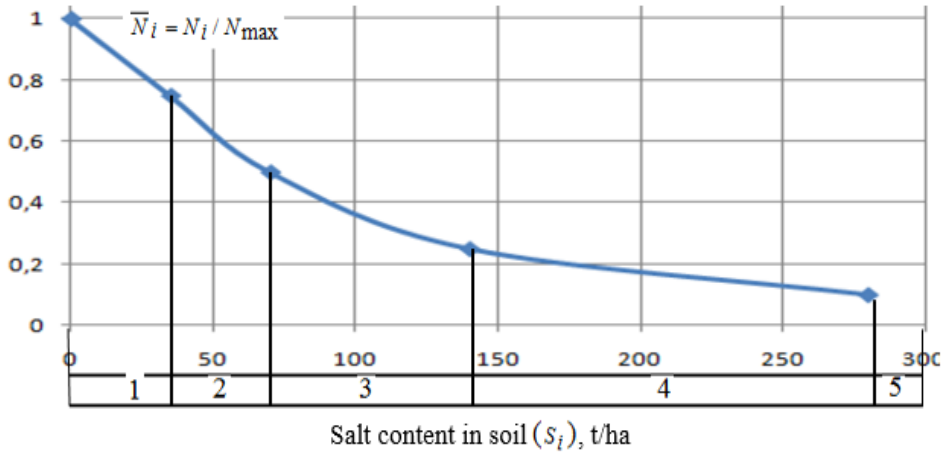

Figure 1 – Distribution of species in the biocenosis by numbers depending on the degree of soil salinity: 1 – non-salted; 2 – slightly salted; 3 – moderately salted; 4 – highly salted; 5 – very highly salted; N_i – number of *i*- plant species; N_{max} – maximum number of plant species

A wide range of wild-growing grasses are much less responsive to changes in natural conditions than communities consisting of a small number of species. Using the species diversity of communities and the Shannon information measure of diversity as a characteristic of the sustainability of the ecosystem, it is possible to estimate the relative resistance of the plant community depending on the degree of soil salinity based on the quantitative composition of plant species (when $P_i = 1/n$) [10; 11]:

$$D = -\sum_{i=1}^{n} P_i \cdot \ln P_i ;\ P_i = N_i / N ;\ N = \sum_{i=1}^{n} N_i ,$$

where n – number of plant species in the community; N_i – number of *i*-species; D – community resilience; P_I – share of this species in the community.

As can be seen from Figure 1, the number of plant species in landscape systems largely depends on the degree of salinity, which species diversity is formed strictly by their salt tolerance. In general, the success of bioorganisms in the struggle for existence on saline lands can be achieved in various ways. One of them is the adaptability properties of organisms to changing environmental conditions by increasing the number of the species, expanding the area of its settlement. At the same time, it should be noted that under conditions of rhythmic fluctuations in the climate, the natural process of desalinization and salinization is observed in nature, which, to a certain extent, has an effect on the quantitative composition and structure of the species plant cover of saline soils. With the process of soil desalinization under natural conditions, more salt-tolerant plant communities give way to more salt-sensitive plant communities.

In the process of cognizing the activity of the natural hydrogeochemical process, an applied model transforms the activity of saline lands, that is, anthropogenic changes in the existing ecological balance to increase their ecological and economic functions, ensuring an increase in the biological productivity of soil and plant cover of natural landscape systems.

At the same time, the applied model transforming the activity of saline lands is based on the principles of coexistence of a plant community on saline soils, where more salt-sensitive plant communities give way to more salt-tolerant plant communities, that is, according to the scheme, very highly saline - highly saline - moderately saline - slightly saline - non-saline, followed by replacement appropriate salt tolerant crops in the soil cover: very tolerant - tolerant - medium tolerant - medium susceptible - sensitive (figure 2).

Based on the laws of the «predator-prey» system in Voltaire, in this case, the role of the «predator» during desalinization of saline soils is played by more salt-sensitive plant communities, and the role of «prey» is played by more salt-tolerant plant communities [12]. At the same time, according to the law of evolutionary-ecological irreversibility, an ecosystem that has lost some of its elements or has been replaced by another as a result of an imbalance of components cannot return to its original state if evolutionary changes occurred in ecological elements during the changes [12]. Therefore, it is necessary to

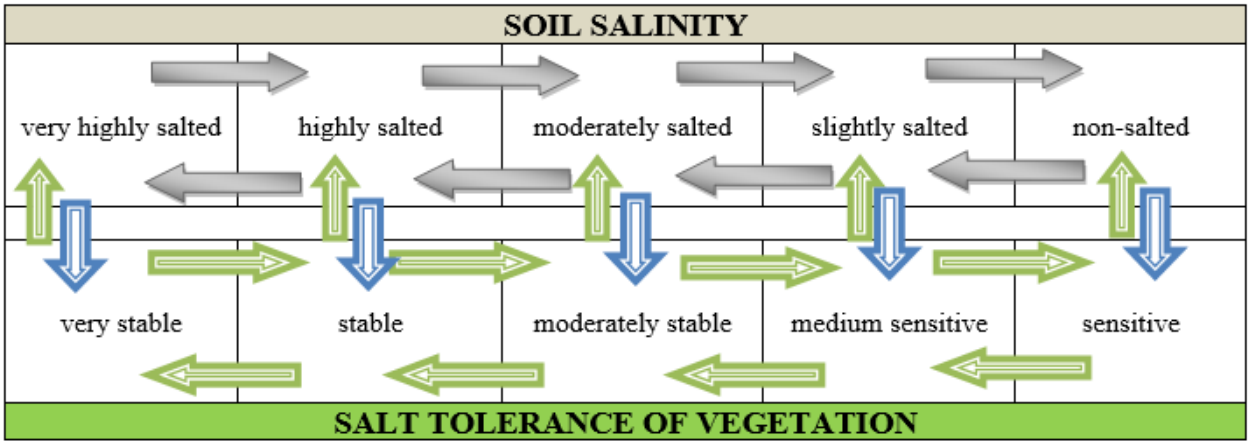

Figure 2 – An applied model transforming the activity of saline lands
(schemes of natural direct and feedback in the soil-hydrogeochemical process and the plant community)

take into account that during the development of saline lands for the agrolandscape system of natural landscapes, an irreversible evolutionary process occurs as a result of a strong decrease in the number of species of the plant community with replacement by cultivated plants.

At the same time, according to the Le Chatelier-Brown principle - under external influence, that is, when saline soils are salted, which brings the system out of a state of stable equilibrium, the equilibrium shifts in the direction in which the effect of external influence is weakened as a result of the structure and composition of the plant community change towards more salt sensitive plant communities [12].

On the basis of the applied model transforming the activity of saline lands, a method for developing saline lands has been developed, including the preparation of temporary irrigation and drainage networks and checks, deep ameliorative loosening of the soil across the drains with alternating loosened strips with the same width, followed by the supply of flushing water to the checks. The method differs in that the development of saline lands is carried out in two symmetrical and parallel-sequential actions in time in annual intervals, with desalinization of saline soils to a certain permissible level with the supply of a leaching rate, taking into account the environmental requirements of environmental management and classification of saline soils and forest tolerance of agricultural crops from very strongly saline to highly saline, from highly saline to medium saline, from medium saline to slightly saline and from slightly saline to non-saline, followed by cultivation of the corresponding salt tolerant crops: very resistant - resistant - medium resistant - medium sensitive [5].

To implement the method for the development of saline lands on the basis of the laws of nature and natural hydrogeochemical processes, a method for flushing saline soils has been developed, including hydrotechnical and agrotechnical measures, is carried out by alternation in a pressure mode until complete moistening, and then before flushing in a non-pressure mode, is carried out in the following order, that is, on fields with zero marks, temporary irrigation networks are cut from the opposite side of the irrigated area and furrows with a deepening towards the center of the site, while the feed of the leaching rate using the furrow is carried out simultaneously with counter jets at the same flow rates, until each collision with the other in the center of the plot, followed by leveling the water layer in the furrow along the front of the water supply [13].

A distinctive feature of the proposed scheme for the development of saline lands from similar developments is the linkage of the method of development of saline lands with the classification of saline soils and salt tolerance of agricultural crops.

At each stage of the development of saline lands, firstly, it is necessary to determine the degree of soil salinity (S_i) and secondly, the level of expected productivity of agricultural crops, taking into account salt tolerance ($\overline{Y}_i = Y_i / Y_{\max}$, where Y_i – crop yield at a given degree of soil salinity, centner/ha; $Y_{\max}$ – maximum yield of agricultural crops with an acceptable degree of soil salinity, centner/ha).

Saline land leaching rates (α) at each stage of development is determined based on the system of the following equations [13]:

$$Y_i = Y_{\max} \cdot \exp\left[-k(S_i / S_{\partial oni} - 1)^b\right];$$

$$N_i = (\alpha / \beta) \cdot \lg(S_i / S_{\partial oni}),$$

where α – salinity coefficient; β – parameter that depends on the stirring speed; $S_{\partial oni}$ – permissible content of soil salts at the stage of development of saline lands, t/ha; k – coefficient of salt tolerance of agricultural crops; b – equation parameter.

If the expected amount of leached salts from the soil layer (0–100 cm) (ΔS_i) at each stage of the development of saline lands will be greater than their maximum permissible value ($\Delta S_{\partial on}$), which is determined based on the level of the anthropogenic load of the natural system in the annual interval, then in this stage of development is divided into several sub-stages, that is, the number of sub-stages is determined by the formula: $n = \Delta S_i / \Delta S_{\partial on}$.

The duration of leaching of saline soils (t_i) at each stage of their development is determined by the formula: $t_i = N_i / [(V_o + K_\phi) / 2]$, where V_o – is the rate of water absorption into the soil at the end of the first hour; K_ϕ – filtration coefficient.

Transformations of natural materials as a result of transforming activities on saline lands – the process of changing the direction and intensity of natural hydrogeochemical processes that ensure sustainable development of the biosphere, which reflects the key position of modern ecology, based on knowledge of the essence of the formation of soil-forming process, which provides sustainable soil desalinization.

Thus, based on the laws of nature and noting the presence of direct and reverse relationships in the soil, one can raise the question of self-regulation and consider the soil as an object of self-regulation and use them to develop environmentally safe ways of developing saline lands for agricultural production.

Moreover, if the technology for the development of saline lands is based on the formation of saline lands and the process of soil desalinization in natural systems, then the change in the natural process under the influence of natural factors will coincide with the direction and intensity of the natural process or will approach them.

Consequently, on the basis of this position, the development of saline soils should be carried out according to a stepwise principle, using the classification of saline soils from saline to highly saline, from highly saline to moderately saline, from moderately saline to slightly saline and from slightly saline to non-saline, which represent an applied model of natural transformations. materials as a result of transforming activities on saline lands (figure 3).

Classification of saline soils depending on the content of solid residue					Indicators	
					$S_{\max}$, t/ha	$\frac{Y_i}{Y_{\max}}$
Salt marshes					<280,0	0,0
Highly salted	Highly salted				280,0	0,25
Moderately salted	Moderately salted	Moderately salted			140,0	0,75
Slightly salted	Slightly salted	Slightly salted	Slightly salted		70,0	0,80
Non-salted	Non-salted	Non-salted	Non-salted	Non-salted	35,0	1,00

Figure 3 – Applied model of transformations of natural materials as a result of transforming activities in saline lands

Thus, in the ecological substantiation of the methods of reclamation of saline lands, an important role belongs to the cultivation of crops that are able to successfully resist the harmful effects of mineral salts, which are components of saline soils. At the same time, the cultivation of salt-tolerant crops, taking into account the degree of soil salinity, creates a favorable agrobiological background and increases not only their fertility, but also the productivity of agricultural crops [2].

In connection with the diversity and dynamism of the hydrogeochemical indicators of the soil system of saline lands in the process of their agricultural development on a time scale, the technology of their optimization should be focused on the regulation and management of the life of the species community of the vegetation cover.

When solving the set goals, the classical classifications of soils by salinity and salt tolerance of agricultural crops and their variations were taken as a basis, which made it possible to draw up an applied model of technological schemes for the development of saline lands for the cultivation of agricultural crops, taking into account the maximum permissible level of technogenic loads of the natural system (figure 4).

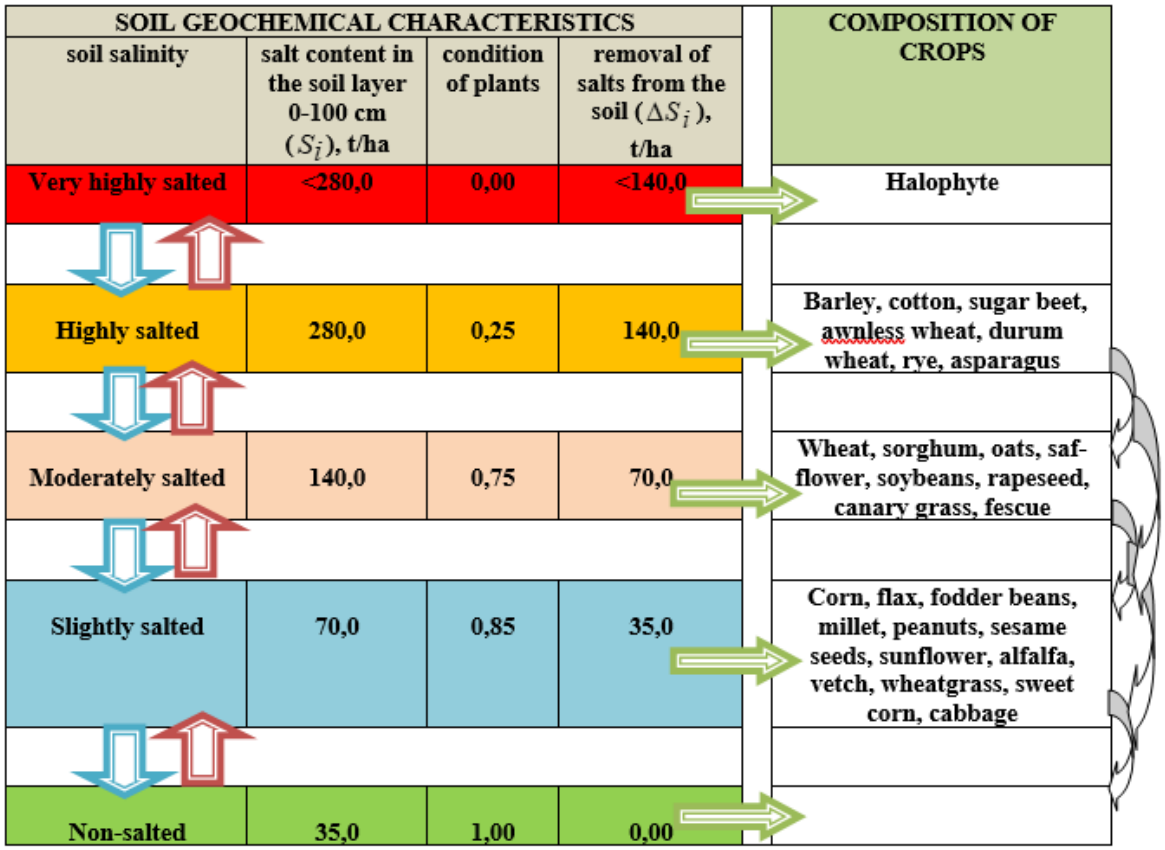

Figure 4 – Applied model of technological schemes for the development of saline lands for the cultivation of agricultural crops, taking into account the environmental requirements of nature management

On the basis of the proposed technological scheme, the development of saline lands should be carried out in stages on a time scale in annual intervals, using the classification of saline soils and salt tolerance of agricultural crops from very highly saline to highly saline, from highly saline to moderately saline, from moderately saline to slightly saline and from slightly saline to non-saline with the cultivation of agricultural crops.

At the same time, at each stage of the development of saline lands, a certain state of the land corresponds to the degree of soil salinity and, therefore, certain reclamation tasks related to this stage are solved.

For the development of an applied model of the formed hydrogeochemical process as a result of anthropogenic activity, as an integral criterion for assessing changes in environmental factors as a result of transforming activity and transformations of natural materials, a hydrothermal regime is used, which characterizes the heat and moisture supply of the soil and vegetation cover («dryness index» M. I. Budyko – $\overline{R}_i$) (figure 5) [14; 15; 16; 17]: $\overline{R} = R / LO_C$, where $\overline{R}_i$ – «dryness index»; R – radiation balance, which determines the influx of solar energy and the amount of photosynthetic active radiation, kJ/cm^2; L – latent heat of vaporization, kJ/cm^3; O_c – atmospheric precipitation, mm.

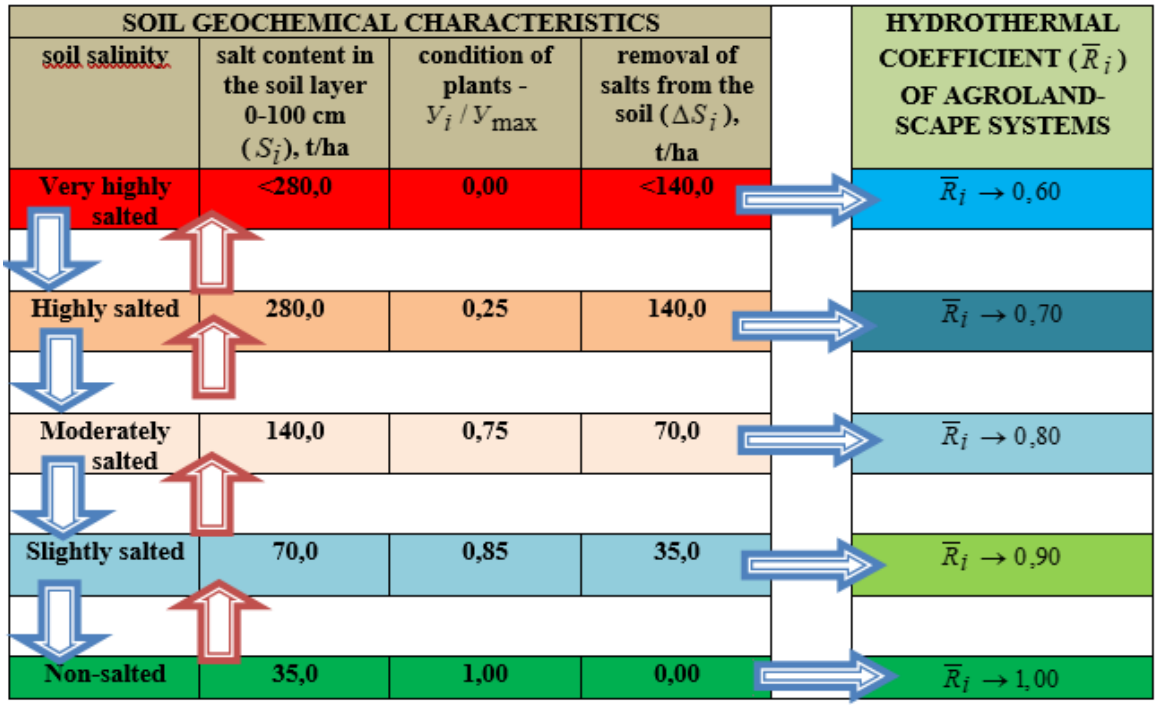

Figure 5 – Applied model of the formed hydrogeochemical regime as a result of anthropogenic activity on saline lands

Consequently, the hydrothermal regime of the soil and vegetation cover ($\overline{R}_i$), characterized by the «dryness index» of M. I. Budyko, determines the general direction of biochemical processes, manifested in balances and modes (water, salt, heat, nutrient) and properties of natural material, consideration of activity-natural processes in the development of saline lands will allow to investigate the causal relationships between cognizing activities, transforming activities, transformations of natural materials and materials formed as a result of anthropogenic activities.

Conclusions. The developed applied model of the method of reclamation of saline lands represents «activity-natural systems», which includes elements of four categories: cognitive activity, transforming activity, transformations of natural materials and formed materials as a result of anthropogenic activity, based on optimization of the conditions of the soil-forming process and growth agricultural crops in agrolandscape systems that perform ecological and economic functions, for farms-land users ensure the adoption of prompt and informed decisions on purposeful management and regulation of soil-reclamation processes hydroagrolandscape systems allow the environmental sustainability of the environment and human habitat.

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ТҰЗДАНҒАН ЖЕРЛЕРДІ ИГЕРУДІҢ ТӘСІЛІНІҢ ҚОЛДАНБАЛЫ ҮЛГІСІ

Аннотация. Табиғаты пайдалану және табиғаты үйлестіру саласындағы зерттеулер және жаратылыстану ғылымының әдістемелік жүйесіндегі қолда бар жетістіктердің негізінде, тұзданған жерлерді игерудің қолданбалы үлгісін құрудың әдістемесін, құрамына антропогендік қызметтің жүргісі ретінде, танымдылық және түрлендіру қызметі, табиғи заттарды тасмалдау және заттардың қалыптасу қызметтері кіретін, «Топырақ» «қызметтік-табиғи жүйе» ретінде қарастыра отырып, тұзданған жерлерді игерудің әдістерінің қолданбалы үлгісі жасалды.

Тұзданған жерлерді түрлендіру қызметінің үлгісі бойынша, құрамына уақытша суғару арықтары, кәріз желілері және атыздар кіретін, тұзданданған жерлерді игерудің тәсілі құрылған және ол ені бірдей атызды, кәрәзге қарама-қайшы топырақты терең қопсыту жүйектерін кезектесу арқылы, шаю мөлшерін атызға беруге негізделген. Тұзданған жерлерді игерудің ерекшелігі, ол жыл ішіндегі уақыт аралығында екі симметриялы және қатарлас-жүйелік тізбектелген әрекет арқылы, тұзданған топырақты белгілі бір шектелген мүмкіншілік деңгейіне дейін шаю мөлшерін, табиғаты үйлестірудің экологиялық талабын ескере отырып, тұзданған топырақтың жіктелуі және ауылшаруашылық дақылдардың тұзға төзімділігін негізделген, яғни өте жоғарғы тұзданудан жоғарғы тұзденуға, жоғары тұзданудан орташа тұзденуға, оратша тұзданудан әлсіз тұзданға, әлсіз тұзданудан тұзданбаған деңгейге дейін, тұздан арылғанша беруге және одан кейін тұздану дәрежесіне сай келетін тұзға төзімді ауылшаруашылық дақылдарды өте төзімді-төзімді-орташа -төзімді-орташа - сезімді -сезімді қатармен өсіруге негізделген.

Түйін сөздер: тұзданған жер, игеру, тұздан арылу, тәсіл, қолданбалы үлгі, әдістеме, топырақ, жүйе, нысан, қызмет, құру, экология, ландшафт.

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ПРИКЛАДНАЯ МОДЕЛЬ СПОСОБОВ ОСВОЕНИЯ ЗАСОЛЕННЫХ ЗЕМЕЛЬ

Аннотация. На основе имеющихся достижений в области методологии естественных наук и исследований в сфере природопользования и природообустройства предлагается методика построения прикладной модели освоения засоленных земель как «деятельностно-природные объекты» «почвы», включающие познающую деятельность, преобразующую деятельность, трансформацию природных материалов и формировавшихся материалов в результате антропогенной деятельности, в рамках которых разработана прикладная модель способов освоения засоленных земель.

На основе прикладной модели преобразующей деятельности засоленных земель разработан способ освоения засоленных земель, включающий подготовку временной оросительной и дренажной сетей и чеков, глубокое мелиоративное рыхление почвы поперек дрен с чередованием рыхленных полос с одинаковой шириной с последующей подачей промывной воды в чеки. Способ отличается тем, что освоение засоленных земель проводится в двух симметричных и параллельно-последовательных действиях по времени в годовых интервалах, с рассолением засоленных почв до определенного допустимого уровня с подачей промывной нормы, с учетом экологических требований природообустройства и классификации засоленных почв и солеустойчивости сельскохозяйственных культур от очень сильнозасоленных до сильнозасоленных, от сильнозасоленных до среднезасоленных, от среднезасоленных до слабозасоленных и от слабозасоленных до незасоленных с последующим возделыванием соответствующих им солеустойчивых культур: очень устойчивые – устойчивые – среднеустойчивые – среднечувствительные – чувствительные.

Ключевые слова: засоленные земли, освоение, рассоление, способ, прикладная модель, методика, почва, система, объект, деятельность, разработка, экология, ландшафт.

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STATISTICAL ANALYSIS OF REAL TRAFFIC OF MACHINE-TO-MACHINE COMMUNICATION (M2M)

Abstract. The development of digital technology has spawned the concept of the Internet of Things (IoT). The concept basis is the machine-to-machine interaction (M2M) technology, which allows devices to exchange information. The most effective data transmission medium for M2M devices is mobile communications. Rapid growth of machine-to-machine M2M traffic in mobile communication network defines the actuality of the research problem, its features and characteristics. Research outcomes are indispensable at the network modeling, planning, analyzing the M2M traffic impact at quality of service (QoS) of mobile network communication. The article analyzes the real traffic in the LoraWan network. Aggregated traffic coming to the network server from all devices is considered. To model the M2M batch traffic, apart from specifying the statistic characteristics it is necessary to assess its self-similarity. In order to define the traffic self-similarity there has been computed Hurst parameter. On the basis of STATISTICA programs batch we have conducted statistical analysis and short-term forecasting of real M2M traffic by method of exponential smoothing.

Key words: Internet of Things (IoT), M2M traffic, mobile communication network, Hurst parameter, forecasting, statistical analysis.

Introduction. International Telecommunications Union ITU-T Y.2060 recommendations [1] define Internet of Things (IoT), as an information community, maintaining innovative services organizing relations between the things (physical or virtual) on the basis of existing and developing compatible information and communication technologies.

An important role in information and communication technologies, securing the future of Internet of Things, will play the compounds in the form of Machine type Communication or “machine-to-machine” (M2M) compound. The compound type thereof represents the form of data transmission between the devices, which does not require obligatory interaction with a human being [2, 3].

The most efficient data transmission media for M2M devices is mobile communication. M2M services market in the years coming shall become one of the perspective and dynamically developing services market for mobile operators.

Rapid growth of M2M traffic envisages the actuality of its properties and characteristics research in the mobile communication network.

M2M traffic exercises a significant influence at services quality in the mobile communication networks and their operation processes. Traffic peculiarities and its characteristics shall be taken into account upon specifying parameters, modeling, designing and operating the communication networks.

In the work herein we have carried out the analysis of real M2M traffic, which allows specify its properties and characteristics, elaborated the model of the incoming traffic’s short-term forecasting. The offered methodology might be used further upon analysis of M2M traffic, formed under other conditions with other type devices.

At the first stage, there has been organized serving with LoRaWAN signals of the country's biggest cities: Almaty, Nur-Sultan, Shymkent. About a hundred base stations were installed. Hardware and software have been developed and produced by Kazakhstan company "Orion System".

Currently, in Almaty, Nur-Sultan and Shymkent the LoRaWAN networks maintain remote collection of readouts from various instrument gages. In future "Kazakhnelecom" plans to install attached sensors at the parks for tracing free places, at street lighting systems for electricity saving, monitor water level in the rivers, conditions of drain covers.

Literature analysis. To research the M2M traffic service process by mobile network, its impact at maintenance quality indices, there is used mathematical modeling. Its integral part is M2M traffic model. The work [4] offers the model and algorithm of data traffic aggregation 5G Network Slicing medium, based on classification and measurement of data traffic to maintain the service quality for smart systems in the city's intelligence medium. For modeling the traffic in the M2M network the researches in [5, 6] apply ON/OFF process. It is assumed, that M2M devices might be in one of four states: OFF, PU, ED and PE. In the state PU, ED and PE there transferred the batches, consequently, there starts the process ON. When batches are transmitted neither from, nor to the corresponding machine, there starts the process OFF. It matches the satiation, when the device is in the wait state. Whereas the M2M communication has multitude of application scenarios, its possible usage in smart networks has been discussed in the article [7]. Modeling outcomes show that occurred delays considerably increase upon corresponding growth of smart meters' amount.

One of the steps, directed to M2M traffic maintenance methods upgrading, is constructing the model, which would allow fulfill traffic prediction in short-time period and match the majority of modern mass applications of M2M devices. There are known models, making use of neuron network technologies apparatus [9], theory of Markoff processes [8], statistical modeling methods [8], etc. Universal model, which could be used for M2M any type forecasting has not been designed by the time being. In our work we have made an attempt to design the model, based on one of time series analysis methods – exponential smoothing method with smoothing parameter value selection. For the traffic type under study the model thereof provides satisfactory prediction outcomes. Let's consider the model elaboration process on the real example.

Analysis of real traffic and prediction. One telecommunication company in Almaty city carries out the traffic monitoring in the LoRa WAN network. There have been collected the data on real M2M traffic, incoming fromM2M devices to network server of LoRa WAN network. The traffic is measured in bit/s. Data were collected within 12 hours. Readings were taken about the amount of traffic received every 15 minutes. Thereat, 48 traffic values have been analyzed.

Data graphical representation is given in the figure 1 in the form of time series.

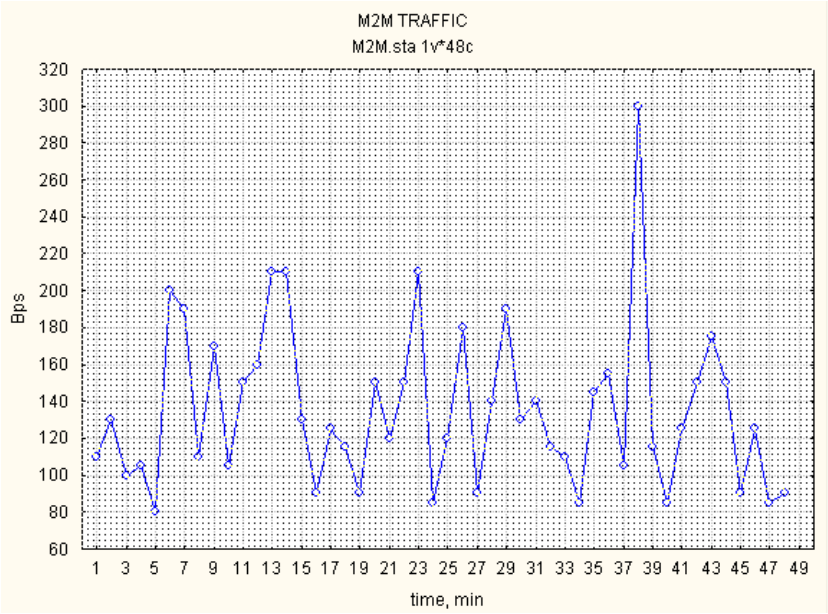

Figure 1 – M2M traffic dynamics

To define the real M2M traffic self-similarity extent let's evaluate Hurst parameter by R/S statistics method. There exist plenty of Hurst parameter assessment methods, which is a complicated task. Upon researching really measured traffic the following problems should be taken into consideration [20].

For measured real M2M traffic, presented in figure 1, there have been obtained the following values log(N/2) and log(R/S), which are given in table.

Let's define Hurst parameter H = 0,47, applying technique of least squares.

For traffic prediction there has been used exponential smoothing method, which is one of routine methods, employed upon some series forecasting.

Values of R/S standardized range

log(N/2)	log(R/S)
1,38	0,57
1,08	0,53
0,78	0,48

Method of time series exponential smoothing assumes establishing the initial series different weight levels which are preliminarily multiplied by corresponding coefficients. The later levels of the series are provided with bigger weight, and previous levels are multiplied by weight coefficients of less value. Levels weight reduction takes place along the exponent, dependent on the value of smoothing parameter, being in the interval from 0 to 1 [10].

Simple exponential smoothing is fulfilled according Brown method. At availability of the trend constituent there is applied Holt method. If the series includes a trend and stepping constituent, there is applied Vinters method.

As the time series of M2M traffic values do not contain the trend and stepping constituent, there has been employed Brown method (simple exponential smoothing).

We have accomplished the short-term prediction of M2M traffic for 1-4 periods (15-60 minutes) beforehand, as there was of paramount importance the prediction for the time period within one hour.

Considering, that the smoothing parameter's value is not known in advance, there were being constructed the prediction models with different parameters and selected the model amongst them, providing the most accurate prediction. Smoothing was fulfilled at smoothing parameters' values: $a = 0,1$, $a = 0,5$ and $a = 0,9$.

As far as the sampling contains 48 data, the forecast has been computed for 49, 50, 51 and 52 15-minutes time periods.

Graphical interpretation of conducted calculation is shown in the figure 2.

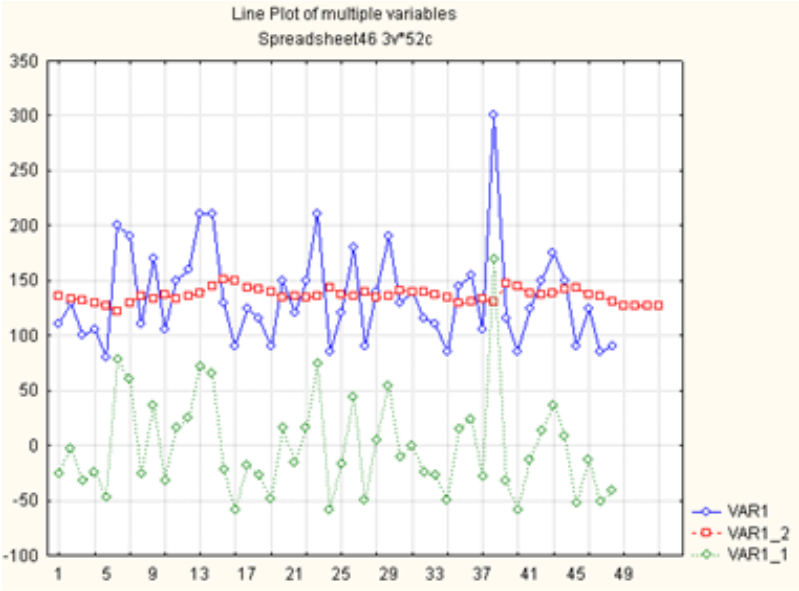

Figure 2 – Graphic representation of exponential smoothing process at $a = 0,1$

In figure 2 the curve VAR1 images the initial time series, VAR1_2 – exponentially smoothed series with predictive estimates. VAR1_1 shows the difference between the initial and smoothed series levels.

To assess the prediction accuracy in STATISTICA packet there have been calculated a number of error types, obtained upon constructing prediction models (figure 3).

Summary of error	Exponential smoothing: S0=135,2 (M2M.sta) No trend,no season; Alpha= ,100 VAR1 **Error**
Mean error	-1,697062711
Mean absolute error	36,224091610
Sums of squares	100188,469352625
Mean square	2087,259778180
Mean percentage error	-11,027103084
Mean abs. perc. error	28,295100511

Figure 3 – Errors calculation at a = 0,1

Researches quite frequently assess the forecast accuracy, using Mean abs.perc. error (MAPE) – mean absolute relative error. At a = 0,1 MAPE value constituted 28,29. It is assumed, that at 20 < MAPE < 50 the obtained prediction is characterized with satisfactory accuracy.

In the same manner, there have been conducted computations of the traffic predicted values by means of exponential smoothing method at other values of smoothing parameter.

Graphic representation of the process modeling at a = 0,5 is given in figure 4. Figure 5 presents modeling calculated errors.

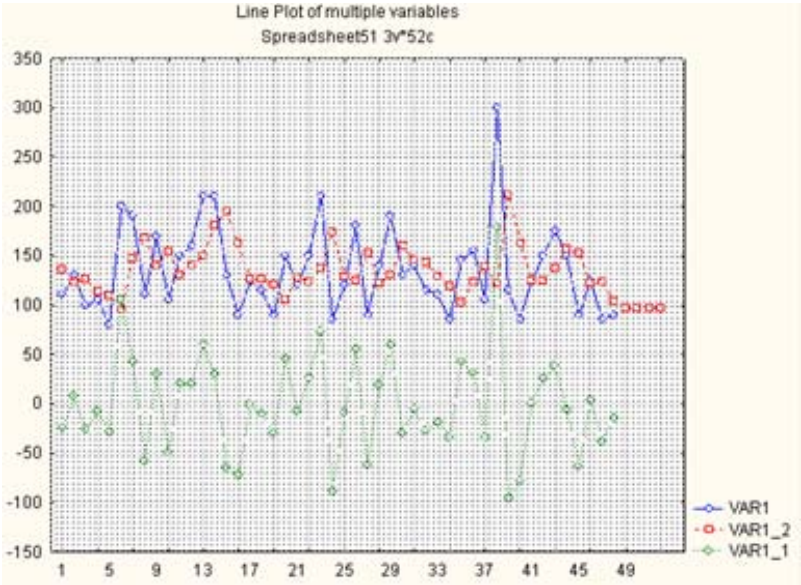

Figure 4 – Graphic representation of exponential smoothing process at a = 0,5

Summary of error	Exponential smoothing: S0=135,2 (M2M.sta) No trend,no season; Alpha= ,500 VAR1 **Error**
Mean error	-1,589243919
Mean absolute error	39,678932427
Sums of squares	126712,037593739
Mean square	2639,834116536
Mean percentage error	-11,048518211
Mean abs. perc. error	30,911961823

Figure 5 – Error computation at a = 0,5

MAPE error magnitude, equaled to 30,91, happened just over than at modeling with a = 0,1.

Upon constructing the exponential smoothing model with a = 0,9 in STATISTICA packet there have been obtained the following outcomes (figure 6, 7).

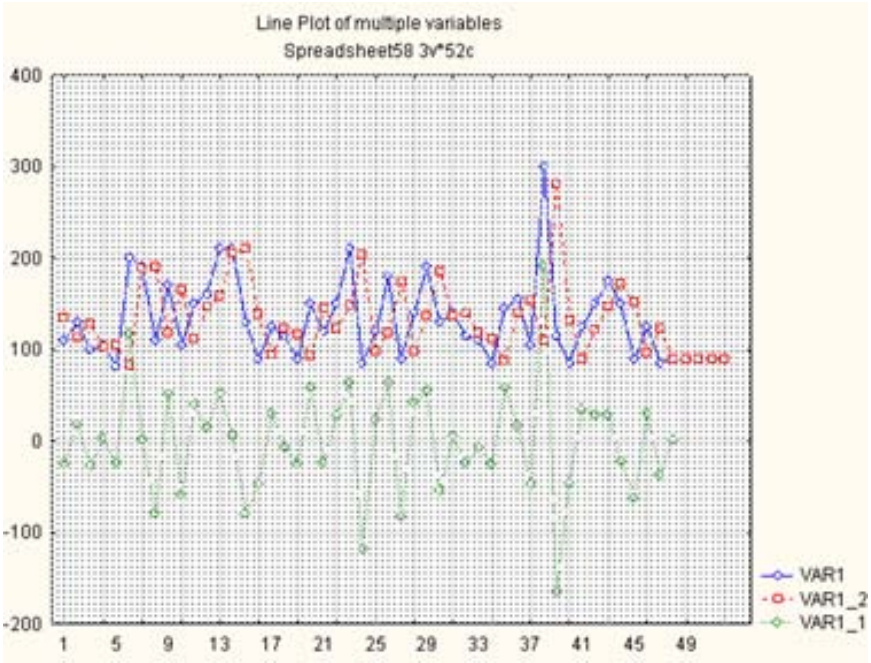

Figure 6 – Graphic display of exponential smoothing process a = 0,9

Summary of error	Exponential smoothing: S0=135,2 (M2M.sta) No trend,no season; Alpha= ,900 VAR1 **Error**
Mean error	-1,049470166
Mean absolute error	44,768216865
Sums of squares	167735,146218579
Mean square	3494,482212887
Mean percentage error	-10,263419710
Mean abs. perc. error	35,026762567

Figure 7 – Error calculation at a = 0,9

Traffic prediction for 49, 50, 51 and 52 15-minute periods composed 89,87 Bps. MAPE error value reached 35,026.

Conclusion. The modeling outcomes of M2M traffic dynamic series by means of exponential smoothing method under different smoothing parameter values were compared. It is possible to make a conclusion, that all considered models secure satisfactory forecast precision. Though, the most accurate outcome has been obtained in consequence of constructing the model with smoothing constant a = 0,1. Prediction value in that case amounted to 127 Bps, and error value of MAPE forecast turned out to be minimal and composed 28,3.

Elaborated prediction model, upon constructing of which, there has been applied Brown method, can be used in M2M networks. At that, prediction shall be fulfilled regularly upon incoming new statistical data.

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МАШИНААРАЛЫҚ ӨЗАРА ӘРЕКЕТТЕСУДІҢ (M2M) НАҚТЫ ТРАФИГІН СТАТИСТИКАЛЫҚ ТАЛДАУ

Аннотация. Машинааралық өзара әрекеттесу түріндегі қосылыстар (Machine-type Communication (MTC)) немесе "машина-машина" (M2M) қосылыстары - бұл адамдармен өзара әрекеттесуді қажет етпейтін құрылғылар арасында деректерді беру нысаны. Қосылыстардың бұл түрі интернет заттарының (IoT) болашағын қамтамасыз ете отырып, ақпараттық-коммуникациялық технологияларда маңызды рөл атқарады.

