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Қ. И. Сәтпаев атындағы Қазақ ұлттық техникалық зерттеу университеті

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ИЗВЕСТИЯ

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NEWS

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ГЕОЛОГИЯ ЖӘНЕ ТЕХНИКАЛЫҚ ҒЫЛЫМДАР СЕРИЯСЫ



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Қазақстан Республикасы Ұлттық ғылым академиясы "ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы" ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Web of Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

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**DECISION-MAKING FOR CHOOSING
OF GEOLOGICAL AND ENGINEERING OPERATIONS:
CURRENT STATUS AND PROSPECTS**

Abstract. It is commonly known that great care is given to upgrading of the efficiency due to implementing of various new technologies and GTM during development of oil fields. Widespread introduction of GTM as well as enhanced oil recovery (EOR) and elaboration of their technologies raise the issues of relevant choice of the best methods ensuring proper technical and economical efficiency in particular conditions. Despite of the profound interest of the researches to the given question, major problems arise currently anyway at comparative evaluation of various types of GTM regarding particular conditions. The issue of upgrading of efficiency of GTM based on the integrated geological and physical and technological information is currently challenging and deserves relevant consideration. Deep analysis of the conditions for applying of various GTM using advanced techniques and corresponding software allows in its turn to give guidance to current possibilities in order to upgrade efficiency of field deposit. For many years the research focused on upgrading of the efficiency of field deposits had been conducted in various scientific and industrial organizations. The analysis of choosing and implementing of GTM at different deposits is of great interest. Review and analysis of up-to-date condition of problem of GTA choosing are illustrated in the article. Examples of application and performance evaluation of GTM are shown at different deposits. Development and upgrading of the analysis methods as well as forecasting of indicators and decision-making have been observed over the recent years. Their implementation allowed upgrading the efficiency of conducted geological and technical operations. As a result of conducted operations the researchers solved the issue of creating of integrated methodology and its mathematic, scheduled and information application for evaluating of efficiency and optimal scheduling of geological and technical operations at field deposits; structure of automated system of decision support and algorithm of its functioning have been created; by transforming the indicators characterizing the formation into the relevant factors, the equations (linear and multiplicative) were made expressing the dependence of the efficiency indicators of GTM from the formed factors; by variants calculation and analysis of comparative efficiency of any GTM in different conditions the directions were shown and the results of making decisions for choosing of the best GTM were obtained.

Key words: geological and technical measure (GTM), field development, decision-making, crude oil production, oil recovery.

Introduction. During operation of oil field well works are reported to be carried out for adjusting of its development and maintenance of crude oil production level. This range of works is called as geological and technical measures (GTM), owing to which oil producing companies provide achieving of the required indicators of field development. It goes without saying there is an operational need for assessing of methods and efficiency criteria of GTM.

It is commonly known that great care is given to upgrading of the efficiency due to implementing of various new technologies and GTM during development of oil fields. Widespread introduction of GTM as well as enhanced oil recovery (EOR) and elaboration of their technologies raises the issues of relevant choice of the best methods ensuring proper technical and economical efficiency in particular conditions. Despite of profound interest of the researches to the given issue, major problems arise currently anyway at

comparative evaluation of various types of GTM regarding particular conditions. It is linked with the lack of research allowing to give prognosis evaluation of the efficiency of GTM for those reasons where it was not applied for whatever reason. State of the art of analysis techniques of information and decision-making allows to achieve this goal upon availability of integrated geological and physical and technological information. At the same time the experience of implementing of different GTM at various fields confirms its great importance for increasing of oil production index as well as provides importance for the investigation of the paths of using to the fullest extent of potential opportunities of the available information, despite of the fact that we have to face its uncertainty both statistical and non-statistical kind very frequently. The specified data demands applying of the methods allowing to build the relevant forecasting models of efficiency indicators and making decisions within the multicriteriality conditions based on the sort of available information.

Accordingly, the issue for the upgrading of the efficiency of GTM based on the integrated geological and physical and technological information is currently challenging and deserves relevant consideration. Deep analysis of the conditions for applying of various GTM using advanced techniques and corresponding software allows in its turn to give guidance to current possibilities in order to upgrade efficiency of field deposit. For many years the research focused on upgrading of the efficiency of field deposits had been conducted in various scientific and industrial organizations. The analysis of choosing and implementing of GTM at different deposits is of great interest.

Summary of the research related to geological and technical measures. Various types of GTM are currently used at oil deposits. They are as follows: bottom hole treatment (BTH), hydraulic fracturing of formation (HFF), extended reach drilling as well as other methods of oil well stimulation and advanced recovery methods (ARM) of geological horizons [1-3].

Various methods for calculation of the efficiency of applied GTM are offered currently [4]. In general all the measures conducted on the wells can be divided into the different types according to impact: technological, maintenance, ARM and oil production intensification, BTH.