M2M құрылғылары үшін деректерді берудің ең тиімді ортасы-ұялы байланыс. Ұялы байланыс желісіндегі M2M машинааралық трафиктің тез өсуі зерттелетін мәселенің өзектілігін, оның ерекшеліктері мен сипаттамаларын анықтайды. Зерттеу нәтижелері желілік модельдеу, жоспарлау, M2M трафигінің мобильді желінің қызмет көрсету сапасына (QoS) әсерін талдау үшін қажет.

Мақалада LoRaWAN желісіндегі нақты трафик талданады. Барлық құрылғылардан желілік серверге кіретін біріктірілген трафик қарастырылады. M2M пакеттік трафигін модельдеу үшін статистикалық сипаттамаларды көрсетумен қатар, оның өзіндік ұқсастығын бағалау қажет. Трафиктің өзіндік ұқсастығын анықтау үшін Херст параметрі есептелді. STATISTICA бағдарламалар пакетінің негізінде статистикалық талдау және экспоненциалды тегістеу әдісімен M2M нақты трафигін қысқа мерзімді болжау жүргізілді.

Түйін сөздер: заттар Интернеті (IoT), M2M трафигі, мобильді байланыс желісі, Херст параметрі, болжау, статистикалық талдау.

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СТАТИСТИЧЕСКИЙ АНАЛИЗ РЕАЛЬНОГО ТРАФИКА МЕЖМАШИННОГО ВЗАИМОДЕЙСТВИЯ (M2M)

Аннотация. Соединения в виде межмашинного взаимодействия (Machine-type Communication (MTC)) или соединения «машина с машиной» (M2M) представляют собой форму передачи данных между устройствами, которая не обязательно требует взаимодействия с человеком. Этот тип соединений будет играть важную роль в информационно-коммуникационных технологиях, обеспечивая будущее Интернета вещей (IoT).

Наиболее эффективной средой передачи данных для M2M устройств является мобильная связь. Стремительный рост межмашинного трафика M2M в сети мобильной связи определяет актуальность исследуемой проблемы, ее особенности и характеристики. Результаты исследований незаменимы при сетевом моделировании, планировании, анализе влияния трафика M2M на качество обслуживания (QoS) мобильной сетевой связи. В статье анализируется реальный трафик в сети LoRaWAN. Рассматривается агрегированный трафик, поступающий на сетевой сервер со всех устройств. Для моделирования пакетного трафика M2M помимо задания статистических характеристик необходимо оценить его самоподобие. Для определения самоподобия трафика был вычислен параметр Херста. На основе пакета программ STATISTICA проведен статистический анализ и краткосрочное прогнозирование реального трафика M2M методом экспоненциального сглаживания.

Ключевые слова: интернет вещей (IoT), трафик M2M, сеть мобильной связи, параметр Херста, прогнозирование, статистический анализ.

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CLUSTER ANALYSIS FOR DATABASES TYPOLOGIZATION CHARACTERISTICS

Abstract. The article deals with basic concepts of cluster analysis and data clustering. The authors give brief information on the history of cluster analysis and its first applications. The article gives the classification of methods by the way of data processing and analysis in cluster analysis. The detailed description of the popular, non-hierarchical K-means algorithm is given. When developing databases, their structure should provide for the division of products into clusters based on various characteristics. It is necessary to consider the division into clusters based on other characteristics, such as allergenicity (whether the product contains an allergic component or not) or carbohydrate content (important for diabetics). The content of protein, potassium and phosphates should be taken into account when developing diets for those suffering from kidney diseases. The presence of specific amino acids - for metabolic diseases, etc. In this way, food composition data and product clustering across different categories allow nutritionists to create interchangeable lists of meals with portion sizes, or lists of permitted and prohibited food products in terms of various diseases. The authors give the clustering of the database fragment of chemical composition of food products on the example of cottage cheese products and confectionary by one of the signs – the content of carbohydrates – in the R software environment by k-means. Food clusters based on carbohydrate content are very important in shaping the diet for diabetics. A visual gradation of products into clusters is demonstrated in the form of a dendrogram showing the degree of proximity of individual clusters. The resulting dendrogram contains 5 clusters. Cluster 4 includes the largest number of products (170 items) with an average carbohydrate content of 1.8 g with a variation range from 0 to 7.1 g. Food products and dishes that fall into this cluster are the least dangerous for people with diabetes. Cluster 5 includes only 8 products with a distribution of carbohydrates within the cluster from 62.60 to 80.40 g. This category of food should be excluded when preparing a diet for people with diabetes.

Keywords: cluster, proximity measure, clustering methods, k-means, dendrogram, characteristic.

Introduction. Clustering means combining objects into groups (clusters) based on the similarity of features for objects in the same group and differences between the groups. Most clustering algorithms do not rely on traditional statistical assumptions; they can be used in conditions where there is almost no information about data distribution laws. Thus, the task of cluster analysis is to divide the initial set of objects into groups that are similar and close to each other. These groups are called clusters or taxons. In addition to the term "clustering", there are a number of terms with similar meanings, such as automatic classification, numerical taxonomy, botryology, and community detection. It is believed that the term "cluster analysis" was first used in the work of the American psychologist Robert C. Tryon from the University of Berkeley [1].

The first works on clustering in the 30-40s of the last century can be attributed to the field of anthropology - Driver and Kroeber [2], psychology - Joseph Zubin [3], Robert Tryon [1] and to the classification of traits in personality psychology [4]. However, the publication of the book Sokal R. R., and Sneath P. H. A. "Principles of Numerical Taxonomy" [5] in 1963 served as an impetus for the development of various methods of cluster analysis. To date, a large number of different clustering algorithms and

their modifications have been developed. For the first time, the monograph of Hartigan J.A. [6] provides an overview of classical (first) methods and algorithms in clustering.

The results obtained by cluster analysis methods are applied in various fields. For example, in the field of medicine, clustering of diseases and symptoms of diseases leads to classifications used to select treatment methods. To create an adequate diet, it is necessary to process large amounts of data related to the chemical composition of food products and dishes. Information such as rules should be stored in databases. The database structure should be divided into clusters, such as "Porridge", "Soups", "Vegetables", etc. Clusters are necessary for the subsequent distribution of food products and dishes included in the diet to separate meals according to time. Along with this, it is necessary to take into account the division into clusters based on various characteristics, such as allergenicity (whether the product contains an allergic component or not), etc. Food clusters can be based on, for example, carbohydrate content for diabetics, or protein, potassium and phosphates for kidney disease sufferers, or specific amino acids for metabolic diseases, and so on. Thus, product composition data and product clustering across different categories allow nutritionists to create interchangeable lists of meals with portion sizes, or lists of permitted and prohibited food products in terms of various diseases.

The purpose of this research is to analyze existing groups of algorithms for classifying food products, ingredients, dishes and diets, and to conduct cluster analysis on the example of cottage cheese products and confectionery.

Organization and research methods. The initial information for clustering is the observation matrix:

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{12} & x_{22} & \dots & x_{2n} \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix}$$

each of its line represents the values of n attributes of one of the Mclusterization objects. The clustering task is to break objects from X into several subsets (clusters), where the objects are more similar to each other than to objects from other clusters. In metric space, the "similarity" is usually defined in terms of a distance. The distance can be calculated either between the source objects (lines of the X matrix), or between these objects to the cluster prototype. Usually, prototype coordinates are not known in advance – they are found simultaneously with data breaking into clusters.

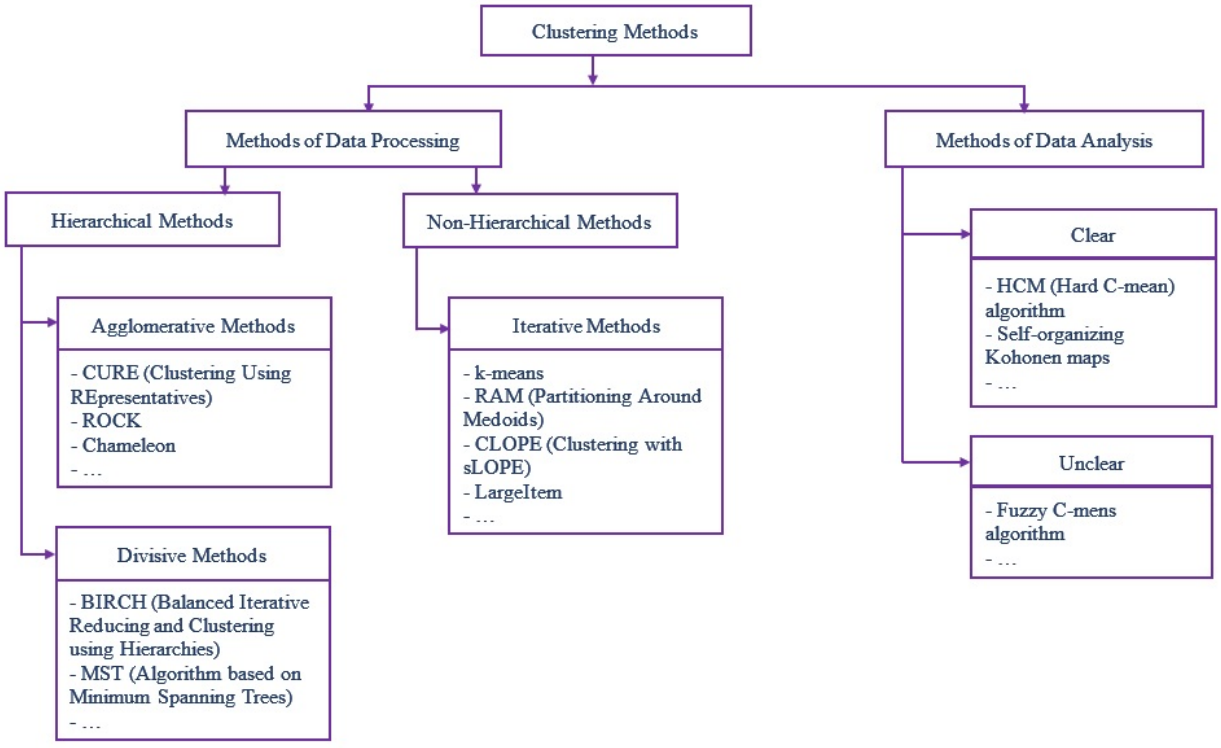


Figure 1 – Classification of methods by the method of data processing and analysis in cluster analysis

Data of the observation matrix must be normalized, i.e., reduced to dimensionless values. If the variables are not normalized, they will not affect the distance equally (i.e. if we measure vitamins in milligrams and micrograms, and protein, fat, and carbohydrates - in grams, then protein, fat, and carbohydrates will not be able to affect anything at all).

There are many clustering methods that can be classified as follows: 1) by the method of data processing [7-14]; 2) by the method of data analysis [15-16]; 3) by the number of applications of clustering algorithms [17-22]; 4) by the possibility of expanding the scope of processed data [23-24]; 5) by the time of clustering [25-26]. A more detailed classification of methods by the method of data processing and analysis in cluster analysis is shown in (figure 1).

All clustering methods work with data as vectors in a multidimensional space. Each vector is determined by the values of several directions, while the directions themselves are the characteristics we know (the content of protein, fat, amino acids, vitamins, etc. in the product). Characteristics can be both quantitative and qualitative, and the art of a data mining specialist is to correctly select and normalize these characteristics, and then choose the appropriate measure of distances. Only then clustering algorithms shall be applied.

Results and discussion. The criterion for determining the similarity and difference of clusters is the distance between points on the scattering diagram. There are several ways to determine the measure of distance between clusters, called the proximity measure: 1) *Mahalanobis distance* (general view); 2) *ordinary Euclidean distance*; 3) *"weighted" Euclidean distance*; 4) *Hemming distance*; 5) *Chebyshev distance*; 6) *power distance*; 7) *percent disagreement*. Depending on the research purpose, one or another formula is chosen to determine the measure of proximity. The authors have analyzed the most used algorithms. One of the most popular non-hierarchical algorithms is the K-means algorithm. It was invented in the 1950s by the mathematician Hugo Steingauz [27] almost simultaneously with Stuart Lloyd [28]. It became particularly popular after McQueen's work [29].

The k-means algorithm is popular due to its ease of implementation and speed [9-10]. Its main drawback is its convergence to the local minimum and dependence of the result on the initial distribution. You also need to know the estimated number of k clusters in advance. The main idea of the k-means algorithm is that the center of mass for each cluster obtained in the previous step is recalculated at each iteration, then vectors are divided into clusters again taking into account the closest of the new centers by the chosen metric. The algorithm ends when there is no change in the intra-cluster distance at some iteration. This happens in a finite number of iterations, since the number of possible breakings of a finite set is finite, and at each step the total square deviation decreases, thus, looping is impossible.

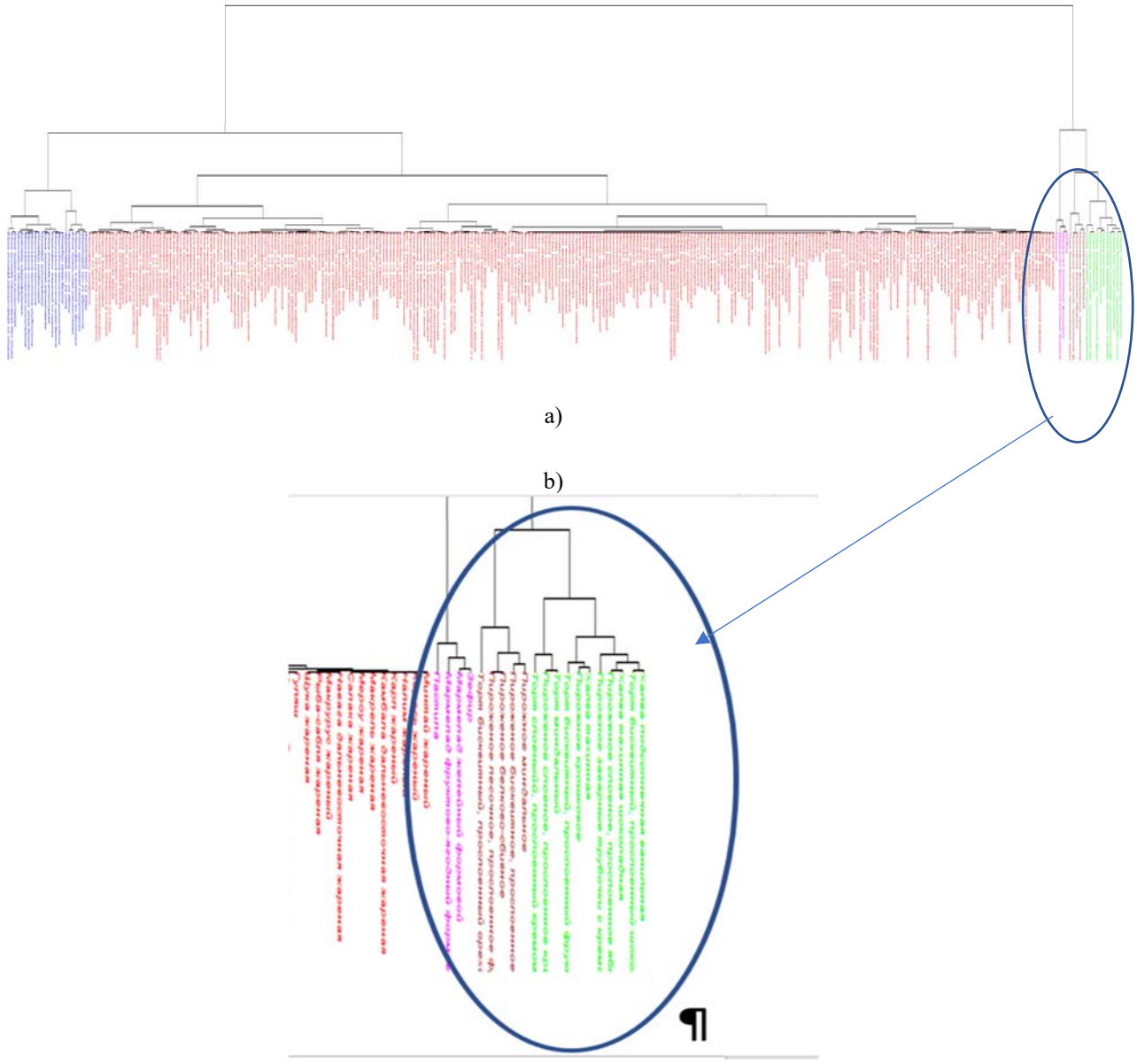
```
# To upload and prepare data
# To output data elements
head(prod)
                                              Carbohydrates
  Borshch with fresh cabbage and tomato             9.8
  Borshchwithsauerkraut                             8.8
  Navy-style borshch with meat                     11.5
  Borshch with fresh cabbage, potatoes and meat     5.7
  Krasnodar borshch with meat                       8.3
# To normalize data
prod <- scale(prod)
# To build a dendrogram
hc<- hclust(dist(prod))
ph<- as.phylo(hc)
groups5 <- cutree(hc, k = 5)
colors = c("red", "blue", "green", "brown","magenta")
plot(ph, tip.color = colors[groups5], cex = 0.6)
# To conduct clusterization using the k-means method
kmeans(prod, 5, 1000000)
```

Figure 2 – Program code listing in the R software environment

It is a well-known fact that to support a healthy lifestyle and maintain health, it is necessary to prepare a diet that meets the needs and capabilities of the human body and is balanced in all indicators of nutritional and biological value. That is, taking into account the human metabolism. For this purpose, decision support systems are being developed. The information basis of such systems is a database of products, ingredients, and dishes that are most common and sold in large cities and megacities. The database structure should provide for the distribution of products into clusters based on various criteria. Dividing products into clusters will allow excluding "undesirable" products from the diet when creating a menu. So, for example, for patients with diabetes – this is the quantitative content of carbohydrates in products. The largest amount of carbohydrates is mainly found in dairy and confectionery products [30-31].

The authors have conducted a clustering of the database fragment by one of the signs – carbohydrate content – on the example of cottage cheese products and confectionary in the R software environment. The software code fragment is shown in (figure 2).

At the beginning of the study, a dendogram was formed. A dendrogram is a visualization of results of hierarchical clustering. It allows visually assessing the degree of proximity of individual objects and clusters, as well as graphically demonstrating the sequence of their association or separation. The number of dendrogram levels corresponds to the number of steps for merging or dividing clusters.



a)

b)

Figure 3 –Dendrogram: a) general view, b) cluster 1 (green font color)

The general view of the dendrogram for clustering products based on carbohydrate content is shown in (figure 3). Color zones (red, blue, green, brown, pink) in the dendogram visually display the division of products into clusters. Note that in the R environment, numbering goes from the right to the left. As can be seen from (figure 3), after classification, food products and dishes are grouped into 5 clusters with different carbohydrate content. The largest number of products included in cluster 4 is of red color.

For the detailed consideration of each formed cluster, one can build one's own dendrogram separately (to display it on the screen). For example, for cluster 1 (it is highlighted in green on the general dendrogram) containing 12 products, the dendrogram looks as follows (figure 4).

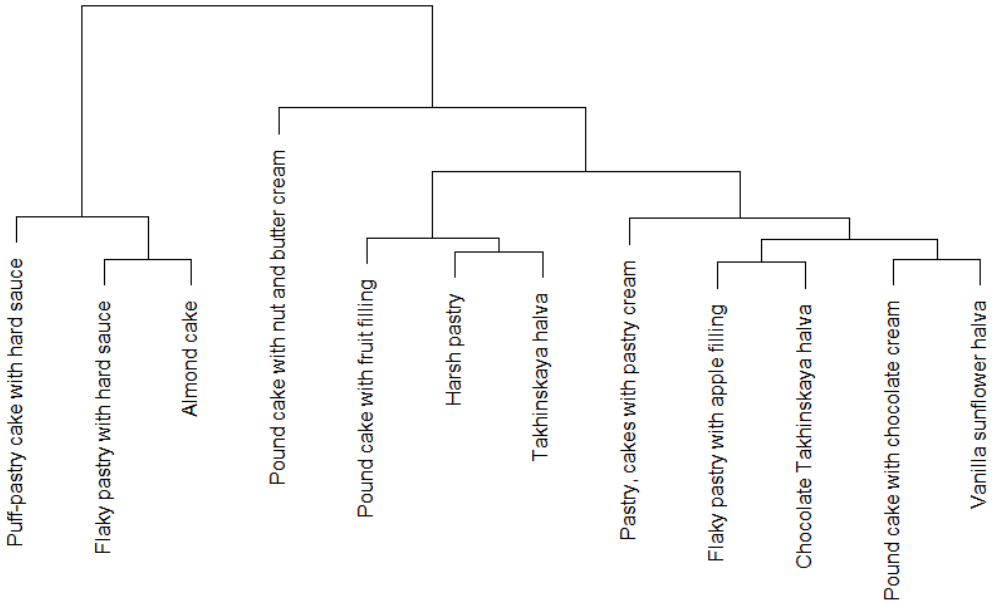


Figure 4 – Dendrogram of cluster 1

Along with the dendrogram, a table is formed with details for each cluster: 1) the number of products included in this cluster; 2) the average value of carbohydrates for this cluster; 3) the maximum content of carbohydrates in the product of this cluster; 4) the minimum content of carbohydrates in the product in this cluster. Thus, as a result of clustering using the k-means algorithm, we have obtained the following division of products provided in table 1, which can be interpreted by the carbohydrate content as products with low carbohydrate content (class 4), medium (class 2) and high carbohydrate content (class 5). The largest number of products (170 items) fell into cluster 4 with an average carbohydrate content of 1.8 g. with a variation range from 0 to 7.1 g. The smallest number of products (8 items) fell into cluster 5 with an average carbohydrate content of 70.91 g. with a variation range from 62.60 to 80.40 g.

Table1 – Clustering results

Cluster	Quantity by the Product field	Average by the Carbohydrates field	Maximum by the Carbohydrates field	Minimum by the Carbohydrates field
5	8	70.91	80.40	62.60
1	12	51.32	58.80	44.00
2	38	22.86	35.40	18.60
3	102	13.20	17.60	7.70
4	170	1.80	7.10	0.00
Grand total	330	11.22	80.40	0.00

Table 2 Products included in cluster 5

Cluster	Quantity by the Product field	Average by the Carbohydrates field	Maximum by the Carbohydrates field	Minimum by the Carbohydrates field
5	8	70.91	80.40	62.60
Marshmallows	1	78.30	78.30	78.30
Jelly shaped marmalade	1	77.70	77.70	77.70
Fruit and berry shaped marmalade	1	76.00	76.00	76.00
Paste	1	80.40	80.40	80.40
Protein-churned cake	1	62.60	62.60	62.60
Pound cake with fruit filling	1	64.20	64.20	64.20
Short pastry with fruit filling	1	62.60	62.60	62.60
Almond cake	1	65.50	65.50	65.50

A user can see more detailed information when each cluster is expanded. Which product subgroups or products are included in this cluster. Table 2 shows the products included in cluster 5.

Conclusion. The article shows the possibility of using cluster analysis to classify food products, ingredients, dishes and diets using the example of cottage cheese products and confectionery. There is a brief information on the history of cluster analysis and its first applications. The article gives the main terms and definitions, classification of methods and algorithms of cluster analysis. Based on the analysis, the k-means method was chosen as the implementation method. The advantage of this method is simplicity and speed of use as well as visibility when dividing elements (products) into clusters. Clustering of the database fragment of the chemical composition of products and dishes based on "carbohydrate content" was performed in the R software environment. The visual gradation of products into clusters in the form of a dendrogram is demonstrated. The resulting dendrogram contains 5 clusters. Cluster 4 in-cludes the largest number of products (170 items), with an average carbohydrate content of 1.8 g. with a variation range from 0 to 7.1 g. Food products and dishes that fall into this cluster are the least dangerous for people with diabetes. Cluster 5 includes only 8 products with a distribution of carbohydrates within the cluster from 62.60 to 80.40 g. This category of food should be excluded when preparing a diet for people with diabetes.

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ТАМАҚ ӨНІМДЕРІН ЖӘНЕ ТАҒАМДАРДЫ КЛАСТЕРЛІК ТАЛДАУ АРҚЫЛЫ ТИПТЕУ

Аннотация. Мақалада кластерлік талдаудың негізгі ұғымдар және кластерлеу деректері қарастырылған. Кластерлік талдаудың пайда болу тарихы, алғашқы салалардағы оның қолдануы бойынша қысқаша мәліметтер берілді. Кластерлік талдауда өңдеу тәсілі бойынша әдістерді жіктеу мен талдау деректері келтірілген. Қолданыстағы әдістер мен деректерді кластерлеу алгоритмдері: 1)өңдеу тәсілі бойынша деректер талданды; 2)деректерді талдау тәсілі бойынша талданды; 3)кластерлеу алгоритмдерін қолдану саны бойынша талданды; 4)өңделетін деректердің көлемін кеңейту мүмкіндігінше талданды; 5)кластерлеу уақыты орындалу бойынша талданды.

Белгілі k-орташа иерархиялықсыз алгоритмі тиянақты сипатталған. Барабар тамақтану рационын жасау кезде көлемі үлкен деректерді, кейде құрылымдық емес немесе әлсіз құрылымдыны пайдалану қажет. Деректер базасын жасау кезінде оның құрылымындағы өнімдерді әр түрлі сипаттамалар бойынша кластерлерге бөлуін қарастыру қажет. Басқа белгілер бойынша кластерлерге бөлінетінін ескеру қажет бөлу, мысалы, аллергендігі бойынша (өнімнің құрамында аллергиялық компонент бар немесе жоғын) немесе көмірсулардың болуы бойынша (диабетиктер үшін маңызды). Ақуыз, калий және фосфаттардың болуын бүйрек ауруларына

шалдыққан адамдардың рационын жобалау кезінде ескеру қажет. Метаболикалық аурулар және т.б. үшін нақты амин қышқылдардың қатысуы. Осылайша, өнімнің құрамы туралы мәліметтер мен әртүрлі санаттағы өнімдердің кластеризациясы диетологтарға порция өлшемдеріне қарай алмастырылатын тағам тізімдерін қалыптастыруға немесе әр түрлі аурулар тұрғысынан алғанда рұқсат етілген және рұқсат етілмеген өнімдерді қалыптастыруға мүмкіндік береді.

Өнімдер мен тағамдар химиялық құрамының деректер базасындағы фрагмент кластеризациясы келтірілген оны ірімшікті өнімдер мен кондитерлік бұйымдардың мысалынан бір қасиеті бойынша–көмірсулардың болуы – R бағдарламалық ортада k-орташа әдісімен көруге болады. Көмірсулар мәні бойынша өнімдердің кластерлері диабетиктер үшін тамақтану рационын қалыптастыру кезінде өте маңызды. Жеке кластерлердің жақын орналасқан дәрежесін көрсететін дендрограмма түрінде құрастыру арқылы өнімдердің кластерлерге визуалды градациясы көрсетілді. Кластерлеу кестесі пайдаланушыға әрбір кластерді ашу кезінде егжей-тегжейлі ақпаратты көруге мүмкіндік береді: нақты қай кластерге қандай топ өнімдері немесе өнімдер кіреді.

Түйін сөздер: кластер, жақындау шарасы, кластерлеу әдістері, k-means, дендрограмма.

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КЛАСТЕРНЫЙ АНАЛИЗ ДЛЯ ТИПОЛОГИЗАЦИИ ПИЩЕВЫХ ПРОДУКТОВ И БЛЮД

Аннотация. В статье рассмотрены основные понятия кластерного анализа и кластеризации данных. Даны краткие сведения по истории возникновения кластерного анализа, первых областях его применения. Приведена классификация методов по способу обработки и анализу данных в кластерном анализе. Проанализированы существующие методы и алгоритмы кластеризации данных: 1) по способу обработки данных; 2) по способу анализа данных; 3) по количеству применений алгоритмов кластеризации; 4) по возможности расширения объема обрабатываемых данных; 5) по времени выполнения кластеризации.

Наиболее подробно описан популярный, неиерархический алгоритм k-средних. При составления адекватного рациона питания необходимо оперировать большим объемом данных, иногда не структурированным или слабоструктурированным. При разработке баз данных, в ее структуре следует предусмотреть деление продуктов на кластеры по различным характеристикам. Наряду с этим необходимо учесть деление на кластеры по другим признакам, например, аллергенности (содержит ли в своем составе продукт аллергический компонент) или содержании углеводов (важно для диабетиков). Содержание белка, калия и фосфатов следует учесть при проектировании рационов для страдающих заболеваниями почек. Присутствие конкретных аминокислот – для метаболических заболеваний и т.д. Таким образом, данные о составе продуктов и кластеризация продуктов по различным категориям позволяют диетологам формировать взаимозаменяемые списки блюд с размерами порций или списки разрешенных и неразрешенных продуктов с точки зрения различных заболеваний.

Приведена кластеризация фрагмента базы данных химического состава продуктов и блюд на примере творожных продуктов и кондитерских изделий по одному из признаков – содержание углеводов – в программной среде R методом k-средних. Кластеры продуктов по содержанию углеводов очень важны при формировании рациона питания для диабетиков. Продемонстрирована визуальная градация продуктов на кластеры в виде построения дендрограммы, показывающая степень близости отдельных кластеров. Кластеризации позволяет пользователю увидеть более детальную информацию при раскрытии каждого кластера: какие подгруппы продуктов или продукты входят в данный кластер.

Ключевые слова: кластер, мера близости, методы кластеризации, k-means, дендрограмма.

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DEFINITION METHODS MECHANICAL CHARACTERISTICS OF SOUND ABSORPTION STRUCTURES

Abstract. Design techniques of Sound Absorption Structures (SAS) used in aviation engines coincide, on the whole, with the techniques of designing honeycomb parts, sandwich structures that are of wide application. However, SAS have their own distinctive features. First of all, perforating of skins decreases parts' stiffness. SAS can have different forms (three- or five-layer SAS) and differ in honeycomb height, and can also be made of different materials. The whole of that is told on effective mechanical characteristics of SAS – stiffness in a skin plane, bending stiffness, strength of joints between separate members, and others. At present, the most sound-absorbing parts are not load-bearing structures and their mechanical damages or failures are not critical. At the same time, SAS, even those made from relatively light composites, are of heavy weight, especially in turbofans, that decreases engine performance. The abovementioned requires the development of techniques for the adequate estimation of SAS mechanical characteristics. The tendency to obtain SAS properties required for designing at lower expenses results in the necessity of their analytical prediction. In connection with this, the given work presents the analytical technique for defining SAS mechanical characteristics. The techniques of averaging are used for determining the characteristics of perforated skins and honeycomb assemblies.

Keywords: honeycomb, stiffness, bending, strength, composite, plates, turbofan.

Introduction. The existing techniques for providing the structure safety are based on the test pyramid [1], they take much time and are expensive. Understanding of SAS behavior at mechanical and acoustic loading permits to shorten tests and to reduce expenses while maintaining the required safety levels.

The design techniques of SAS used in aviation engines coincide, on the whole, with the techniques of designing honeycomb parts, sandwich structures that are of wide application (see, for example [2-4]). In spite of a relatively big height, SAS are considered as a panel or a shell in designing with corrected characteristics of stiffness. The features of SAS members (perforated skins), their different types (three- or five-layer SAS, different honeycomb height and honeycomb structures) are told on effective mechanical characteristics of SAS. Stiffness in a skin plane, bending stiffness, strength of joints between separate members and others characteristics are used in designing. This requires developing the adequate estimation techniques of SAS mechanical characteristics. For life estimation it is necessary to know the stress distribution in each member of SAS. That requires a realization of a transition from a shell structure to a three-dimensional structure. Three-dimensional models use the characteristics of each separate member of SAS.

The analytical approach of determining SAS mechanical characteristics is developed. The skins and honeycombs of SAS may be manufactured of both metal and composite materials. The technique of averaging is used for the definition of elastic characteristics of perforated skins, honeycomb assemblies, and SAS. Moreover, the Maxwell and Voigt models are used in calculation of corrected elastic characteristics of multilayer SAS. The experimental technique for defining the elastic and strength characteristics of SAS both in a layer plane and in the direction of honeycomb height is developed. The results of analytical estimations of SAS mechanical characteristics agree with experimental data.

1. Analytical definition of elastic characteristics of SAS and their members. The complex of elastic and strength characteristics of SAS is used at designing of structures. The analytical estimation of elastic characteristics is sufficiently reliable while the achievement of required accuracy at strength predictions produces some difficulties. Below the analytical technique of defining SAS elasticity characteristics is described [5-7]. SAS represent a mixed structure consisting of several skins and honeycomb layers between them. The load-bearing skin is solid, the other ones are perforated. The mechanical characteristics of skins without perforation as well as those of honeycomb material are considered specified.

1.1. Elastic characteristics of perforated skin. The mechanical characteristics of perforated skin depend on behavior of initial material as well as on the form, degree and distribution of perforation [8-10]. They are determined by numerical solution of a problem of real skin tension at a specified value of displacement u_{sp} of a sample free end (rigid loading) by using solid elements of CAD program.

Figure 1 shows the form and sizes of a typical perforated skin. The distribution of displacements and stresses in skins with 10% of perforation are given in figures 2a,b. The character of displacements and stresses distribution on the skins with other degree of perforation does not qualitatively differ from the data in figsures 2a,b.

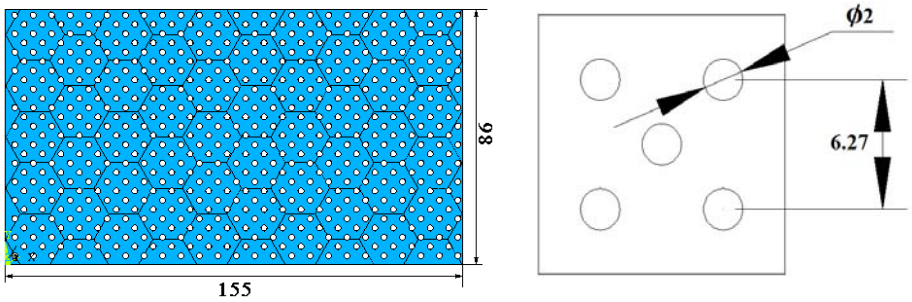

Figure 1 – The form, distribution and sizes of a typical perforated skin

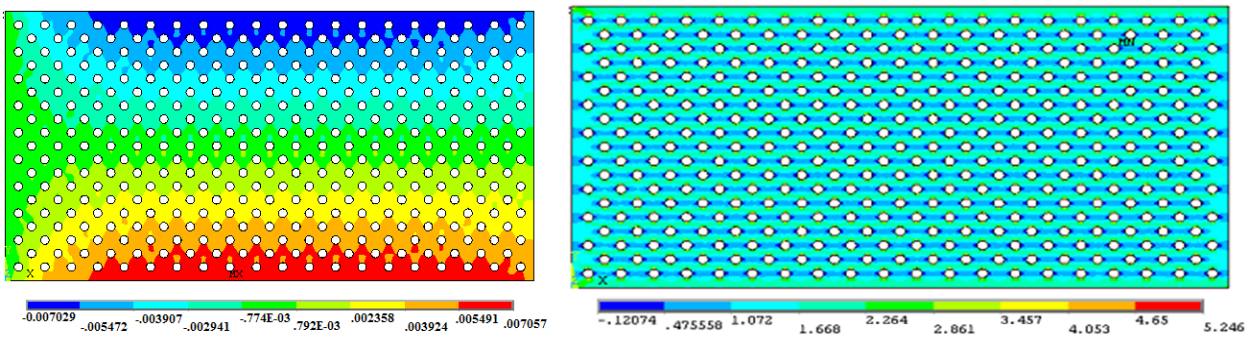

Figure 2 – a) Transversal displacements of perforated skin at tension (10% of perforation);
b) Longitudinal stresses of perforated skin at tension (10% of perforation)

The distribution of axial displacements u_x along the skin length is even, the longitudinal strains εx are permanent. The stress distribution in the cross-section is complicated. The average value of longitudinal stresses $\sigma_{x,mean}$ in nodes of the skin cross-section is calculated. Relation between mean stress $\sigma_{x,mean}$ and longitudinal strain ε_x is taken as a relative elastic modulus [11,12].

$$E_x^{rel} = \sigma_{x,mean} / \varepsilon_x, \ \nu_{xy} = -\varepsilon_y / \varepsilon_x, \tag{1}$$

Here, parameter ν_{xy} is Poisson's coefficient. The elastic modulus at soft loading by force P is determined from relation

$$E_x^{rel} = P/(F_{rel} \cdot \varepsilon_x), \ \sigma_x = P / F_{rel} \tag{2}$$

Value of F_{rel} is an area of "alive" cross-section of the perforated skin. Effective elastic modulus is calculated from equality

$$E_x^{eff} = (F_{rel} / F) E_x^{rel} \tag{3}$$

Here, F is a cross-section total (including voids) area. If materials of the perforated skins are anisotropic or in the case where either a character of perforation arrangement or perforation form are the reason of the dependence of mechanical characteristics on loading directions then the described above actions should be carried out in the main axis of anisotropy [13].

1.2. Elastic characteristics of honeycomb sandwich. The honeycomb sandwiches have an increased stiffness along honeycomb height. The honeycomb stiffness in the skin plane is minor, and the influence of honeycomb sandwich is neglected [14].

However, the honeycombs may contribute to elastic characteristics in SAS plane in conditions of low stiffness of perforated skins and constrained strains. The technique of elastic characteristic calculation coincides with the above-described technique for perforated skins. Relation between the longitudinal stress σ_x and the longitudinal strain ε_x is considered as a relative elasticity modulus $(E_x^{rel})_I$ in i-nodal point. The mean value of modulus $(E_x^{rel})_i$ at all nodal points of cross-section is taken as a relative elasticity modulus. The ratio of transversal strain ε_y to longitudinal strain ε_x with the inverse sign is taken as Poisson's coefficient. A transversal strain ε_y is taken as a ratio of sample contraction to its width. The maximum degree of perforation of the mentioned below perforated skins does not exceed 10%. In this case, the calculation shows that the influence of honeycomb stiffness in the skin plane is negligible (less than 3%).

1.3. Elastic characteristics of SAS. Two techniques are used for the analytical estimation of the effective elastic characteristics of SAS. The effective elastic characteristics of SAS in the direction of a load-bearing layer base were found by mixture rule (Maxwell's model) including well-known behaviors of each layer

$$E_x^{eff} = v_k (E_x^{eff})^k, \; v_{xy}^{eff} = v_k (v_{xy}^{eff})^k \tag{4}$$

The transversal characteristics and shear modulus were determined by Voigt's relations

$$E_y^{eff} = [v_k / (E_y^{eff})^k]^{-1}, \; v_{yx}^{eff} = v_k (v_{yx}^{eff})^k, \; G_{xy}^{eff} = [v_k / (G_{xy}^{eff})^k]^{-1} \tag{5}$$

Here, k is the number of SAS member, $v_k = h_k/h$ – relative thickness of k- elements, h ($h = \sum h_k$) – total thickness of SAS cross-section.

The solution of a compound structure tensile-stressed plate problem at given displacement of the free end is the second technique of effective elastic characteristics estimation. In this case, the mechanical characteristics of all SAS members are considered well-known – they may be determined by either above-described analytic technique or experimentally. The definition technique of the SAS relative and effective characteristics coincide with the above-described technique for perforated skins. The calculated relations between SAS relative elastic characteristics and elasticity modulus of the load-bearing layer are given in table 1. Figure 3 presents the distribution of SAS stresses defined by CAD program.

Table 1 – Relative values of SAS relative elasticity modulus defined by two approaches

Approach	Estimated characteristics		
	Elasticity modulus, GPa	Poisson's coefficients	
	E^{exp}_x/E_x	ν_{xy}	ν_{xz}
Finite element	0,97	0,31	0,31
Relations (4)-(5)	0,98	0,3	0,3
Experimental	1,0	0,3	0,3

The SAS elasticity moduli defined by using FE software ANSYS and relations (4)-(5) have identical values.

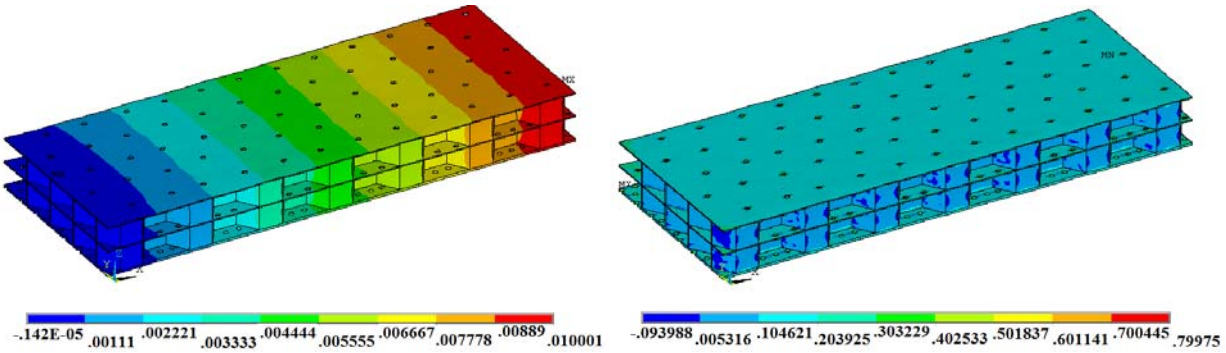

Figure 3 – Longitudinal displacements and axial stresses distribution in SAS at tension

SAS is considered as a perfect structure when determining effective elastic characteristics by developed analytical technique. In practice, all SAS contain technological imperfection [4] in the form of fiber ruptures, matrix or (and) interface damages, hole surface defects, face wrinkling and crimpling, burrs in the area of honeycomb and skins joints, and other. All this is not taken into consideration for the described analytical approaches. The results of analytical predictions must be confirmed by tests, on the other side, they can serve as a criterion of perfection of SAS manufacturing technique.