According to the literature analysis different models are used for problem solving of oil production forecasting in order to choose the most efficient GTM. Estimated figures are defined by existing trends of oil production and efficiency of scheduled GTM. Recent research including upgrading of the existing approaches to the assessment of efficiency of GTM make possible wide implementation of new systems of programming, automation of automation process of engineering efficiency of the applied methods of the enhanced oil recovery. This includes the development of software complex EOR–Office representing modern tool designated for automation of the whole complex of tasks for experts engaged in enhanced oil recovery [5, 6]. One of the main approaches to the assessment of technological efficiency of various GTM in oil production is extrapolation. The core of extrapolation methods for the assessment of technological efficiency of various GTM consists in building of oil production base level. For this purpose actual oil production during conducting of GTM is comparing with projection data obtained during extrapolation of background. Herewith even minor mistakes in building of base oil production level as noted by experts lead to inadequate matching and planning of effective GTM [7]. In practical terms the real efficiency of GTM is assumed to assess by the methods of characteristics of water-oil displacement, i.e. by watering curves – connections of type $V_{\text{H}} = f(V_{\text{ж}})$ and by curves of oil production variation – connections of type $V_{\text{H}} = f(t)$: here V_{H} and $V_{\text{ж}}$ – are accumulated selections of oil and liquid; t – time. According to [7] the cumulative effect can be divided into the effect conditioned by changing of oil displacement nature and effect related to liquid drainage intensification. Additional quantity of produced water is calculated. Cumulative effect of GTM is defined by oil production rate decline curves – connections of type $V_{\text{H}} = f(t)$.

Currently the tens of different types of displacement characteristics [8, 9] are calculated and one of the problems is a choice of such displacement characteristic which was coordinated in the best way with production history of the object and ensured the most precise extrapolation when forecasting [10]. For example work [11] shows some issues related to choosing of the most precise methods of assessment of GTM as well as connections are given for reflecting of possible cases of differentiation of technological benefit of enhanced oil recovery method. According to the author's opinion forecasting of the effect (i.e. calculation of the estimated effect) of GTM based on the extrapolation curves of actual and base oil production using methods of characteristics cannot be always reliable. The author thinks that such circumstance appears due to the following reasons. According to his opinion, despite of the fact that

duration of the effect from applying of some types of GTM (for example, HFF) vary between 5-7 years, the using of watering curves for relatively long-ranged forecasts can be reliable only in case of high watering, exceeding 50-70% as a rule. In case of lower watering (at early stages) the duration of the forecast shall not increase 3-6 months. However many types of GTM are conducted in non-aqueous or less water-producing wells.

It is also noted in the work that upon availability of representative information on declining oil production after conducting of GTM (at least 4-6 points) the reliable extrapolation of displacement characteristics is possible. In such conditions the applying of forecasting methods can be viable, which are based on using of oil production decline ratios. In case if the information of oil uptake is not representative the ratios of declining of uptakes by the other wells are possible with more extended operational period after GTM. Based on the above the upgrading of the methods of displacement characteristics currently appears on the agenda and is quite up-to-date [12]. According to work [13] the object of the forecast is wells, bushes, areas, (well fields), shop, horizon, oil and gas production enterprise and etc., forecast intervals - month, quarter, year. Based on the kind and sequence of planned measures there is a possibility of conducting of multiple-path calculations which in its turn demands corresponding software using modern mathematical apparatus. According to this work [13] considers technology of calculations of forecast indicators implemented in integral software complex (ISC) «Baspro-analytic» (developed by CJSC «Analytical center SibINKor») and applied in practice of indicators analysis of oil deposits of the Nizhnevartovsky district. Two programmable modules are supposed to use for task solving: «Baspro-characteristics» – ensures calculation of base production under existing development system and assessment of impact from conducted GTM; «Baspro-forecast» – estimates anticipated oil production including intended effect from estimated GTM.

Diagrams showing the process of calculation of baseline of oil production as well as its forecasting option are illustrated in the work. Classification of indexes of technological efficiency of GTM conducting is shown. Efficiency of various GTM is installed according to the geological structure of the Ershovoe field. As the authors note, the given principle was used to the fullest extent for making of GTM and forecasting of technological performance data of the development of the Ershovoe oil field effected by CJSC «Tyumen Oil Company». The estimate indicators for the assessment of GTM effect are defined in accordance with «Guidance for the assessment of technological efficiency of applying of enhanced oil recovery methods». The methods applied in the program are based on defining of displacement characteristics approximating in the best way the actual data of oil production history. Approximation is carried out in the setting of user-defined interval and belonging to history interval. Approximation error is estimated «in the least-squared sense». The effect in «Baspro-characteristics» is automatically divided into two constituents: oil production effect and intensification effect. Effect from volume reduction of produced water is calculated alongside with two main effects. If characteristic of base production was already calculated and kept in the base of «anticipated production», «Baspro-characteristics» allows to calculate effect comparing this data and actual production [14].

Development of the mathematical modeling techniques and state-of-the-art instruments of computer science enables defining of technological efficiency of GTM for concerned oil and gas object by two possible ways, considers the author of harmonized calculation methods of the efficiency of GTM [9]: by ongoing multidimensional deterministic filtration model; small parameter random and statistical model on the basis of data of production history.

In the first instance creating of geological and filtration models of the object is required and presence of the relevant software describing processes in place. This approach demands relatively big time and funds costs.

In the second instance the assessment of technological efficiency is performed without involving filtration model of the object. The second approach does not demand big time and funds costs and can be used when using efficiency of GTM.

The methods provide confidence estimate of the initial data, theoretical assumptions, testing of the proposed methods as well as manual to software application. This allows increasing quality and confidence of the made decisions. Other authors [10] conduct analysis of currently used methodological issues on assessment of technological efficiency of GTM as well as provide the results of numerical experiments on the assessment of efficiency of GTM using software application «BASPRO-Characteristics» (methods

SibNIINP) at actual data (a range of areas of the Samotlorskoe field) and at the model characteristics estimated on idealized three-dimensional hydrodynamic model.

On the basis of three-dimensional hydrodynamic calculations of model and real sections of oil formations they conducted experimental calculations using software applications «Tempest MORE (Roxar) and Eclipse (Schlumberger), which results were compared with engineering design by the following methods of assessment of technological efficiency of GTM: methods of All-Union RDE of Oil [8, 15], SibNIINP [16], Kazakova A.A. [7, 8, 17] and Shakhverdieva A. Kh. [18]. Such approach to applying of hydrodynamic models enables testing methods of assessment of technological efficiency at «synthetic» development indicators obtained in the modeling process by individual wells. Resulting from data analysis and decision support of GTM by experts from Tyumen [19] the concept of corporate knowledge bases of Tyumen Oil Company was offered designated for keeping, development, using of the experience and empirical knowledge of the experts of the company engaged in geological and technical operations (GTM) [11]. The organization of work with knowledge basis is based on Internet using. The content of the knowledge basis is structured as pairs “GTM – situation under which the operation was conducted”. Mathematical tool of hypergraphs is used for formalizing of representation of the situations, development of the algorithms of the situational analysis (methods of common situational approach) and search.

Situational method (situational models in corporate knowledge basis) is based on searching and using of analogies known from the real experience of the professional activity. The reality of the experience for the engineer can be more important than the results of mathematical modeling. Combination of both approaches where situations – analogues will be used for choosing of the estimated parameters of GTM can be of great interest.

Work [5] describes building of database of GTM by wells recommended for production as well as corresponding criteria for GTM choosing. According to this work building of GTM database by wells by each formation the following criteria shall be chosen: current oil-filled thickness is at most 2 m; formation is not left out or by current fund non-recovery well; formation without coagulation with perforated formation or non-recovery well (this criteria may not be taken into account); in radius of at least 500 m there are no wells by the current fund working on the given formation; bed shaliness is less than 6% (this criteria may not be considered, if the application of EOR (filter cake dissolving) is estimated; the formation permeability is over $0.07 \mu\text{m}^2$. Forecasting flowrates are calculated by all considered formations. Allocation of chosen wells is checked according to the maps of current oil-filled thicknesses. The chosen wells are incorporated into GTM base as recommended for rendering to oil production. According to the authors' opinion the offered criteria enable performing choice of wells for building of the computer-based database with the following verification by the compiled maps which is more effective in case of big scope of information than manual well locations selection. This database building order for the development of GTM was applied upon the drawing-up recommendations by Abdrakhmanovskaya, Tchishminskaya and Eastern – Suleevskaya areas in the Romashkinkoe field [20].

Article [21] considers problem solving of creating of data base of GTM by wells recommended for production using method of fuzzy sets on the example of formation «a» of the horizon Π_1 of the Eastern - Suleevskaya area of the Romashkinskoe field. Fuzzy set is here an object belonging to which can be judged only with certain volume of concern. Problem solving of well locations selection for recommendation for producing for each formation reduces to defining for all wells of membership functions to multitude «well recommended for rendering for production». Presence of many criteria, frequently contradictory, offers difficulties in choosing of the best solution [22]. In this regard the authors reduce the solution of multicriterion problem to one-criterion using fuzzy set theory, considering this criterion as practicability measure of conducting of provided GTM, that in their view allows effecting fast ranging of possible options of decision by degree of practicability and form the most favorite operation schedule.

The author [23] offers the following concept under assessment of efficiency of measures for increasing of oil production and final oil recovery.

To determine the efficiency of any additional technical measure on increasing of current production and final oil recovery two design options of development of oil deposit (production facility) shall be estimated: without additional action (base option); with additional measure. Regular and precise satisfactory information on the operation of producers and injectors (their flowrates of oil and liquid, water injection

and bottom-hole pressure) on the concerned production facilities [23, 24] is required in order to determine confidently of the initial recoverable reserves of oil and liquid actually brought into production, and their changes.

The analysis of the completed operations indicates that most of the authors consider that performance evaluation of application of methods of enhanced oil recovery (EOR) and performing forecasting for new deposit areas building of geological and filtration models is required for updating of geological conditions of distributing of current reserves of oil. In this regard methodological approach is considered relating to the development and implementation of enterprise software products, oriented at mass user and designated for operation of geological and filtration to tasks of enhanced oil recovery of formations.

Operational solving of production tasks by the authors program products was used – three-dimensional enterprise information system (TDEIS), developed by the employees of RDE of mathematics and mechanics named after N.G. Tchebotareva and LLC “Vensis” under active participation of experts of industrial organizations [25].

The concept of ongoing model is used within the scope of this system. Ongoing system is understood as a single computer technology representing assembly of digital integrated geological, geophysical, hydrodynamic information (database), 3D geological and filtration models and software tools of building and viewing of models, issuing of reporting graphical and tabular material. Description of the basic functions of programmable modules is given in the work. The estimated group consists of three modules designated for building of geological, filtration models and GTM model. Module of building of geological model is working in the presence of database by the initial indicators, filtration model modeling module (Fluid) functions under condition of built geological model (Geo), module for assessment and forecasting of efficiency of GTM uses the results of geological and filtration model for work.