2. Experimental determination of SAS characteristics. The complex of SAS elastic and strength behaviors is determined experimentally. SAS represent compound structures, and SAS failure may take place in either their separate members or in the areas of their joints. In this case, the SAS stiffness and strength characteristics are determined in the tests of samples of different forms [15-18].

2.1. Test results. Below some test results of SAS are presented.

2.2.1. SAS characteristics in skin plane. Elasticity modulus and Poisson's coefficient are determined at 50% of limiting strain.

The failure of practically all samples took place in linear strain area, as a rule with exhaustion of carrying capability of perforated skin with the greatest of perforation degree (see figure 4a). This circumstance demonstrates the uniformity of strains in separate members of SAS.

a) b) c)

Figure 4 – a) Typical failure at tension in SAS skin plane;
b) Samples tested for tension along honeycomb height; c) Typical failure of SAS samples at shear

The tests showed that both the effective modulus and the strength of SAS samples having small height more than 2 times exceed such parameters of samples with big height. It is possible that the SAS height influences their mechanical characteristics.

Finally, it should be noted that the analytical and experimental results differ slightly (see table 2).

2.2.2. Honeycomb sandwich characteristics.

a. Tension. The results of samples tension test are presented in table 2. The elasticity modulus and strength limit at tension were determined by tests of different samples. Figure 4b shows failure type of samples. The tested samples have failure in the area of honeycomb sandwich joint with inside perforated skin having low height. It is necessary to notice that the dispersion of elasticity modulus is not statistically essential whereas dispersion of strength is more essential.

b. Compression. The results of samples compression test are presented in table 2. Again it can be seen that the dispersion of elasticity modulus is not considerable. However, their values are less than the values of elasticity modulus at tension by a factor of 1.5. Apparently, this experimental result can be explained in the following way. The middle perforated layer influences the sample total resistance at tension, and at compression the honeycomb sandwich only contributes to load-carrying capacity. The influence of honeycomb height on strength value is not determined. At the same time, the samples with bigger height had lower strength at compression. Loss of stability is a typical failure of honeycomb samples with large height.

Table 2 – The results of samples tension test are

	Strength		Elasticity modulus		Limited strain
	σ^{eff}	σ^{rel}	E^{eff}	$E^{rel,}$	
Tension	0.091	2.048	0.509*		–
	0.080	1.802	0.515*		–
	0.092	2.063	0.496*		–
	0.074	1.667	0.579*		–
	0.101	2.27	0.582*		
Compression	0.148	3.314	0.367	8.23	0.0009
	0.237	5.326	0.380	8.61	0.0008
	0.142	3.188	0.362	8.11	0.00075
	0.211	4.73	0.355	7.97	0.00085
	0.193	4.320	0.343	7.70	0.0008

The adhesion between honeycomb and skins does not have such influence on the ultimate strength at compression as it has as at tension. In connection with this, the strength at compression exceeds the one at tension by a factor of eight.

2.2.3. SAS characteristics at shear. The results of testing the samples of two types are presented in table 3. The tested samples differed in honeycomb height. The typical mode of samples' failure at shear is shown in figure 4c. Summarizing, one can notice:

– the tests at shear were more time –consuming,

– the elasticity moduli of samples with small height are higher than those of samples with big height,

– the honeycomb shear strength values exceeded their strength values at rupture.

Table 3 – Results of shear tests of different height samples

Samples		Strength	Elasticity Modulus a	Ultimate strain
High	1	0.31	70	1.12
	2	0.7	61	1.77
	3	0.53	65	0.81
	4	0.64	66	1.29
	5	0.47	65	1.1
		0.56; 0.15; 27%	65.4; 2.8; 5%	1.22
Low		0.52; 0.15; 29%	83; 11.9; 14%	2.39

Conclusions. The calculation technique of elastic characteristics definition for both the SAS members and the SAS as a whole has been developed.

The tests for definition of elasticity and strength characteristics at longitudinal tension in the skin plane at both tension and compression along the honeycomb height and finally at shear in the skin plane have been carried out. The procedure of SAS panels testing for strength has been developed.

The results of the work show:

– calculated values of elastic characteristics agree with experimental data,

– dispersion of elastic characteristics is less than those of strength ones,
– elasticity moduli at tension and compression along honeycomb height are different,
– loss of honeycomb stability is a typical failure mode at compression along honeycomb height,

SAS panels of lower height are stiffer at shear.

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МЕТОДЫ ОПРЕДЕЛЕНИЯ МЕХАНИЧЕСКИХ ХАРАКТЕРИСТИК ЗВУКОВОЙ АБСОРБЦИОННОЙ СТРУКТУРЫ

Аннотация. Методы проектирования звукопоглощающих конструкций (SAS), используемые в авиационных двигателях, в целом совпадают с методиками проектирования сотовых деталей, многослойных конструкций, которые имеют широкое применение. Однако у SAS есть свои отличительные особенности. Прежде всего, перфорирование шкур уменьшает жесткость деталей. SAS могут иметь различные формы (трех- или пятислойные SAS) и различаться по высоте сот, а также могут быть изготовлены из разных материалов. Все это говорит об эффективных механических характеристиках SAS - жесткость в плоскости слоя, жесткость на изгиб, прочность стыков между отдельными элементами и другие. В настоящее время большинство звукопоглощающих деталей не являются несущими конструкциями, и их механические повреждения или поломки не являются критическими. В то же время SAS, даже изготовленные из относительно легких композитов, имеют большой вес, особенно у турбовентиляторов, что снижает производительность двигателя. Вышеуказанное требует разработки методик для адекватной оценки механических характеристик SAS. Тенденция к получению свойств SAS, необходимых для проектирования при меньших затратах, приводит к необходимости их аналитического прогнозирования.

В связи с этим в данной работе представлена аналитическая методика определения механических характеристик SAS. Методы усреднения используются для определения характеристик перфорированных слоев и сотовых сборок.

Ключевые слова: соты, жесткость, изгиб, прочность, композит, пластины, турбовентилятор.

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ДЫБЫСТЫҚ АБСОРБЦИОНДЫҚ ҚҰРЫЛЫМНЫҢ МЕХАНИКАЛЫҚ СИПАТТАМАЛАРЫН АНЫҚТАУ ӘДІСТЕРІ

Аннотация. Авиациялық қозғалтқыштарда қолданылатын дыбыс сіңіргіш конструкциялардың (SAS) құрылғысын жобалау әдістері, тұтастай алғанда көп қабатты құрылымдарда кеңінен қолданылатын ұялы бөліктерді жобалау әдістерімен сәйкес келеді. Дегенмен, SAS өзінің ерекшеліктері бар. Ең алдымен, қабатты ұрып-соғу бөліктердің қаттылығын азайтады. SAS әртүрлі түрлері бар (үш немесе бес қабатты SAS) және ұяшықтың биіктіктері әртүрлі және сондай-ақ түрлі материалдардан жасалған болуы мүмкін. Мұның бәрі SAS тиімді механикалық сипаттамаларын анықтайды, яғни – қабат жазықтығының қаттылығы, иілу қаттылығы, жекелеген элементтер арасындағы буындардың беріктігі және т.с.с. Қазіргі уақытта дыбыс сіңіргіш бөлшектердің көпшілігі тірек конструкциялары емес және олардың механикалық зақымдануы немесе сынуы маңызды емес. Сонымен қатар SAS, әсіресе турбиналық желдеткіштер үшін, тіпті салыстырмалы жеңіл композиттерден жасалсада ауыр болады, бұл қозғалтқыштың жұмыс өнімділігін азайтады. Жоғарыда айтылғандар SAS механикалық сипаттамаларын барабар бағалау әдістемесін әзірлеуді талап етеді. Осыған сәйкес, SAS қасиеттерін арзан бағамен жобалау үшін талап етілетін үрдіс, оларды аналитикалық болжау қажеттілігін қажет етеді.

Осыған байланысты, осы жұмыста SAS механикалық сипаттамаларын анықтаудың аналитикалық әдісі көрсетілген. Орташа әдістер перфорацияланған қабаттар мен ұялы құрылымдардың сипаттамаларын анықтау үшін қолданылады.

Түйін сөздер: соттар, қатаңдық, иілу, төзімділік, композит, пластиналар, турбиналық желдеткіш.

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ENVIRONMENTAL SAFETY OF PHYTOGENIC FIELDS FORMATION ON COAL MINES TAILINGS

Abstract. Objective of the study is to research peculiarities of phytogenic fields formation of natural and artificial plantations of shrub and ruderal vegetation on coal mining waste heaps within the Novovolynsk mining area (Ukraine). The biometric analysis of the growth of artificial plantations on tailings has been carried out applying forest inventory methodology, which involves laying temporary experimental areas, measuring the diameter of tree species at a height of 1.3 m, the total height of trees and the parameters of crowns. Variation was applied to study the spatial structure of vegetation on reclaimed and damped waste heaps. The models of artificial phytocenoses and ameliorants on waste heaps of coal mines, which are formed during forest reclamation, have been described. The paper presents an analysis of forest inventory characteristics of the crops phytocenosis on waste heaps. The spatial structure of phytogenic fields basing on variation of the most common species in natural and artificial plantations on waste heaps has been established. This allows us to select an assortment of species to conduct effective vegetative reclamation on the surface of tailings. The article presents result of studies on the formation of phytogenic fields on waste heaps of coal mines, which presuppose formation of aggregations. It has been proved that formation of phytogenic fields is inextricably connected with vegetative reclamation. The conducted research of the origin and distribution of phytogenic fields makes it possible to assess the degree of suitability of tailings for afforestation, regardless of the country in which they are formed. Research of phytogenic fields on tailings and waste heaps of coal mines will improve bioindication research methodology for studying forest crops on their surface and suggest innovative methods of handling. In particular, it is possible to raise the level of environmental safety and aesthetics of the devastated territories, and to reduce cost of vegetative reclamation.

Keywords: environmental safety, phytogenic field, coal mine, tailing, phytocenosis, forest crops, reclamation.

Introduction. The rehabilitation of ecosystems cannot be imagined without plant communities. Vegetation communities on the devastated landscapes are individualized in order to characterize them according to ectopic characteristics (foot, slopes, terraces, plateau) and development stages. Taking into account that ecological successions are evaluated by the material, energy and information components, they should be considered as a phytogenic field. The development of the doctrine of the phytogenic field began in the 1960s and is closely interwoven with vegetative reclamation. The phytogenic field consists of two separate parts: internal and external. The external part of the phytogenic field is limited to the space where the living or dead parts of the plant are physically present. The boundaries of the external part of the phytogenic field are also determined by the extent of the penetration of the horizontal roots, in the presence of leaf litter. The size of the inner part of the phytogenic field is determined by the diameter of the aboveground or underground spheres, that is, the space occupied by the main body of the root system of the plant or the diameter of the crown of the tree or shrub. The allelopathy which determines the chemical interaction between plants, can play a significant role in phytogenic fields of plants along with light, trophic, temperature, humidity regimes. Devastated landscapes are present in many countries around the world where industry is aimed at extraction of minerals. Among them are Germany, the USA, China,

Russia, Mexico, South Africa, Australia, India and Ukraine. Although in rare cases, when during mineral deposits development the technology of goaf backfill with rock dump waste utilization is used the dumping is reduced [1, 2]. It should be noted that in Ukraine a significant amount of coal mining waste is accumulated annually due to the development of thin coal seams with a thickness of 0.7-1.2 m, which makes it necessary to coal-cutting with stone in stopping faces and carry out continuous mining of coal and rock during mining and produce coal enrichment processes [3, 4]. On the spoil heaps, like on the devastated landscapes, specific edaphic and climatic conditions for the development of vegetation were established [5]. The problem of vegetative reclamation of devastated landscapes is actively explored by many scientists. Some important issues of vegetative reclamation of devastated landscapes are not sufficiently explored. Among them are the investigation of the phytocoenotic structure of vegetation of various tailings types and the influence of environmental factors on the development of vegetation cover. The most pressing is the development of the ecological safety of phytogenic fields in devastated landscapes, where the plants are under significant man-made pressure caused by anthropogenic human activities [6]. The investigation of the features of phytogenic fields interference on the tailings is important for developing a reliable forecast of species coexistence and the formation of the continuum.

Purpose, tasks and methods of research. The aim of the research is to investigate the features of ecological safety of the phytogenic fields formation of artificial and natural plantations of tree-and-shrub and ruderal vegetation on coal mine tailings within the Novovolynsk mining area (Ukraine). According to the aim, the following tasks were foreseen: to establish the ecological safety of forest plantations by describing models of artificial phytocoenoses-ameliorants on waste heaps of coal mines, which are formed during forest remediation; to describe of the ecological succession of tailings; to establish the spatial structure of phytogenic fields on the basis of dispersion of the most common types in natural and artificial plantings of waste heaps.

A lot of scientific works were devoted to the concept of the phytogenic fields formation in different environmental conditions. We'll concentrate on the analysis of scientific works, which significantly influenced the development of the theory of phytogenic field of individuals and phytocoenoses in conditions of devastated territories. The scientific work [7] is devoted to the development of the phytogenic field for the standpoint of a single-growing plant. The illumination and ultraviolet regime of the inner part of the phytogenic field is investigated. It is established that the regime of ultraviolet radiation correlates with the illumination regime in the visible range, which is determined by morphostructural features of plants. Significant contribution to the theory of the phytogenic field formation in different conditions of inhabitation places is made in the work [8]. The main types of phytogenic fields of the plants of different biomorphs and changes in the process of ontogenesis are described. According to the presented theory, the phytogenic field is a set of phytogenic fields of cenopopulations of certain species, which form phytocenosis. Such theory is true, since the phytogenic field of a single plant does not have a significant effect on the development of phytocenotic cover. The disadvantage of this work is the lack of a description of the phytogenic fields in the devastated territories, because in conditions of landscape-transforming factors, the dynamics of development and the resistance of phytocoenoses are different from the conditions of the meadows. In the research paper [9] the author concludes that there are three concentration zones of phytogenic fields in the tailings that depend on the distance from tree stem, that is undertree, top, external. Identification characteristic of the undertree zone of phytogenic field is the forest litter with 100 % projective cover. Top zone takes into account moss cover and has a low growth rate. The external zone is characterized by herb species. The external zone has a high coefficient of similarity to the background values. The numerous studies presented are valuable in terms of influence of climatological and edaphic conditions on the formation and development of the phytogenic field. However, these studies describe only one species – the Scotch pine. This is not enough to evaluate the transformative function of vegetative cover on mine tailings. In [10] it was found that specific microbial functional communities on rock dumps are associated with groups of plants, and not with individual species. This relationship proves that it is the phytogenic fields of the communities that create the conditions for the further development of successions. It has been proved that the development of phytogenic fields and the characteristics of soil infiltration have a correlation (positive correlation) with age. This suggests that the recultivation approach to ecosystem rehabilitation is effective. However, complete recovery is a long process [11].

Applied investigations of improvement of efficiency of coal mines ecological restoration by phytomelioration methods are reflected in [12]. An experiment and field studies were conducted to

investigate the effect of micromycetes on plant growth performance. This approach has led to the development of environmentally safe technologies for soil restoration through phytoremediation. The ways of remediation works are closely related to the planning of land use [13]. The tailings body may remain in its original state or undergo minimal changes of its surface. Another possibility is partial dispose of the waste to the dump, and further aligning according to the needs. The best option is a complete dismantling of the dump and remediation of the area. According to the experimental results of the research [14] vegetative reclamation of the tailings is an effective way to reduce runoff and soil erosion and it is a key element in ecosystems restoring in environmentally hazardous regions. In the research paper [15] changes in the species diversity of plants, physical and chemical properties of soils on tailings of all ages have been investigated. It has been proved that species diversity, as well as the coverage and biomass of herb species, has increased significantly over time. Phytogenic fields of populations have been generated. However, for shrubs, the initial increase in species diversity was observed during the first 10 years, after which there was a gradual decrease. In general, the vegetation cover on the mines tailings is typical of the tops. On the slopes of a significant gradient, the overgrown is much smaller. The revegetation cover on the aged tailings is much more stable than freshly placed ones [16]. The research [17] reflected the influence of vegetative reclamation on the hydrological processes of the rock refuse. It was concluded that the infiltration rate and hydraulic conductivity were significantly higher in the afforestation area. In the research paper [18] the use of local species for the mechanical stability of landfills on the surface of an iron ore dump for the long-term environmental protection is investigated. It was established that the mechanical stability of the dump significantly improved after vegetative reclamation of the slopes. The positive role of soil algae in the development of higher plants on the rock refuses should be noted. The research [19] has shown that a large number of soil algae in dumps of copper mines increases due to the decrease of the heavy metals content and improvement of nutritional conditions. The growth of soil algae has created good conditions for the higher plants dispersal and growth. The appearance of moss and vascular plants inhibited the development of soil algae in dumps of copper mines.

The peculiarities of the phytogenic field formation the on the rock dumps of coal mines have not yet been fully studied and are the first thing that require the vegetative reclamation processes to be set and, as a consequence, the proper conditions to be established for the phytocenoses development. It should be noted that the investigations of the shrubs phytogenic fields are not numerous. This situation is caused by the fact that, in contrast to the well-known transformative function of trees, shrubs in forest populations have a subordinate role of underwood with a small cenotic role.

Results and their discussion. Since some mines of the Novovolynsk mining area ("Mines No 2, 3, 4, 6, 7, 8 Novovolinsk") were abandoned, the process of recultivation of damping heaps was not carried out properly. It is caused by insufficient financing of reclamation, obsolete technical equipment and the lack of effective methods for plantations creating in consonance with the region's specificity. In the process of artificial vegetation, which was carried out on the heaps of "Mine No. 2, 3, 8 Novovolynsk", the dominant species was *Robinia pseudoacacia* L., which is present on all the waste heaps. This species grows mainly on the slopes. During the investigation other species were found - *Betula pendula* Roth., *Salix caprea* L., *Quercus robur* L. According to the results of field studies, it has been found that representatives of following families are present on reclaimed heaps: *Asteraceae, Menyanthaceae, Scrophulariaceae, Urticaceae, Rosaceae, Compositae, Fabaceae, Lamiaceae, Caryophyllaceae, Brassicaceae Burnett (Cruciferae Juss.), Poaceae, Plantaginaceae, Violaceae, Umbelliferae, Malvales, Apiacaeae, Geraniaceae, Betulaceae, Fagaceae, Salicaceae, Rubiaceae*. Characteristic of heaps with artificial vegetation is that green plantations cover the slopes and only partially the top. At the same time, on the northern slope of the heap colonization by vegetation is more intense due to the higher humidity of the substrate. On the eastern slope there are the typical for Small Polesye forest plants *Calamagrostis epigeios (L.) Roth., Galium verum L., Fragaria vesca L.* On the reclaimed tailings a plantation was created by: *Sorbus aucuparia L., Ligustrum vulgare L., Sambucus nigra L.* The wood-shrub mixing type (single-shrub version): *Robinia pseudoacacia L.* (main species - M) and *Ligustrum vulgare L.* (shrub - S) was used according to the following scheme: M-S-M-S-M-S-M-S-…; S-M-S-M-S-M-S-M-…

The distance between rows was 2.5 m, in the series - 2.0 m. The formation of phytogenic medium in the intermediate row was provided. These plantations were created on all slopes and surfaces of the reclaimed waste heap "Mine No.2 Novovolinska". The highest development of the plantation was on the

northern slope, and the lowest - on the western side. The undergrowth of Robinia is represented by shrubs: *Ligustrum vulgare L., Rubus caesius L., Sambucus nigra L.* The tree-shrub formation provided a successful vegetative reclamation due to phytogenic fields (nutrient requirements, temperature regime, humidity, shade density). On the waste heap of "Mine No.8 Novovolinska" artificial forest communities were found, where the main species is *Betula pendula Roth*., and the shrub of *Salix caprea L.* The tree-shrub mixing type with a two-shrub variant is used on the reclamated waste heap of "Mine No 3 Novovolynska": *Robinia pseudoacacia L.* (main species – M), *Sambucus nigra L.* (low shrub — S), *Salix caprea L.* (high shrub – Hs): M-S-Hs-S-M-S-…; S-M-S-Hs-S-M-…

A biometric analysis of the growth parameters of wood species, namely, the height and diameter of trees and crowns in table, was carried out to evaluate the peculiarities of phytogenic fields formation. It is determined that the highest average values of the analyzed parameters are observed on the slopes of the northern exposure. Biometric parameters of trees on the slopes of southern exposure are a little bit lower. It is caused by lower humidity of the surface layer and moisture content of bulk soil compositions. These data are valid for the planting of a single heap of the "Chervonogradska" mine belonging to the Chervonograd mining region of the Lviv-Volyn coal basin. According to the results of taxational analysis of trees on the waste heaps, it was found that the highest parameters are typical of northern slope exposures: Robinia pseudoacacia L. - reclaimed tailings of "Mine No.2 Novovolinska" and "Mine No. 3 Novovolynska" - is about 8.6-91 cm (picture 1). This phenomenon occurs due to the sufficient moisture content in the substrates of the northern slope exposure, as well as favorable microclimatic conditions. The lowest diameters are observed at the top of the heaps, caused by the negative effect of the wind masses, the temperature of the substrate and the aggressive medium.

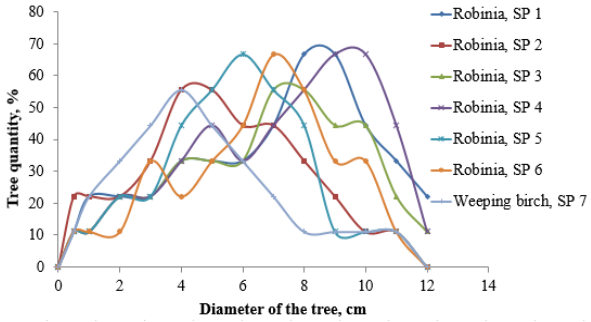
Silvicultural and taxation characteristics of crops of waste heaps phytocoenoses

No.	Substrate	Exposure	Synfolium	Reforestation type	Species	Age, yrs	Diametr, cm	Height, m	Crown diameter, m
Recultivated waste heap of "Mine №2 Novovolynska"									
1	Soil mix	northern	medium	artificial	*Robinia pseudoacacia*	25	$8.6^{\pm0,4}$	$9.7^{\pm0,2}$	$2.5^{\pm0,2}$
2	Soil mix	–	upper plateau	artificial	*Robinia pseudoacacia*	25	$5.5^{\pm0,3}$	$6.5^{\pm0,2}$	$2.2^{\pm0,5}$
3	Soil mix	southern	medium	artificial	*Robinia pseudoacacia*	25	$7.2^{\pm0,4}$	$7^{\pm0,2}$	$2.2^{\pm0,2}$
Recultivated waste heap of "Mine №3 Novovolynska"									
4	Soil mix	northern	medium	artificial	*Robinia pseudoacacia*	26	$9.1^{\pm0,4}$	$10^{\pm0,2}$	$2.6^{\pm0,2}$
5	Soil mix	–	upper plateau	artificial	*Robinia pseudoacacia*	26	$5.6^{\pm0,2}$	$6.3^{\pm0,2}$	$2.0^{\pm0,2}$
6	Soil mix	southern	medium	artificial	*Robinia pseudoacacia*	26	$7.3^{\pm0,4}$	$7^{\pm0,2}$	$2.5^{\pm0,2}$
Recultivated waste heap of "Mine №8 Novovolynska"									
7	Soil mix	northern	medium	artificial	*Betula pendula*	All ages	$4.6^{\pm0,4}$	$9.5^{\pm0,2}$	$2.5^{\pm0,2}$

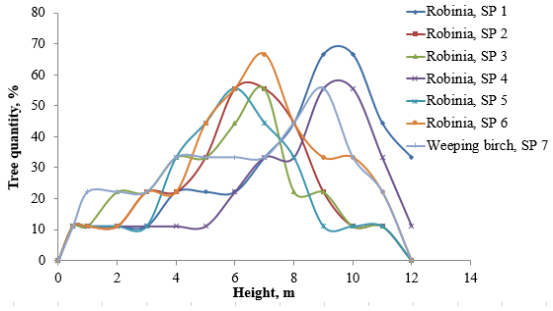
The maximum height of trees (9.5-10 m for all wood species) is also found on the northern exposures of the slopes of waste heaps. At the top of the reclaimed heaps, the height of the trees is lower and averages 6.5 m (picture 2). By the diameter of crowns, the trees were distributed as follows: in the northern slope exposures the diameter of the crowns is 2.5, on the top - 2.0 m, on the southern slope - 2.2 m (picture 3).

At different stages of succession some species aggregate (cluster of individuals), that is, the clumped distribution of individuals in the population is pronounced. At the pioneer stage on damping waste heaps, an aggregation is characteristic for *Plantago lanceolata*; in simple phytocenosis - *Artemisia absinthium, Plantago lanceolata, Trifolium campestre*; in complex phytocenosis - *Artemisia vulgaris, Arctium lappa,*

Trifolium pratense, Calamagrostis epigeios, Daucus carota. The even distribution is inherent for phytocoenoses on reclaimed tailings, namely for *Robinia pseudoacacia*. Random distribution is typical for a significant number of populations, in particular *Tussilago farfara, Chamomilla suaveolens, Taraxacum officinale*. The same way, ruderalcenoses form their own phytogenic field.

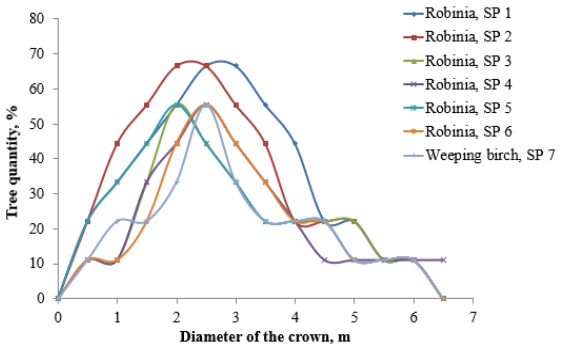


Picture 1 – Diameter of the trees on the survey plot

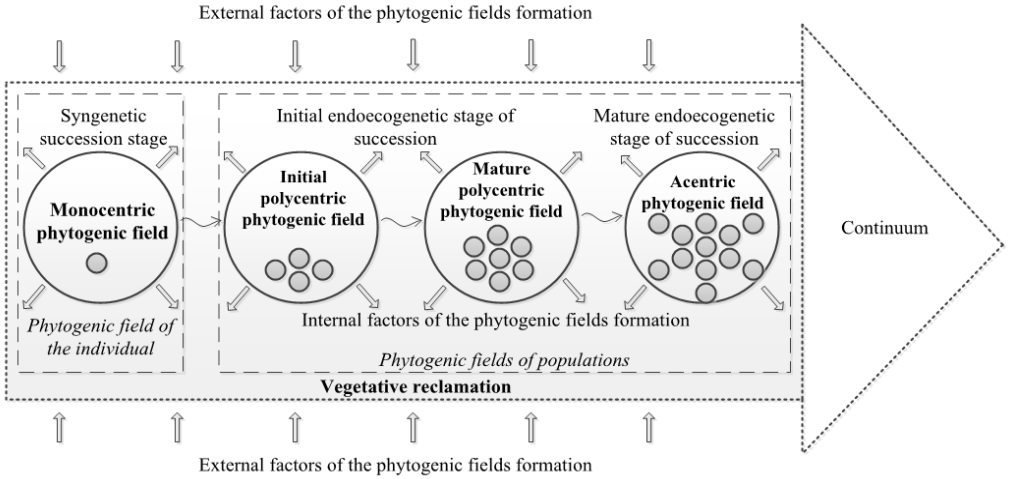


Picture 2 – Height of the trees on the survey plot

Picture 3 – Diameter of crowns of the trees on the survey plot



The phytogenic field makes evident in the continuous life of phytocoenoses, which support the continuum - a wide overlap of ecological amplitudes and the dispersion of population distribution centers along the gradient of the medium [20]. Vegetation distribution in populations may be: random (spontaneous), uniform and uneven. Random distribution occurs only in a homogeneous environment where plants strive to unite into groups. A uniform distribution is observed with strong competition and causes steady reproduction. Uneven (group) distribution is inherent to the plants intent to group formation. In this case, the distribution is close to the random [21, 22]. Theoretical aspects of the phytogenic field formation on the waste heaps of coal mines are shown in picture 4.



Picture 4 – Theoretical aspects of the phytogenic field formation on the coal mines tailings

The floral composition of the formed groups is largely depends on the conditions of the species cites - edafic and microclimate conditions. In this case, the vegetation due to aggregates creates its own phytogenic fields. The investigation of phytogenic fields on devastated landscapes of the waste heaps and coal mines tailings will also improve the bioindicative methods of forest plantations research on the surface and create innovative methods of handling.

Results of artificial phytocoenoses-meliorants and phytogenic fields research. The research of ecological safety of phytogenic fields make it possible to assess the suitability of waste heaps for afforestation, regardless of the country they are formed in. As it turned out, vegetative reclamation and phytogenic fields are inextricably linked. The phytogenic field is formed around a single plant and develops over time, combining the phytogenic fields of other individuals. Thus, plants on the waste heaps of coal mines themselves form an environment for development and reproduction. At the moment of research it was possible to evaluate the substance, energy and information component of the phytogenic field. Taking into account the environment beginning to change by the cenosis, vegetative reclamation investigates the transformation of biotic, geophysical, geochemical flows, as well as improves the aesthetics of the environment and attractiveness. The phytogenic field is a theoretical aspect of evaluating of plant cover formation. Vegetative reclamation is a practical aspect of the evaluation of the phyto-coenoses development, which, due to changes in geoprocesses, improves the attractiveness of the devastated landscapes. In order to assess the environmental safety of the phytogenic fields formation on the waste heaps of coal mines, it is necessary to take into account the microclimate and edaphotope factors. Substantial interest about the phytogenic fields formation is represented by the damping tailings. On these types of waste heaps, the forming syngenesis is under the influence of thermal regimes and insufficient humidity of the substrate. Here, the phytogenic fields, obviously, are formed with the involvement of drought-resistant species. Further research may be aimed at establishing the internal and external factors for the formation of phytogenic fields on coal mine tailings and the communication with the processes of syngenesis.

Conclusions. The decisive role of the phytogenic field in optimization of the devastated landscapes of coal mining in technogenically transformed environment has been established. Data on the species diversity, structure and trend of ecological succession formed during forest reclamation were obtained. The processes of vegetative reclamation on the waste heaps proceed in two ways: the formation of plant phytocenoses with the involvement of trees (acacia, weeping birch); natural vegetation with the involving of autochthonous species. Forest-taxonomic indicators of phytocoenoses formed in the process of artificial vegetative reclamation have been analyzed. These data make it possible to distinguish the ecological safety of places of tree-and-shrub vegetation on the surface of the waste heaps. The phytogenic field here is manifested in the continuous life of phytocoenoses. The structure of the phytogenic field in artificial phytocoenoses depends on the succession stage.

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КӨМІР ШАХТАЛАРЫНЫҢ ТЕРРИКОНДАРЫНДА ФИТОГЕНИКАЛЫҚ ӨРІСТЕРДІ ҚАЛЫПТАСТЫРУДЫҢ ЭКОЛОГИЯЛЫҚ ҚАУІПСІЗДІГІ

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ЭКОЛОГИЧЕСКАЯ БЕЗОПАСНОСТЬ ФОРМИРОВАНИЯ ФИТОГЕННЫХ ПОЛЕЙ НА ТЕРРИКОНАХ УГОЛЬНЫХ ШАХТ

Аннотация. Цель исследования – изучить особенности формирования фитогенных полей естественных и искусственных насаждений кустарниковой и рудеральной растительности на отвалах угольных шахт в пределах Нововолынского горнопромышленного района (Украина). Биометрический анализ роста искусственных насаждений на отвалах проводился по методике, которая включает закладку временных экспериментальных площадок, измерение диаметра древесных пород на высоте 1,3 м общей высоты деревьев и параметров кроны. Вариация применялась для изучения пространственной структуры растительности на рекультивированных и затухающих отвалах. Приведены модели искусственных фитоценозов и мелиорантов на отвалах угольных шахт, образующихся при лесомелиорации.

В статье представлен анализ лесоустроительных характеристик фитоценоза сельскохозяйственных культур на отвалах. Установлена пространственная структура фитогенных полей по изменчивости наиболее распространенных видов в естественных и искусственных насаждениях на отвалах. Это позволяет подобрать ассортимент пород для проведения эффективной фитомелиорации на поверхности отвалов. В статье представлены результаты исследований по формированию фитогенных полей на отвалах угольных шахт, которые предполагают образование сообществ растений. Доказано, что формирование фитогенных полей неразрывно связано с фитомелиорацией. Проведенное исследование происхождения и распространения фитогенных полей позволяет оценить степень пригодности отвалов для облесения независимо от страны, в которой они образованы. Исследование фитогенных полей на терриконах и отвалах угольных шахт улучшит методологию биоиндикационных исследований для изучения лесных культур на их поверхности и предложит инновационные методы обработки данных. В частности, можно повысить уровень экологической безопасности и эстетики опустошенных территорий, а также снизить затраты на фитомелиорацию.

Ключевые слова: экологическая безопасность, фитогенное поле, угольная шахта, породный отвал, фитоценоз, лесные культуры, мелиорация.

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METHODOLOGY FOR CONDUCTING VIRTUAL TESTS BY CREATING A FINITE ELEMENT MODEL OF ROAD SAFETY FENCING

Abstract. In this paper, we formulated the concept of the process of hitting a car on a fence as a movement along a curved trajectory with a certain radius of curvature. Special attention was paid to the contact of parts of different stiffness (when modeling the fence, these are ground-stand contacts), since the stiffness of the spring added to the contacting surfaces directly depends on the stiffness of the bodies being contacted. When soft bodies contact, its rigidity may be small, which can lead to instability of the solution. Also, the critical deflection of the fence (the transverse deflection of the fence, equal to twice the value of the console departure), after which the beam is inevitably lowered along with the deviated posts and the vehicles move over the fence.

Keywords: fence, safety, simulation, method, rack, console, beam, strength, test, car, finite element, construction, virtual analysis.

Initially, it was assumed that the retaining capacity of the fence should be provided by the strength of the posts, and the beams should work in elastic deformation with a small deflection.

The first works devoted to the problems of designing road barrier fences appeared in the 1960s. Among foreign studies, the first published works were Moore R. L., Jehu V [8].

In this paper, we formulated the concept of the process of hitting a car on a fence as a movement along a curved trajectory with a certain radius of curvature. V. Giavotto [9] proposed the principle of equality of the kinetic energy of the movement of the car and the work of the deformation of the fence. In Giavotto, as already mentioned above, he proposed a scheme for two-stage work of the fence created by a passenger car (first stage) and a heavy vehicle (second stage). M. Graham [7], analyzing the test results, proved the need to take into account the permissible overloads of passengers when the vehicle hits the fence, which later became one of the main criteria for the safety of the fence.

In Russia, the issues of designing and calculating road fence structures were considered in the works of V. I. Shestikov [10], B. M. Eliseev [11], E. E. Gibshman [3], P. K. Malinin [12], V. A. Karo-Made [13], V. P. Zaluga [14], V. V. Astrov [1].

The proposed methods contained a significant number of assumptions. So, Jehu V. I considered the vehicle as an absolutely rigid point. The methods of V. I. Shestikov [10] contain numerous empirical coefficients, which makes it possible to use the method only for a certain construction of the fence.

The method proposed by V. A. Astrov [2] can be considered the closest to the real situation, according to which the retaining capacity of the fence is determined by the sum of the work of bending its beam, bending the posts and tension of the beam. The main achievements of this technique should be considered:

a) determination of the critical deflection of the fence (the transverse deflection of the fence, equal to twice the value of the console departure), after which the beam is inevitably lowered together with the

deflected posts and the vehicle moves over the fence. Thus, in order to prevent lowering of the beam in case of supercritical deflection, it is necessary to separate it from the struts. This idea was the beginning of the development of detachable consoles (CO);

b) the development of criteria for the quality of the fence, which allows:

- simplify the visualization of the fence on the general background of the road;
- make an assessment of the minimum height of the fence, which is a condition for preventing the car wheel from moving over the fence;
- determine the distance between the lower part of the beam and the road surface, preventing the wheel of a passenger car from entering under the beam;
- ensure that the vehicle does not directly interact with the racks.

However, the proposed method does not allow us to determine all the necessary consumer safety characteristics of road barriers (BDO) - the values of the dynamic deflection and the working width of the fence [4, 6],

All the calculation methods discussed above are largely based on empirical and semi-empirical models, which does not allow us to transfer the results and conclusions to other constructions. These methods do not consider joint deformations of the entire system – beams, posts, consoles, soil, road surface structure, friction between the vehicle and the fence, etc. [4].

Numerous developments carried out in a number of countries, primarily in the United States and Canada [9] We have shown that the most acceptable tool for computational analysis for road barriers is the finite element method (FEM), and the possibility of its application to this problem appeared only with the development of powerful computational systems for engineering analysis, such as LS-DYNA, ANSYS, ABAQUS, MSC.Software. A special feature of the calculation problem is the need to consider the collision of a deformable body (TC) with a deformable fence system, and the problem is essentially nonlinear and is associated with the consideration of fast-flowing processes.

The use of methods of numerical nonlinear analysis of the dynamics of the processes of collision of deformable bodies allows us to conduct studies that take into account all the features of the materials and structures of the fences themselves, their location on the road and the design of the road surface. Now it is possible to simulate full-scale tests and, together with the data from these tests, to be able to effectively solve the problems of selecting and installing fences [16, 18]. Currently, foreign publications contain a significant amount of data on such virtual analysis, they study the collisions of various vehicles, various fence designs, the behavior of fence installation elements in the ground and on the road surface, and conduct research on the choice of the optimal location of the fence on the roadside and on the dividing strip [17]. However, the application of this approach for domestic BDO structures required the development of simulation techniques, taking into account the specifics of materials and structures, and, most importantly, determining the scope of virtual tests in the road fence certification system, developing appropriate regulatory requirements and implementing these techniques in the domestic practice of designing barrier road fences.

The main structural elements of road safety fencing (BDO) are racks, consoles and beams. A three-dimensional 3D model of the BDO structure is shown in figure 1. A geometric model can be created in any CAD system. The considered structural elements of BDO are thin-walled profiles, the thickness of which is much smaller than other sizes, so it is advisable to model them with shell elements. The shell from the 3D model is most easily obtained by selecting the median surface.

The next step is to create a finite element grid (KES) The success of the calculation is mainly determined by the quality of the grid. When creating the CES, regular grids were used, which better reflect the shape loss during deformation, and also significantly reduce the calculation time compared to irregular grids (figure 2) [17].

The smaller the grid, the more accurate the calculation results will be, but it must be taken into account that for the stability of the solution in explicit methods, the time step must be less than the time of the perturbation wave passing through the element, and this time directly depends on its size. Therefore, reducing the size of the element leads to a significant increase in the duration of the process (without changing other parameters). On the other hand, a rough grid may not show the correct shape of the part's deformation or a sharp change in stress in the area under consideration. Numerous calculations have shown that for the main structural elements, the optimal KES is 20x20 mm [16].

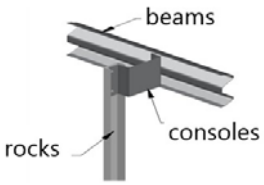
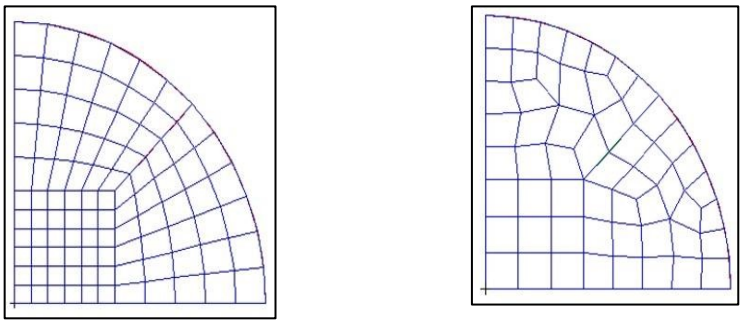


Figure 1 – BDO design

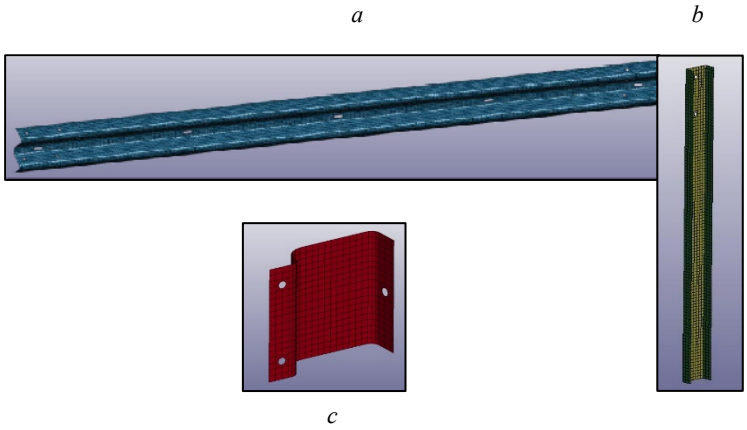


a *b*

Figure 2 – Grid types: *a* – regular, *b* – irregular

The construction of the KES console-shock absorber and rack fully corresponds to the construction of the beam stack. CE models of the main structural elements of the fence are shown in figure 3.