In such a way almost all field-geological information is covered. Classes of oil-field tasks are detailed. Due to GTM the estimated group of software modules consists of GTM module performing two functions: assessment of efficiency of GTM application; analysis of efficiency of GTM in the different geological and industrial conditions.

The review stated above represents profound interest of the researchers to the issue of assessment of efficiency of GTM, development of scientifically-based methodological approaches, analysis and choosing of the best options of the decisions and therefore confirms importance and applicability of decision-making on upgrading of efficiency of GTM.

As you can see from the above mentioned brief survey large number of studies has been performed, related to the assessment of technological efficiency as a separate type of GTM as well as the relevant guidance documents was developed.

This research as well as the results of GTM conducted in several districts allow to solve a number of tasks under their generalization responding several questions in particular predictive estimates of the relative efficiency of the different types of GTM on the concerned specified object, as well as determining of the object which is best suited for certain type of GTM.

Solving of these issues becomes difficult by the lack of the approach concluding in careful statistical analysis of integrated geological and geophysical and technological information, models expressing connection of efficiency indicators of any type of GTM with parameters describing the discovered object (formation). Moreover, in a number of cases the decision-making on choosing of GTM becomes very difficult by the lack or insufficient information.

Modern level of development of mathematical methods and informational technologies as well as the results of their successful using at various stages of the research works enable solving the assigned tasks in the conditions of limited information.

As you can see from the review this circumstance was considered in a number of works related to the efficiency of certain types of GTM.

All known methods for defining of technological and economical efficiency of applying of GTM are based on the comparing of certain dependencies based as a result of its implementing with base. For example, when assessing of the efficiency of the watering actual displacement correspondences are used using this method and without it. At the same time it is obvious that the main task concludes in correct approximation of the natural base process operation without using of GTM [8, 18, 26, 27].

In view of presented information alongside with the development of effective methods of evaluation of technological and economical efficiency of GTM the development of new approaches acquires particular importance enabling to give technological and economical assessment to not only one particular GTM in the certain conditions but comparative efficiency of any GTM in different physical and geological and technical and geological conditions.

This allows performing reasonable matching for these or those GTM wellbores, deposits and their technologies.

Resulting from which work [26] offers calculation system of performance indicators of GTM on the basis of data of technological, physical and geological and commercial characteristics characterizing conditions of conducting of any GTM. Accordingly we performed the research pursuant to slightly simplified and upgraded option of a system [26]. According to the stated diagram the condition of the wells, equipment, history of conversion, the technology of conducting of GTM is characterized by technological features; physical and geological indicators – condition and features of oil deposit, namely: porosity, permeability, hydrocarbon saturation, productivity of deposits and etc.; commercial – deposit development system, current and cumulative oil production before and after conducting of GTM, characteristics of well interaction and etc.

In such a way the chosen technological, physical and geological and commercial indicators generate information collection allowing characterizing the involved facility, technology of conduction of GTM and their impact to the results of conducted measures.

Analysis and assessment of impact of geological and technological characteristics of the object to the efficiency indicators of GTM. As a result from the analysis of the research accumulated to the present time large number of different GTM is used for upgrading the efficiency of the development of oil fields and intensification of oil production. Efficiency of their using depends on reasonable combination of large number of physical and geological, technological and industrial indicators characterizing in an integrated manner the conditions of conducting of any GTM. In practical terms, as a rule, for particular deposits choosing of GTM, their parameters as well as their technological and economical assessment, is performed in geological services of oil and gas production department on the ground of gained experience. However very often despite of experience and knowledge of geological services of oil and gas production department the choice of sites, GTM and their technology is conducted not always properly to certain geological and technological development terms. In practice there is no single approach using which we can give correct technological and economical assessment to not only separately taken GTM in certain conditions but also give predictive estimate of comparative efficiency in various physical and geological and technical and technological conditions.

Owing to recent development of the methods considering marked circumstances, there is a possibility to decide the assigned tasks on the higher level. It is intended here possibility of creating different models as well as the relevant programs based on the integrated geological and geophysical and technical and technological information and allowing making the most grounded technological decisions.

In order to create such models, data of geological and technical measures are used which is conducted on the facilities of different deposits of Kazakhstan [26, 28, 37]. The following factors serve as indicators which impact the efficiency of geological and technical measure: total thickness of formation, m (x_1), oil-filled thickness, m (x_2), uncovered oil-filled thickness, m (x_3), net sand coefficient (x_4), porosity unit fraction (x_5), permeability, $K_p \cdot 10^{-3} \mu\text{m}^2$ (x_6), oil viscosity, mPa*s (formation condition) (x_7), oil density t/m^3 (x_8), gas content, m^3/t (x_9), initial oil saturation, unit fraction (x_{10}), formation temperature, $^\circ\text{C}$ (x_{11}), wax content in oil, % (x_{12}), sulfur content in oil, % (x_{13}), oil flowrate to geological and technical measure, t/day (x_{14}), liquid flowrate to geological and technical measure, t/day (x_{15}), watering to geological and technical measure, % (x_{16}). The following factors serve as indicators of geological and technical measure: duration of the effect, day. (Y_1), additional oil production, t. (Y_2), incremental oil rate, t (Y_3), oil flowrate after geological and technical measure, t/day (Y_4), watering after geological and technical measure, % (Y_5).

Thus, initial data consist of 16 indicators and 5 efficiency indicators by each type of GTM. Further according to works [30, 32, 41], transforming of initial data is conducted in order to reduce a number of input variables.

Then correlation analysis enables installing dependencies of indicators of GTM from the marked factors and before going to correlation analysis, there is a need to ensure in dependency of data to normal

law of distributions which is one of the requirements. There are many different criteria for verifying of the given condition. Verification for normality is a binding procedure within conducting of measurements, control, tests, processing according to the Russian GOST. There are different criteria, but we used criteria of Shapiro-Wilk [29, 37].

The criterion of Shapiro-Wilk is based on relation of optimum linear unbiased estimate to its common estimate by the method of maximum likelihood. Statistics of criterion is as follows:

$$W = \frac{1}{s^2} \left[\sum_{i=1}^n a_{n-i+1} \cdot (x_{n-i+1} - x_i) \right]^2, \quad (1)$$

$$\text{where } s^2 = \sum_{i=1}^n (x_i - \bar{x})^2, \bar{x} = \frac{1}{n} \sum_{i=1}^n x_i$$

Numerator is the square of estimate of root-mean-square deviation of Lloyd [30]. Critical statistical values $W(\alpha)$ were defined according to literature data, for example, [29]. If $W < W(\alpha)$, null hypothesis normality of distribution deviates on the level of significance α .

The conducted calculations give opportunity to ground application of data at correlation analysis.

In order to build the dependencies of the selected criteria from the influential factors data of conditions and results of GTM were subjected to the correlation analysis. Moreover the data were subjected to the statistical processing by two ways using the program of linear regression.

1. Dependencies of the efficiency indicators from geological and technological factors by their natural values:

$$Y = a_0 + \sum_{i=1}^9 a_i x_i \quad (2)$$

2. All the data were preliminary logarithmed, the linear dependency was made in a such way that using exponentiation transformed into multiplicative with further specification by successive approximation:

$$Y = a_0 x_1^{b_1} \cdot x_2^{b_2} \cdot \dots \cdot x_9^{b_9} \quad (3)$$

Each equation represented the dependency of any efficiency indicator from the chosen factors. Such equations were made for each type of GTM.

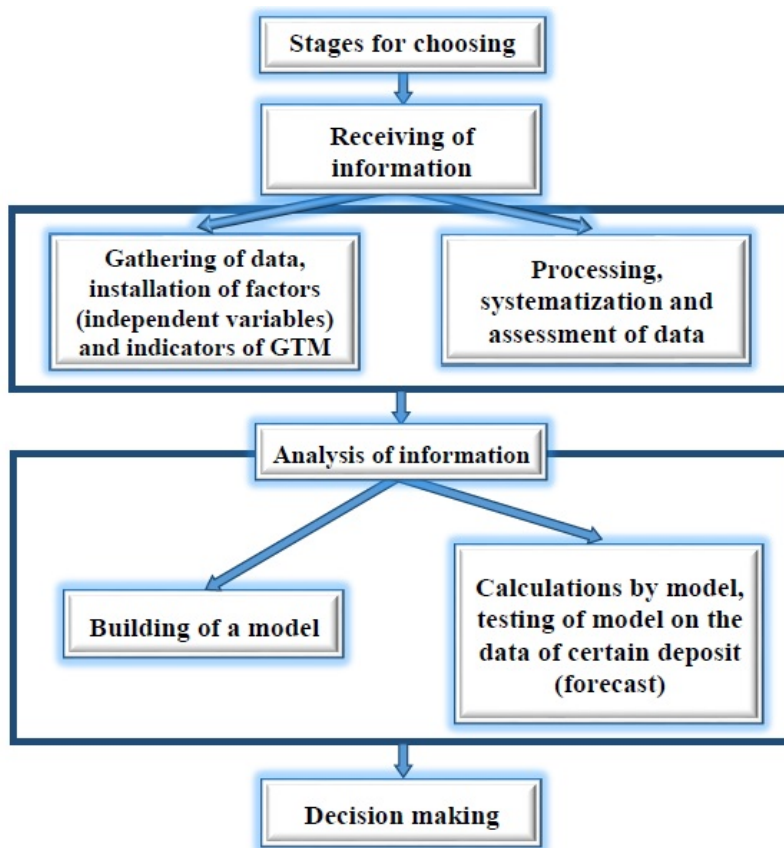
After receiving of regression equations the degree of correspondence of calculated values of the efficiency indicators were installed for different GTM by actual equations. The quantitative assessment of degree of conformity is defined by identical measure according to the formula given in work [31], which values shall be changed within $0 \leq I \leq 1$:

$$I = \frac{1}{1 + \frac{\sum_{i=1}^N (Y_{расч} i - Y)^2}{\sum_{i=1}^N (Y_{расч} i - \bar{Y})^2}} \quad (4)$$

When using integrated geological and geophysical and technical and technological information for taking of the most grounded technological decision depending on type of GTM that type of regression equation having large identity measure is chosen.