In the process of collision with the vehicle, the fence elements experience plastic deformations. In the LS-DYNA CE complex, there are a large number of different material models (more than 200). For BDO, the most optimal material is MAT_024 [22], its formulation will be discussed in more detail below.



a *b*

c

Figure 3 – CE-models of structural elements of the barrier fence:
a – beam; *b* – console shock absorber; *c* – rack

Model implements the Prandtl-Reiss material model [18], which describes the behavior of metals in the case of a complex stress state under elastic-plastic deformations. The deformation curve is approximated piecewise-linearly: the deformations are divided into segments and it is assumed that the plastic modulus is constant on each of these segments. Hardening in the MAT_024 material occurs only due to the rate of deformation. The MAT_024 model allows the use of isotropic or kinematic hardening, but in this work they were not taken into account due to the small cycle of the processes. Let's consider the basic equations describing the work of the material.

Deformations in the material are divided into elastic, which are removed after the load, and plastic - irreversible. Therefore, the total increment of deformations can be represented as:

$$d\epsilon_{ij} = d\epsilon_{ij}^{e} + d\epsilon_{ij}^{p}\,, \tag{1}$$

where $d\epsilon_{ij}{}^{e}$ – elastic deformations; $d\epsilon_{ij}{}^{p}$ – plastic deformations.

The increment of elastic deformations is found from Hooke's law. To formulate the general system of equations, we use the form of Hooke's law in terms of the first stress invariant I1 and the stress deviatorss_{ij}:

$$\epsilon_{ij}^{e} = \frac{1}{9k} I_1 \delta_{ij} + \frac{1}{2G} S_{ij}\,, \tag{2}$$

where K is the volume modulus of elasticity; G is the shear modulus; δ_{ij} – Kronecker delta.

This form of Hooke's law is convenient from the point of view of numerical methods, since in most modern programs the hydroscopic and deviatory parts of the stress are calculated separately.

If the stresses fall on the surface of the material's flowability, then in addition to elastic deformations, plastic deformations begin to accumulate.

The yield surface of the material * MAT_24 is determined by the Mises equation:

$$f(J_2) = J_2 - k^2 = \frac{1}{2}S_{ij}S_{ij} - k^2 = 0\,, \tag{3}$$

where $J_2 = 0.5*s_{ij}* s_{ij}$ – the second invariant of the stress deviator, k, is the material constant associated with the yield strength.

According to the Prandtl-Reuss theory, the direction of the increments of plastic deformations is perpendicular to the yield surface (figure 4).

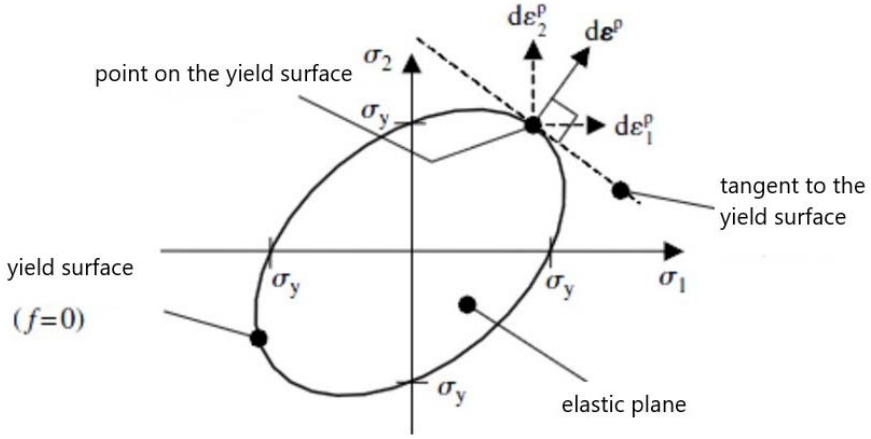


Figure 4 – Increment of plastic deformations in the flat case

The values of the increments of plastic deformations are derived from the associated flow law, and it is assumed that the yield surface coincides with the function of the plastic potential. Therefore, given the Mises flow surface, the flow surface takes the following form:

$$d\epsilon_{ij}^{p} = d\lambda \frac{\partial f}{\partial \sigma_{ij}} = d\lambda * S_{ij}\,. \tag{4}$$

where $d\lambda$ – scale factor, s_{ij}- the maximum deviator stress.

The scale factor $d\lambda$ is found from the rate of plastic deformation:

$$d\lambda = \frac{dW_p}{2k^2} = \frac{S_{mn}*de_{mn}}{2k^2}\,, \tag{5}$$

where de_{mn} – deviator of the strain tensor.

To get the incremental ratios *MAT_24, we substituteequations (2), (4), (5) in equation (1). The general relation takes the form:

$$d\epsilon_{ij} = \frac{ds_{ij}}{2G} + \frac{dI_1}{9K}\delta_{ij} + \frac{S_{mn}*de_{mn}}{2k^2} * S_{ij} \tag{6}$$

Equation (6) relates the increment of deformations to the stresses at each step for the MAT_024 material. The first step of the program is using the above equations and knowing the current value of the hydrostatic pressure I1=3p and the stress deviatorss_{ij}, allows you to find the total increment of deformations $d\epsilon_{ij}$. In the second step, using finite-difference schemes, we obtain the deformed state at time t+1. At the third step, knowing the deformations, the position of the medium at time t+1 is determined, after which the stress state is recalculated, and the process is repeated from step 1.

The yield surface is modified depending on the rate of plastic deformations by changing the material constant *k*. In * MAT_24, the Cooper-Symonds hardening model is adopted as a function of the strain rate ϵ_{ij}:

$$\beta = 1 + (\frac{\epsilon_{ij}}{C})^{\frac{1}{p}}, \tag{7}$$

where p, C – experimental hardening constants.

Taking into account the law of strengthening, the von Mises yield surface-formula (3) takes the form:

$$f(J_2) = J_2 - \beta k^2. \quad (8)$$

The possibility of destruction was set in the model. Destruction in the material occurred when equivalent plastic deformations occurred $\bar{\epsilon}$achieved fracture deformations ϵ_f:

$$\bar{\epsilon} = \epsilon_f.$$

The fracture deformations were determined experimentally. If the equivalent deformations in the element reach the fracture deformations, then the element is removed.

The map of the MAT_24 material model and the deformation diagram are shown in figure 5.

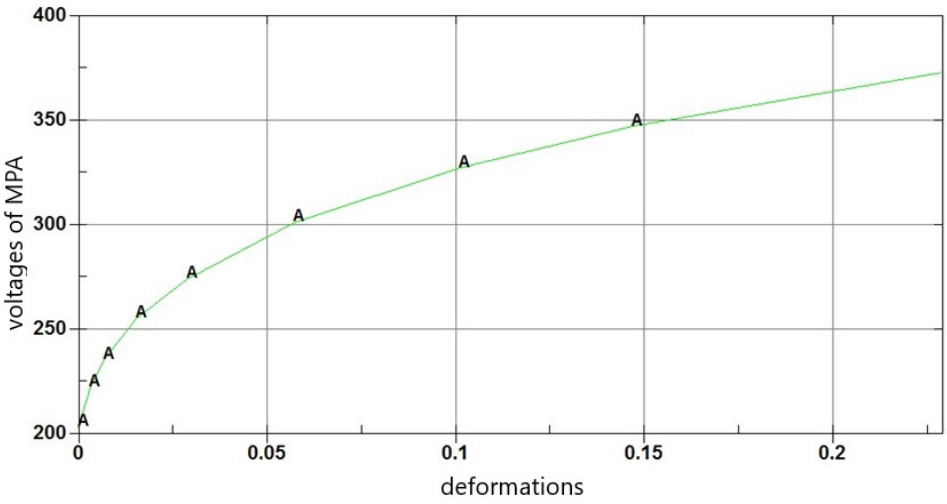


Figure 5 – St 3 material deformation diagram for MAT_024

The soil is a loose medium, the particles of which rub against each other. When the material is hydrostatically compressed, it becomes more difficult for the soil particles to move relative to each other, and the overall strength of the soil increases. Therefore, when describing the behavior of the soil, it is necessary to take into account the first stress invariant, which characterizes the hydrostatic compression of the material. In this case, the material *MAT_005, described by Craig [17], was used to model the soil.

$$f(I_1, J_2) = J_2 - [a_0 + a_1 p + a_2 p^2] = 0, \quad (9)$$

where p – hydrostatic pressure; a_0, a_1, a_2 – constants of the material.

To obtain incremental relations that relate stresses and deformations, we use the same approach that was used to derive the relations for * MAT_24. The main prerequisites will be the division of the total stress tensor into elastic and plastic components. Using formulas (1), (2), and (4), we obtain:

$$d\epsilon_{ij} = d\epsilon_{ij}^e + d\epsilon_{ij}^p = \frac{dI_1}{9k}\delta_{ij} + \frac{ds_{ij}}{2G} + d\lambda\frac{\partial g}{\partial \lambda_{ij}}, \quad (10)$$

To obtain an incremental model, it is necessary to find the flow surface g and the scale factor $d\lambda$.

The material model * MAT_005 is based on the associated flow model, so the flow surface f coincides with the flow surface g. We find the derivative of the yield surface with respect to plastic deformations, the first invariant of the stress tensor, and the second invariant of the stress deviator:

$$\frac{\partial f}{\partial \sigma_{ij}} = \left(S_{ij} - \frac{1}{3}a_1\delta_{ij} - \frac{2}{3}a_2 p\delta_{ij}\right),$$

$$\frac{\partial f}{\partial I_1} = -\frac{1}{3a_1} - \frac{2}{9}I_1 a_2;$$

$$\frac{\partial f}{\sqrt{\partial j_2}} = 0. \quad (11)$$

To find the scale factor$d\lambda$, we use the general formula [29] for isotropic materials:

$$d\lambda = \frac{3K*d\epsilon_{kk}\left(\frac{\partial f}{\partial I_1}\right)+\left(\frac{G}{\sqrt{J_2}}\right)*\left(\frac{\partial f}{\partial \sqrt{J_2}}\right)*s_{mn}*de_{mn}}{9K*(\frac{\partial f}{\partial I_1})^2+G(\frac{\partial f}{\partial \sqrt{J_2}})^2}. \quad (12)$$

To find the scale factor, we substitute equations (11) into equation (12). After substituting the result into formula (10), we get the general incremental relations for the MAT_005 material.

The contacts between the elements were set by automatic single surface contact [17]. Special attention was paid to the contact details of different stiffness (in the simulation fencing is groundstone contacts), since the spring stiffness to be added to the contact surfaces, depends on the stiffness of the contacting bodies. When soft bodies contact, its rigidity may be small, which can lead to instability of the solution. To solve this problem, contact shells from MAT_009 are added on top of the contact body. When modeling the BDO of the bridge group, the reinforced concrete base was modeled with solid-state elements without the possibility of destruction. These assumptions were introduced after analyzing the protocols of field tests of BDO, according to which the reinforced concrete base does not collapse, the separation of the struts occurs when the anchor pins break.

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ВИРТУАЛДЫ СЫНАҚТАРДЫ ЖҮРГІЗУ ӘДІСТЕМЕСІ ЖОЛ ҚОРШАУЛАРЫНЫҢ ҚАУІПСІЗДІК МОДЕЛІНІҢ СОҢҒЫ ЭЛЕМЕНТТЕРІН ЖАСАУ ӘДІСІ

Аннотация. Жұмыста автомобильдің қоршауға соқтығысу процесі қисықтықтың белгілі бір радиусы мен қисық сызықты траектория бойымен қозғалу туралы идеялар тұжырымдалды. Әртүрлі қаттылықтағы бөлшектердің байланысына ерекше назар аударылды (қоршауды модельдеу кезінде – бұл топырақ-тірек түйіспесі), өйткені түйісу беттерге қосылған серіппенің қаттылығы түйісу денелердің қаттылығына тікелей байланысты. Жұмсақ денелермен байланыста болған кезде оның қаттылығы аз болуы мүмкін, бұл шешімнің тұрақсыздығына әкелуі мүмкін. Сондай-ақ, біліктер қоршаудың критикалық ауытқуын анықтады (консольдің шығарылуының екі есе мөлшеріне тең қоршаудың көлденең ауытқуы), содан кейін қисайған ауытқыдан тіректермен бірге түсуі және көлік құралдарының қоршау арқылы асып өтуі сөзсіз.

Түйін сөздер: қоршау, қауіпсіздік, модельдеу, әдіс, тірек, консоль, беріктік, сынақ, автомобиль, соңғы элементтер, құрылыс, виртуалды талдау.

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МЕТОДИКА ПРОВЕДЕНИЯ ВИРТУАЛЬНЫХ ИСПЫТАНИЙ МЕТОДОМ СОЗДАНИЯ КОНЕЧНЫХ ЭЛЕМЕНТОВ МОДЕЛИ БЕЗОПАСНОСТИ ДОРОЖНЫХ ОГРАЖДЕНИЙ

Аннотация. В работе были сформулированы представления о процессе наезда автомобиля на ограждение как о движении по криволинейной траектории с определенным радиусом кривизны. Особое внимание было уделено контакту деталей разной жесткости (при моделировании ограждения – это контакты грунт-стойка), так как жесткость пружины, добавляемой к контактирующим поверхностям, напрямую зависит от жесткости контактируемых тел. При контакте мягких тел ее жесткость может быть мала, что может привести

к неустойчивости решения. Также были определены критический прогиб ограждения (поперечный прогиб ограждения, равный удвоенной величине вылета консоли), после которого неизбежны опускание балки вместе с отклонившимися стойками и переезд транспортных средств через ограждение.

Ключевые слова: ограждение, безопасность, моделирование, метод, стойка, консоль, балка, прочность, испытание, автомобиль, конечных элементов, конструкция, виртуальный анализ.

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N E W S
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METHOD FOR DETERMINING THE OPTIMAL LOCATION OF FIREFIGHTING EQUIPMENT FOR LOCALIZATION OF GROUND FOREST FIRES

Abstract. Localization and forest fire suppression is an urgent problem for the whole world. Given the heterogeneity of forests on the planet, approaches to modeling the spread of fires and their extinguishing are different. In this article a method for determining the required number of forces and means for the localization of ground forest fires is offered, taking into account the location of firefighting equipment in forests. To forecast the spread of fire, equidistant places from the fire departments in forests were chosen using Voronoi diagrams. The results of the calculation make it possible to conclude whether there are enough available forces and means to localize the predicted fire and to suggest additional firefighting equipment locations. The use of Voronoi diagrams for the State Enterprise "Zhovkva Forestry" in the Lviv region showed 12 dangerous areas, which are located the furthest from the fire departments. The method for determining the optimal location of firefighting equipment was applied to the Butynskyi forestry in Zhovkva forestry enterprise. Reducing the time of free spread of ground forest fires by 25% using rational placement of firefighting equipment and machinery, allows to reduce the number of employees for its localization by 53.8%.

Keywords: ground forest fire, fire localization, Voronoi diagram, firefighting equipment.

1. Introduction. On the territory of Lviv region in Ukraine the number of forest fires amounted to 41 in 2019. About 20 hectares of forests were destroyed. It should be noted that according to the legislation of Ukraine, forest users are in charge of forest fire extinguishing and accordingly the management of this process. Despite this, in 2019, 65 units of equipment of the State Emergency Service of Ukraine, 10 units of equipment of local fire brigades and only 10 forest users were involved in firefighting process. Voluntary fire brigades, created on the initiative of forest users, are rarely involved in extinguishing of such fires. Thus, in 2019, only 10% of the total number of people were involved in extinguishing of forest fires. Fires have a negative impact on the environment. Ways to solve environmental problems were considered in [1].

Successful and rapid firefighting is ensured by responding quickly to fires. Most scientific works are devoted to methods of decision-making in case of fires, traffic routing and distribution of forces and means to suppress forest fires [2]. However, the rational placement of firefighting equipment near forests, taking into account the location of existing state, local and forest fire departments, significantly reduces the cost of their elimination. In addition, in order to respond quickly to forest fires, it is advisable to create and involve voluntary fire brigades from settlements that are in close proximity to forests, the distance from the existing units to which is quite large.

To define the location of firefighting equipment near forests, it is necessary to predict the probable spread of fire. A number of analytical and experimental models and techniques are used to determine the speed of flame propagation. The most common way to determine this parameter is the Rothermel model, which has been improved by many scientists in recent years [3]. This model is based on the energy conservation equation, where the flame propagation speed depends on the density of the combustible material layer, the particle size of the forest combustible materials and their burning velocity. This model

also takes into account the effect of wind speed on the spread of flame along the front, but does not consider the terrain. The slope of the terrain has an impact on the speed of fire propagation that is considered in [4] the fire spread model as a combustion wave based on the Hamilton-Jacobi equations. However, this method can only be used using a computer. An analytical method of the fire propagation speed in forests is presented in [5]. According to the law of conservation of energy for a stable combustion process, the authors developed a method for determining the speed. The model is as follows:

$$V_f = f(I_R, \xi, \rho, \varepsilon, Q, \varphi_w, \varphi_s),$$

where I_R – intensity of combustion reaction; ζ – a coefficient that takes into account the properties of the combustible material; ρ – the density of the combustible material layer; ε – efficiency coefficient of combustible material heating that shows which part of combustible material participates in ignition during its heating by a fire due to all types of heat transfer; Q – heat of ignition; φ_w – coefficient that takes into account the direction of the wind; φ_S – coefficient that takes into account the slope of the terrain.

Based on the forecast of possible fire size depending on the characteristics of the combustible load, fire hazard class, weather conditions, etc., it is possible to determine the optimal location of fire equipment to extinguish a possible fire. Most methods of fire departments location apply to large cities. An example of such methods is given in the article [6], where a mathematical model for determining locations of new fire stations in Istanbul is offered. However, there are works that consider the location of firefighting equipment in rural areas in order to respond in a timely manner to forest fires [7].

One of the methods that takes into account the possible occurrence of fires in forests was proposed in [8], where the number and location of firefighting equipment were determined depending on the risk of fires due to power grid failures. However, considering that the cause of forest fires in most cases is anthropogenic factor, it is necessary to take into account the possible fires occurrence in any place in the forest. This approach is used in the article [9], where determining the location of fire stations and routing them to the place of fire is based on the results of forecasting a possible fire. This method is used for large-scale forest fires. The aim of optimal placement of firefighting equipment should be to minimize the total time of forest fire extinguishing and the number of involved fire engines, the algorithm for this task is given in [10]. Another method of the location optimization of fire equipment is particle swarm method used in [11]. In [12] a model of firefighting equipment placement was developed taking into account the minimization of costs on the example of South Hobart, Tasmania, Australia.

The cost minimization problem in responding to forest fires is also discussed in articles [13] and [14]. The cost of fire suppression will be minimal in case of rational placement of firefighting equipment for rapid response to such fires. Therefore, it is necessary to develop a methodology in order to determine the level of forces for the localization of ground fire at its initial stage.

Given the above, the purpose of this work is to determine the required number of forces for localization of ground fires considering the most remote places in forests from the location of firefighting equipment.

2. Material and method. In this article the forests used by the State Enterprise "Zhovkva Forestry" are considered. The State Enterprise is located in the north-western part of the Lviv region on the territory of three administrative districts - Zhovkva, Sokal and Kamianka-Buzka. Geographically the territory of the forestry is located on the border of two districts: the southern part of the forestry (part of Viazivskyi forestry) belongs to the Opilsko-Roztotskyi district, and the rest of the enterprise to the Malopolisska lowland of Small Polissia. The length of the enterprise from north to south is 57 km, from east to west - 34 km. The total area of the forest fund lands is 33,679 hectares; 28,591 hectares are covered with forest vegetation. The main tree species on the territory of the forestry are Scots pine (54%), Scots oak (17%), European beech (7%), Silver birch (3%) and Black alder (15%). The class of natural fire danger of this forest fund is 3 [15].

According to the Mobilization Plan, 64 employees are involved in fire extinguishing on the territory of Zhovkva Forestry. The time of their readiness to extinguish is 45 minutes. In addition, the following equipment is used to localize and extinguish fires: 2 fire trucks, 1 water tank, a bulldozer and 7 tractors. This equipment is located on the territory of the administrations of 7 forestries. Furthermore, fire units of the State Emergency Service of Ukraine and local fire brigades may be involved in extinguishing the fire.

Determination of equidistant places in forests from the locations of firefighting equipment was carried out using Voronoi diagrams [16]. Forecasting of the forest fires spread was performed according to

existing methods, taking into account wind strength and terrain slope. The defining of the number of forces for the localization of the ground forest fire was performed taking into account the time of localization and productivity of one firefighter.

3. Results and discussion. The calculation of the required number of forces and means for extinguishing forest fires must be carried out in several stages. The first stage is to determine equidistant points on the map to the forests from fire rescue units, forest fire stations and strongholds with firefighting equipment. The second stage is forecasting of forest fire spread depending on the terrain and weather conditions. At the same time, the most unfavorable conditions should be considered in order to predict the most dangerous fire spread. The third stage is for calculation of the number of employees and equipment for extinguishing the forest fire. Based on the calculations, a conclusion is made to clarify whether the successful extinguishing of the predicted fire is ensured.

3.1. Determination of the most remote points from the location of fire departments. To determine the most distant points from the location of fire brigades to the place of fire occurrence, Voronoi diagrams are used. The vertices of the diagram are a set of equidistant places between two adjacent locations of fire brigades. Nodes of cell edges are points equidistant from three adjacent locations of fire brigades.

As an example, forests used by the State Enterprise "Zhovkva Forestry" are taken for consideration.

Figure 1 shows the location of forests used by Zhovkva Forestry Enterprise and fire rescue units (state, local stations and strongholds, which have firefighting equipment for extinguishing forest fires).

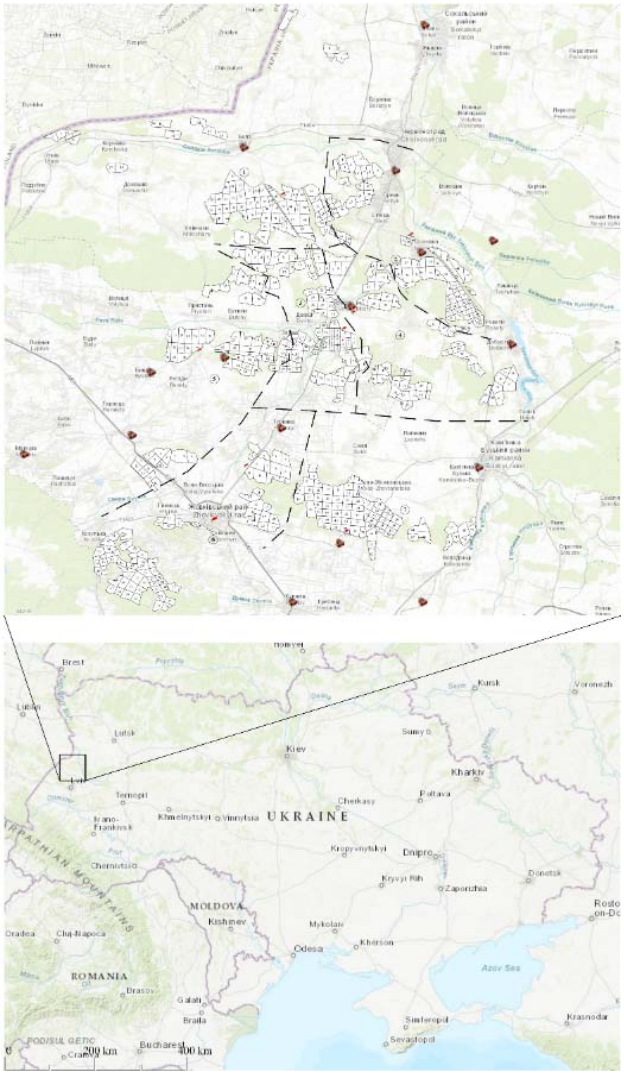

Figure 1 – Location of forests used by Zhovkva forestry enterprise and fire rescue units

For this area the Voronoi diagram is applied. The top of the Dirichlet cells is the location of fire departments and strongholds with firefighting equipment. To build the diagram, the Fortune's algorithm is used. The Voronoi diagram for our case is shown in figure 2.

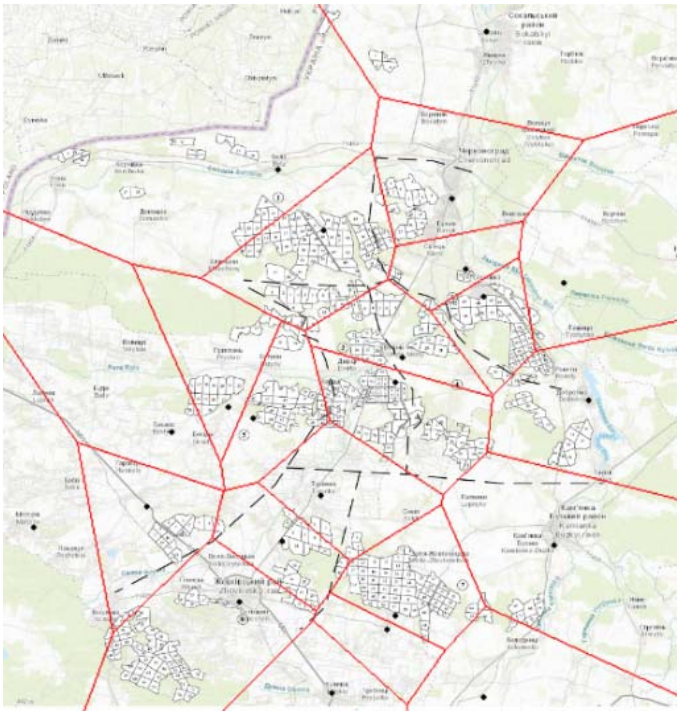

Figure 2 – Construction of Voronoi diagram for forests of Zhovkva forestry enterprise taking into account the location of fire departments and strongholds with firefighting equipment:
1 – Nyzivskyi; 2 – Sosnivskyi; 3 – Butynskyi; 4 – Velykomostivskyi; 5 – Liubelskyi; 6 – Viazivskyi; 7 – Zibolkivskyi forestry

Considering the Voronoi diagram, we can conclude that equidistant from the locations of fire departments are 19 and 50 quarters of Butynskyi forestry, 26 and 73 quarters of Sosnivskyi forestry, 11 and 62 quarters of Velykomostivskyi forestry, 34 quarters of Liubelskyi forestry, 5, 23 and 33 quarters of Viazivskyi forestry, 10th and 63rd quarters of Zibolkivskyi forestry. In addition, the forest quarters of the Nyzivskyi forestry near the border, namely 5-10 quarters, are problematic in terms of detecting and extinguishing fires.

3.2 Predicting the spread of ground forest fire. To calculate the number of employees needed to be involved in extinguishing a fire, it is necessary to know the speed of the forest fire spread and the perimeter of the fire. To calculate these parameters, we use the method described in [17].

The general formula for determining the speed of the fire propagation edge is as follows:

$$V_f = V_o \cdot K_\delta \cdot K_\varphi \cdot K_w ,$$

where V_0 – base speed, m/min; K_δ, K_φ, K_w – influence coefficients of surface slope, relative humidity of air and wind. These coefficients are given in the work [17].

For example, the spread of a ground fire around the perimeter in case of its occurrence in the 19th quarter of Butynskyi forestry of Zhovkva forestry enterprise is considered. The basis of the forest litter burning is fallen pine needles and tree leaves. In accordance with [17], the velocity of burning of such combustible material is 0.41 m / min. The angle of inclination of the terrain in this area does not exceed 10°, so the coefficient K_δ is equal to 1.2. Humidity is taken as for the driest period, then the coefficient K_φ will be 1.7. According to the Ukrainian Hydrometeorological Center, the wind speed is 4.0 m/s, then the coefficient K_w will be 7.0 for the head, 1.6 for the rear and 4.5 for the flanks. Based on the results of the calculation the speed of spread of the head, flanks and rear of the forest fire, it is possible to determine the geometric parameters of the fire in a certain period of time. We shall calculate the geometric parameters of the fire for 30, 60, 90 and 120 minutes. The results of the calculation are shown in figure 3.

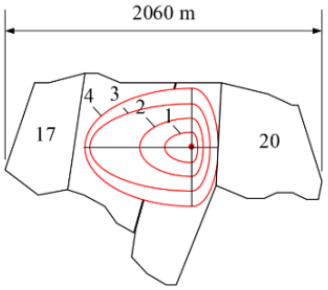

Figure 3 –
Forecasting of the fire spread in the 19th quarter
of Butynskyi forestry of Zhovkva forestry enterprise
for 1 – 30 minutes; 2 – 60 minutes; 3 – 90 minutes;
4 – for 120 minutes

The perimeter of the fire was defined as the perimeter of the two half-elipses. In the first half-ellipse, the semi-major axis is the distance from the fire occurrence area to the edge of the fire at the head, the semi-minor axis is from the fire occurrence area to the edge of the fire on flanks. In the second half-ellipse, the semi-major axis is the distance from the fire occurrence place to the edge of the fire on flanks, the semi-minor axis is from the fire occurrence place to the edge of the fire at the head. The obtained values of the fire perimeter at certain points in time allow to calculate the growth speed of the perimeter.

3.3. Determining of the required number of forces to localize a ground forest fire. In order to determine the number of employees needed to extinguish a ground fire in the forest around the perimeter using hand tools, following formula is used [18]:

$$n_{\Pi} = \frac{\frac{L}{\sqrt{W_1^2 - V_p^2}} - \frac{L}{V_m}}{\tau_{loc} - \frac{L}{V_m}},$$

where L – the length of the edge of the fire, m; W_1 – productivity of work of one firefighter, /min [17]; V_m – average movement speed of firefighters in the forest, m/min; V_p – speed of fire propagation, m/min; τ_{loc} – time of fire localization, min.

Figure 4 shows the results of calculating the required number of firefighters for localization and subsequent successful elimination of the fire depending on the time of free fire spread and estimated time of localization of the fire.

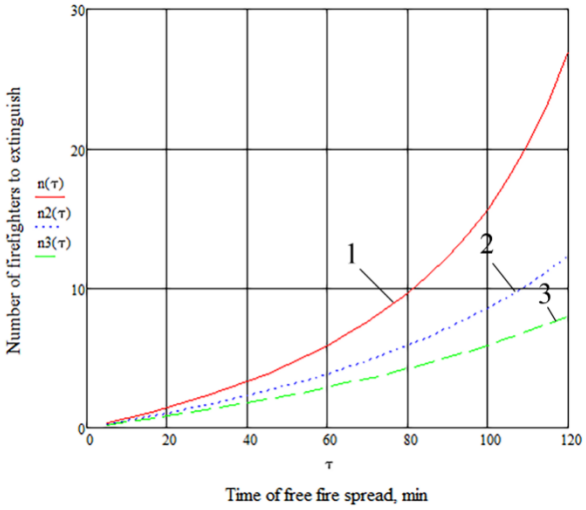

Figure 4 –
The required number of firefighters to extinguish
a ground forest fire, depending on the time of free fire spread
and estimated time of localization of the fire:
1 – 30 minutes; 2 – 40 minutes; 3 – 50 minutes

For successful and rapid localization of the fire, it is necessary to reduce the time of free fire spread that can be achieved by localization of fire brigades near forests. Time of getting from existing fire departments to 19th quarter of Butynskyi forestry is about 30 minutes: from the state fire department of Velyki Mosty - 25 minutes, from the stronghold of Liubelskyi forestry - 27 minutes, form the local fire brigade of Lubelskyi - 38 minutes, from the stronghold of Nyzivskyi forestry – 52 minutes.

The larger is distance to the forests, the larger number of personnel must be involved in fire suppression. According to the mobilization plan in case of fire in Zhovkva forestry enterprise, the time of getting ready and arrival of personnel is 45 minutes. In case of fire detection one hour after its start, taking into account arrival time to the place, the time of free spread of fire will be about 2 hours. Even in case of immediate departure of the state fire brigade from the city of Velyki Mosty, the number of personnel will not be enough to localize the fire. Therefore, for its rapid localization upon arrival of forestry workers, up to 26 people should be involved.

If a stronghold with firefighting equipment is placed in the village Butyn, in order to deliver them to the place of the fire and attract volunteers living in the village, the time of free spread of the fire can be reduced by 1.5 times. In this case only 12 people are needed to be involved for quick localization.

4. Conclusion. Efficient localization of fire equipment can significantly reduce the number of forces and means needed to localize a possible fire in the forests. In addition, it reduces the scale of the fire. Thus, according to the conducted calculations, in case of time decrease of the ground forest fire spread by 25%, the value of the required number of employees is reduced by 53.8%. Similar calculations should be made for other forestries in western Ukraine as well.

This method can be applied only to areas where forests are divided into small sections located near settlements. For large areas of forests, it is advisable to use modern methods of monitoring to detect fires in the early stages and the location of firefighting equipment directly in the forests.

Further development of this method is the study of fire danger in the forests of western Ukraine and forecasting the spread of ground fires in forests using FDS-models to determine the required number of forces and means for their localization and extinguishing.

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ОРМАН ӨРТТЕРІН ОҚШАУЛАУ ҮШІН ӨРТКЕ ҚАРСЫ ТЕХНИКА МЕН ЖАБДЫҚТЫҢ ОҢТАЙЛЫ ОРНАЛАСУЫН АНЫҚТАУ ӘДІСІ

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МЕТОД ОПРЕДЕЛЕНИЯ ОПТИМАЛЬНОГО РАСПОЛОЖЕНИЯ ПРОТИВОПОЖАРНОЙ ТЕХНИКИ И ОБОРУДОВАНИЯ ДЛЯ ЛОКАЛИЗАЦИИ НИЗОВЫХ ЛЕСНЫХ ПОЖАРОВ

Аннотация. Локализация и тушение лесных пожаров – актуальная проблема для всего мира. Учитывая неоднородность лесов на планете, подходы к моделированию распространения пожаров и их тушению различны. В данной статье предложена методика определения необходимого количества сил и средств для локализации наземных лесных пожаров с учетом расположения противопожарной техники в лесах. Для прогноза распространения пожара были выбраны равноудаленные от пожарных частей места в лесах с использованием диаграмм Вороного. Результаты расчета позволяют сделать вывод о достаточности имеющихся сил и средств для локализации прогнозируемого пожара и предложить дополнительные места размещения противопожарной техники. Использование диаграмм Вороного для Государственного предприятия "Жолковское лесное хозяйство" во Львовской области показало 12 опасных участков, которые расположены дальше всего от пожарных частей. Метод определения оптимального расположения противопожарной техники и оборудования применен в Бутынском лесничестве Жолковского лесхоза. Сокращение времени свободного распространения наземных лесных пожаров на 25% за счет рационального размещения противопожарной техники и техники позволяет сократить численность работников по ее локализации на 53,8%.

Ключевые слова: низовой лесной пожар, локализация пожара, диаграмма Вороного, противопожарная техника, противопожарное оборудование.

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PROBLEMS OF STORAGE, REFINERY AND DISPOSING OF DRILLING WASTE OF THE EXPLORATION AND PRODUCTION SECTOR OF KAZAKHSTAN. ARRANGEMENT AND OPERATION FEATURES OF SLUDGE COLLECTORS AND OIL STORAGE PITS

Abstract. A lot of drilling wastes with various content of oil products is formed annually during production of hydrocarbons in the result of accidents at the facilities of transportation and oil production, soil is polluted. So, main contaminants of the environment are drilling wastes such as drilling, drilling waste water, waste drilling fluid and places of their disposition - sludge pits. Total amount of the oil slurry annually formed at enterprises of the oil sector of Kazakhstan is about 100 thousand ton, and resources of these wastes are estimated in more than 40 mln. ton. The wastes are placed in special sludge pits equipped with watertight screen. However, in spite of the available modern technologies for arrangement of waterproof finish of the drilling waste disposal facilities, high level of soil pollution is still observed. As a rule, pollutions are related to violation of the requirements of the standards during construction and operation of sludge pits, products pipelines, tailing dumps, sludge collectors and temporary storages. Therefore it is necessary to build reliable storages for temporary placement of the formed wastes until their delivery for recovery or disposing, during operation of which there will be no migration of pollutants to the environment.

It is suggested to use bentonitic mats as waterproof finish of such facilities - this is innovative by properties, multifunctional composite material, which is combination of textile materials with the layer of the natural self-recovering mineral component - bentonite.

Key words: oil slurry, drilling wastes, bentonitic mats, oil contaminated soil, environmental protection.

Oil and gas sector is the leading sector of economy of Kazakhstan. Nowadays there are more 250 oil and gas deposits with the total volume of oil resources about 30.0 Bbbl or 1.7% of the world reserves. The Republic of Kazakhstan takes the twelfth place in the world [1] by the explored reserves. With the growth of oil extraction, increase in the volumes of its processing and transportation, the problems of disposal of the ever-increasing oil and other toxic waste, negatively affecting the environment, are aggravated. According to the Ministry of Environment of the Republic of Kazakhstan, soil pollution with oil and oil products is noted on the territory of more than 1.5 mln. ha.

Exploration, drilling of oil, gas and gas condensate deposits are environmentally dangerous kinds of work and are accompanied by:

- mechanical terrain disturbance;
- chemical pollution of soils, surface and underground natural waters, phyto- and zooplankton, atmospheric air, flora;

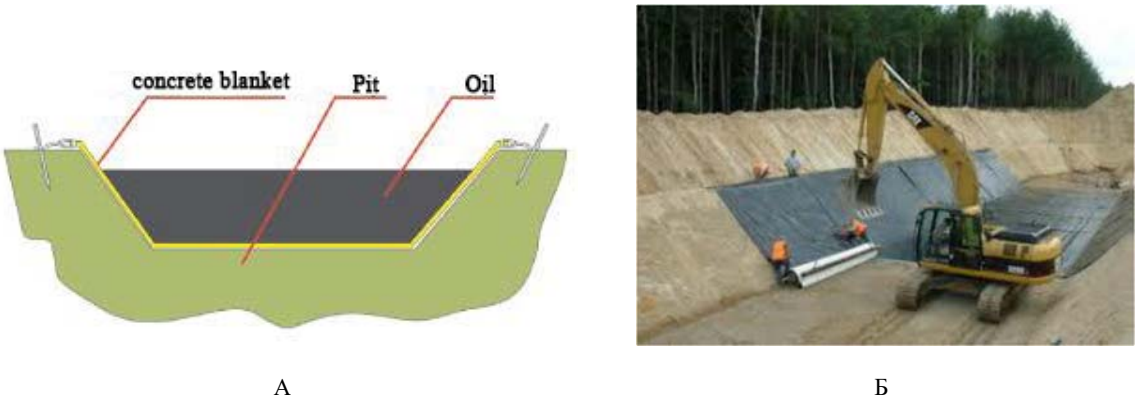
thermal abuse of exogenous geological processes (thermokarst, thermal erosion, settlement, etc.) with their possible adverse event (open flowing, gryphon formation, well walls collapses),

- contamination of the subsoil and the environment in the result of interformational cross flows and fluid exit from abandoned wells to the surface [2].

The main sources of the environmental pollution during wells drilling are: block of preparation and chemical treatment of drilling and cement slurries; wellhead; storage containers of drilling fluid; drilling waste (drill cuttings, drilling waste water, used drilling mud) and their placement (sludge pits); domestic sewages; solid household waste.

Among all oily wastes which have a harmful influence on the components of the natural environment, particularly, surface and underground natural waters, soil and vegetation cover, atmospheric air, not only oil slurries (oil sludges) - complex physical and chemical mixtures consisting of oil products , mechanical impurities (clay, metal oxides, sand) and water [3], are of special hazard, but also drilling waste, which are part of the main volume of the drilling waste.

Total amount of the oil slurry annually formed at enterprises of the oil sector of Kazakhstan is about 100 thousand ton, and resources of these wastes are estimated in more than 40 mln. ton [4]. They are placed in special sludge pits equipped with watertight screen made of a geomembrane, which can effectively prevent the migration of pollutants into ground water. The structure diagram of the pit is shown in figure 1.



А Б

Figure 1 – Pit arrangement:
А – structure section of the pit with oil slurries; Б – pit arrangement with roll waterproof material

In spite of the available modern technologies for waterproofing of the drilling waste disposal facilities/oil slurries, there is a high level of soil pollution with oil products, which is 194 thousand hectares of lands only in the Western Kazakhstan, and the volume of spilled oil is more than 5 mln. tons, and Atyrau area accounts for - 59%, Aktyubinsk - 19%, West-Kazakhstani - 13% and Mangistau - 9%. Maximum content of oil products is 172 480 mg/kg at very bituminous areas with the maximum permissible concentration (MPC) for soil in the Republic of Kazakhstan of 100 mg/kg. High levels of soil pollution with oil products have been identified near the deposits Makat, Dossor, Komsomolskoye, Tanatar, Tenteksor, Iskenes. Here, the registered oil products' concentrations in the soil vary from 24 to 138 mg/kg.

As a rule, pollutions are related to violation of the requirements of the standards during construction and operation of sludge pits, products pipelines, tailing dumps, sludge collectors and temporary storages.