Decision-making at choosing of GTM. Results of calculations by received models are used when making decisions for choosing the best GTM for the considered conditions. This was made using efficiency indicators of GTM, adopted as criteria in such a way that the desired solution was satisfied to conditions of 5 criteria. As it is shown from the review different authors used various criteria for choosing of GTM. The whole process can be presented as a system which simplified diagram is represented on figure. When solving multicriteria tasks the difficulties arise due to the simultaneous satisfying of all the criteria, i.e. it is required to take decisions in the conditions of uncertainty.

Recently various methods are used for solving of such tasks, such as method of combining of criteria into one, generalized method of «the least concessions», positions of fuzzy set theory engineered by L.Zade. Classification of uncertainties given in works [2, 17] enables estimating the situation and choosing the best method for decision-making. Further when making decisions the method called “the least concessions” [32, 37] was used.



Simplified diagram for system of choosing of GTM.

When using the given method the decision of multicriteria task reduces to successive maximization (minimization) of private criteria and choosing of values of concessions. Besides qualitative analysis of the relative importance of private criteria is made first and they are numbered in order of decreasing of the importance. Then the value of the permissible reduction of the value of first importance criterion is designated and the second importance criterion is maximized provided that the value of the first criterion should not differ from maximum by more than the value of installed reduction. The recession value is redesignated but according to the second criterion and the maximum value of the third importance criterion is found provided that the values of the first two criteria should not differ from the previously found maximum values by more than values of the corresponding recessions. Further all the other partial criteria are used. The resulting strategies are considered optimal.

Recently the problems of management and decision-making have increasingly attracted the attention of researchers – oil industry workers. A.A. Koltun in his work [39]. Choosing of geological and technical measures uses the data of the development history (base curve method), which does not enable considering hydrodynamic processes and interference of wells to the fullest extent thereby reducing the reliability of the obtained decisions. However wide development of the hydrodynamic modeling as a mean for choosing of geological and technical measures laid the groundwork for automation of their choosing [33].

The work by A. Cottini-Loureiro and M. Araujo [33, 34] using efficiency maps was suggested for choosing of well pad distribution patterns but time expenditures for building of efficiency maps drastically depend on dimension of the hydrodynamic models and is a process demanding to computing resources. When setting into operation of new wells changing of dynamics of existing wells occurs which does not allow to analyzed method to consider interference of wells in time and employ high requirements to computing resources.

Owing to close location of wells their arrangement diagram as shown in work by G. Santellani and B.Hansen [35], leads to difficulties of consideration of their interference it should also be noted that applying of the method stated in the given work force to stop using reputable existing well pad distribution pattern.

The issues of building of informational decision-making support system are considered in a number of studies when using type of geological and technical measure on the oil well for enhancing of its performance. In some of them choosing of options for performing of the certain type of measure is conducting according to the stages of the system analysis of problem situations, [36]. Describing of work of informational system is given on the example of the main software module in the given work allowing to calculate economical efficiency of the geological and technical measure such as formation fracturing [36]. Main stages of decision-making are described when choosing of GTM type. Therewith the process for choosing of wells for conducting of the certain type of GTM undergo the following stages: analysis of the situation (identification of need for conducting of GTM for the certain well); defining of goals (estimating of parameters, on which changing GTM shall be directed); producing of decisions and analysis of alternatives (building of the list of possible types of GTM for achieving of the estimated goals, assessment of their efficiency); implementation of the decision (conducting of GTM); assessment of the results (monitoring of condition of the well after conducting of GTM, analysis of the results). The proposed informational system consists of several software modules by the number of types of GTM [36]. According to the authors' opinion such indicator as achieving of estimated incremental oil rate shall not be considered as a single criterion for assessment of the efficiency of conducting of geological and technical measures. It goes without saying that the more complete analysis requires performing additional analysis of such indicators as quantity of oil, recovered additionally due to conducting of GTM as well as duration of the effect from the measure. The results of analysis of the efficiency of GTM for the period of 2011-2014 are given in the article using the mentioned approach.

Considering significant number of fields developed by LLC «LUKOIL-PERM», all of them are conditionally divided into the groups by geographic principle [38]. The information of the conducted geological and technical measures conducted in 2011-2014 on the wells by the groups of wells for increasing of well efficiency such as hydraulic fracturing of formation, acid treatment, radial drilling, repeated and additional perforations are shown in the stated work.

As follows from the presented data the repeated and (or) additional perforation is conducted more often at the wells of deposits of all the groups, excluding the northern group. The authors note that the most common type of impact is hydraulic fracturing on the wells of the northern group of wells.

In such a way, the research in this direction shows the opportunity of assessment of the comparative efficiency and decision-making when choosing of GTM in various conditions.

Conclusion. Practice of the applying of GTM shows that their implementation appears ineffective. Thus conducting of comparative analysis for the assessment of the efficiency of their using is of great interest not only in conditions of their conducting but in the conditions where they were not conducted. Such assessment shall be based on the relevant models expressing the dependence of indicators of efficiency from the indicators characterizing geological and physical conditions of using any measure in the considered or similar conditions of the other field.

The models obtained for such purpose allow forecasting of the indicators of the efficiency of any type of GTM in new geological and physical conditions. In this regard the systems and design models were used for the purpose of forecasting of indicators for the conditions different from those where GTM were used. The results of the calculations were used when making decisions for choosing of the best GTM for considered conditions. This was performed using efficiency indicators of GTM taken as criteria of GTM adopted as criteria in such a way that the decision would satisfy all the adopted criteria.