To improve the situation in the largest Kazakhstani companies, which main activity is extraction of crude oil and accompanying gas, waste management programs are being developed and implemented. Mining waste management is one of the most important environmental aspects for the whole Kazakhstani oil-extracting complex. Criticality is, firstly, in the significant volumes of accumulated and formed hazardous waste peculiar to the whole oil industry [1-3].

Taking into account the huge role of the contractors during the waste recycling and disposal, the Companies try to increase the criteria for selection of the potential suppliers to guarantee the performance of work at high level and with complete transparency of the cycle - from waste generation and transportation to recycling and final disposal.

The largest Kazakhstani company Tengizchevroil (hereinafter - TCO), which total explored reserves is 3.2 billion tons (25.5 Bbbl) in Tengiz reservoir and 200 million tons (1.6 Bbbl) in the deposit Korolev, invested 3.1 bln. USD in the environmental projects since 2000. Main production wastes from activity of

TCO are: oil sludge, drilling waste, dry and liquid chemicals, activated carbon, spent catalysts, molecular sieves and caustic-containing sludge [1, 5]. 64% of the waste formed in Tengiz was transferred for recycling or to the specialized companies for processing and storage in 2018. TCO implemented a program on reduction of waste generation prohibited to disposal at landfills, and began to expand the area for temporary storage of materials which are subject to secondary use and recycling at Tengiz Eco Center. TCO transfers more than 25 kinds of waste for recycling. The total share of the recycled waste as of the third quarter of 2019 was 68.42%.

Expired chemicals and oily waste are subject to burning and heat treatment, and oily waste is subject to biological cleaning. In general, the volume of recycled and disposed waste is increasing every year. Waste management facilities "TengizEcoCentre" were founded. The company uses the first landfill in Kazakhstan equipped with a double geomembrane coating, collecting system of evolved gases and filtrate, and leak detection system.

The largest Kazakhstani Company "KazMunayGas" (hereinafter - KMG), the volume of waste from oil production in 2018 amounted to 288.3 thousand tons, among which waste classified as "hazardous" - 268.9 thousand tons, and "non-hazardous" - 19.4 thousand tons, respectively. The most part of the hazardous waste - 67% - is drilling waste (drill cuttings and waste drilling fluids). More 80% of all waste is transferred for disposal by the specialized companies. Other significant waste management methods are burning, placement at a landfill and recovery. The single roadmap was formed in 2019 by all historical pollution at the deposits of KMG, and the Company is going to liquidate them completely by 2024.

The Company MI SWACO has been working in the market of Kazakhstan since 1993, and joint Kazakh-American venture, Kaz M-I SWACO LLP, was founded in 2008, the activity of which is aimed at drilling waste recycling, and also production and sale of drill fluids (water, hydrocarbon and synthetic-based), supply of oil fields reagents and pipeline additives, equipment for mechanical cleaning of hole shank, renders drilling services with the controlled pressure.

So, the relevant task of all modern enterprises of the Republic of Kazakhstan is disposal and processing of oil and drill cuttings within the oil production facilities, as the main carriers of the considered pollutant. Taking into account the current situation with the global depletion of energy resources, the processing of oily waste can become one of the options for the economic use of the total reserves of hydrocarbons on the planet. Moreover, the analysis of the qualitative and quantitative composition of oil and slime waste demonstrated that they contain up to 80% of hydrocarbon raw materials, which is a valuable fuel and energy resource, which means that processing of such waste can be economically sound and reasonable [6].

However, despite the fact that the disposal of oil slurries is aimed at improvement of the environmental situation, it can be much more harmful to the environment than its absence. Many methods of disposal and recycling of waste containing oil products cause direct or indirect damage to the environment. So, for example, a significant part of harmful fumes directly enters the atmospheric air [5, 6] during thermal treatment of oil sludge (evaporation).

A common disadvantage of all known technologies for disposal and processing of oil sludge is their low productivity and high material, energy and financial costs for their implementation. Therefore, enterprises shall organize the process correctly to ensure the profitability of the used methods [7,8]. Introduction of one or another processing technology depends, first of all, on the composition of the raw materials used, the nature of oil sludge, the ratio of organic and inorganic components in them, environmental requirements, and also on specific conditions - the profile of the enterprise, its technical capabilities, etc. All these factors makes the complete and intensive processing of sludge with the maximum environmental safety for the environment difficult [9].

In this regard, the problems of safe placement and storage of oil slurries, construction and operation of sludge collectors and sludge pits, taking into account the long-term functioning and mitigation of their negative impact on the environment, come at an opportune time. There is a need to strengthen the requirements to the design and operation of sludge collectors and pits, using modern technologies and materials which enable long-term storage with the guaranteed exclusion of pollutants migration from waste to soil.

The analysis of the legislative norms in the Republic of Kazakhstan demonstrated that the modern requirements are aimed at exclusion of drilling waste penetration on the territory of the drilling site and

the migration of toxic substances into the natural objects. These requirements stipulate for engineering systems for organized collection, storage and waterproofing of the technological sites. Moreover, deposits construction stipulate for application of method for preparation and cleaning of drilling fluid, processing of drilling waste using method "under bench". Construction of sludge collectors and pits is allowed only in agreement with the relevant state bodies, including the Ministry of Ecology, Geology and Natural Resources of the Republic of Kazakhstan. If the deposits are built in specially protected natural areas, only drilling method without pits shall be used. Drilling deposits in terms of absorption, it is prohibited that solutions and materials enter layers containing domestic potable water. Quick-setting mixtures, various devices and technological processes are used, such as drilling using aerated solutions, foams, etc.

Main materials used in the oil industry for insulation during construction of oil facilities are bitumen based and imported materials and polymer materials with thickness of 1.0-2.5 mm based on high and low density of polyethylene, polyvinyl chloride, etc. Also geomembrane is used for waterproofing - based on high and low pressure polyethylene.

Bituminen-containing membranes (GSB) can be classified depending on kind of the basis: with cardboard basis - roofing board is impregnated with a bituminous binder, most often from oxidized bitumen and filler (Filler). Mineral dressing can be applied from top; with the basis of glass-fiber mat, glass tissue or polyester, which is usually impregnated with modified bitumen. Polymer watertight screens have a number of incontestable advantages, including simplicity of arrangement, relative cheapness, however, application of geosynthetic membranes does not exclude an essential disadvantage of this kind of material, which consists in reducing the strength factor of the material due to creep in the course of long-term operational time-temperature factors [10-12].

Taking into account visco-elastic nature of synthetic polymers, of which the most geosynthetic materials are made [13-15], and also taking into account all positive and negative aspects of the waterproofing technologies application using polymer materials and bitumen-based materials, in our opinion, the best solution for waterproofing, sludge collectors, reservoirs, pits for storage of oil slurries and fuels and lubricants is the use of bentonite mats - innovative in properties, representing a combination of textile materials with the layer of natural self-recovering mineral component - bentonite [16].

Bentonite mats **are** a multifunctional composite material in the form of a needle-punched bracing made of polypropylene fibers, which has inside powder or granules of sodium bentonite - one of the montmorillonite clay types of natural origin, with mat sizes 4-5 m wide and up to 40-50 m long (figure 2).

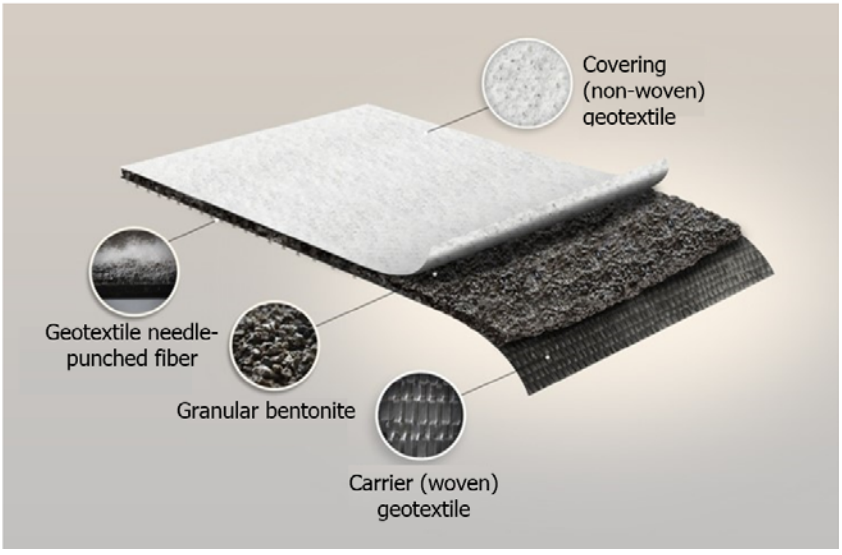


Figure 2 – Bentonite Mat Structure

Mats are used in the oil industry as a reliable waterproofing material for various storage facilities and technological sites. Also they act as watertight screen, which is designed for protection against penetration of various pollutants from sludge pits into the soil and groundwater from sludge pits, tanks for oil and fuels and lubricants storage.

The use of bentonite mats has tremendous advantages during construction and operation of sludge pits, tanks for oil and fuels and lubricants storage:

– one layer of bentonite mat (thickness 6 mm) substitutes clay waterproofing layer (clay retainer) with thickness 1.0 m;

– can sustain high hydrostatic pressure (up to 70 m w.c.);

– bentonite clay, which is component of mat, absorbs oil products well;

– very low permeability coefficient ($1x10^{-6}$ m/day);

– able to self-healing due to swelling (in contact with water) of clay matter and filling the cavities with gel in the result of mechanical damage and cracks at the base;

– possibility to work at low temperatures (up to -20 °C);

– sustain large number of cycles "freeze - thawing" and "hydration - dehydration", without significant change in consumer properties (for example, after exposure to variable temperatures, 10 cycles: tensile strength, decreased by 3% for certain bentonite mats).

All these factors stipulate the wide application of this material by large companies operating in the area of subsoil use in the Russian Federation and abroad, such as: PJSC NC Rosneft, PJSC Gazprom Neft, LLC Gazprom Burenie and PJSC Surgutneftegaz and other.

There is a need to consider the requirements to arrangement of impervious protective screens in the modern practice of construction and operation of sludge collectors and pits for oil slurries, which shall minimize the pollution of the environmental components. Introduction of such regulatory requirements with the development of the National Standards of the Republic of Kazakhstan, specialized Recommendations on application of bentonite mats for design, construction and other designated organizations could contribute to the development of local production of the innovative domestic materials based on bentonite deposits in Kazakhstan.

For instance, on the basis of the Taganskoye deposit in East Kazakhstan, which is represented by three industrial horizons of alkaline, alkaline-earth and pharmaceutical bentonites [17].

They are one of the high quality in terms of their technical characteristics not only in Kazakhstan, but also abroad. Due to its unique chemical composition, Taganskiy bentonite has a wide range of applications in the various industries [18]. High efficiency of the clays of the deposit Taganskoye with respect to the oil products sorption was proved during the laboratory tests (2020) carried out on the basis of the laboratory of the Ministry of Natural Resources of the Russian Federation - the Federal State Budgetary Institution "Centre of Laboratory Analysis and Technical Metrology in the Ural Federal District". The results of the tests demonstrated that the content of oil products is reduced by 3-4 times compared to the initial pollution.

The rights for development of the deposit Taganskoye are owned by the Group of Companies Bentonite (Russian Federation), one of the five world producers of bentonite products, one of subdivisions is Altai Materials LLP. The Group of Companies Bentonite has an great experience in production of bentonite mats under BentIzol brand, which is a new multifunctional material for arrangement of watertight screens (figure 3) not only during construction and reclamation of landfills of industrial and

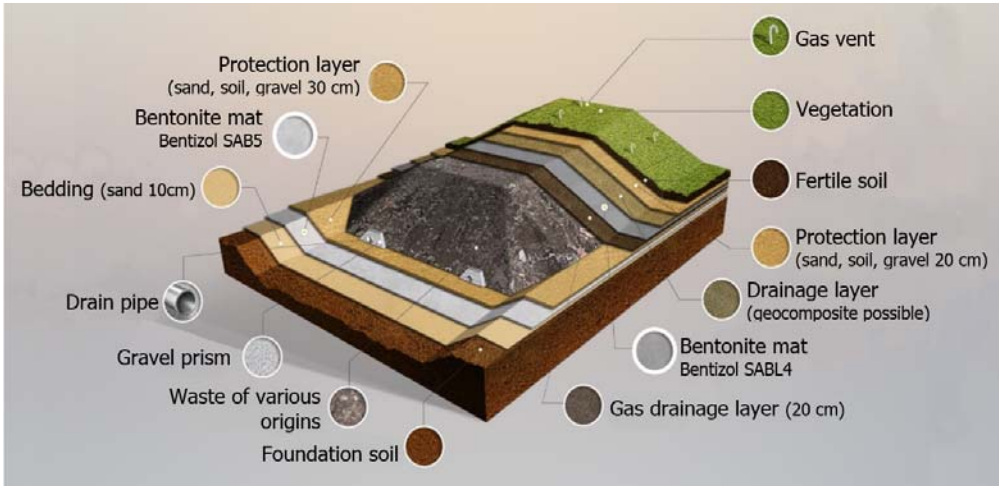


Figure 3 – BentIzol Bentonite Mats Application Scheme during construction and reclamation of the landfill

solid domestic waste of various origins, but also during creation of engineering safety barriers during conservation and burial of radioactive waste and nuclear and radiation hazardous facilities. Bentonite mats are the most effective compared to the traditional and polymer materials (figure 2), which production can be developed in Kazakhstan if there is an appropriate market niche.

Thus, strengthening the norms for arrangement of waterproofing and watertight screens during construction dumping facilities of production and consumption waste, on the one hand, enables solving the problems of their reliability and reducing the impact on the environment in the long term, on the other hand, it contributes to the creation of a new own innovative production with additional job opportunities.

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ҚАЗАҚСТАННЫҢ МҰНАЙ ӨНДІРУ САЛАСЫНДАҒЫ ҚАЛДЫҚТАРДЫ БҰРҒЫЛАУ, САҚТАУ, ӨҢДЕУ ЖӘНЕ ҚАЙТА ӨҢДЕУ МӘСЕЛЕЛЕРІ. МҰНАЙ ҚОЙМАЛАРЫН ЖӘНЕ ШЛАМ ЖИНАҚТАҒЫШТАРДЫ ПАЙДАЛАНУ ЖӘНЕ ҚҰРЫЛЫМ ЕРЕКШЕЛІКТЕРІ

Аннотация. Мақалада біз мұнай өнімдерінің құрамында әр түрлі бұрғылау қалдықтарының көп мөлшерін қалыптастыру, сондай-ақ тасымалдау және мұнай өндіру объектілерінде топырақтың ластануына әкелетін төтенше жағдайларды қарастырдық. Қоршаған ортаның ластануының негізгі көздері, ең алдымен, бұрғылау шламы, бұрғылау ағынды сулары, бұрғылау қалдықтары және олардың орналасқан жері - шлам қоймалары сияқты бұрғылау қалдықтары екені белгілі.

Қазақстанның мұнай өнеркәсібі кәсіпорындарындағы жыл сайынғы шығарылатын мұнай шламының жалпы мөлшері шамамен 100 мың тоннаны құрайды, ал бұл қалдықтардың ресурстары 40 миллион тоннадан асады. Қалдықтар фильтрге қарсы экранмен жабдықталған арнайы шлам қоймаларына орналастырылады. Алайда, бұрғылау қалдықтарын орналастыру қондырғыларын гидроизоляциялаудың қолда бар заманауи технологияларына қарамастан, топырақтың ластануының жоғары деңгейі сақталуда. Әдетте, бұл ластану шлам қоймаларын, өнім құбырларын, қалдық қоймаларын, шлам тоғандарын және уақытша сақтау қоймаларын пайдалану кезінде, сондай-ақ құрылыс кезінде стандарттар талаптарының бұзылуымен байланысты. Сондықтан, пайда болған қалдықтарды оны өңдеуге немесе көмуге жібермес бұрын уақытша орналастыру үшін, қоршаған ортаға ластаушы заттардың қоныс аударуы болмайтын сенімді сақтау қоймаларын салу қажет.

Осылайша осындай объектілерді салу және пайдалану кезінде гидроизоляциялауға арналған фильтрге қарсы бентонит төсеніштерін экран ретінде пайдалану ұсынылады, бұл қасиеттері бойынша инновациалық, көпфункционалды композициялық материал, ол табиғи өзін-өзі қалпына келтіретін минералды компоненттің қабаты бар тоқыма материалдарының үйлесімі – бентонит. Сондай-ақ, қазіргі уақытта шлам жинағыштар мен қоймаларды жобалау және пайдалану үшін ұзақ мерзімді сақтауға мүмкіндік беретін заманауи технологиялар мен материалдарды қолдануға қойылатын талаптарды қатаңдатудың өткір проблемасы бар. Сондықтан жобалау, құрылыс және басқа мамандандырылған ұйымдар үшін бентонит төсеніштерін пайдалану бойынша ұлттық стандарттар мен мамандандырылған ұсыныстарды әзірлеумен Қазақстан Республикасындағы нормативтік талаптарды қайта қарау қажет.

Түйін сөздер: мұнай шламы, бұрғылау қалдықтары, бентонит төсеніштері, мұнаймен ластанған жерлер, қоршаған ортаны қорғау.

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ПРОБЛЕМЫ ХРАНЕНИЯ, ПЕРЕРАБОТКИ И УТИЛИЗАЦИИ ОТХОДОВ БУРЕНИЯ НЕФТЕДОБЫВАЮЩЕЙ ОТРАСЛИ КАЗАХСТАНА. ОСОБЕННОСТИ УСТРОЙСТВА И ЭКСПЛУАТАЦИИ ШЛАМОНАКОПИТЕЛЕЙ И НЕФТЯНЫХ АМБАРОВ

Аннотация. В статье нами рассмотрена проблематика образования большого количества отходов бурения с различным содержанием нефтепродуктов, а также аварийных ситуаций на объектах транспортировки и нефтедобычи, в результате которых происходит загрязнение почв. Известно, что основными источниками загрязнения окружающей среды являются, прежде всего, отходы бурения, такие как буровой шлам, буровые сточные воды, отработанный буровой раствор и места их размещения – шламовые амбары.

Общее число ежегодно образующегося нефтешлама на предприятиях нефтяной отрасли Казахстана составляет около 100 тыс. тонн, а ресурсы этих отходов оцениваются более чем в 40 млн тонн. Размещаются отходы в специальных шламовых амбарах, оснащенных противофильтрационным экраном. Однако, несмотря на имеющиеся современные технологии для устройства гидроизоляции объектов размещения отходов бурения, по-прежнему наблюдается высокий уровень загрязнения почв. Как правило, эти загрязнения связаны с нарушением требований стандартов при строительстве, а также при эксплуатации шламовых амбаров, продуктопроводов, хвостохранилищ, шламонакопителей и временных хранилищ. Поэтому для временного размещения образующихся отходов до передачи их на переработку либо утилизацию необходимо строить надежные хранилища, при эксплуатации которых не будет процесса миграции загрязняющих веществ в окружающую среду.

Таким образом, в качестве противофильтрационного экрана для гидроизоляции таких объектов при строительстве и эксплуатации предлагается использовать бентонитовые маты, являющиеся инновационным по свойствам, многофункциональным композиционным материалом, представляющим собой комбинацию текстильных материалов с прослойкой природного самовосстанавливающегося минерального компонента – бентонита. Также в настоящее время остро стоит проблема ужесточения требований к проектированию и эксплуатации шламонакопителей и амбаров, с применением современных технологий и материалов, которые дают возможность долгосрочного хранения. Поэтому необходим обязательный пересмотр нормативных требований в РК с разработкой Национальных стандартов и специализированных Рекомендаций по применению бентонитовых матов для проектных, строительных и других профильных организаций, который мог бы способствовать скорейшему развитию локального производства отечественных материалов на базе бентонитовых месторождений Казахстана.

Ключевые слова: нефтешлам, отходы бурения, бентонитовые маты, нефтезагрязненные земли, охрана окружающей среды.

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STATE OF MICROPHYTE CENOSES AT THE WATER'S EDGE IN THE VICINITY OF THE PORT OF YERSAI AND THE VILLAGE OF KURYK (EASTERN CASPIAN SEA)

Abstract. Microphytic cenoses that develop on coastal rocks in the area of the water's edge can serve as particularly bright indicator biosystems that clearly display any harmful effects on their habitat. Developing, in fact, in the water-land boundary conditions, in the area of direct impact of the surface film of continuously moving water, they are a kind of " sponges " that collect a variety of agents carried by sea currents from sources of pollution. Accumulating in these communities, such agents are able to change the balance of species in the structure of these coenoses in a short time, as well as cause morphological changes in the species themselves. These modifications of the appearance can be caused both by their phenotypic norm of reaction to the presence and high concentrations of the contaminating agent, and by mutations provoked by one or another agent. Based on the obtained results describing the state of microepiphytic and microepilitic cenoses in various locations located at the end of July 2019 in the vicinity of the port of Ersai and the village of Kuryk, it can be concluded that the communities of all three locations were under stress – however, to a significantly different degree.

Key words: the coastal area, water basin, microepiphyton,, macrozoobenthos, biosystem, port Ersai, water area, East of Caspian sea.

Introduction. Communities of microscopic organisms that form in the coastal zone of water bodies are complex, multicomponent systems that are sensitive to various types of anthropogenic impact. The composition, structure, spatial organization of these communities, as well as the morphotypic characteristics of the species that accompany them, look very different - depending on the conditions of the habitat at the current time. Due to the high rate of reproduction of microorganisms, these cenoses react to environmental conditions faster and more clearly than communities of larger organisms. For example, microepiphiton on macroalgae or microepiphiton on coastal rocks reflect changes in the habitat already in the first day or three after the start of events. At the same time, macrozoobenthos developing in the same habitats displays any events that metamorphize the habitat, already indirectly and over longer time intervals.

It should be noted that microphytic cenoses that develop on coastal rocks in the area of the water's edge can serve as particularly bright indicator biosystems that clearly display any harmful effects on their habitat. Developing, in fact, in the water-land boundary conditions, in the area of direct impact of the surface film of continuously moving water, they are a kind of" sponges " that collect a variety of agents carried by sea currents from sources of pollution. Accumulating in these communities, such agents are able to change the balance of species in the structure of these coenoses in a short time, as well as cause morphological changes in the species themselves. These modifications of the appearance can be caused both by their phenotypic norm of reaction to the presence and high concentrations of the contaminating agent, and by mutations provoked by one or another agent.

Objects and methods of research. To study the possible effects of the Kuryk port and the LLP (in the post construction period) of the surrounding coastal waters East of the Caspian sea, in the period 26-28 July 2019 was sampled epilithic benthic communities. The material was taken on the surface of coastal rocks, in the area of the water's edge, at three points.

So, at the point Ep-1, located at a distance of 147 m to the South-West of the beginning of the Western Dam of the port, two samples of macrophytic growth were cut from the surface of flat stone blocks piled under a low coastal chink. The communities from which samples were taken in this location were different in macrophyte balance. In both cases, the growth of up to three centimeters was formed by a dense growth of filamentous scarlet (*Rhodophyta:Ceramiales*). However, in one case, this living red-brown carpet, absorbing the foam of the rolling wave, was formed mainly by thallomas of Ceramium elegans, with a small admixture of *Polysiphonia caspica*. And in another case, *P. caspica* prevailed, with a slight presence of *C. elegans*. In general, such modifications of phytofouling communities are quite typical for habitats at the water's edge in the eastern part of the Central Caspian Sea: both species of scarlet in these biotopes are usually found together [1], but the ratio of their abundance, according to our observations, may be different.

The point Ep-2 was located on a small rock outlet, at a distance of 2807 m to the East of the beginning of the Eastern Dam of the port. Samples of the growth were taken on the surface of calcareous blocks going into the water and from the surf-sanded calcareous rock wall, in the area of the water's edge, in three different communities. In the first case, it was thickets of *Cladophora sericea*, massively developed by a layer of up to 10 cm on blocks, in the shadow of a rock mass; in the second case, a gray fibrous-curd growth on a solid rock formed by colonial diatoms; in the third, also on the rock, there is a scattering of cartilaginous-jelly-like "plaques" of cyanobacteria, the structure-forming basis of which were macrocolonies of Rivularia atra.

Finally, the point of Ep-3 was localized even further to the East, in the area of the village Kuryk, at a distance of 4312 m from the beginning of the Eastern dam of the port, on the sea edge of a rocky promontory that protrudes into the sea almost 900 m from the main contour of the coastline. Here, on flat calcareous rocks, smoothly polished by the surf, only small placers of "plaques" of cyanobacteria based on *R. atra* colonies grew. At the same time, a gray mass of rotting filamentous algae lay in large numbers on the rocks, exuding a strong smell of hydrogen sulfide.

All samples were recorded with a 45% ethanol solution immediately after sampling and delivered to Moscow, to the laboratory of the Institute of Oceanology of the Russian Academy of Sciences, in a dark box. Thus, the material for microscopy of microepiphiton on macrophytes and microepiliton was obtained in the form that best corresponds to the lifetime state of the communities.

The general location of material collection locations in the water area in the vicinity of the port is shown in figure 1.

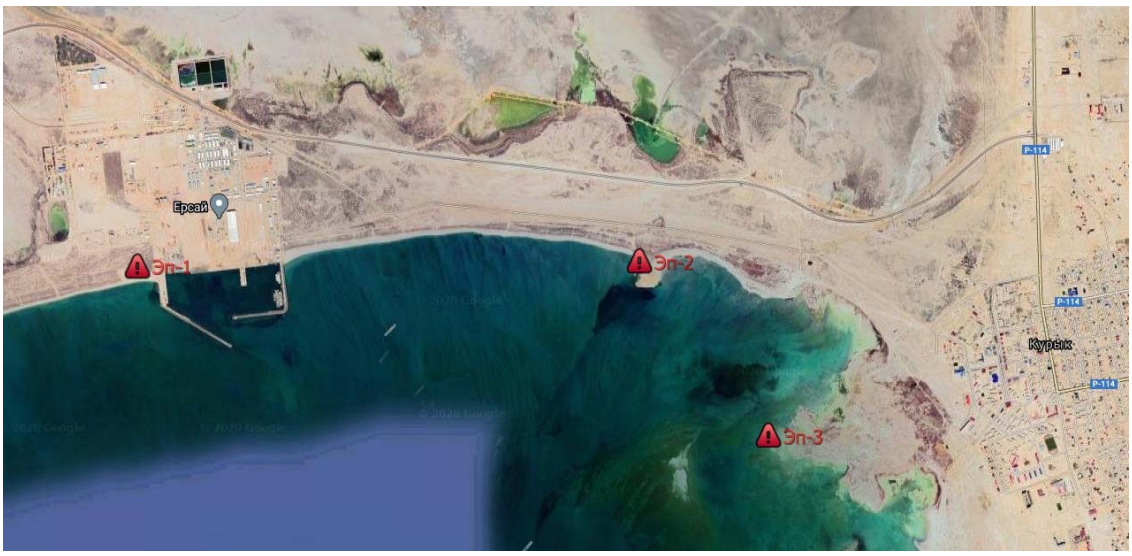

Figure 1 – Location of microepiliton and micro epiphyton sampling points in the waters of the Eastern Caspian Sea in the vicinity of the port of Ersai and the village of Kuryk

Microscopy of the samples was performed on raw material, as well as on permanent preparations made on the basis of the light-refractive medium "Rosin". Observation of fouling in its raw form allowed us to identify tiering in their structure, as well as other features of spatial organization inherent in the studied communities. In addition, the identification of cyanoprokaryotes is possible only in raw form - in the manufacture of permanent preparations, when a concentrated oxidizer is used to clean the shells of diatoms from organic components of cells, many cyanobacteria are dissolved. Working magnifications X400 and X1000 of Leica DMLS and Leica DM2500 light microscopes were used for identification, accounting and photo documentation of microphytes. The determination of the taxonomic affiliation of organisms was established using modern atlases, determinants and taxonomic summaries [2-17].

Results. The total taxonomic richness of the microphytic flora of the 6 studied microbiotopes located within three locations (points) in the vicinity of the port of Yerasay and the village of Kuryk was 88 species and subspecies. Among them, diatoms significantly prevailed (78 species and subspecies, or 88.64% of the total flora), followed by cyanobacteria (9 species, or 10.23%). One type of microepiphyte is *Acrochaetium* sp. 1, which lived in the status of rare on the surface of filamentous scarlet *C. elegans* and *P. caspica*, also belonged to the scarlet (*Rhodophyta*). In some communities, the number of microphyte species and vvt varied from 6 to 73 (table 4), averaging 26.83.

The richest (in terms of α - diversity, the number of species and vvt) was a community fiber - cheesy oposta on the rocks at location EP-2, East of the port (73 and vvt). Especially poor (with the lowest α-diversity) were the epiphytic community on *S. sericea*, an overgrown block of limestone at the Ep-2 location, and the epiliton of flat rocks at the Ep-z location, represented on the cape to the East of the port by small placers of" plaques " of *R. atra* and 6 accompanying species. For comparison, the" plaques " of *R. atra*, which formed dense placers on the rocks at the location of Ep-2, in the shadow of the southern dam of the port, included, in addition to the matrix-forming species-edifier, 11 more species and vvt. It should be noted that the microepiphyton on *Ceramium* (33 species and vvt) and *Polysiphonia* (30 species and vvt) differed in significant diversity. The average similarity of cenoses in the sample was 29,092% - the communities differed significantly in composition.

Only 3 species were recorded in 5 of the 6 studied cenoses - in different combinations - and, accordingly, can be considered as widespread in the vicinity of the port: These were diatoms *Diatoma moniliformis*, *Licmophora debilis* and *Tabularia affinis-attached*, colony-forming forms. At the same time, 42 species and vvt (47.73% of the total flora found) were observed only at one of the stations, that is, they differed in significant biotope / cenozoic specificity.

Considering the hierarchical roles of species in communities, due to the share of each of them in the total abundance of coenosis, as well as the distribution of species in the sample of coenoses, we can distinguish groups of communities: floristic (by composition) and coenotic (by structure).

Using a sample of 46 species and VVTs recorded in more than one cenosis, we evaluated the similarity of communities by qualitative characteristics using the Sierensen index, and by quantitative characteristics using the Bray-Curtis index.

The mean qualitative similarity of the coenosis on a truncated sample of the types made 35,36% community still differed widely among themselves in composition, which is logical considering only a truncated α - diversity in each of them (6-35 types and VVT, with an average 18,83).

We were able to identify 3 floristic groups differ on sound level (Global R = 1, p=1,7%).

In this floristic group, which included fiber - curdled epilithon location EP-2 and microaspiration of plaques locations EP-1 (group "diatoms + plaques"), described 33 species and vvt. In this case, the floristic similarity of the communities combined with the intragroup similarity at the level of 66.93% led to many common species of diatoms. At the top of the list were *Licmophora debilis, Berkeleya* cf. *rutilans, Epithemia sorex, Navicula* sp. 1, *Amphora hyalina, Cocconeis scutellum var. Parva, Entomoneis gigantea, Grammatophora marina, Grammatophora oceanica, Mastogloia smithii, Pleurosigma strigosum* и *Rhopalodia gibberula*.

The second floristic grouping ("Ep-2 *Cladophora+Rivularia*"), with an intra-group similarity of 55.56%, was formed by coenoses of microepiphytes on *C. sericea* and "plaques" of *R. atra* on the rocks of the Ep-2 location. Here, with an intra-group similarity of 55.56%, the grouping was already characterized by only 5 species and vvt: *Diatoma moniliformis, Licmophora debilis, Tabularia affinis, Heteroleibleinia epiphytica и Tabularia fasciculata.*

Finally, the third group ("Ep-3 *Rivularia*") was represented by a community of *Rivularia*" plaques " on the flat rocks of the Ep-3 location, which grew in small groups among rags of decaying *filamentous algae*. Here, as part of the matrix of *Rivularia* colonies and in the folds of its surface, only 7 species of microphytes lived: *Rivularia atra, Diatoma moniliformis, Tabularia affinis, Berkeleya* cf. *rutilans, Navicula* sp. 1, *Calothrix scopulorum* и *Lyngbya aestuari*i.

Of course, the qualitative composition of communities and their quantitative structure, determined by the hierarchy of contributions of individual species to the total abundance, often determine the similarities and differences of communities in different ways.

The average similarity of coenoses (in the truncated composition) in the quantitative structure was 24.03% - the communities, as a whole, differed greatly among themselves in the hierarchy of the species that form them. We were able to distinguish three cenotic groups with a general reliable level of differences (Global R = 1, p=1,7%).

The first group ("diatoms") was formed by communities of fibrous-curd growth on the rocks of the Ep-2 location, formed on the basis of macrocolonies of diatoms. These cenoses were characterized by a set of 23 species and vvt (table 1). Here, the main structure-forming role was played by branched colonies of *Diatoma moniliformis*. They served as a kind of spongy substance, inside which branched tubular colonies of *Berkeleya cf. rutilans* and *Berkeleya scopulorum*, long branching trichomes of the cyanobacterium *Diphothrix sp*. 1, small polymer sacs of *Gloeocapsa alpina* colonies, and 68 other diatomaceous species living a mobile and attached lifestyle. It should be noted that *Mastogloia species* in communities of this type lived without capsules, which they usually form when settling on solid substrates - here, among dense colonies of *D. moniliformis*, they retained mobility.

Table 1 – Set of species that characterized the coenotic grouping of "diatoms" at the Ep-2 location, East of the port of Ersai

Species and subspecies	Contribution to the overall abundance of cenosis, %
Diatoma moniliformis	27,24
Epithemia sorex	6,43
Amphora hyalina	5,71
Craticula subhalophila	5,49
Mastogloia smithii	5,15
Rhopalodia gibberula	4,93
Amphora lineolata	4,52
Berkeleya scopulorum	4,27
Cylindrotheca closterium	3,66

In the structure of the communities of this group, we noted the presence of mutant (aberrant) cell forms of some diatoms. Most often, these were *Epithemia turgida* and *Phopalodia gibba*, whose shells were significantly deformed, and their ornamentation was characterized by violations of the ornament.

The second coenotic group ("filaments"), with an intragroup similarity of 49.54%, was formed by communities of microepiphyton of filaments: both on the surface of scarlet in the Ep-1 location and on *C. sericea* in the Ep-2 location. These coenoses were characterized by a set of 5 species (table 2), and the main structure-forming role among them was played by the epiphytic thin-trichomal cyanobacteria *Heteroleibleinia epiphytica*. *Mastogloia* species included in the structure of the magenta microepiphyton in the Ep-1 location lived on their surface in an encapsulated state. Note also that in the cenosis on *C. sericea* the role of the second dominant was played by branched colonies of *D. moniliformis*, and already they were followed by *Tabularia affinis* and *T. fasciculata* in the status of mass.

The third group ("*Rivularia*"), with an intragroup similarity of 84.67%, was formed by cenoses based on the matrix of *Rivularia* macrocolonies that lived on rocks in the locations of Ep-2 and Ep-3. Trichomes played a major role in their structure *R. atra* (table 3).

Table 2 – Set of species that characterize the coenotic grouping of "filaments" formed by microepiphytic communities on the surface of filamentous macroalgae in the vicinity of the port of Ersai

Species and subspecies	Av.Abund	Av.Sim	Sim/SD	Contrib, %	Cum., %
Heteroleibleinia epiphytica	0,42	38,82	51,45	78,35	78,35
Licmophora debilis	0,03	1,8	6,32	3,63	81,99
Pteroncola inane	0,1	1,66	0,58	3,35	85,34
Cocconeis scutellum var. *scutellum*	0,03	1,64	0,58	3,3	88,64
Tabularia affinis	0,04	1,58	0,58	3,19	91,83

Table 3 – A set of species that characterize the coenotic group "Rivularia" formed by microepiphytic communities on the surface of filamentous macroalgae in the vicinity of the village of Kuryk

Species and subspecies	Av.Abund	Av.Sim	Contrib, %	Cum., %
Rivularia atra	0,87	80,21	94,74	94,74

Turning to the topic of diversity and equiobility of the species structure of coenoses, we evaluated these parameters using the Shannon-Weaver indices (diversity, H`), Pielow (J`) and the interspecific Encounter Probability Index (EPI). The highest diversity in H` was distinguished by the coenosis of fibrous-curd fouling on rocks (location Ep-2) (table 4). Here, the highest value of EPI and one of the highest values of J` were noted - the cenosis was most diverse, rich in species and balanced. Nevertheless, the value of J` at a level below 0.8 still indicates a strong influence of the first dominant on the structure of the cenosis, which was actually expressed in the structure-forming role *Diatoma moniliformis*.

Table 4 – Values of diversity indices (H`) and equalization of species structure (J`, EPI) for communities of different locations in the vicinity of the port of Ersai and the village of Kuryk. In accordance with the selection of indices for each cenosis, its α - diversity (species richness) is given

Locations and communities	α- diversity	J`	H`	EPI
Ep -1 *Ceramium elegans*	33	0.597	2.088	0.785
Ep -1 *Polysiphonia caspica*	30	0.722	2.455	0.832
Ep -2 Волокнисто-твор. оброст	70	0.708	3.008	0.899
Ep -2 *Cladophora sericea*	6	0.640	1.146	0.615
Ep -2 *Rivularia atra*	12	0.351	0.872	0.350
Ep -3 *Rivularia atra*	7	0.141	0.274	0.113

Microepiphyton on the surface of filamentous scarlet was characterized by medium-low (for *Polysiphonia*) and low (for *Ceramium*) indicators of diversity and equalization. However, in the conditions of the Caspian Sea, it is difficult to count on particularly high indicators of these indices for microepiphyton. For example, in the northern part of the sea-lake, only 2-3 species of microepiphytes can be found on *Polysiphonia species*, with a significant dominance of one of them. Given the high number of microepiphyton species in the coenoses we studied in the port area, we can say that the relatively low values of H`, J` and EPI are due to the significant roles of the dominant species (*Heteroleibleinia epiphytica* and, on *Ceramium,* also *Pteroncola inane*) in their structure.

The microepiphyton of *S. sericea*, represented by a small number of species, was characterized by the lowest indices of all indices among the coenotic group of "filaments". However, this is generally characteristic of epiphytic communities on *Cladophora*, which are forced to live on a well-washed, rarely branching cylindrical substrate with a fibrous-cellulose cell surface. Nevertheless, it should be noted that a certain stress was manifested for this cenosis through low diversity indicators and significant roles of dominants.

In turn, the lowest indicators of diversity and equalization against the background of a small number of species were characterized by cenoses based on *Rivularia* "plaques". Nevertheless, a significant difference in all 4 indicators was clearly noted between the cenoses of this type that lived within the Ep-2

and Ep-3 locations – in favor of the cenosis at the Ep-2 location. *Rivularia*-based communities at the Ep-3 location grew under the most severe stress.

Based on the obtained results describing the state of microepiphytic and microepilitic cenoses in various locations located at the end of July 2019 in the vicinity of the port of Ersai and the village of Kuryk, it can be concluded that the communities of all three locations were under stress – however, to a significantly different degree.

Thus, the least stressful effect was observed in the location of Ep-1, at a distance of about 150 m to the South-West of the port. Here, only abundant organic pollution of the coastal water area affected. In turn, the cenoses of the Ep-2 location bore, first, the imprints of organic pollution, which stimulated the violent development of "garbage" species, such as *Diatoma moniliformis, Tabularia affinis, T. fasciculata* and-on *Cladophora – Heteroleibleinia epiphytica*. Secondly, the coenosis of the fibrous-curd-like growth of rocks, which takes on, like a sponge, the effect of all the agents dissolved in the surface film of water, was clearly affected by a certain toxic pollution, clearly manifested in the presence of aberrant forms of diatoms from the genera, albeit insignificant *Epithemia, Mastogloia* and *Rhopalodia*.

Finally, the flat rocks of the Ep-3 location were already located, in fact, on the distribution line along the coast of those agents that can go to the water area of the coastal zone with the sewage of the village of Kuryk. The communities here were actually knocked out and slowly rotted away. The same microepilitic coenoses based on the dense polysaccharide matrix of *Rivularia* macrocolonies that survived here were in an extremely depressed state.

The longshore current in this area moves from East to West. The dams of the port, in fact, play the role of cut-offs, thanks to which the flow carrying the bulk of the sewage of the village Kuryk, partly turns towards the open sea. As a result, coastal communities to the west of the port are significantly less polluted than those to the East. Bottom microphyte communities of the surf strip were studied for this area of the Caspian coast for the first time.