Thus, development and upgrading of methods of the analysis, forecasting of the indicators and decision-making which implementation allowed to increase the efficiency of conducted geological and technical measures have been watched recently. As a result of conducted works the researchers solved the task of creating of comprehensive methodology and its mathematical, software and information application for assessment of the efficiency and optimal planning of geological and technical measures on the oil fields; the structure of the automated system of decision support and algorithm of its functioning have been developed; by transforming the indicators characterizing the formation into the relevant factors, the equations (linear and multiplicative) were made expressing the dependence of the efficiency indicators of GTM from the formed factors; by variants calculation and analysis of comparative efficiency of any GTM in different conditions the directions were shown and the results of making decisions for choosing of the best GTM were obtained.

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ҚАЗІРГІ ЗАМАНҒЫ ЖАҒДАЙЫ ЖӘНЕ ЖЕТІСТІКТЕРІ: ГЕОЛОГО-ТЕХНИКАЛЫҚ ШАРАЛАРДЫ ТАҢДАУ БОЙЫНША ШЕШІМНІҢ ҚАБЫЛДАНУЫ

Аннотация. Мұнай кенорындарын игеру кезінде ГТШ және әртүрлі жаңа технологияларды қолдану есебінен тиімділікті арттыруға көп көңіл бөлінеді. Нақты жағдайда қажетті технологиялық тиімділікті қамтамасыз етуде, ең жақсы әдісті дұрыс таңдауда, олардың технологияларын дамуы және МАӨ, сонымен қатар ГТШ кеңінен қолдануда көптеген сұрақтар қойылады. Мұндай сұрақтарға зерттеушілердің үлкен қызығушылықтарымен қатар, қазіргі таңда нақты жағдайда әртүрлі ГТШ түрлерін салыстырмалы бағалау кезінде маңызды қиыншылықтар туындайды. Қазіргі таңда кешенді геолого-физикалық және технологиялық ақпараттар негізінде ГТШ тиімділіктерін арттыру мәселелері актуалды және сәйкесінше шешім қабылдануға ие болады. Кенорынды игерудің тиімділігін арттыру мақсатында алдымен бар мүмкіндікті дұрыс реттеу сәйкесінше дұрыс бағыттауға мүмкіндігі бар бағдарламаларды және қазіргі таңдағы әдістерді қолданумен әртүрлі ГТШ қолдану жағдайы мұқият талдау жасауға мүмкіндік береді. Көп жылдар бойы зерттеулер әртүрлі ғылыми және өндірістік ұйымдарда, кенорында игерудің тиімділігін арттыруға бағытталып жүргізілді. Әртүрлі кенорында ГТШ енгізу және таңдау тәжірибелерін талдау қызығушылықты тудырады. Мақалада ГТШ таңдаудың қазіргі таңдағы жағдайын талдау және жинақтар келтіріледі. Әртүрлі кенорындарда ГТШ тиімділіктерін бағалау және қолдану мысалдары көрсетілген. Соңғы жылдары өткізілген геолого-техникалық шаралардың тиімділігін арттыру реализациясы, шешімдер қабылдану және көрсеткіштер болжамдары, талдау әдістерін жетілдіру және дамуы байқалады. Мұнай кенорындарында геолого-техникалық шараларын тиімді жоспарлау және тиімділікті бағалау үшін кешенді әдістерді құру және олардың математикалық, бағдарламалық және ақпараттық қамтамасыз ету тапсырмалары зерттеушілердің жүргізілген жұмыстары нәтижелерінде шешілген; шешімді қабылдауды қолдаудың және оның алгоритмінің жұмыс істеуінің автоматтандырылған жүйелер құрылымы игерілген; қалыптасқан факторлардан ГТШ тиімділігінің көрсеткіштерін көрсететін, сәйкесінше факторларға қабатты сипаттайтын, қайта құру белгілері жолымен (сызықты және мультипликативтік) теңдеулер құрастырылды; ең жақсы таңдау бойынша шешім қабылдау нәтижелері алынды және нұсқалық есептеулер жолымен және салыстырмалы тиімділікті талдау әртүрлі жағдайдағы сол немесе өзге ГТШ жолдары көрсетілген.

Түйін сөздер: геолого-техникалық шаралар (ГТШ), кенорынды игеру, шешім қабылдануы, мұнайды өндіру, мұнайбергіштік.