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ЕРСАЙ ПОРТЫ МЕН ҚҰРЫҚ АУЫЛЫНЫҢ (ШЫҒЫС КАСПИЙ) МАҢЫНДАҒЫ СУ КЕМЕРІНДЕГІ МИКРОФИТТІК ЦЕНОЗДАРДЫҢ ЖАЙ-КҮЙІ

Аннотация. Су кемері аймағындағы жағалаудың жартастарында пайда болатын микрофиттік ценоздар, тіршілік ету ортасына қандай да бір зиянды әсерлерді айқын көрсететін ерекше жарқын индикаторлық биожүйелер болып табылады. Су-құрлықтық шекаралық жағдайында, үздіксіз қозғалатын судың беткі қабатының тікелей әсер ету аймағында дамып, олар ластану көздерінен теңіз ағындарымен тасымалданатын әртүрлі агенттерді жинайтын "сіңіргіштер" болып табылады. Осындай қауымдастықтарда жинақтала отырып, мұндай агенттер қысқа мерзімде осы ценоздардың құрылымындағы түрлердің тепе-теңдігін өзгерте алады, сонымен қатар түрлердің морфологиялық өзгерістерін тудырады. Сыртқы көріністің бұл модификациясы олардың ластаушы заттың болуына және жоғары концентрациясына фенотиптік реакция нормасына, сондай-ақ белгілі бір агент қоздыратын мутацияға байланысты болуы мүмкін. 2019 жылғы шілде айының соңында Ерсай порты мен Құрық ауылының маңында орналасқан түрлі локациялардағы микроэпифиттік және микроэпилиттік ценоздардың жай-күйін сипаттайтын алынған нәтижелер негізінде барлық үш жердегі қауымдастықтар күйзеліске ұшырады деген қорытынды жасауға болады, дегенмен, көрсеткіштер әртүрлі дәрежеде болды.

Түйін сөздер: жағалау аймағы, су айдыны, микроэпифитон, макрозообентос, биожүйе, Ерсай порты, акватория, Шығыс Каспий.

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СОСТОЯНИЕ МИКРОФИТНЫХ ЦЕНОЗОВ НА УРЕЗЕ ВОДЫ В ОКРЕСТНОСТЯХ ПОРТА ЕРСАЙ И ПОС. КУРЫК (ВОСТОЧНЫЙ КАСПИЙ)

Аннотация. Микрофитные ценозы, развивающиеся на береговых скалах в области уреза воды, могут служить особенно яркими индикаторными биосистемами, наглядно отображающими какие-либо вредоносные воздействия на среду их обитания. Развиваясь, по сути, в граничных условиях вода-суша, в области прямого воздействия поверхностной плёнки непрерывно движущейся воды, они являются своего рода «губками», собирающими в себя самые разные агенты, разносимые морскими течениями от источников загрязнения. Накапливаясь в этих сообществах, такие агенты способны в короткие сроки изменять баланс видов в структуре этих ценозов, а также вызывать морфологические изменения самих видов. Эти модификации облика могут быть обусловлены как их фенотипической нормой реакции на присутствие и высокие концентрации загрязняющего агента, так и мутациями, провоцируемыми тем или иным агентом. На основании полученных результатов, описывающих состояние микроэпифитных и микроэпилитных ценозов в различных локациях, располагавшихся в конце июля 2019 года в окрестностях порта Ерсай и пос. Курык, можно сделать заключение, что сообщества всех трёх локаций находились в состоянии стресса – однако в существенно разной степени.

Ключевые слова: прибрежная зона, водоём, микроэпифитон, макрозообентос, биосистема, порт Ерсай, акватория, Восточный Каспий.

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NUMERICAL SIMULATION MODELLING OF TEMPERATURE DISTRIBUTION IN THE PROCESS OF COAL SELF-HEATING IN THE MINED-OUT SPACES

Abstract. Researches of thermodynamic processes of oxidation, self-heating and self-ignition of coal are necessary for studying of dependence of terminal parameters on a set of the influencing factors. In practice of coal mining by the underground method cases of coal self-ignition in the mined-out spaces of production units (lavas) are frequent. In this case one of the tasks consists in determination of temperature in arbitrary point of the nubbly-porous medium of the mined-out space. Need of the solution of this difficult task is caused by the probability of emergency situations in places with the explosive concentration of methane. It is possible that for each seam and grade of coal it is necessary to develop, substantiate and accept an individual indicator for assessing the state of fire hazard. It is proposed to systematize and methodically process the results of field measurements and observations on the analyzed and investigated cases of endogenous fires in problem areas of mines in order to create basin databases for subsequent operational decisions in emergency situations.

Keywords: mined-out spaces, oxidation, self-heating, coal self-ignition, temperature distribution, heat conductivity, partial differential equations, numerical simulation, application program package.

Of course, the most reliable results can be received in the process of physical modeling in natural conditions. In laboratory conditions these researches are almost impracticable for a number of reasons. In particular, the known laboratory researches on oxidation and self-heating of coal are carried out with small amounts of initial material and are directed, mainly, to determination of tendency to self-ignition or quantitative analysis of the gases which are emitted in the process of oxidation. For example, in one of the latest works on physical laboratory modeling [1-5] "the method of thermal effects assessment of oxidation process of solid carbon substances in the conditions of the constant speed of heating is offered". Authors set the purpose definition of quantitative power characteristics of theoretic-chemical justification of oxidation process and self-ignition of coal.

The large-scale natural experiment which completely simulate conditions of the mined-out space and directed to instrumental measurement of temperature in all volume is very difficult, demands the installation of thermal sensors network on the area and on height of the left coal congestion [2]. Besides danger and the high cost of similar experiments they are quite labor-consuming in terms of the change at the different levels even of the most significant operating external factors (heat efflux by air flows, heat transfer in the adjacent strata, thermal characteristics of coal and refuse stones).

Having regard to the above said, nowadays mathematical methods of thermal processes modeling of self-heating and self-ignition including the coal get larger value and application. Here, two directions are mainly developed.

The first is based on the basic equations of thermal balance of a heat transfer with the use of empirical dependences in the process of heating in the result of oxidation and is focused on engineering approach to a problem. For the first time in this direction the problem of distribution of the thermal field in the result of self-heating in volume of nubbly-porous congestion of the goafed coal was solved in works [5-9] within the research works of group of scientists of the Karaganda department of the All-Union Research Institute of Mine-rescue Work (AURIMRW) under the direction of the Doctor of Engineering Science Chekhovskikh A.M. More general approach to such modeling of thermodynamics of the endogenous fires is offered in the work of the famous scientist in this question of Pashkovskiy P.S [10].

Other direction, more strict, is developed with the use of classical partial differential equations of heat conductivity, allowing to realize numerical models of a non-stationary heat transfer in solid bodies. One of the first works describing mathematical model of coal self-ignition by the system of the isolated partial differential equations in relation to endogenous fires in coal mines, it is possible to mention works of Gluzberg E.I. [11-13]. In the subsequent, along with a number of works devoted to theoretical researches of self-ignition processes of solid combustible materials (for example [10]), fundamental work of Vengerov I. R. [14-16] on thermophysics of mines and excavating plants was published.

However, difficult partial differential equations practically impossible to solve in a general view that makes them inaccessible for wide use in practical applications. There are works which offer numerical methods of modeling for the solution of various model problems of heat-mass-transfer by grid method with justification of convergence and stability of various schemes [18-20].

Nowadays difficulties with numerical realization of mathematical models described by partial differential equations are almost overcome that is connected, in our opinion, with two moments. The first is development and improvement of numerical methods of the model equations solution of any complexity. These methods are proved theoretically and focused on the numerical solution with the obtaining of model output parameters. Nevertheless, their implementation is quite labor-consuming and demands certain mathematical preparation from specialists in modeling.

The second moment is an emergence of powerful computers with large random access memory and speed, development of universal application computer programs of the differential equations solution including in partial differential equations. Such packages of application programs allow to model many physical processes, without demanding profound knowledge of subtleties of a mathematical apparatus. The most known of them MATLAB, MATCAD, COMSOL and others are widely applied for the solution of difficult tasks of physical processes modeling in many fields of science.

Methodical approach to a problem of numerical modeling of temperature field distribution in the process of coal self-heating in the mined-out lava space with the use of the integrated MATLAB software package focused on the solution of scientific tasks is presented in this article.

Process of non-stationary temperature field distribution in the solid or porous medium is described by the classical differential equation of heat conductivity [21-22]

$$\rho \cdot C \cdot \frac{\partial T}{\partial \tau} - \nabla \cdot (k \nabla T) = Q + h \cdot (T_{\text{вс}} - T),$$

where T is the current temperature in the investigated medium point, °K; ρ – density of the medium material, kg/m^3; C – specific heat of the medium material, J/kg ·°K; k – coefficient of heat conductivity of the medium material, W/m ·°K; h – coefficient of convective heat exchange, J / · °K; $T_{\text{вс}}$ – temperature of the external environment, · °K; Q – external source of heat, J; ∇ – differential operator.

For modeling of processes of temperature field distribution from coal self-heating the package of application programs MATLAB intended especially for scientific research is used [15]. The solution of the equation of temperature distribution from self-heating in a coal congestion is made with the use of the «Heat Transfer and Diffuzion» module (Heat conductivity and diffusion) of a MATLAB package [16].

The problem of temperature distribution in the above-noted module is solved on the basis of use of a finite element method which theoretical and methodical provisions are stated in [22-23]. In this article temperature change from self-heating of a coal congestion in the isolated mined-out space of the mine working area in the process of development of flammable coal layer is modelled. The design diagram of temperature distribution modeling of self-heating of coal congestion by a finite element method is provided on figure 1.

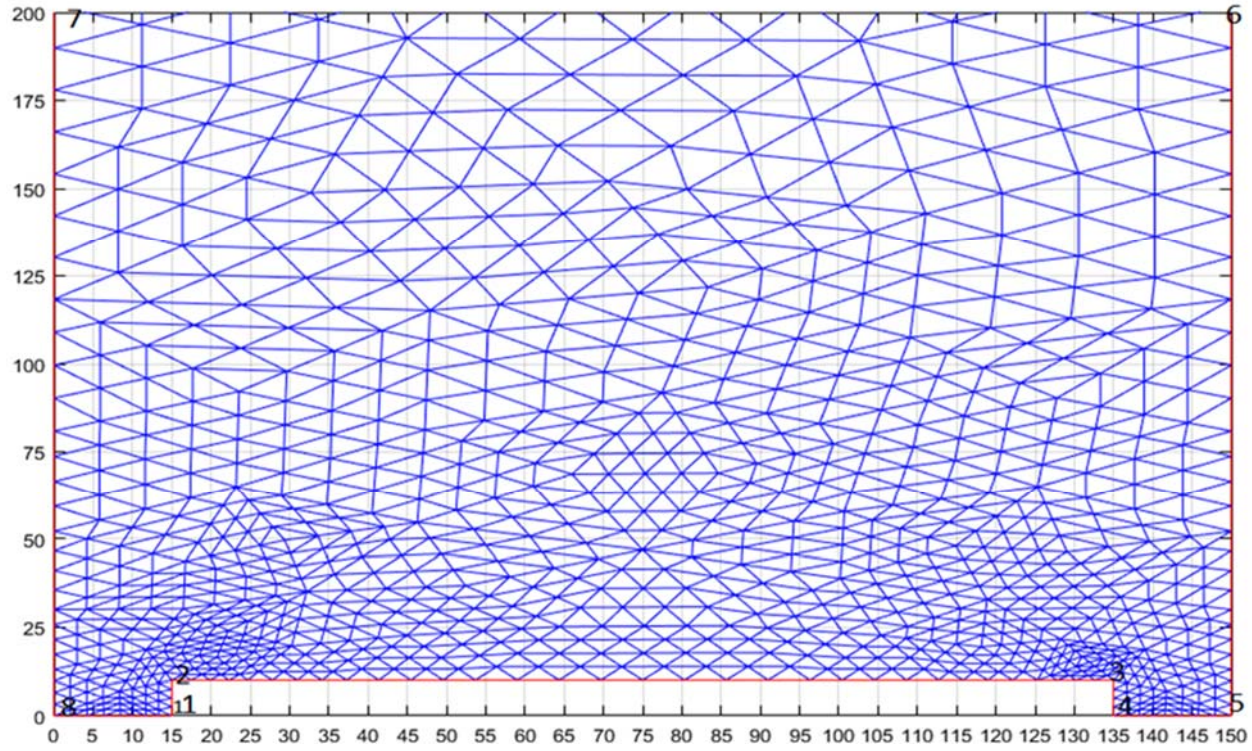

Figure 1 – The design diagram of temperature distribution modeling of self-heating of coal congestion by a finite element method

On the given scheme the mined-out space of a mining lava is conditionally shown in the plan. Length of a wide place is 120 m, the extension of the robbed-out part is 200 m. The situation of self-heating of the goafed coal in the mined-out space as a result of penetration of ventilation loss is modelled. Basic data: density of the nubbly-porous medium is $\rho = 0.011 Mn/m^3$ (1100 kg/m^3); the specific heat of the medium is $C=1.4 \cdot 10^{-3}$ mJ/kg ·°K; heat conductivity is $k = 0{,}1 \cdot 10^4$ W/m ·°K; coefficient of convective heat exchange is h = 0.5 J/°K. The insignificant external source 20 mJ, which models the transfer of heat flux by means of leaks through the isolating constructions is accepted. Temperature of the external environment (surrounding massif) on the border of the mined-out space is constant and is 20°C. On figure 2 the dialog box of the MATLAB programming environment with basic data for the solution of a task is shown.

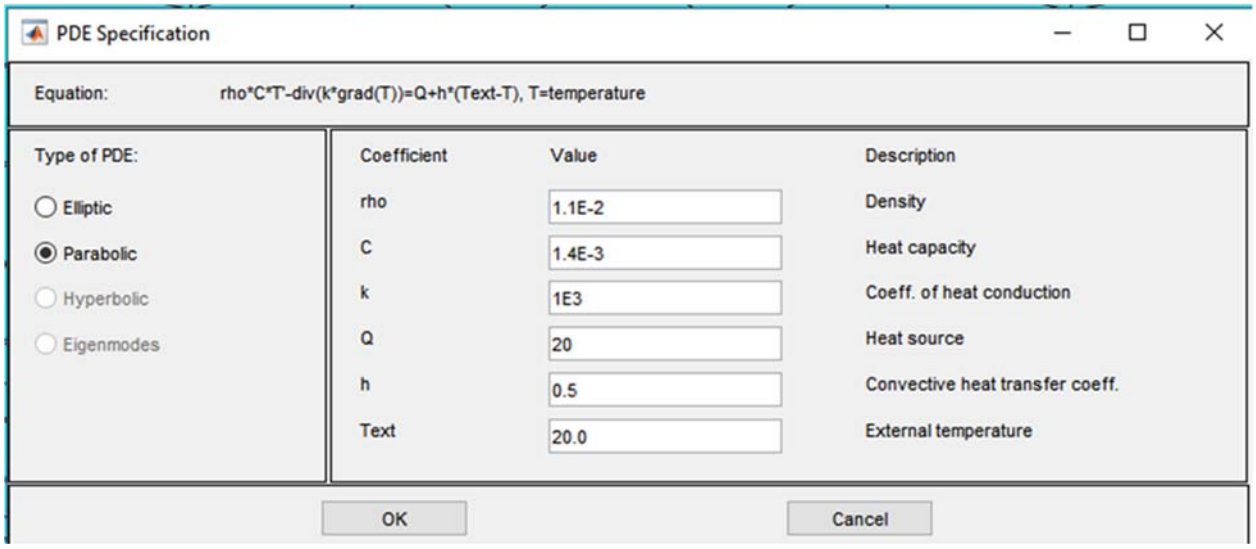

Figure 2 – The dialog box of task of environment initial parameters for the solution of heat conductivity equation

The field of design temperature distribution received in the result of numerical modeling of self-heating of coal congestion on the border 2-3 and its distribution from border into the depth by means of heat conductivity is presented on figure 3.

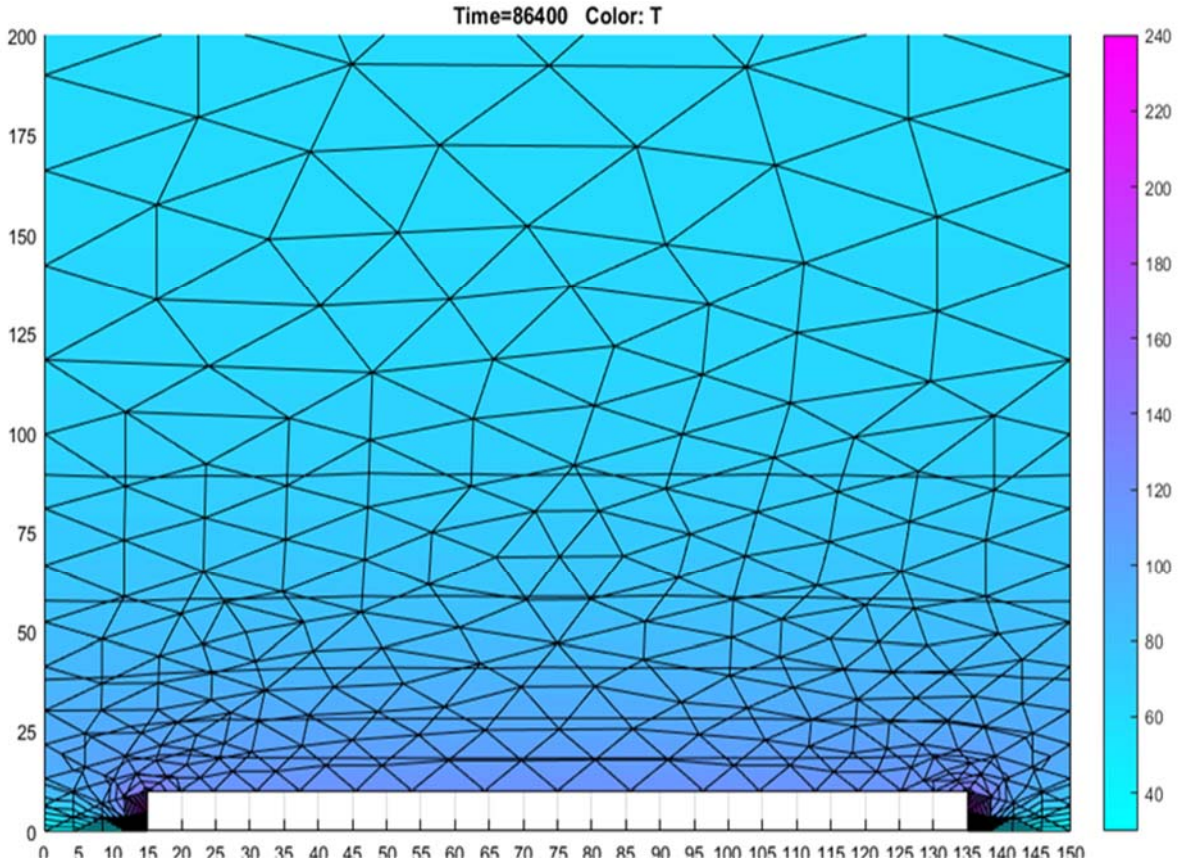

Figure 3 – Graphical representation of the field of design temperature distribution in the process of self-heating of coal congestion.

On a color temperature scale it can be seen that its size decreases with distance from the border of area of coal self-heating. In the interactive mode in the process of modeling it is possible to receive the numerical size of temperature in any point of the explored area of the mined-out space.

Numerical values of design temperature in the process of modeling and research of temperature change of coal congestion in course of time are given in table.

Numerical values of design temperature in the process of modeling by a finite element method

Distance from the border of self-heating, m	Temperature (°C) within time τ		
	τ = 1 hour	τ = 1day	τ = 5 days
1	119	117	111
10	110	103	101
25	101	93	87
50	82	72	63
100	66	51	40
125	65	47	30
150	63	44	26
175	61	42	24
200	59	41	22

Results of numerical modeling show that in the absence of inflow of thermal energy by means of oxidation process continuation (atmospheric oxygen access termination) temperature quickly enough decreases to safe, close to temperature of the surrounding massif. This process of temperature distribution by means of heat conductivity from a self-heating zone into the depth of the mined-out space substantially depends on heat physical parameters of the environment and quality of isolation. As the coefficients of heat conductivity and thermal diffusivity of the nubbly-porous medium modeling the goafed coal congestion is substantially less, than of monolithic coal, transfer of thermal energy and temperature in the environment occurs very slowly.

The given example shows that processes modeling of heat transfer in the environment of special package of application programs allows to receive fuller problem solution of temperature distribution on the basis of the classical equations of heat conductivity.

Conclusions:

1. The main objective of mathematical modeling of thermal processes and calculations by numerical methods in the theory and practice of prevention of the endogenous fires consists in the possibility of finding the places of spontaneous combustion for their localization and elimination.

2. In practice of the research of coal self-heating and self-ignition engineering and empirical techniques for calculations and forecasting of distribution of fire-explosive zones are often used.

3. For process modeling of temperature distribution from coal self-heating in the mined-out space of lava it is more expedient to apply the approved software packages specially focused on the solution of difficult physical tasks and allowing to receive more exact and full decisions.

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ӨҢДЕЛГЕН КЕҢІСТІКТЕ КӨМІРДІҢ ӨЗДІГІНЕН ҚЫЗУЫ КЕЗІНДЕ ТЕМПЕРАТУРАНЫҢ ТАРАЛУЫН ИМИТАЦИЯЛЫҚ САНДЫҚ МОДЕЛЬДЕУ

Аннотация. Аннотация. Термодинамикалық тотығу, өзін-өзі қыздыру және көмірдің тұтану процестерін зерттеу терминал параметрлерінің көптеген әсер етуші факторларға тәуелділігін зерттеу үшін қажет. Көмірді жерасты тәсілімен өндіру практикасында өндірістік агрегаттардың (лавалардың) қазылған кеңістігінде көмірдің өздігінен тұтану жағдайлары жиі кездеседі. Бұл жағдайда міндеттердің бірі-өндірілген кеңістіктің түтікшелі-кеуекті ортасының еркін нүктесіндегі температураны анықтау. Бұл күрделі міндетті шешу қажеттілігі метанның жарылыс қаупі бар шоғырлануы бар жерлерде авариялық жағдайлардың туындау ықтималдығына негізделген. Көмірдің әрбір қабаты мен сорты үшін өрт қауіптілігінің жай-күйін бағалаудың жеке көрсеткішін әзірлеу, негіздеу және қабылдау қажет болуы мүмкін.

Авариялық жағдайларда кейінгі жедел шешімдер үшін бассейндік деректер базасын құру мақсатында шахталардың проблемалық учаскелерінде эндогендік өрттердің туындауының талданатын және зерттелетін жағдайлары бойынша заттай өлшеулер мен бақылаулардың нәтижелерін жүйелендіру және әдістемелік өңдеу ұсынылады.

Түйін сөздер: өңделген кеңістіктер, қышқылдану, көмірдің өздігінен қызуы, көмірдің өздігінен жануы, температураның таралуы, жылу өткізгіштік, сандық модельдеу,жартылай туындылардағы дифференциалдық теңдеулер,численное моделирование, қолданбалы бағдарламалар пакеттері.

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ЧИСЛЕННОЕ ИМИТАЦИОННОЕ МОДЕЛИРОВАНИЕ РАСПРОСТРАНЕНИЯ ТЕМПЕРАТУРЫ ПРИ САМОНАГРЕВАНИИ УГЛЯ В ВЫРАБОТАННОМ ПРОСТРАНСТВЕ

Аннотация. Исследования термодинамических процессов окисления, саморазогрева и самовоспламенения угля необходимы для изучения зависимости терминальных параметров от множества влияющих факторов. В практике добычи угля подземным способом нередки случаи самовозгорания угля в выработанных пространствах производственных агрегатов (лав). В этом случае одна из задач состоит в определении температуры в произвольной точке бугристо-пористой среды выработанного пространства. Необходимость решения этой сложной задачи обусловлена вероятностью возникновения аварийных ситуаций в местах с взрывоопасной концентрацией метана. Не исключено, что для каждого пласта и сорта угля необходимо разработать, обосновать и принять индивидуальный показатель оценки состояния пожарной опасности.

Предлагается систематизировать и методически обрабатывать результаты натурных измерений и наблюдений по анализируемым и расследуемым случаям возникновения эндогенных пожаров на проблемных участках шахт с целью создания бассейновых баз данных для последующих оперативных решений в аварийных ситуациях.

Ключевые слова: выработанные пространства, окисление, самонагревание самовозгорание угля, распределение температуры, теплопроводность, дифференциальные уравнения в частных производных, численное моделирование, пакеты прикладных программ.

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COMPLEX STABILIZATION OF SOILS AND BASE COURSE MATERIALS DURING CONSTRUCTION AND REPAIR OF THE HIGHWAYS

Abstract. The article represents the results for investigation of a new technology of complex soil consolidation and stabilization and reuse of the material from stripping of the existing roads (cold recycling technology) with portlandcement and enzyme agent Roadzyme (USA), which allows reducing the energy costs significantly and improving ecological situation.

Cold recycling has a number of significant advantages before other means of reconstruction.

The absence of environmental pollution is due to the complete use of the material of the old pavement. There is no need in disposal sites, and the volume of the new delivered materials is the minimum one and reduces the area of contamination, which is certain during opening of new borrow-pits and rock quarries. Transportation is very small, therefore the consumption of the energy is considerably reduced, as well as devastating impact of vehicles on the road network.

Effect of the use of the agent "Roadzyme" is based on the activation of physics and chemical processes, which increase the strength, water resistance and frost resistance of the consolidated soils and materials, reducing material consumption at provision of the required elasticity modulus for pavement structure due to reduction of the thickness for pavement layers, the use of local materials and saving of binders and inert materials.

The decrease is noted for the stiffness of the materials, strengthened by complex method (binder with the agent "Roadzyme"), compared to the treatment only with the binder, which allows forecasting the increase of the crack resistance.

Key words: soil, stabilization, consolidation, cold recycling, granular asphalt.

Introduction. One of the most urgent tasks for the development of a road transport complex of the Republic of Kazakhstan is the accelerated development of the highway network, including connection of rural settlements with public roads.

Implementation of this program requires the non-standard approach from the road organizations. The overview of modern technologies for the construction of the highways all over the world shows the growing tendency of the maximum use for the local materials aiming at the reduction in cost and reducing the period for the construction.

The technology of complex soil stabilization is used for the construction of layers of base course and subgrade in recent years in Kazakhstan.

Complex soil stabilization with the use of inorganic binder and soil stabilizers provides basic change of properties for the stabilized soil and gives the required durability to them, as well as water resistance and frost resistance. The use of soil stabilizers at the same time allows receiving of the required strength characteristics and necessary rates for frost resistance in case of small amount of inorganic binder [1-3].

One of the main causes for the deformations on the roads resulting in the step-by-step failure is the soil loosening of working layer of subgrade and unstabilized lower layers of pavements. The use of complex stabilized soil in upper part of the subgrade or stabilized lower layers of the base course of pavements allows solving of this problem. During construction of layers for base course and anti-frost

heavy course of carriageway and shoulders from stabilized soils the income of moisture to the material of the subgrade from the top through pavement and shoulders is practically excluded.

The results of our investigations have shown the possibility for the essential increase of the operational characteristics for road bitumens and asphalt concretes by their modification with carbon nanopowder [4-10] and polymers [11-14]. An asphalt concrete pavement with the improved operational characteristics will function efficiently only in case when layers of base and soil of subgrade are sufficiently strong. Therefore, the possibility for the increase of a strength and other characteristics of a soil and a material are experimentally studied in this work for a pavement base by two methods of stabilization.

MATERIALS.

2.1. Soil stabilizers. Nowadays the wide range of materials for soil modification is used, which allows improving of properties for soil and materials of base course. Ionic stabilizers relate to them (Perma-Zym, LBS, Roadzym, SoilGrip - the USA, ANT - Russia, etc.) which after entering of their water solution into soil actively interact with its fine dusty and clay fraction and allows excluding the ability of clay soil to interact with water due to neutralization of forces of the superficial attraction of water.

For complex consolidation of soils during applying in road construction it is possible to use practically any soils, including clays and loams with plasticity number not more than 12.

In case of bigger plasticity value, the upgrading of soil with nonplastic local materials (sand, natural gravel sand mix, sifting and others) is carried out to achieve the required aggregative state.

Very good results are achieved when asphalt concrete granulars and complex stabilized soil during middle repair of the existing highways with asphalt concrete pavements (technology of cold recycling). The existing pavement and underlayers of the base course are milled for the desired depth, with addition of the binder and, if required, a water solution of the soil stabilizer. Further the obtained mix is profiled by a grader, and then the compaction is carried out by a smooth drum or a pneumatic-tired roller. Subsequently, if it is provided by the project documentation, it is possible construction of an asphalt concrete layer or construction of a wearing course in the form of double surface treatment. The need for stripping of the existing pavement and delivery of a large volume of sand and crushed stone is eliminated. Strength characteristics of the layer constructed under such technology allow using it as the top layer of the base course for the roads of IV and V categories or as the lower layers of the base course for the roads of the highest categories.

2.2. Roadzyme soil stabilizer. In Kazakhstan over the last 5 years the wide experience is gained for the middle repair of highways under the technology of cold recycling using the organic soil stabilizer - the enzyme agent Roadzyme. Operation of road sections repaired with the use of this method for 1-4 years showed cost and technical efficiency of such approach.

The organic soil stabilizer Roadzyme, the enzyme agent obtained on the basis of the wastes processing of the food production represents by itself the liquid of dark-brown color and it is used for road mixes in water solution. The effect of the use of the agent Roadzyme is based on activation of the physical and chemical processes increasing durability, water resistance and frost resistance of the stabilized soil and materials. At the same time the material consumption is decreased for the construction when providing the required elasticity modulus for pavement design due to reduction of the thickness for pavement layers, the use of the local materials and industrial wastes, and saving of binders and inert materials.

METHODS.

3.1. Complex stabilization. During the research of the materials strengthened by complex method, the mixes were prepared in the following ways: pre-dried mineral materials in the amount, prescribed for the mix design, were placed into vessel, then the required amount of cement and, if necessary, ash was added. The compound was carefully mixed up dry in the mixer. Then water solution of Roadzyme was added to it in the amount required for bringing the compound to optimum compaction moisture. The stabilizer Roadzyme in the form of a concentrate was included into water in the amount of 0.002% of the mass of the mix.

Cylindrical samples are formed after mixing from a compound. Load is selected according to the index of the maximum density for the optimum moisture. The samples are kept for 28 days in standard curing (95% of moisture).

Test regime of the samples for frost resistance is the following: 15 and 25 cycles of freezing and defrosting in the freezer (at a freezing temperature minus (18 ± 2) ° C) is assigned under [16-17] according to standard techniques.

For the comparative analysis the mixes (No. 1 and No. 2) were prepared using the stabilized soil with 4% of Roadzyme and 6% of cement without stabilizer, as well as soil mixes with the skeletal component of GSM in the amount of 24%.

3.2. Cold recycling. When using the technology of the cold recycling for reuse of materials from the stripping of the existing pavement it is necessary to reveal optimum amount of the included additives irrespective of the layer thickness of the existing design. The need for the research of the mixes of various compositions is explained by the fact that the old asphalt roads have different and often unpredictable pavements (asphalt concretes thickness, thickness of the base course, etc.) and it is even more complicated by the fact that for the small length of the road the pavement can change. Such conditions result in impossibility of selection for the required percent of binder in the mix for each specified road section.

The purpose of the research was the selection of the unique minimum amount of the binder, ensuring the obtaining of the required strength characteristics, including frost resistance, for any mix.

Mix designs of the recycled layer were selected based on the thickness of the asphalt concrete pavement layers and total thickness of the recycled layer.

Determination of the maximum density and optimum moisture of structures of the recycled layer with adding of the stabilizer Roadzyme and cement was carried out according to ST PK 1285 (Table 4) [15] under the modified Proctor's method.

According to GOST 23558 (Table A) [16] grade for compression strength of the treated materials and the stabilized soil for the base courses of pavements of the capital and facilitated type not below than M40. At the same time frost resistance of such mixes shall be not below than F15 or F25 depending on pavement type and average temperature of the coldest month in the area of the specific highway.

RESULTS AND DISCUSSION.

4.1. Complex stabilization. According to the test results (table 1) inclusion of Roadzyme into composition of soil with 4% of cement allows increasing tension in bending in 3 times. At the same time the composition with 6% of cement without Roadzyme with compression strength of 2.5 MPa has frost resistance of (F15), similar to the investigated composition.

Table 1 – Characteristics of soil stabilized samples

No. of the mix	Mix design, %				Strength, MPa		Grade	
	Soil	GSM	Cement	Roadzyme	At compression	Tension in bending	As per strength	As per frost resistance
1	97	0	4	0.002	2.0	0.6	M10	F15
2	97	0	4	0	1.2	0.2	M10	–
2	97	0	6	0	2.5	0.3	M10	F15
3	73	24	4	0.002	3.0	0.93	M20	F25
4	73	24	4	0	2.6	0.35	M10	–
5	70	24	6	0	3.5	0.6	M20	F25

Inclusion of skeletal additives allows raising the strength rates of the samples.

The increase in a ratio of R_u/R_{sj} should be noted with the use of the organic stabilizer Roadzyme which characterizes the material strengthened by the complex method with the use of the stabilizer Roadzyme as the most crack resistant one. Test results of the samples of the stabilized soil for alternate "freezing-thawing" also characterize the material treated by the complex method as the most frost-resistant one.

4.2. Cold recycling. The analysis of test results (table 2) shows that the strength characteristics are also increased with the use of the stabilizer Roadzyme under the cold recycling technology. The grade on samples strength with the use of Roadzyme in the mix No. 6 with 4% of Portlandcement was M40, and without Roadzyme – M20, at the same time the stiffness (ratio of compression strength to tension in bending) in the samples with Roadzyme is 10% lower.

Table 2 – Characteristics of samples from stabilized recycled material

No. of the mix	Mix design, %					Strength, MPa		Grade	
	Material from stripping of the existing road (100%)			Cement	Roadzyme	At compression	Tension in bending	As per strength	As per frost resistance
	Granular asphalt	GSM	Soil						
1	50	35	15	4	0.002	4.2	0.8	M40	F15
	50	35	15	4	–	3.5	0.6	M20	F15
	50	35	15	5	0.002	5.6	1.1	M40	F25
	50	35	15	5	–	3.9	0.7	M20	F15
2	20	55	25	4	0.002	4.1	1.0	M40	F15
	20	55	25	5	0.002	5.4	1.2	M40	F25
3	70	20	10	4	0.002	4.4	1.0	M40	F25
	70	20	10	5	0.002	5.2	1.1	M40	F25

For the samples of the mix No. 6 with 5% of Portlandcement the grade for the samples strength with Roadzyme was M 40, for frost resistance - F25, without Roadzyme – M 20 and F15. Thus, with complex strengthening of the recycled material with Portlandcement and the stabilizer Roadzyme the density increases, the water consumption decreases, strength characteristics and resistance to the crack formation increase.

The standard industry document was developed on the basis of the performed laboratory research and experimental-industrial implementation [17].

Conclusion.

1. Complex soil stabilization (Portland cement+organic stabilizer Roadzyme) increase essentially the compression strength (nearly 2 times) and bending strength (nearly 3 times), as well as crack resistance.

2. Density, strength and crack resistance are increased, and water consumption is decreased at complex stabilization of the recycled material with Portland cement and stabilizer Roadzyme.

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АВТОМОБИЛЬ ЖОЛДАРЫН САЛУ ЖӘНЕ ЖӨНДЕУ КЕЗІНДЕ ТОПЫРАҚТАР МЕН НЕГІЗ МАТЕРИАЛДАРЫН КЕШЕНДІ ТҰРАҚТАНДЫРУ

Аннотация. Мақалада топырақты кешенді нығайту мен тұрақтандырудың жаңа технологиясын және қолданыстағы жолдарды бөлшектеудің қайта пайдаланылатын материалын (суық ресайклинг технологиясы) портландцементпен және Roadzyme (АҚШ) ферменттік тұрақтандырғышымен энергетикалық шығындарды айтарлықтай қысқартуға және экологиялық жағдайды жақсартуға мүмкіндік беретін Зерттеу нәтижелері ұсынылған.

Суық қайта өңдеуді қалпына келтірудің басқа әдістеріне қарағанда бірқатар маңызды артықшылықтары бар.

Ескі жол төсемінің материалын толық пайдаланудың арқасында қоршаған ортаның ластанбауы. Үйінділерге арналған алаңдарға қажеттілік жоқ, ал жаңа жеткізілетін материалдардың көлемі аз, бұл жаңа карьерлер мен тас қашалған орындарды ашу кезінде орын алатын жергілікті жердің ластануын азайтады. Тасымалдау өте аз, сәйкесінше энергия шығыны да, көлік құралдарының жол желісіне бұзу әсері де айтарлықтай төмен.

«Roadzyme» препаратын қолданудың әсері нығайтылған топырақтар мен материалдардың беріктігін, ылғалға және аязға төзімділігін арттыратын, жол төсемесі қабаттарының қалыңдығын азайту, жергілікті материалдарды пайдалану және тұтқыр, инертті материалдарды үнемдеу арқылы жол төсемесі құрылымының қажетті серпімді модулін қамтамасыз ету кезінде құрылыстың материал шығынын төмендететін физика-химиялық үдерістерді белсендіруге негізделген.

Кешенді әдіспен өңделген материалдардың қаттылығы («Roadzyme» препараты бар тұтқырғыш) тек тұтқырғышпен салыстырғанда төмендегені байқалады, бұл олардың жарыққа төзімділігінің артқанын болжауға мүмкіндік береді.

Түйін сөздер: топырақ, тұрақтандыру, нығайту, суық ресайклинг, асфальт түйіршіктері.

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КОМПЛЕКСНАЯ СТАБИЛИЗАЦИЯ ГРУНТОВ И МАТЕРИАЛОВ ОСНОВАНИЯ ПРИ СТРОИТЕЛЬСТВЕ И РЕМОНТЕ АВТОМОБИЛЬНЫХ ДОРОГ

Аннотация. В статье представлены результаты по исследованию новой технологии комплексного укрепления и стабилизации грунтов и повторно используемого материала разборки существующих дорог (технология холодного ресайклинга) портландцементом, и ферментным стабилизатором Roadzyme (США), позволяющей существенно сократить энергетические затраты и улучшить экологическую обстановку.

Холодный ресайклинг имеет ряд значительных преимуществ перед другими способами реконструкции.

Отсутствие загрязнения окружающей среды благодаря полному использованию материала старой дорожной одежды. Нет необходимости в площадках для отвалов, а объем новых привозных материалов минимален, что снижает загрязнение местности, неизбежное при открытии новых карьеров и каменоломен. Перевозки очень невелики, соответственно, расход энергии значительно снижается, как и разрушительное воздействие транспортных средств на дорожную сеть.

Эффект от применения препарата «Roadzyme» основан на активизации физико-химических процессов, повышающих прочность, влагостойкость и морозостойкость укрепленных грунтов и материалов, снижающих материалоемкость строительства при обеспечении требуемого модуля упругости конструкции дорожной одежды за счет уменьшения толщины слоев дорожной одежды, использования местных материалов и экономии вяжущих и инертных материалов.

Отмечается снижение жесткости материалов, обработанных комплексным методом (вяжущим с препаратом «Roadzyme»), по сравнению с обработкой только вяжущим, что позволяет прогнозировать повышение их трещиностойкости.

Ключевые слова: грунт, стабилизация, укрепление, холодный ресайклинг, асфальтогранулят.

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ROBOTIC COMPLEX FOR THE RUNWAY LEVELING

Abstract. There is a global trend towards an increase in the weight and dimensions of the aircraft fleet. At the same time, the load on aerodrome pavements increases, which contributes to their faster wear, changes in the pavement profile, and the appearance of defects that threaten flight safety. Therefore, constant monitoring of the condition of airfield pavements is carried out, in particular, the determination of its profile.

A robotic complex has been developed for leveling the runway. The complex includes mobile leveling devices, mobile leveling rods, which are located on the runway during the performance of leveling, and a control device located at the central control station of technical systems of the airport.

The control device contains the following blocks: control with a monitor; processing and storage of information; an intelligent subsystem with a set of logistics programs; geographic information system with GPS receiver; signal coding; reception and transmission of radio signals.

Mobile levelers and mobile leveling rods are controlled from the central station and transmit coded information to the central station via radio communication channels.

The mobile leveling rod is similar in design to a mobile leveling device due to the absence of a rangefinder measurement unit, a turning unit and the optoelectronic device itself.

The movement of robotic mobile leveling devices and sighting targets with stops for measurements is carried out according to a pre-compiled program transmitted via coded radio communication channels. For the initial ones, the marks of the benchmarks are used, the horizontal plates of which are laid flush with the surface of the runway at its lateral ends, along which the steps of precise leveling are preliminarily laid.

The proposed robotic complex allows to quickly determine the marks of the runway in automatic mode with an adjustable scanning step and build longitudinal and transverse surface profiles.

Keywords: leveling, runway, GPS-leveling, robotic complex, mobile leveling works.

Relevance of the topic. In a relatively short period of time, the aviation fleet has significantly expanded both in Ukraine and abroad. There appeared heavy and super-heavy aircrafts (AV), and this tendency is continuing (table 1) [1],[2].

Table 1 – Weight characteristics of passenger aircrafts

Name of the AV	An-24	An-158	Tu-134	Tu-204	Boeing-737	Boeing-777
Weight, tons	21,8	43,7	47,0	107,9	52,8	242,6

The increase in the weight of the aircraft leads to an increase in the load on the aerodrome surfaces during taxiing, takeoff and landing. This in turn leads to faster wear of airfield surfaces and the appearance of their defects that threaten flight safety, change of the profile of the surface. Therefore, the condition of aerodrome surfaces is constantly monitored [3],[4].

Analysis of recent research and publications. An important indicator of the condition of the aerodrome surface is the profile of its surface, in other words – the unevenness of the surface. The value of

the unevenness of the aerodrome surface is determined by several methods, which can be attributed to geodetic ones, because during their implementation, geodetic instruments and methods are used.

In the first case, a 3 m long rail and a wedge gauge are used [5],[6]. The clearance between the plane of the coating and the lower face of the rail is measured using a wedge gauge. The wedge gauge has divisions on the oblique face, which determine the distance from the plane of the rail to the surface of the coating. Moreover, the measurements are performed at several intervals of rail length. Measurements are made in sections of 300÷400 m, and the total length of the sections must be at least 10 % of the total length of the pavement. In this way, the short-period deviations of the coating surface from the plane are determined.

The unevenness of the aerodrome surface can be determined using a level and a rail [5]. The method is based on determining the deviation of the points of the coating surface on which the rail is installed, from the horizontal plane specified by the sighting beam of the level. The leveling step is 5 m along the pavement. The relative excesses (marks) of the coverage points are determined and the deviations δh_i of these points are calculated (except the first and last in the measurement area) relatively to the line passing through the previous (i – 1) and next (i + 1) points relatively to i point by the formula:

$$\delta h_i = \frac{h_{i-1} - h_{i+1}}{2} - h_i . \quad (1)$$

The length of the measurement area is 400 m. In this way, longer periodic values of unevenness are determined, in comparison with the previous method.

It is possible to process the results of leveling aerodrome surfaces in another way [7]. Thus, the starting point of the leveling is assigned a positive value of the mark, relative to which the calculation of excesses h_n is performed in the areas of leveling. Next, the values of the slopes i_a are calculated for the distances between adjacent points a = 5, 10, 20 m by the formula:

$$i_a = \frac{h_{i+1} - h_i}{a} . \quad (2)$$

According to the results of calculations, a longitudinal profile is built on the leveling areas. In this way the deviation of the points of the surface of the coating with periods of 5 m, 10 m, 20 m is determined, as well as the deviations of the surface at the same intervals.

The satellite leveling technique called GSP-leveling is widely used to determine the ellipsoidal (geodetic) heights of the Earth's surface relative to the reference surface (ellipsoid), in the creation and development of state geodetic networks [8], in determining the geoid surface, when the obtained GPS ellipsoidal heights are converted into orthometric ones using an exact geoid model [9] and when constructing or refining digital terrain models [10].

In [11], a study of the accuracy of height determination using GPS-leveling in real time has been performed, based on a comparison of the results of GPS-leveling and high-precision geometric leveling. The obtained results showed the accuracy of height determination using GPS-leveling with a mean square error of almost 15 mm at a stroke length of 933 m, which corresponds to the IV leveling class.

These methods and means of their implementation to determine the unevenness of the aerodrome surfaces, which have a large length, require significant time to perform field measurements and a large group of performers.

There is a mobile device for automated leveling of surfaces [12] figure 1, which will give the opportunity to obtain the value of the high point in the automatic mode of a given tape line with adjustable scanning.

The disadvantage of this device for automated leveling of surfaces is the presence of a significant amount of manual labor: the installation and movement of sighting marks for each level of alignment and marking the places of their installation. This in turn slows down the pace of surface leveling work. To perform the leveling of the runway, which is intensively used for the departure and reception of aircraft, the time factor is a priority.

Presentation of the main material. A robotic complex has been developed for leveling the runway (RCLR) [13]. The RCLR includes mobile levelers (ML), mobile leveling rails (MLR) located on the runway, and control devices located at the central control station of the airport's technical systems, which is located on the control tower.

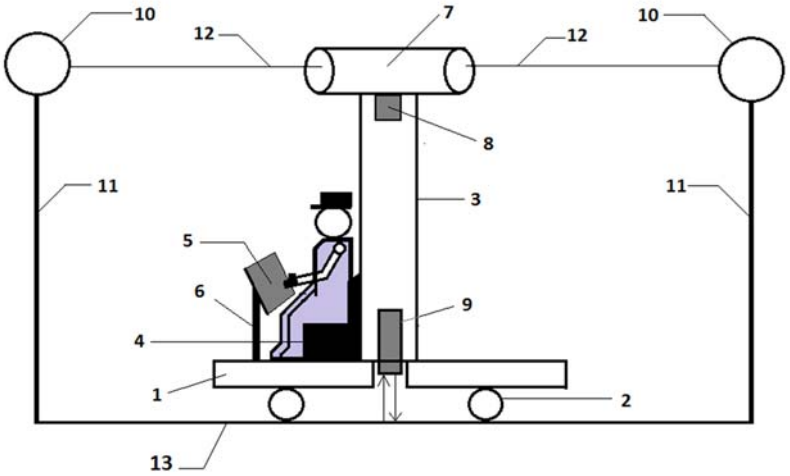

Figure 1 – Scheme of the device for automated leveling:
1 – mobile device; 2 – running gear; 3 – top rack; 4 – operator's seat; 5 – remote control; 6 – control panel rack;
7 – leveling optoelectronic device; 8 – the mechanism of rotation of the block 7; 9 – ultrasonic location unit;
10 – sighting marks; 11 – racks of sighting marks; 12 – sighting rays; 13 – the surface of the site

Figure 2 shows the interaction of mobile devices and units of the central control station of the technical systems of the airport. Blocks 1, 2, 3, 4, 5, 6 are located at the central control station of the airport's technical systems. ML 7 and MLR 8 are controlled from the central station and transmit information through the unit 6 to the central control station of the technical systems of the airport via radio channels.

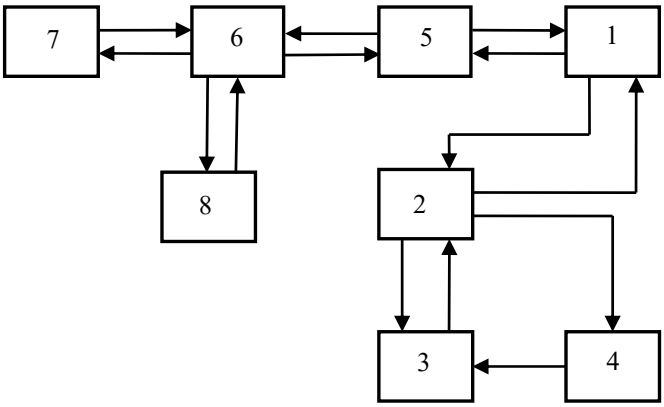

Figure 2 – Interaction of mobile devices and units of the central station of control over the airport's technical systems:
1 – control unit with a monitor; 2 – information processing and storage unit; 3 – intelligent subsystem unit with
a set of logistics programs; 4 – geographic information system unit with GPS receiver; 5 – signal coding unit;
6 – unit for receiving and transmitting radio signals; 7 – mobile leveler (ML); 8 – mobile leveling rail (MLR)

Signal coding units are required to eliminate unauthorized access to the operation of the RCLR.

Figure 3 shows the location of the mobile leveler and mobile leveling rails on the runway plane during leveling.

ML 7 has an optoelectronic device (OED) 9 with a double photodetector array and two lenses forming two optical tubes with sight axes in mutually opposite directions, below which there are two light-range units with the same directions of light probing rays. The plane of the sighting target of 11 ML is located parallel to the sighting beam 20 of the optoelectronic device 7. The sighting targets 11 of ML 7 and MLR 8 contain planes with a set of LED matrices, and in the lower part of the sighting target there is a reflector for long-range measurements. The benchmarks 19 are made in the form of metal plates with flat horizontal surfaces laid flush with the runway coating.

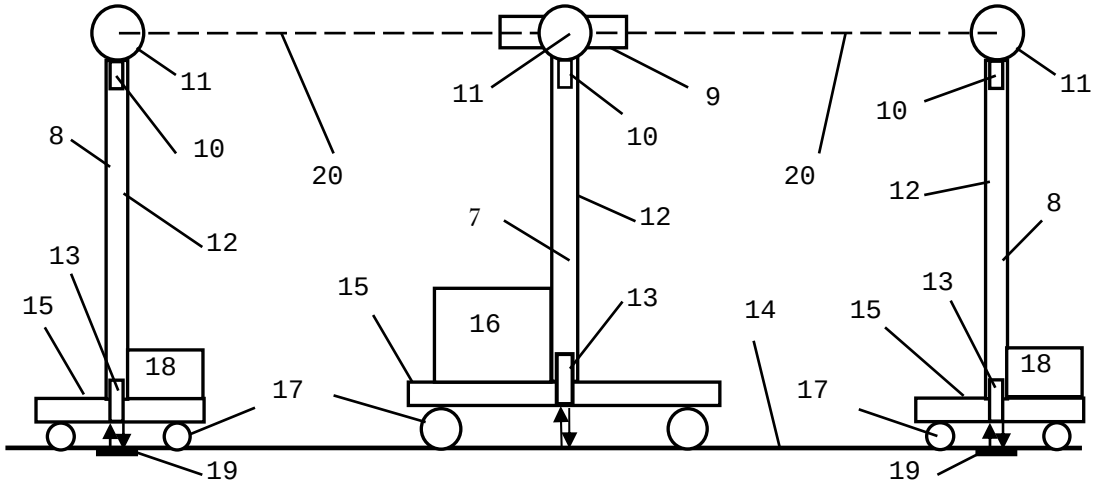

Figure 3 – Location of the mobile leveler and mobile leveling rails on the runway plane:
9 – optoelectronic device (OED) and light rangefinder units; 10 – the mechanism of rotation of OED 9 and the sighting target 11;
12 – vertical rack; 13 – ultrasonic sensor of the excess of the base over the surface 14, which is leveled; 15 – stand;
16 – boxing with a set of ML blocks; 17 – running gear of the cart; 18 – set of MLR blocks 8;
19 – high-altitude training benchmark; 20 – sighting beam

The operation of the light rangefinder unit is based on the principle that is described in [14]. Figure 4 shows the interaction of a set of blocks of a mobile leveler.

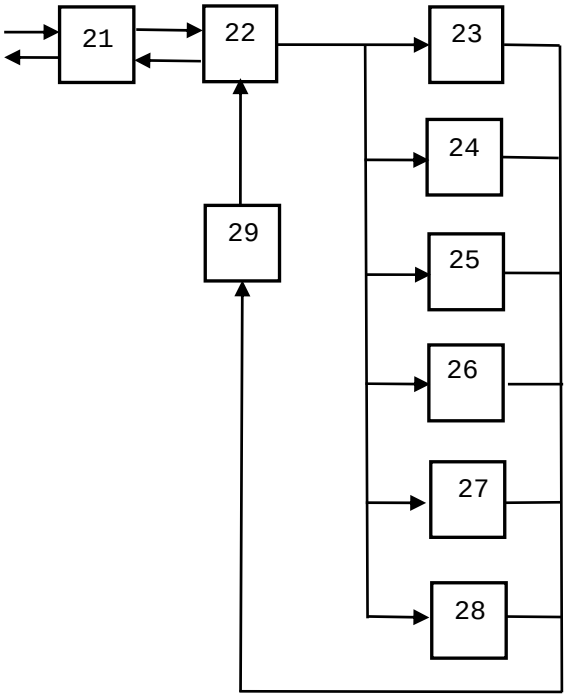

Figure 4 – The composition of the blocks of the mobile leveler:
21 – unit for receiving and transmitting radio signals; 22 – signal coding unit; 23 – electronic control unit for the running gear;
24 – block of light range measurements; 25 – ultrasonic location unit; 26 – GPS receiver;
27 – rotation unit of the OED, sighting target and light-range measuring unit; 28 – OED; 29 – signal generating unit

Figure 5 shows the interaction of a set of blocks of a mobile leveling rail.

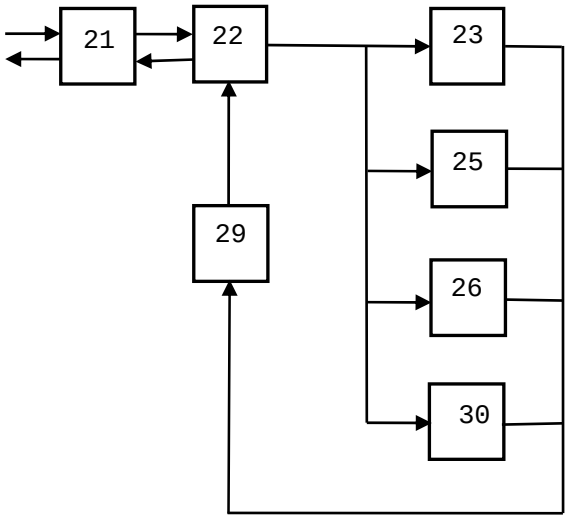

Figure 5 – Set of blocks of a mobile leveling rail:
21 – unit for receiving and transmitting radio signals; 22 – signal coding unit;
23 – electronic control unit for the running gear; 25 – ultrasonic location unit;
26 – GPS receiver; 30 – the unit of rotation of the sighting target

The operation of the RCLR is as follows. After turning on the power of the complex of units located at the central control station of the airport technical systems (see figure 2), from the control unit 1 through the information processing and storage unit 2 comes a command to the intelligent subsystem 3 to select a logistics program to solve specific tasks of the runway leveling. These programs provide the order of placement of ML and MLR on the runway plane and the routes of their movement in the areas of runway leveling. Also in block 3 there is a program for search and recognition of images - to identify sighting targets on their images obtained by OED of ML. At the request of block 3 from the block of geographic information system 4 there come the planned coordinates of the leveling points and benchmarks of altitude training 19 (see figure 3), the data of which are entered in advance in block 4. In addition, the marks of the height training benchmarks H_{R_i} are determined in advance by geometric leveling, the distances l_{N_i} on the vertical racks from the centers of sighting targets to the sensitive plane of ultrasonic sensors MLR 8 and l – the length of the vertical rack of ML from the transceiver plane of the ultrasonic sensor to the central point of the optoelectronic device, which are input to block 4. The GPS receiver of unit 4 operates in the base station mode and performs coordinate support of the ML and MLR with the required accuracy. The information from blocks 4 and 3 enters the information processing unit 2, where signal processing and creation of an information packet is performed, which through the control unit 1 enters the coding unit 5, in which the information packet signal is encoded and transmitted by the radio signal receiving and transmitting unit 6.

MLR 8 (see figure 3) receive radio signals from the central station in the block of reception and transmission of radio signals 21, which (see figure 5) are decoded in block 22 and undergo the procedure of selection of component signals from the information package in each of the respective blocks: 23, 25, 26, 29. According to the signal of the electronic control unit of the running gear 23 and the actual coordinates of the MLR from the GPS receiver unit 26, the MLR 8 is moved to the location of the high-altitude training benchmarks 19 (see figure 2), the coordinates of which came from the central station. After stopping the MLR 8 over the benchmarks of altitude training and the command from the central station, and selecting it from the information package in block 22 (see figure 8, figure 6), the ultrasonic location unit 25 measures the distances Δl_{N_1}, Δl_{N_2} from the runway surface 14 to the receiving and transmitting planes ultrasonic sensors 13 MLR №1 and MLR №2, respectively. According to the

commands from the unit of rotation of the sighting target 30 and the operation of the mechanisms of rotation 10 sighting targets are set in the direction of leveling. Information from block 25 about the measured exceedance, from block 26 about the coordinates of the location of the MLR and the execution of commands to move the MLR from block 23 and from the unit of rotation of the sighting targets 30 enters the signal generating unit 29 transmitted by radio unit 21 to the central station. ML 7 receives radio signals from the central station in block 21, which are decoded (see figure 3, figure 4) in block 22, and the selection of components of signals from the information packet in each of the respective blocks is performed: 23-28. By command from the block 24 ML 7 performs maneuvering and by the actual coordinates from block 26 go to the leveling point, the coordinates of which came from the central station.

According to the commands from the OED unit 28 and the OED rotation unit 27, the sighting targets 11 of the MLR 8 are searched and the OED sighting axes are set to the sighting targets 11. According to the signals from block 28, the registration of readings a_1 and a_2 is carried out on the matrices of the OED. At the command of the light range measurement unit 24, the distances S_1 and S_2 are measured by the light range unit ML 7 to the reflectors of the sighting targets 11 MLR №1 and MLR №2, respectively. By the command from block 25 the distance Δl is measured from the surface of the runway 14 to the transceiver plane of the ultrasonic sensor 13 of ML 7. Data on measurements and execution of commands from blocks 23 - 28 are sent to the signal generating unit 29, are formed into an information packet, are coded in block 22 and are transmitted by block 21 to the central station.

At the central station (see figure 2) radio signals are received by block 6, decoded in block 5 and through block 1 come to block 2. Here the information packet is decomposed into appropriate component signals that come to the control unit - for operator intervention in the system (if necessary), to the intelligent subsystem - to compare the actual coordinates of MLR and ML with the planned ones and to produce corrective signals and transmit them back to MLR and ML. In addition, in block 3, the calculation of the marks of the runway plane 14 under the ultrasonic sensors of excesses 13 is performed according to the formula

$$H = \frac{1}{2}\left[H_{M_1} + H_{M_2} - \frac{(S_1 - S_2)(H_{M_1} - H_{M_2})}{S_1 + S_2} \right] - \frac{1}{2f}(S_1 a_1 + S_2 a_2) - l - \frac{1}{2}(\Delta l_{N_1} + \Delta l_{N_2}) \qquad (3)$$

where $\left.\begin{array}{l} H_{M_1} = H_{R_1} + l + \Delta l_{N_1} \\ H_{M_2} = H_{R_2} + l + \Delta l_{N_2} \end{array}\right\}$ - marks of heights of the centers of sighting targets of MLR №1 and MLR №2; H_{R_1} and H_{R_2} – marks of reference benchmarks R_1 and R_2; l – the length of the vertical rack of ML from the receiving and transmitting plane of the ultrasonic sensor to the central point of the optoelectronic device; Δl_{N_1}, Δl_{N_2} – the distance from the runway surface to the receiving and transmitting planes of the ultrasonic sensor of MLR №1 and MLR №2; f – focal lengths of digital cameras of optoelectronic device; S_1 and S_2 – horizontal distances measured from the optoelectronic device to the centers of sighting targets of MLR №1 and MLR №2; a_1 and a_2 – readings in pixel fractions on the sensitive elements of the double matrix of the optoelectronic device.

The value of the calculated mark from block 3 is sent for storage to the unit for processing and storage of information 2 and on request from block 1 - on the monitor screen.

Figure 6 shows the location of ML and MLR on the first section of alignment.

Figure 7 shows the location of ML and MLR on the following sections of leveling. Leveling of the last section of sight is performed by placing the ML and MLR as on the first section.

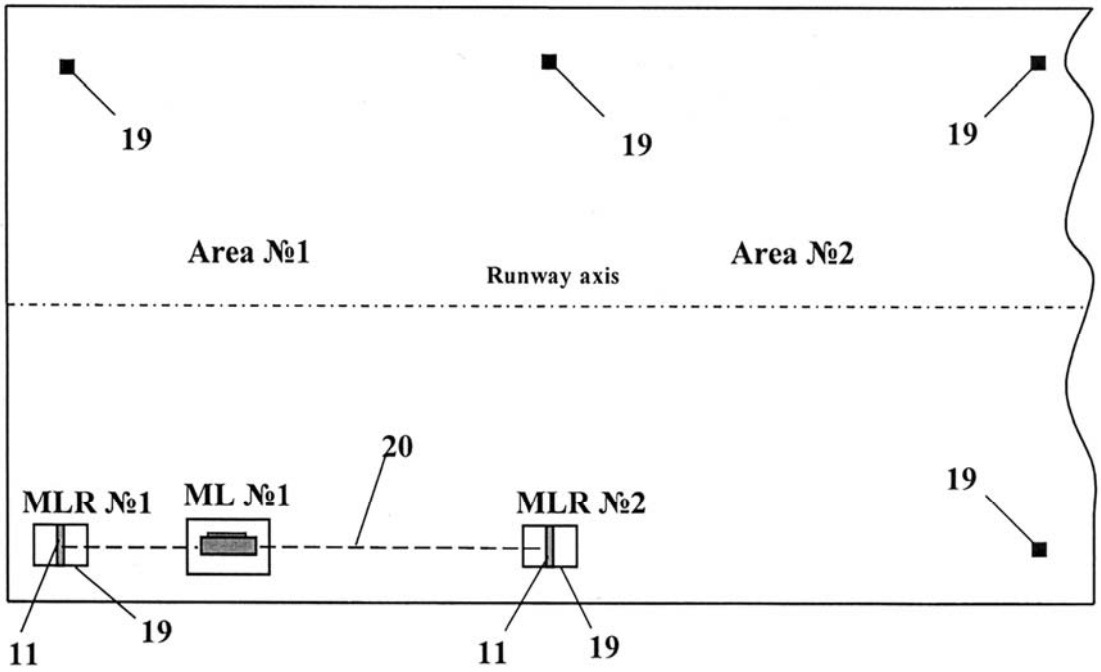

Figure 6 – Location of ML and MLR on the first section of leveling

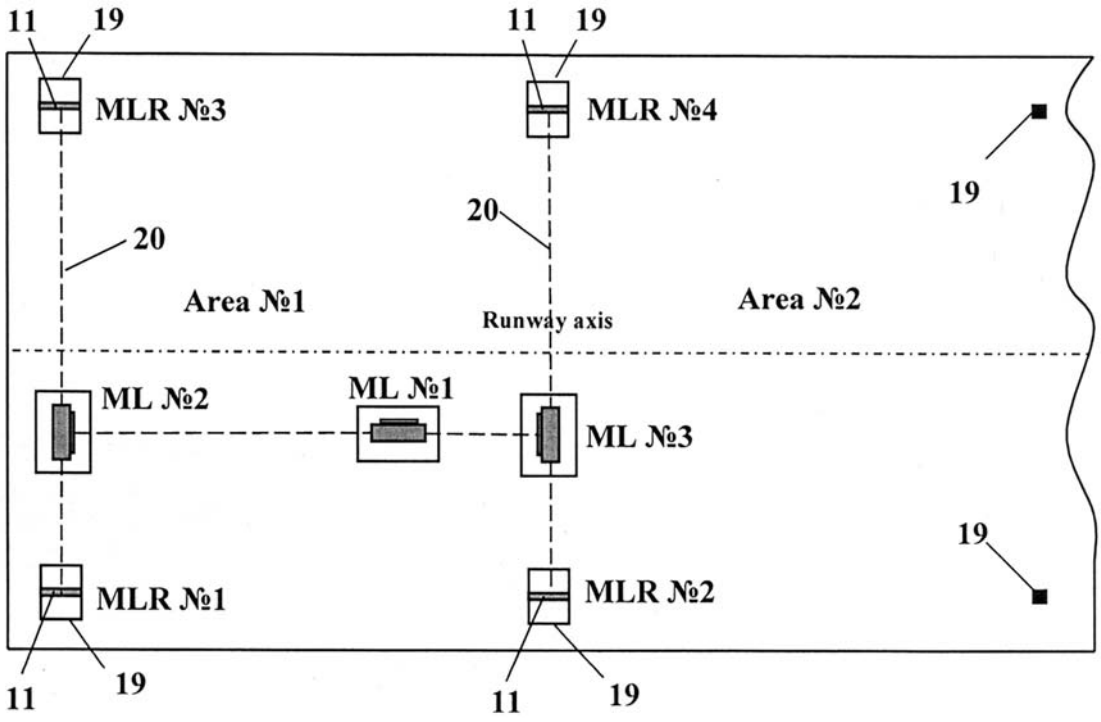

Figure 7 – Location of MLR and ML on the following sections of leveling

Runway surface profiles are built based on the leveling results.

Conclusions. The proposed robotic complex allows to quickly determine the marks of the runway in the mode of remote GIS / GPS control of the complex of mobile leveling robots in automatic mode with adjustable scanning step and to build longitudinal and transverse profiles of the surface.

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ҰШЫП-ҚОНУ ЖОЛАҒЫН НИВЕЛИРЛЕУГЕ АРНАЛҒАН РОБОТТАНДЫРЫЛҒАН КЕШЕН

Аннотация. Әуе кемелері паркінің салмағы мен ауқымының ұлғаюына қатысты әлемдік тенденция байқалады. Бұл ретте әуеайлақ жабындыларына жүктеме артады әрі бұл олардың неғұрлым жылдам тозуына, жабын бейінінің өзгеруіне, ұшу қауіпсіздігіне қатер төндіретін ақаудың пайда болуына ықпал етеді. Сондықтан әуеайлақ жабындарының ахуалына, атап айтқанда, бейінін анықтау үшін тұрақты мониторинг жүргізіледі.

Ұшып-қону жолағын нивелирлеуге арналған роботтандырылған кешен әзірленді. Кешен құрамына: нивелирлеу өндірісі барысында ұшып-қону жолағында орналасқан бейімделгіш нивелирлеушілер, мобильді нивелирлік төрткілдеш (рейка) және әуежайдың техникалық жүйесін басқарудың орталық станциясында орналасқан басқару құрылғысы кіреді.

Басқару құрылғысы келесі блоктардан тұрады: монитормен басқару; ақпаратты өңдеу және сақтау; логистикалық бағдарламалар жиынтығы бар интеллектуалды ішкі жүйе; GPS қабылдағышы бар геоақпараттық жүйе; сигналдарды кодтау; радиосигналдарды қабылдау және беру. Мобильді нивелирлеушілер мен мобильді нивелирлі төрткілдештер (рейка) орталық стансадан басқарылады және радиобайланыс арналары арқылы орталық станцияға кодталған ақпарат жібереді. Мобильді нивелирлік төрткілдеш (рейка) құрылымы бойынша жарықты алыстан өлшегіш блоктың, бұрылу блогының және оптикалық-электрондық аспаптың болмауы себепті мобильді нивелирлеушіге ұқсас келеді.

Роботтандырылған бейімделгіш нивелирлеушілер мен өлшеуге арналған аялдамалары бар нысаналық мақсаттарды ауыстыру кодталған радиобайланыс арналары арқылы берілетін алдын ала жасалған бағдарлама бойынша жүзеге асырылады. Бастапқы ретінде репер белгілері пайдаланылады, олардың көлденең пластиналары ұшып-қону жолағының бетімен оның бүйірлік ұшында орналасқан, олар арқылы дәл нивелирлеу жолдары алдын ала белгіленген.

Ұсынылған роботтандырылған кешен реттелетін сканерлеу қадамымен автоматты режимде ұшып-қону жолағының белгілерін жылдам анықтауға және беттің бойлық және көлденең бейіндерін құруға мүмкіндік береді.

Түйін сөздер: нивелирлеу, ұшып-қону жолағы, GPS-нивелирлеу, робототехника кешені, мобильді нивелирлік жұмыстар.

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РОБОТИЗИРОВАННЫЙ КОМПЛЕКС ДЛЯ НИВЕЛИРОВАНИЯ ВЗЛЁТНО-ПОСАДОЧНОЙ ПОЛОСЫ

Аннотация. Наблюдается мировая тенденция увеличения веса и габаритов парка воздушных суден. При этом возрастает нагрузка на аэродромные покрытия, что способствует их более быстрому износу, изменению профиля покрытия, появлению дефектов, угрожающих безопасности полетов. Поэтому проводится постоянный мониторинг за состоянием аэродромных покрытий, в частности – определение их профиля.

Разработан роботизированный комплекс для нивелирования взлетно-посадочной полосы. В состав комплекса входят: мобильные нивелировщики, мобильные нивелирные рейки, которые при производстве нивелирования располагаются на взлетно-посадочной полосе, и управляющее устройство, находящееся на центральной станции управления техническими системами аэропорта.

Управляющее устройство содержит следующие блоки: управления с монитором; обработки и хранения информации; интеллектуальной подсистемы с комплектом логистических программ; геоинформационной системы с приемником GPS; кодирования сигналов; приема и передачи радиосигналов.

Мобильные нивелировщики и мобильные нивелирные рейки управляются с центральной станции и передают кодированную информацию на центральную станцию по каналам радиосвязи. Мобильная нивелирная рейка аналогична по конструкции мобильному нивелировщику за отсутствием блока светодальномерных

измерений, блока поворота и самого оптико-электронного прибора. Перемещение роботизированных мобильных нивелировщиков и визирных целей с остановками для измерений осуществляется по предварительно составленной программе, передаваемой по кодированным каналам радиосвязи. В качестве исходных используются отметки реперов, горизонтальные пластины которых заложены заподлицо с поверхностью взлетно-посадочной полосы на боковых ее торцах, по которым предварительно проложены ходы точного нивелирования.

Предложенный роботизированный комплекс позволяет быстро определить отметки взлетно-посадочной полосы в автоматическом режиме с регулируемым шагом сканирования и строить продольные и поперечные профили поверхности.

Ключевые слова: нивелирование, взлётно-посадочная полоса, GPS-нивелирование, робототехнический комплекс, мобильные нивелирные работы.

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THE CONTROL OF FLEXIBLE AUTOMATED PRODUCTION OF THE SCRAPER CONVEYERS

Abstract. The analysis of possible energy saving in in the technological process of production of elements of scraper conveyors containing flexible automated production is given. It consists of complex subordinate aggregate installations consisting of conveyor lines, robot manipulators and tripods.

The studied technological processes and control systems for electric drives of actuators are multi-connected, distributed in space, stochastic and multidimensional in the number of control and monitoring coordinates. It is proposed a methodology of reducing energy consumption of actuators by means of physical-virtual modeling and parameterization based on estimates of energy costs, by means of planning factor experiments, steep ascending in the anti-gradient direction of integral quadratic estimates of the control system, which are proportional to the costs of electricity in transient modes of actuators. The methodology, in comparison with the well-known optimization methods, is invariant to the type of products developed in flexible automated production, to the laws of distribution of the semi-finished products flows entering the production line, and is focused on predicting the boundaries of the saved energy and the life of the electromechanical equipment and improving reliability of electric drive control systems operation as a part of industrial complexes.

The uniqueness of the method consists in applicability of the developed algorithm of evaluating energy savings and optimizing technological processes according to the criterion of energy consumption in real time in the conditions of the probabilistic situation of input parameters, regardless of the selected method of setting the optimal parameters of production line facilities.

Key words: power consumption, electric drive, robotic production, control system, scraper conveyor, methodology, criterion, optimization, parameterization, structure, forecast, resource.

Introduction. Electric motors and systems driven by electric drives are the largest energy consumers (up to 46% of the total world consumption). It is expected that by 2030, without comprehensive and effective measures in the field of energy efficiency, energy consumption by electric motors will increase to 13,360 TWh per year, CO^2 emissions from energy production for their provision will rise to 8,570 tons per year, and consumer spending for electricity used in the systems with electric drives, will increase up to 900 billion US dollars [1], p. 11]. Due to the undeniable importance of energy consumption by electric drives, including robotics in the industrial sector, measures to improve energy efficiency in industry have a positive potential in environmental, economic and social aspects [2]. In this paper it is studied a multiply connected, multidimensional, distributed in space, stochastic, “large” in a multitude of coordinates, control, object of monitoring and controlling representing a complex technological process (TP), which is a flexible automated production (FAP) in which interrelated work operations under semi-finished products (SF) performed by robotic arms, robotic tripods and conveyors. In the materials of subsequent studies, we will call this object as "a large object, mechatronic and robotic", LOMR [3],[4].

Examples of the technological processes in the mining industry are the FAP of mass production of steel gratings for scraper conveyors, rollers and roller supports of belt conveyors, elements of hydraulic mechanized supports. In the automotive industry, this is the FAP of manufacturing complex structural

elements of bodies and subsequent car Assembly processes. In mass light, food and pharmaceutical production, these are processes related to point contact operations (for example, spot welding and/or marking, milling and drilling, stamping and screw fastening), with continuous and discrete movement of parts, partially finished semi-finished products and finished products. Scraper conveyors are constructed from strips of metal by cutting, welding, drilling, milling, stamping, marking, and manipulation in space. One of the criteria of the LOMR efficiency is minimization of electrical consumption per unit of the FAP finished products. This problem is the subject and purpose of research in this paper.

At the same time, the technology of electric energy consumption minimization proposed in this paper is based on the possibility of using global and local networks to transfer physically received information from the LOMR to the server of the hierarchical monitoring and control system (MC HCS) of the FAP, in order to analyze the proximity of the LOMR operation modes to the reference values of power consumption, with the subsequent development in the ICS of MC algorithms that allow finding the state of the LOMR and the LOMR control systems (by mathematical and simulation in a virtual server environment) that improve power consumption, and then changing the LOMR operating modes directly by transmitting new values of the control device settings (optimal settings: tuning parameters) of the LOMR control systems.

I. The directions of research in the field of energy savings and energy consumptions efficiency assessment. The optimization methods, in their calculations do not take into account the laws of probability associated with stochasticity of real processes. This leads to the fact that any results of the above studies at real plants will correspond to experimental ones with only a certain degree of probability.

This paper presents methods of monitoring and analyzing energy consumption, which allow to develop mathematical models for estimating parameters in order to further optimization of energy consumption and, consequently, minimization of production costs, taking into account stochasticity of the processed flows. The developed methodology makes it possible to design new and to modernize the existing production lines according to the criteria of energy efficiency and to minimize energy consumption in the long term.

II. Methodology of assessing energy consumption reducing in flexible automated production.

2.1. Objects of the system that affect energy saving in the FAP conditions. Considering the properties and characteristics of robots, conveyors, local and global networks, flows of structural elements, semi-finished products, it is proposed to optimize power consumption by parameterizing automatic drive control systems. The processes of searching for the optimal parameters of control systems are solved virtually, using the mathematical and simulation methods and planning of factor experiments on the server of the FAP hierarchical control system (HCS).

The FAP HCS, including telecommunication networks, servers and specialized software and hardware, provides integrated management of technological structural elements and solves systemic problems of optimizing FAP power consumption. Input semi-finished product flows are received for processing by the LOMR elements in stochastic sequences, the patterns of which are known but can change. The information of the SF flows is transmitted through the global and local telecommunication channels. The treatment processes of each semi-finished product and groups of SF robots, manipulators, robots, tripods and the movement of SF conveyor plants are characterized as deterministic processes. This suggests that ranges of criteria for controlling robots and conveyors can be calculated both by direct and integral estimations, as well as stability conditions for the LOMR elements with their automatic control systems.

2.2. The Sources of minimizing energy consumption in the FAP. In deterministic automatic control systems, it makes no sense to look for some unique methods and tools of saving energy consumption [5]. This is a technical task of parametric optimization with various options for the electric drive and the structure of the ATS. The selected types of electric drives and the structure of the ATS in the FAP are a means of minimizing electric energy consumption, and the probabilities of a possible level of energy consumption are determined by the existing laws of stochastic processes in the FAP and are the aim of research in this scientific work.

2.3. Algorithms for minimizing power consumption by LOMR control systems. The stochastic nature of receiving semi-finished products creates a problem of estimating the ranges of possible energy values in the FAP.

Supposing that characteristics of the semi-finished products flows to various lines of robotic manipulators are known, and that these flows are characterized by well-known distribution laws (for example: normal, Poisson, etc.).

The enlarged algorithm of minimizing power consumption in flexible automated production using the LOMR automated electric drive, targeted parametric optimization of the LOMR ATS and under the supervision of a hierarchical control, monitoring and control system (MC HCS) of the FAP is presented below.

The information of the semi-finished products flows is transmitted through global and local channels of telecommunication, is placed in the database and can be processed on the MC HCS server. It is assumed that the distribution law of the semi-finished product flow arriving at the input R_1 of the robotic arm is known. The moment of receiving the first semi-finished product is fixed and the SF processing program is launched by means of the robot manipulator. The parameters and structure of the automated electric drive are taken from the FAP database, where they were previously located. Each SF treatment process is controlled by the monitoring system in the form of recording the coordinates of automated robotic electric drives and the conveyor in the FAP database. The times of the SF arrival for processing by the tripod robot k_1 and its subsequent movement by the conveyor Q_1 are recorded and placed in the database of the FAP MC HCS server. Using the coordinate records, the energy costs of the electric drives for each robot and conveyor work session can be calculated. The ranges of permissible energy costs per finished product unit for various drive options and local LOMR control structures are placed in the database in the MC HCS server. In the control period of the LOMR and FAP operation, the possible electric costs are calculated and compared with the permissible ranges of energy costs. The comparison results are used to carry out virtual experiments, the purpose of which is to select (by means of simulation according to the plans of optimal factor experiments and steep ascent in the direction of the anti-gradient of the integral quadratic estimation of automatic control systems [6], [7], [8] promising options for the LOMR control systems structures and parameters in the FAP MC HCS. Permissible changes in the structure and parameters of automated electric drives and the LOMR ATS from the MC HCS are introduced and technological operations are carried out in the next period of the FAP operation.

3.4. Stochastic characteristics of the semi-finished products flow effect on power consumption in the FAP. In figure 1 the analyzed flexible automated production is considered in the first approximation as a Markov process with discrete states and continuous time. According to [9], p. 182] the processes (objects and systems) with discrete states and continuous in time have the following property: "...For each moment of time t_0 the probability of any state of the system in the future (for $t > t_0$) depends only on its current state (at $t = t_0$) and does not depend on when and how the system came into this state (that is, how the process developed in the past)".

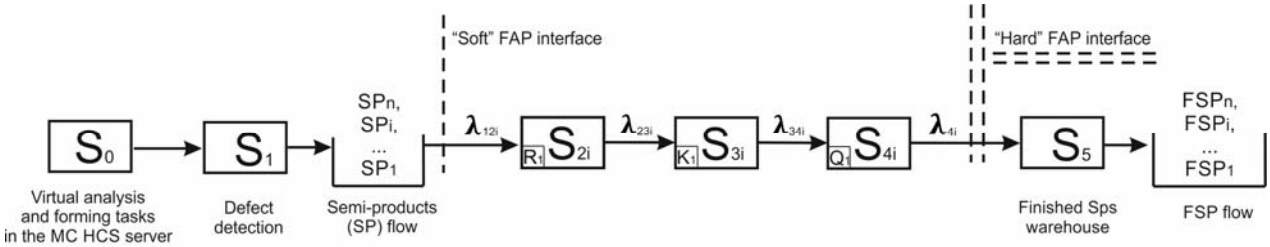

Figure 1 – Flexible automated production as a Markov process:
R_1 – robot-manipulator; K_1 – robot-tripod; Q_1 – conveyor, $S_{2i} \rightarrow R_1 \cdot SF_i$; $S_{3i} \rightarrow k_i R_1 \cdot SF_i$; $S4_i \rightarrow Q_1 k_1 R_1 \cdot SF_i$

The S_0 event is related to the quality control processes taking place in the MC HCS, and the preparation of the SF flow for subsequent deformation in the LOMR. The detection of a defective SF in the flow as a Markov process, as well as its removal from the processing line, is event S_1. The appearance of a defective SF can affect the SF flow and then remove it from the circuit (event S_1). Therefore, the state of the SFi obtained for processing by the manipulator R_1 is controversial and is further characterized as a probabilistic phenomenon with the estimate: $0 \leq \lambda_{12i} \leq 1$. The information of the design, geometric and mass characteristics of the SF, as well as time stamps and periods of the movement of the SF between the soft FAP boundary and the R1 robotic arm, is important. This is associated with the adjustment of the control

systems R_1, and subsequently the control systems of the robot tripod k_1 and the conveyor Q_1, according to the direct and integral quality criteria.

2.4. Analyzing the LOMR into FAP transient processes. The LOMR technological process consists in the performing by the R_1 robot of spot welding on SF_i, gluing a label on the SF_i by the robot-tripod and moving by the SF_i conveyor. The settings of the control systems of electric drives R_1, k_1 and Q_1 are the only means of affecting the dynamic processes associated with the LOMR. In the enlarged algorithm, technological operations are promptly performed and information is transmitted via telecommunication networks to the MC HCS [4], [10]. The actions for the parametric optimization of the LOMR control systems are performed virtually in the MC HCS by simulation using the technology of planning special factor experiments in the settings of various control systems for the LOMR electric drives. Figure 2 provides an interpretation of the processes of minimizing power consumption by means of the LOMR electric drive control systems.

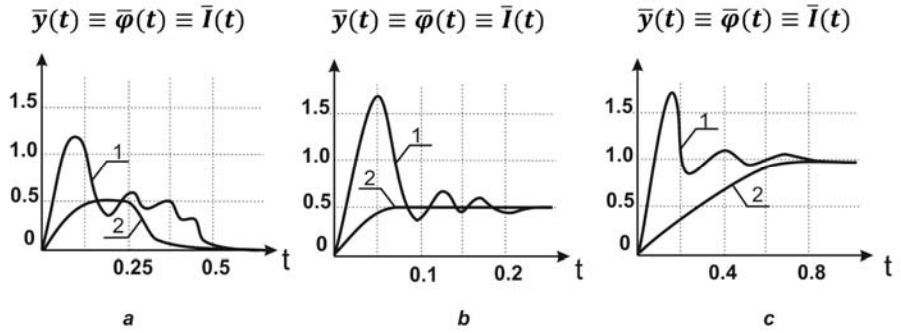

Figure 2 – Transit processes in the LOMR ACS. Transit processes execution units in control systems:
a – of the robot manipulator; b – of the robot tripod; c – of the conveyor.
Trajectories of movement of executive bodies: 1 - tuning, 2 – optimal

An estimate of the boundaries of possible power consumption can be made on the assumption that there is a direct relationship between the quality of dynamic processes, estimated by the time dependences of the coordinates R_1, k_1, Q_1, and the cost of electricity for moving actuators, which are proportional to the square of the deviations of the analyzed coordinates from the reference values.

The situation when the motor of the R_1 robot's gripper is positioned geographically by the coordinate of spot welding (figure 2a, graph 1). Evaluation of the qualitative characteristics of graph 1 (obviously, they are unsatisfactory) starts the process of parametric optimization, in accordance with paragraphs 9 and 10 of Section 2.3. The result of the decision on the next cycle of the R1 operation is graph 2 of the grip movement.

The situations are similarly interpreted when the k_1 robot tripod sticks a label on the SF_i located on the moving traction belt of the Q_1 conveyor. Then, virtually in accordance with paragraphs 9 and 10, there is made a search for the optimal settings, characterized by graphs 2 (figure 2, b and c).

III. The methodology of assessing the boundaries of the probable energy consumption of energy conservation in the FAP. Supposing that the process equipment R_1, k_1 and Q_1 is installed in the FAP (look at figure 1). In modern reality, the state of the means of collecting and processing information, various implementations of monitoring and control systems for technological units R_1, k_1 and Q_1 are possible. Next, we consider several options for operation of the FAP and R_1, k_1 and Q_1 in order to assess the minimum energy consumption ranges in the FAP, including:

FAP1. Computer vision systems (CVS) record the moments of receiving SFi for processing R_1, k_1 and Q_1. The CVS information is transmitted via global and local telecommunication channels, placed in a database and can be processed in the MC HCS server. All processes in the FAP are considered deterministic;

FAP2. The FAP in figure 1 is considered as a Markov process with discrete states and continuous time;

FAP3. The operation of the FAP with the CVS (i.e., as in FAP1) is affected by the possible occurrence of defects in the elements of the SF;

FAP4. The FAP functioning is considered as a Markov process (as in FAP2) and the impact on the work of the FAP is considered to be the occurrence of defective SFs (as in FAP3).

3.1. Analyzing possible energy consumption reducing in FAP1. The number of operations in AAP 1 for the conversion of Si, where i = $\overline{1,n}$, using R_1, k_1 and Q_1 is 3n. let's suppose that the energy costs for translating the EDO are proportional to the areas of deviations of the transients from the given values of the adjustable coordinates in figure 2, and the settings of the ATS, in order to move from processes characterized by temporary, not optimal dependences 1 (figure 2) require at least m virtual experiments in the MC HCS (m = m_{By1}+m_{By2}+m_{By3}, where m_{By1}, m_{By2}, m_{By3} is the number of virtual experiments with models and control systems of the R_1, k_1 and Q_1 installations. For example, for the controllers with two tuning parameters, the planning matrix requires no less than (2^2+1) experiments [11], coefficient MK [[Energy units]/[$\overline{y}$] [Reg. values]] and supposing that in the first approximation of the area S_{1y} (for R_1), S_{2y} (for k_1) and S_{3y} (for Q_1) the deviations of transients from the given values of the controlled coordinates of type 2 (see figure 2) are no less than SK-times smaller than the corresponding areas of processes 1 in figure 2 (for example, when SK = 0.5, the area of type 2 is two times smaller than the area of type 1).

Taking into account the introduced notations and assumptions, we determine the energy indicators of FAP1.

1. The total energy consumption for carrying out technological operations on R_1, k_1 and Q_1 with the initial (not optimal) parameters of the regulators:

$$\mathrm{Q_{max}} = \mathrm{MK} * (S_{1y} + S_{2y} + S_{3y}) \cdot (3\mathrm{n}). \quad (1)$$

2. Power consumption for the R_1, k_1, Q_1 EDO ATS tuning:

$$\mathrm{Q_{conf}} = \mathrm{MK} \cdot \left(S_{1y} + S_{2y} + S_{3y}\right) \cdot (m). \quad (2)$$

3. Power consumption after the R_1, k_1, Q_1 EDO ATS tuning:

$$\mathrm{Q_{min}} = \mathrm{SK} \cdot \mathrm{MK} \cdot \left(S_{1y} + S_{2y} + S_{3y}\right) \cdot (3\mathrm{n} - \mathrm{m}). \quad (3)$$

4. The value of maximally possible energy saving:

$$\Delta Q_{max} = Q_{max} - Q_{min}. \quad (4)$$

5. The range of possible energy saving:

$$Q_{conf} \leq \Delta Q \leq \Delta Q_{max}. \quad (5)$$

3.2. Analysis of possible reducing of energy consumption of FAP2. The following assumptions might be done regarding to FAP2 (T – the period of operation): the SF_i flow entering for processing at R_1 is a Markov process; the time cycle of processing SF_i on R_1, k_1 and Q_1 is a known value equal to t_{sf}; SF_i processing ends when the SF_i arrives beyond the "hard" FAP boundary; processing the SF_{i+1} of the semi-finished product begins after the end of the t_{sf} period (relative to the beginning of the processing of SF_i) and subject to the appearance of SF_{i+1} at the "soft" FAP interface (figure 1); the conditions, designations and parameters previously adopted for FAP1 are also valid in the case under consideration. These assumptions simplifying the analysis process allow obtaining for FAP2 conditions of type (5) with a probabilistic characteristic of the left and right boundaries. It is obvious that in the LOMR monitoring and control system, quantity counting devices processed at a specific point in the SF_i time will be required. It is technically not difficult to develop a discrete system that controls the passage time of SF_i through R_1, k_1, Q_1, fixing the duration of the operation t_{jsf} and its cycle number j_{isf}. At the moment of the end of the FAP2 T operation period, the number of processed SF_i will be equal to $N_{jsf} = T/t_{jsf}$. Then Q_{min} is calculated from:

$$\mathrm{Q_{min}} = \mathrm{SK} \cdot \mathrm{MK} \cdot \left(S_{1y} + S_{2y} + S_{3y}\right) \cdot (3N_{jsf} - \mathrm{m}), \quad (6)$$

and Q_{max} as follows:

$$\mathrm{Q_{max}} = \mathrm{MK} * (S_{1y} + S_{2y} + S_{3y}) * (3N_{jsf}) \quad (7)$$

For FAP2 relations (4) and (5) are valid in the probabilistic setting, due to the fact that the SF_i flow at the input of FAP2 is a Markov process. Suppose that the laws corresponding to the flow of SF_i characterize it as follows: "...stationary, without aftereffect, ordinary. Such a flow is called the simplest

one (... or stationary Poisson flow)" [9], p.202] that plays the same role in the queuing theory as the normal distribution of random variables in the probability theory [12], p.11]. Then, we assume that the intensity S_{sfi} as the average number of possible SF_i receiving at the input of the FAP is a constant value: S_{sfi} = const, the probability of receiving semi-finished products SF_i in the interval of time t in the amount of k will be calculated by the Poisson formula [9], [12]:

$$P_k(t) = \frac{(S_{sfi} \cdot t)^k}{k!} \cdot e^{-(S_{sfi} \cdot t)}. \quad (8)$$

Using an algorithm for calculating the probabilistic characteristics of an element of the simplest flow of events with intensity S_{sfi}=const [9] to estimate the time interval tt_{sfi} between the occurrence of the SF_i event on the "soft" FAP interface and the next SF_{i+1} event on the time axis T.

The distribution function determines the probability of the fact that the tt_{sfi} value will become smaller than the time axis T: $F(t) = (tt_{sfi} < T)$.

Supposing that the SF_i arrives at the soft boundary of the FAP at time tt_0. The possible time of receiving the next semi-finished product can occur during the TT period. It is necessary to determine the probability that the interval $tt_{sfi,}$ through which SF_{i+1} will be smaller than TT. For this, it is necessary that at least one flow event falls on a section of the TT length adjacent to the point $tt_{0.}$ The calculation of the probability of this F(t) is possible through the probability of the opposite event (i.e., to assume that no flow event will fall on the TT section) [8, p. 204]:

$$F(t) = (1 - P_0). \quad (9)$$

Here the P_0 probability is found by formula (8) at k = 0:

$$P_0(t) = \frac{(S_{sfi} \cdot t)^0}{0!} e^{-(S_{sfi} \cdot t)} = e^{-S_{sfi} \cdot t}, \quad (10)$$

then the function of tt_{sfi} distribution will be:

$$F(t) = 1 - e^{-(S_{sfi} \cdot t)}, (t > 0), \quad (11)$$

and the density of the random value tt_{sfi} distribution will be:

$$f(t) = S_{sfi}\, e^{-s_{sfi} \cdot t}, (t > 0). \quad (12)$$

The tt_{sfi} with the density of distribution (12) is described by the exponential law of distribution. At this mathematical expectation and the mean quadratic deflection of the tt_{sfi} for the conditions considered are equal to each other and inverse to the S_{sfi} parameter [[9], pp.204, 205]. For FAP2 expression "the element of probability of the event occurrence" is also important [[9]]. For the period of tuning FAP2 SF_i, (i.e. at i=1, …, m) and the last in the flow semi-finished product in FAP2, SF_i, (i.e. at i= N_{jsf}) "the element of probability of the event occurrence'' is calculated by formula (8) and defines the probability of successful tuning the EDO ACS $R_{1,}$ k_1, Q_1 (for k = m):

$$P_k(t) = \frac{(S_{sfi} \cdot t)^m}{m!} \cdot e^{-S_{sfi} \cdot t} \quad (13)$$

i.e. it is the probability of the "left" range of power saving (5) for FAP2, and for the "right" range (5), when k = N_{jsf}, the probability will be equal to:

$$P_k(t) = \frac{(S_{sfi} \cdot t)^{N_{jsf}}}{N_{jsf}!} \cdot e^{-S_{sfi} \cdot t}. \quad (14)$$

3.3. Analyzing possible power consumption reducing in FAP3. The structure of FAP3 will be considered as a closed collection of series-connected devices and virtual information packets. Supposing that the production line receives SFs, among which there are defective items, which lead to the omission of its processing. To increase the reliability and efficiency of this process, it is necessary to use formal mathematical and simulation methods [13] and take into account the probabilistic nature of the appearance of a defective SF on the processing line. The time T of the FAP operation and the processing cycle of the SF, - $tj_{пф}$ remain unchanged, but the total number of SFs supplied to the processing will decrease and will

be equal to $n_{деф}$<n, respectively, the number of processed semi-finished products at the end of T will be Nn_{def}< Nj_{sfi}. Then, when evaluating the energy savings in formulas (6) and (7), Nj_{sfi} should be replaced by Nn_{def}:

$$\mathrm{Q_{min}} = \mathrm{SK} \cdot \mathrm{MK} \cdot \left(S_{1y} + S_{2y} + S_{3y}\right) \cdot (3\mathrm{Nn}_{def} - \mathrm{m}), \quad (15)$$

$$\mathrm{Q_{max}} = \mathrm{MK} \cdot (S_{1y} + S_{2y} + S_{3y}) \cdot (3\mathrm{Nn}_{def}). \quad (16)$$

The probability of operability of a system consisting of series-connected devices is equal to the product of the probabilities of each device, and the failure (inoperability) of one device makes the entire system inoperative [14].

We characterize the magnitude of the energy savings ΔQ in FAP3 as a random value equal to the difference between the actual value ΔQ_{max} and the estimate $\Delta\bar{Q}_{max}$. Then, with probability λ, the ΔQ_{max}value is determined in a certain confidence interval I_λ:

$$P\left((\Delta Q_{max} - \Delta\bar{Q}_{max}) < \varepsilon_e\right) \leq \lambda, \quad (17)$$

where $\Delta\bar{Q}_{max}$ is an unbiased estimate ΔQ_{max}, determined as mathematical expectation M (ΔQ_{max}) = = $\Delta\bar{Q}_{max}$.

The range of possible ΔQ_{max}, values when replacing it by $\Delta\bar{Q}_{max}$, will be $\pm\varepsilon_e$ and (17) can be presented in the form [12]:

$$P\left\{(\Delta Q_{max} - \varepsilon_e)(\Delta Q_{max} + \varepsilon_e)\right\} = \lambda. \quad (18)$$

Equality (18) means that the ΔQ_{max} value with probability λ falls into the interval

$$I_\lambda = \left\{(\Delta Q_{max} - \varepsilon_e)(\Delta Q_{max} + \varepsilon_e)\right\}. \quad (19)$$

Here, the ΔQ_{max} value is not random but the I_λ interval is random. The interval I_λ position is random and is defined by the $\Delta\bar{Q}_{max}$ center. The interval length is also random and is equal to $2\cdot\varepsilon_e$. From here it follows that with observing condition (17), the energy saving value ΔQ_{max} in the $2\cdot\varepsilon_e$ interval can be equal to 0.607ΔQ. Here the ΔQ_{max}= 0.607Δ value will depend on the S_1 event that reflects the state of the sequence closed structure of FAP3, and the probabilistic assessment of this state can change periodically in the range of 0≤ λ≤ 1 (in figure 1 λ_{12i} = λ).

3.4 Analyzing the probability of power consumption reducing in FAP4. Possible results of decreasing power consumption in FAP2 and FAP3 do not imply estimates other than those already obtained above. In this case, the only new control will be switching the FAP state from the FAP2 option to FAP3 and vice versa.

Conclusion. The above theoretical principles and algorithms for evaluating power consumption, as well as structural and algorithmic proposals for the implementation of control, monitoring, regulation, automatic and automated control processes with parameterization of control systems for executive devices according to criteria for minimizing power consumption, suggest the possibility of developing a universal methodology that is invariant to the type of products developed in the FAP and the laws of distribution of the semi-finished products flows entering the FAP. In the work an urgent scientific problem of developing a methodology of building principles, studying and improving of flexible automated productions with aggregated robotic installations driven by electric drives of has been solved.

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СКРЕПЕРЛІ КОНВЕЙЕР ӨНДІРІСІНІҢ ИКЕМДІ АВТОМАТТАНДЫРЫЛҒАН ӨНДІРІСІН БАСҚАРУ

Аннотация. Икемді автоматтандырылған өндіріс құрамына кіретін скреперлі конвейерлер элементтерін (бөлшектерін) өндірудің технологиялық процесінде энергияны үнемдеудің ықтимал талдауы келтірілген. Бұл өндірістің құрамына күрделі бағынышты агрегатталған қондырғылар, атап айтқанда конвейерлік желілер,

робот-манипуляторлар және триподтар кіреді. Зерттеліп отырған технологиялық процестер мен атқарушы құрылғылардың электр жетегін басқару жүйелері көпбайланысты, кеңістікте таратылған және басқару мен бақылау координаталар саны бойынша көпөлшемді және стохастикалық болып табылады. Атқарушы құрылғылардың ауыспалы режимдерінде электр энергия шығындарына пропорционалды болып табылатын факторлы эксперименттер мен басқару жүйесінің интегралды квадраттық антиградиентінің бағытына тік көтерілуді жоспарлау негізінде физикалық-виртуалды модельдеу мен электр энергиясының шығындарын бағалауға негізделген параметризация құралдары арқылы электр энергиясын тұтынуды азайту әдісі ұсынылған. Ұсынылып отырған әдіс белгілі оңтайландыру әдістерімен салыстырғанда, икемді автоматтандырылған өндірісте жасалған өнім түріне, өндіріс желісіне түсетін жартылай фабрикаттар ағындарының таралу заңдылықтарына байланысты өзгермейді және электрмеханикалық жабдықтың үнемделген энергиясының шекаралығын және тозу мерзімдерін болжауға, сонымен қатар өндірістік кешендердің құрамына кіретін электр жетектерін басқару жүйелерінің жұмысының сенімділігін арттыруа бағытталған.

Ұсынылып отырған әдістің бірегейлігі - жасалынған (мақалада ұсынылып отырған) алгоритмді технологиялық процестердің кіріс параметрлерінің ықтималдық сипаты жағдайында нақты уақыт режимінде энергияны тұтыну критерийі бойынша энергия үнемдеуді бағалау және технологиялық процестерді оңтайландыру үшін қолданылуында жатыр.

Түйін сөздер: электр энергиясын тұтыну, электр жетегі, робот өндірісі, басқару жүйесі, скреперлі конвейер, әдістеме, критерий, оңтайландыру, параметризация, құрылым, болжам, ресурс.

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УПРАВЛЕНИЕ ГИБКИМ АВТОМАТИЗИРОВАННЫМ ПРОИЗВОДСТВОМ ИЗГОТОВЛЕНИЯ СКРЕБКОВЫХ КОНВЕЙЕРОВ

Аннотация. Приведен анализ возможного энергосбережения в технологическом процессе производства элементов (деталей) скребковых конвейеров, содержащем гибкое автоматизированное производство. В его состав входят сложноподчинённые агрегатированные установки из конвейерных линий, роботов-манипуляторов и триподов. Исследуемые технологические процессы и системы управления электроприводами исполнительных устройств являются многосвязными, распределенными в пространстве, стохастическими и многомерными по количеству координат контроля, управления и мониторинга. Предлагается методика снижения потребления электроэнергии исполнительными устройствами средствами физико-виртуального моделирования и параметрирования на основе оценок затрат электроэнергии, путем планирования факторных экспериментов, крутого восхождения в направлении антиградиента интегральных квадратичных оценок системы управления, пропорциональных затратам электроэнергии в переходных режимах исполнительных устройств. Предложенная методика, в сравнении с известными методами оптимизации, инвариантна к типу изделий создаваемых в гибком автоматизированном производстве, законам распределения потоков полуфабрикатов, поступающих на производственную линию, и ориентирована на прогнозирование границ сэкономленной энергии, износного ресурса электромеханического оборудования и повышения надежности эксплуатации систем управления электроприводами в составе промышленных комплексов.

Уникальность предложенного метода заключается в применимости разработанного алгоритма для оценки экономии электроэнергии и оптимизации технологических процессов по критерию энергопотребления в режиме реального времени в условиях вероятностного характера входных параметров технологических процессов.

Ключевые слова: электропотребление, электропривод, робототизированное производство, система управления, скребковый конвейер, методика, критерий, оптимизация, параметрирование, структура, прогноз, ресурс.

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RESEARCH OF THE INTERNAL LEAKAGE PROCESS OF A LIQUID IN THE DESIGN OF A GEAR PUMP WITH A TWO-AXIAL CONNECTION

Abstract. This article presents the results of a study of the process of internal fluid leakage in the design of a gear pump with a biaxial connection. It is known that the volumetric efficiency mainly depends on the leakage of the working fluid through the gaps formed by the tooth heads and the pump casing, as well as between the end surfaces of the gears and the side walls of the casing. In addition, additional leaks occur along the contact line of the teeth. To reduce radial leaks, the gap between the gears and the pump casing is minimized, and to reduce end-leakage, the side walls are automatically pressed against the end surfaces of the gears by liquid under operating pressure. The design of the pump shows that the main internal fluid leaks occur in the gap between the gears and the housing. Naturally, these leaks require excessive energy consumption and, thereby, reduce the efficiency of the pump. The natural way to combat this circumstance is to reduce the marked gaps to a minimum. This is possible using an additional element - a biaxial sleeve. The dependence of the spring force on the fluid flow rate and the guaranteed gap between the ring gear and the pump casing has been analytically established. They are characterized by a drop in force with an increase in clearance and a rise in flow rate. This is due to an increase in the dynamic force in the gaps, which must be compensated by the spring.

Keywords: wear of rubbing surfaces, clearance, fluid leakage, biaxial connection, gear pump, eccentricity.

Introduction. The reliability and durability of hydraulic systems is largely determined by the ability of the working fluids used in them to help reduce wear on rubbing surfaces and prevent them from seizing. The wear of gear oil pumps and precision pairs of setting and control parts has a significant impact on pump performance and causes excessive power losses due to significant leaks through leaks resulting from wear [1].

The pressure developed by the pump when operating in a closed loop affects the volumetric capacity of the pump. As pressure rises, the volumetric capacity of the pump decreases. This is due to an increase in internal leakage of fluid from the discharge cavity of the pump to the suction, i.e., with a kind of slipping of the fluid. Since internal leakage is observed in all pumps, it is more convenient to judge the pump performance by the volume of liquid supplied at a given pressure per unit time. The amount of internal leakage depends on the type of pump and on the degree of wear it determines the volumetric efficiency of the pump [1].

The analysis showed that a huge number of scientific publications and works are devoted to general issues of the theory and practice of gear pumps. In particular, they are reflected in the works of Rybkin EA, Usova EA [2], Yudina E.M. [3], Osipova A.F. [4,5] and others [6,7,8,9,10]. In these works, it is noted that the main structural features of gear pumps are associated with the presence of gearing, which should meet the specifics of volumetric hydraulic machines [11,12,13,14].

Depending on the type of gearing, gear pumps can be of two types - external and internal, used in all engineering industries. The simplest type of gear pump is an external gearing device. It is a structure consisting of a housing and two gears. These wheels are engaged and are distinguished by their involute. Gear pumps and hydraulic motors due to their simple design and operational reliability are widespread in hydraulic drives of road cars [15,16]. Figure 1 shows a gear pump diagram.

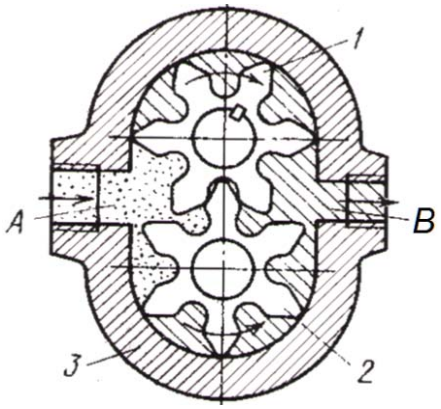


Figure 1 – Scheme of gear pump: 1, 2 – gears; 3 – case

The principle of operation of the gear pump is as follows. Two gears of equal width leading 1 and driven 2 are meshed and located in the housing 3 with a minimum radial clearance. To the end surfaces of the gears are adjacent the side walls of the pump. When the gears rotate, the fluid filling the cavities between the teeth is transferred by the gears along the inner surface of the housing (shown by arrows) from the suction cavity A to the discharge cavity B. Volumetric efficiency mainly depends on the leakage of the working fluid through the gaps formed by the tooth heads and the pump casing, as well as between the end surfaces of the gears and the side walls of the casing. In addition, additional leaks occur along the contact line of the teeth. To reduce radial leaks, the gap between the gears and the pump casing is minimized, and to reduce end-leakage, the side walls are automatically pressed against the end surfaces of the gears by liquid under operating pressure [17].

In all designs, dimensional bonds in the “shaft-bore” joint are generally considered. Such connections are the connection of the diameter of the support sleeve in the hole of the pump housing, the connection of the diameter instead of the teeth of the gear shaft in the hole of the pump housing, as well as the connection of the diameter of the shaft of the gear shaft in the hole of the support sleeve. These connections are traditional corresponding bore diameters standardized by existing standards. Structural analysis and technological requirements of the NS pumps showed that when designing the working unit of the NS pumps, it is possible to use biaxial joints [18]. Figure 2 shows the working element of the NS pump using a biaxial connection.

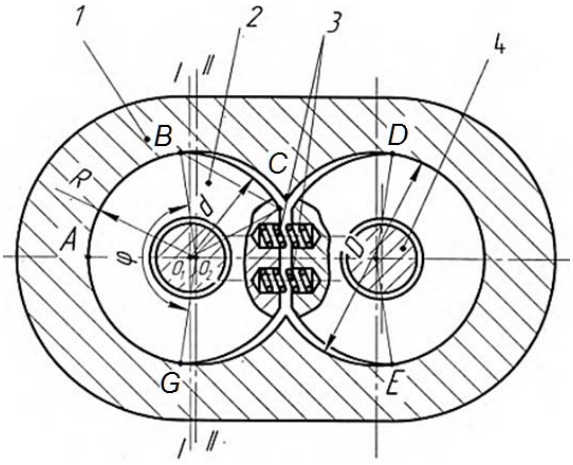


Figure 2 –
The working body of the NS pump using a biaxial connection:
1 – NS housing; 2 – supporting bushings; 3 – expandable elements; 4 – axis shaft - gears; D – the diameter of the hole in the housing; d – the outer diameter of the support sleeve; R – the radius of the landing diameter of the supporting sleeve; O_1 – diameter center of the support sleeve; O_2 – center radius of the bushing diameter of the support sleeve;
points A, B – the points of the arc of the landing diameter of the opening of the NS housing;
$\cup BG$ and $\cup DE$ – two arcs of two support bushings having a landing radius R: φ – angle covering arc $\cup BG$ and $\cup DE$

From the design in figure 2 it follows that the supporting sleeve is pressed by the BG arc having a radius R to the opening of the NS housing. In this case, the radius R can be chosen equal to R = 0.5D. Such a choice of the value of R will allow us to combine for their average values the center of the hole in the NS housing with the center of the arc of radius R.

In [18, 19, 20, 21], dispersion fields of the diameters of the sleeve and holes for biaxial joints were shown. Depending on the task, the desired option for the mutual arrangement of tolerance fields of size R and size 0.5D can be selected.

Investigation of the process of internal fluid leakage. The design and scheme of the pump shows that the main internal fluid leaks occur in the gap between the gears and the housing. Naturally, these leaks require excessive energy consumption and, thus, reduce the efficiency of the pump [22]. The natural way to combat this circumstance is to reduce the marked gaps to a minimum. This is possible using an additional element - a biaxial sleeve. When studying the process of internal fluid leakage, the design scheme shown in figure 3 is used.

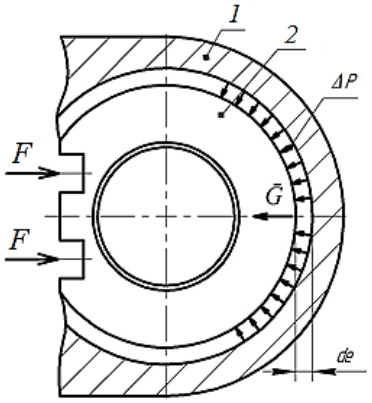


Figure 3 – Fluid leakage design scheme: 1 – pump housing; 2 – sleeve;
F – the force from the side of the compensating spring; Δp – the pressure drop during fluid leakage;
G – resultant forces acting on the sleeve

The most effective in the analysis of hydrodynamic losses during fluid motion is the Bernoulli equation [23,24]. For the case under consideration, we have:

$$\Delta P = \rho \frac{v^2}{2}$$

where ρ - the density of the liquid; υ - the fluid velocity in the gap.

With the steady laminar motion we have:

$$v = \frac{Q}{S'}$$

where Q – nominal fluid flow rate; S is the cross-sectional area of the gap.

Given that the force acting on the cross-sectional area of the sleeve *de* is equal to:

$$dG = \Delta p \cdot de$$

and integrating the resulting expression, we have:

$$G = \int_{S_B} \rho \frac{v^2}{2} de$$

where S_B – sectional area of the side surface of the sleeve:

$$S_B = he; e = \frac{S_B}{h}; de = \frac{dS_B}{h}$$

where h – sleeve surface width.

Then we get:

$$G = \rho \frac{v^2 e^2}{4} = \rho \frac{Q^2 e^2}{4S^2}$$

With a sufficiently small gap due to the eccentricity of the biaxial surface δ, an approximate value can be used:

$$S = e \cdot \delta$$

we get the dependence:

$$G = \rho \frac{Q^2}{4\delta^2}$$

The dependence of the force on the eccentricity value is obtained (see figure 4).

$$\rho = 890 \text{ kg/m}^3.$$

The formula determines the indicator G (H) for three parameters for the pumped liquid:

Q, m^3/sec	0,42 ×10^{-3} (25 l/min)			0,67 ×10^{-3} (40 l/min)			0,83 ×10^{-3} (50 l/min)		
δ, 10^{-3} м	0,4	1	2	0,4	1	2	0,4	1	2

I.

$$G_1 = \frac{890 \times 0{,}42^2 \times 10^{-6}}{4 \times 0{,}4^2 \times 10^{-6}} = 245 \text{ H}$$

$$G_2 = \frac{890 \times 0{,}42^2 \times 10^{-6}}{4 \times 1^2 \times 10^{-6}} = 39 \text{ H}$$

$$G_3 = \frac{890 \times 0{,}42^2 \times 10^{-6}}{4 \times 2^2 \times 10^{-6}} = 9{,}8 \text{ H}$$

II.

$$G_1 = \frac{890 \times 0{,}67^2 \times 10^{-6}}{4 \times 0{,}4^2 \times 10^{-6}} = 624 \text{ H}$$

$$G_2 = \frac{890 \times 0{,}67^2 \times 10^{-6}}{4 \times 1^2 \times 10^{-6}} = 99{,}8 \text{ H}$$

$$G_3 = \frac{890 \times 0{,}67^2 \times 10^{-6}}{4 \times 2^2 \times 10^{-6}} = 25 \text{ H}$$

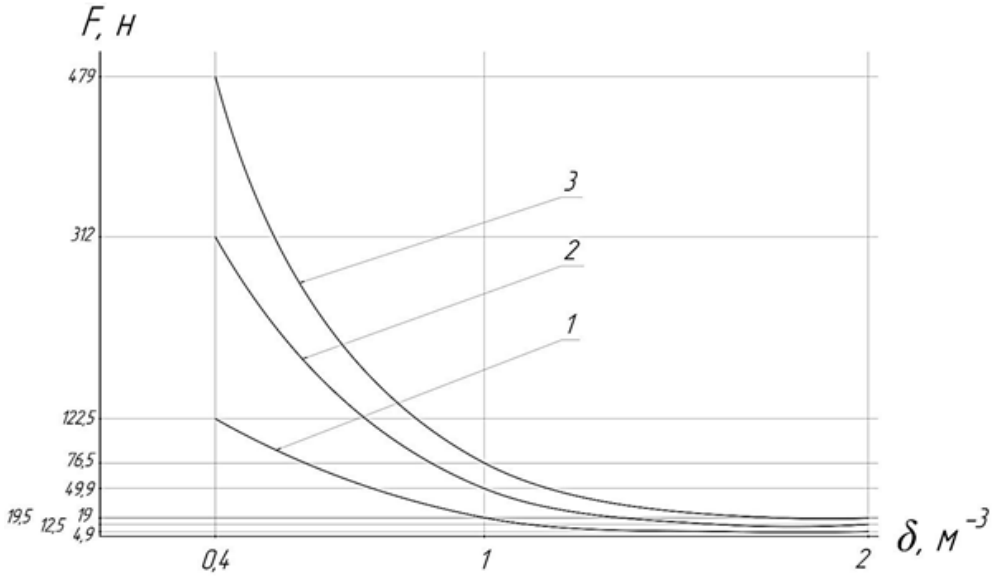
III.

$$G_1 = \frac{890 \times 0{,}83^2 \times 10^{-6}}{4 \times 0{,}4^2 \times 10^{-6}} = 958 \text{ H}$$

$$G_2 = \frac{890 \times 0{,}83^2 \times 10^{-6}}{4 \times 1^2 \times 10^{-6}} = 153 \text{ H}$$

$$G_3 = \frac{890 \times 0{,}83^2 \times 10^{-6}}{4 \times 2^2 \times 10^{-6}} = 38 \text{ H}$$

Q, m^3/sec	0,42 ×10^{-3} (25 l/min)			0,67 ×10^{-3} (40 l/min)			0,83 ×10^{-3} (50 l/min)		
δ, 10^{-3} m	0,4	1	2	0,4	1	2	0,4	1	2
G, H	245	39	9,8	624	99,8	25	958	153	38



Consumption Q: 1 – Q = 0,4 m^3/s; 2 – Q = 1 m^3/s; 3 – Q = 2 m^3/s

Figure 4 – The dependence of the force acting on the sleeve G on the eccentricity of the biaxial connection δ for various values of flow Q

To ensure guaranteed pressing of the sleeve to the surface of the housing, according to the design scheme, the condition must be provided

$$2F > G$$

Using Hooke's Law for Elastic Strength

$$F = C\lambda$$

where C – stiffness coefficient; λ is the amount of compression of the spring, we get:

$$C\lambda > \frac{G}{2}; C\lambda > \rho\frac{Q^2}{8\delta^2}$$

Conclusions:

1. The dependence of the spring force on the fluid flow rate and the guaranteed gap between the ring gear and the pump casing has been analytically established. They are characterized by a drop in force with an increase in the gap and an increase with an increase in flow. This is due to an increase in the dynamic force in the gaps, which must be compensated by the spring.

2. The above dependences allow choosing the characteristics of the spring at the pump design stage with guaranteed gaps between the ring gear and the pump casing and at specified costs.

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ЕКІ ОСЬТІ ҚОСЫЛЫСЫ БАР ТІСТЕГЕРШІКТІ СОРҒЫНЫҢ КОНСТРУКЦИЯСЫНДАҒЫ СҰЙЫҚТЫҚТЫҢ ІШКІ АҒУ ПРОЦЕСІН ЗЕРТТЕУ

Аннотация. Мақалада екі осьті қосылысы бар тістегершікті сорғының конструкциясында сұйықтықтың ішкі ағуын зерттеу нәтижелері келтіріледі.

Көлемді ПӘК негізінен тістердің бас тиектерімен және сорғы корпусымен, сондай-ақ, тістегершіктің бүйір беті мен корпустың бүйір қабырғалары арасында пайда болған саңылаулар арқылы жұмыс сұйықты-

ғының ағып кетуіне байланысты. Сонымен қатар, тістің түйісуі бойынша ағулар қосымша пайда болады. Радиалды ағуларды азайту үшін, тістегершіктер мен сорғы корпусы арасындағы саңылауды ең аз шамада жасайды, ал бүйір қабырғалары жұмыс қысымымен тістегершіктің бүйір бетіне сұйықтықпен автоматты түрде қысылады. Сорғының дизайны сұйықтықтың негізгі ішкі ағуы редукторлар мен корпус арасындағы алшақтықта болатындығын көрсетеді. Әрине, бұл ағып кетулер шамадан тыс энергия шығынын қажет етеді және сол арқылы сорғының тиімділігін төмендетеді. Бұл жағдаймен күресудің табиғи әдісі - белгіленген олқылықтарды азайту. Бұл қосымша элементтің көмегімен мүмкін-биаксиалды жең.

Серіппенің күштің сұйықтықтың шығынына және тістің тәжі мен сорғы корпусы арасындағы кепілді саңылауға тәуелділігі аналитикалық түрде анықталды. Олар саңылау ұлғайған кезде күштің құлауымен және шығынның ұлғаюымен сипатталады. Бұл серіппемен басылатын саңылаулардағы динамикалық күштің өсуімен байланысты.

Түйін сөздер: жанасатын беттердің тозуы, саңылау, сұйықтықтың ағуы, екі осьті қосылыс, тістегершікті сорғы, эксцентриктілік.

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ИССЛЕДОВАНИЕ ПРОЦЕССА ВНУТРЕННЕЙ УТЕЧКИ ЖИДКОСТИ В КОНСТРУКЦИИ НАСОСА ШЕСТЕРЕННОГО С ДВУХОСНЫМ СОЕДИНЕНИЕМ

Аннотация. В статье представлены результаты исследования процесса внутренней утечки жидкости в конструкции шестеренчатого насоса с двухосным соединением. Известно, что объемный КПД в основном зависит от утечки рабочей жидкости через зазоры, образованные головками зубьев и корпусом насоса, а также между торцевыми поверхностями шестерен и боковыми стенками корпуса. Кроме того, по линии соприкосновения зубьев возникают дополнительные утечки. Для уменьшения радиальных утечек зазор между шестернями и корпусом насоса сводится к минимуму, а для уменьшения торцевых утечек боковые стенки автоматически прижимаются к торцевым поверхностям шестерен жидкостью под рабочим давлением. Конструкция насоса показывает, что основные внутренние утечки жидкости происходят в зазоре между шестернями и корпусом. Естественно, эти утечки требуют чрезмерного расхода энергии и тем самым снижают КПД насоса. Естественный способ борьбы с этим обстоятельством – свести отмеченные пробелы к минимуму. Это возможно с помощью дополнительного элемента – двухосной втулки.

Аналитически установлена зависимость усилия пружины от расхода жидкости и гарантированного зазора между зубчатым венцом и корпусом насоса. Они характеризуются падением силы при увеличении зазора и возрастанием при увеличении расхода. Это обусловлено возрастанием динамической силы в зазорах, которая должна компенсироваться пружиной.

Ключевые слова: износ трущихся поверхностей, зазор, утечка жидкости, двухосное соединение, насос шестеренный, эксцентриситет.

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Рецензия
на монографию Ракишева Б.Р., Битимбаева М.Ж., Минигулова А.М. «НОВЫЕ ТЕХНОЛОГИИ БУРОВЗРЫВНЫХ РАБОТ НА РУДНИКАХ ТОО “КОРПОРАЦИЯ КАЗАХМЫС”» Алматы: «Жибек жолы», 2020. 380 с.

В первых трех главах монографии «Современное состояние взрывной подготовки горных пород к отработке», «Современное состояние буровых работ на подземных рудниках», «Взрывчатые материалы, средства их изготовления» приведена краткая информация о составляющих, характеристиках и достигнутых результатах буровзрывных работ (БВР) на ведущих горных предприятиях мира.

Достаточное внимание уделено ключевым проблемам буровзрывных работ при подземной разработке полезных ископаемых. Отмечены предпосылки к совершенствованию буровзрывных работ на рудниках «Корпорации Казахмыс». В целях обоснованного выбора бурового оборудования дано описание продукций компаний «Sandvik», «Epiroc», приведены характеристики способов бурения шпуров и скважин. Проанализированы результаты использования современных взрывчатых вещества (ВВ), мини-заводов – стационарных пунктов изготовления ВВ в непосредственной близости от потребителей.

Эти данные совместно с основными горно-геологическими и горно-техническими характеристиками месторождений «Корпорации Казахмыс» послужили основанием для проведения целенаправленных исследований по коренному повышению эффективности взрывного разрушения реального массива пород в различных условиях.

Для теоретического обобщения фактических результатов взрывного разрушения горных пород произведены замеры блочности массивов пород путем их фотографирования с применением высокоточного объектива с использованием для обработки программы AutoCAD 15. Создание структурно-иерархических моделей массивов пород реализовывалось с помощью MC Excel 2009.

По измеренному гранулометрическому составу естественных отдельностей установлены аналитические зависимости их процентного содержания от размеров отдельностей в мелкоблочных, среднеблочных, крупноблочных и весьма крупноблочных массивах пород и выявлены зависимости процентного содержания отдельностей в массиве от известного (заданного) среднего размера естественной отдельности. На их основе создан программный модуль «Гранулометрический состав естественных отдельностей в массиве пород».

С использованием установленных закономерностей расширения взрывной полости при взрыве цилиндрических зарядов ВВ в массиве пород выведено аналитическое выражение для расчета прочностной характеристики горных пород в условиях взрывного нагружения и предельного относительного радиуса взрывной полости во взрываемом массиве пород в зависимости от начального давления продуктов детонации (ПД) и прочностной характеристики пород в условиях взрывного нагружения. Создано программное обеспечение для автоматизированного определения указанных характеристик взрыва в массиве пород. Выведены уравнения для определения размеров зон мелкого дробления и радиальных трещин в зависимости от конкретного сочетания исходных данных, что позволило создать программный модуль «Размеры зон интенсивного дробления пород».

С учетом совокупного влияния волн напряжений, отраженных волн и газообразных продуктов взрыва ВВ на результаты дробления пород, сформулирован принцип рационального размещения заряда ВВ во взрываемом массиве и получены аналитические зависимости для определения параметров расположения зарядов ВВ в отбиваемом слое массива. Разработан программный продукт «Рациональные параметры расположения зарядов в отбиваемом слое массива пород».

Установлены закономерности формирования гранулометрического состава взорванных горных пород в зависимости от различного сочетания физико-механических свойств пород массива, химико-физических характеристик применяемого ВВ, параметров БВР, разработан теоретический метод определения гранулометрического состава взорванных пород и создан программный модуль «Гранулометрический состав взорванной горной массы».

Принципиальное отличие разработанных методов от известных заключается в том, что впервые в горной науке в качестве определяющего показателя результатов взрыва ВВ в твердой среде принят предельный радиус взрывной полости, образованной взрывом ВВ в породе, который надежно взаимоувязывает интегральный результат взрыва с физико-механическими свойствами пород и физико-химическими характеристиками применяемого ВВ.

Совокупность разработанных программных модулей определения технологических характеристик взорванных горных пород представляет собой систему автоматизированного проектирования (САПР) буровзрывных работ на горнодобывающих предприятиях с открытым и подземным способом разработки полезных ископаемых (САПР БВР). Она позволила для рудников ТОО «Корпорация Казахмыс» создать реальные возможности для проектирования, моделирования и управления процессом взрывного дробления пород при различных условиях горного производства для достижения требуемых результатов взрыва. Регулируя исходные данные взрыва, можно определять показатели последующих технологических процессов добычи руды, что, в свою очередь, решает конечную задачу – получение товарного продукта с минимальными затратами и с максимальной производительностью труда.

Предложенные новые технологии БВР на подземных рудниках позволили уменьшить удельный расход ВВ на 5-6% при увеличении выхода горной массы 1 пог.м. шпура (скважины) на 5-6%, обеспечить выход кусков размером менее 300-400 мм в пределах 85-90 %. Доля конвейерного транспорта достигла 50% от общего объема перевозки горной массы.

Содержание, научный уровень и достигнутые практические результаты, описанные в монографии, позволяют высоко оценивать ее научную и практическую ценность. Она может служить действенным руководством для существенного повышения эффективности БВР на горнодобывающих предприятиях.

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