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ПРИНЯТИЕ РЕШЕНИЙ ПО ВЫБОРУ ГЕОЛОГО-ТЕХНИЧЕСКИХ МЕРОПРИЯТИЙ: СОВРЕМЕННОЕ СОСТОЯНИЕ И ПЕРСПЕКТИВЫ

Аннотация. Как известно, повышению эффективности за счет применения различных новых технологий и ГТМ уделяется большое внимание при разработке нефтяных месторождений. Широкое внедрение ГТМ, а также е МУН и развитие их технологий ставит вопросы адекватного выбора наилучших методов, обеспечивающих должную технологическую эффективность в конкретных условиях. Несмотря на большой интерес исследователей к данному вопросу, все же в настоящее время серьезные затруднения возникают при сравнительной оценке различных видов ГТМ применительно к конкретным условиям. Проблема повышения эффективности ГТМ на основе комплексной геолого-физической и технологической информации в настоящее время является актуальной и заслуживает соответствующего внимания. Тщательный анализ условий применения различных ГТМ с использованием современных методов и соответствующего программного обеспечения позволит в свою очередь правильно сориентировать имеющиеся возможности с целью повышения эффективности разработки месторождений. На протяжении многих лет исследования, направленные на повышение эффективности разработки месторождений, проводились в различных научных и производственных организациях. Представляет интерес анализ опыта выбора и внедрения ГТМ на различных месторождениях. В статье приводится обзор и анализ современного состояния проблемы выбора ГТМ. Показаны примеры применения и оценки эффективности ГТМ на различных месторождениях. В последние годы наблюдается развитие и совершенствование методов анализа, прогнозирования показателей и принятия решений, реализация которых позволила повысить эффективность проводимых геолого-технических мероприятий. В результате проведенных работ исследователями решена задача создания комплексной методики и ее математического, программного и информационного обеспечения для оценки эффективности и оптимального планирования геолого-технических мероприятий на нефтяных месторождениях; разработана структура автоматизированной системы поддержки принятия решения и алгоритм ее функционирования; путем преобразования признаков, характеризующих пласт, в соответствующие факторы, построены уравнения (линейное и мультипликативное), выражающие зависимость показателей эффективности ГТМ от сформированных факторов; путем вариантных расчетов и анализа сравнительной эффективности того или иного ГТМ в различных условиях показаны пути и получены результаты принятия решений по выбору наилучшего ГТМ.

Ключевые слова: геолого-техническое мероприятие (ГТМ), разработка месторождений, принятие решений, добыча нефти, нефтеотдача.

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SOLAR-DRIVEN RESOURCES OF THE REPUBLIC OF KAZAKHSTAN

Abstract. The present article considers the solar-driven resources of the Republic of Kazakhstan. To assess the solar energy potential, falling onto the territory in any region, it is necessary to have data on the solar energy potential. Based on actual observations and theoretical calculations generalizing, there exists the data: annual and latitudinal motion of possible monthly and annual sums of the direct solar irradiation falling onto the perpendicular surface under the conditions of clear sky, data on sunshine duration, daily motion of solar radiation for typical days of the year, maps of distributing the average monthly radiation sums for June and December on the territory as well as the maps of distributing «technically applicable and economically profitable solar capacity», developed criteria of defining the notion thereof. All solar systems estimates upon assessing the solar-driven resources on Kazakhstan territory are based on quantitative characteristics of the direct solar radiation onto the horizontal surface from which there might be done recalculation from the horizontal to inclined plane of any orientation. Proceeding from the results of average values of the direct, total irradiation and duration of the sunshine statistical treatment there have been differentiated five zones and compiled a histogram characterizing the possibility of introducing the solar plants onto Kazakhstan territory.

Keywords: solar energy, solar collector, solar-driven resources, solar radiation.

Introduction. Upon specifying the solar plants usage feasibility at any location there conducted preliminary calculations, taking into account the average annual, average monthly total amount of solar radiation, number of clear and dull days, duration of frostless period, cost of solar plant, their efficiency factor, etc.

At that, there was used reference data and passport data of solar stations with their technical specifications.

To assess the solar energy potential falling onto the territory in any region it is necessary to have the data on the solar energy potential.

In the article [1] there is analyzed the current energetic situation in Kazakhstan, including fossil energy sources and renewable energy sources and have been studied political factors in the energetic sector. The main aim of the article [2] is studying the prospects of the energy renewable sources development. It has been proved, that about 18% of the world energy consumption has been received from the renewable energy sources. In the article herein [3] there were presented some offers for developing the solar industry in Kazakhstan, based on the analysis of the global solar energetic model. In the document [4] the principal attention was paid to discussing the new technological components, which might be used for developing the system of renewable sources monitoring. There are being discussed the principles and architectural technologies which can be applied to such system implementation. As well, there were considered several

examples of monitoring systems and engineering aspects behind such system. The article [5] considers different potential local resources, unrelated to fossil fuels, water power, solar power, wind, biomass and uranium, and there is being installed the structure of those resources' priority evaluation.

Similar studies are being conducted abroad, the work [6] demonstrates the data on the average monthly, daily global and direct solar radiation in the area of Jordanian University of science and engineering in the North Jordan. Maximum, average and minimum values, of both global and direct radiation were given in the period of 1990-1996 proceeding from the measurement data. Offered mathematical model for computing the maximum global daily radiation has been represented as the day of year function. Other mathematical regressions for various radiation characteristics have been presented as well.

The work [7] used several linear regression models using 9 variables to define the average monthly value of global radiation in the area of Antalya (Turkey) Outcomes show, that the total solar radiation can be defined with a percentage error from $-5,7$ to $3,9$ %, average error $2,0$ % and root-mean-square $-2,5$ %.

The article [8] creates a long-term database of monthly solar radiation in Zimbabwe. There was taken account of meteorological data, pyranometric measurements of semi sphere radiation. Simulation based on the data has been executed by means of two methods, calculation results are failed no more than for 7% .

On the ground of the hourly data on the total solar radiation in Quetta (Pakistan) within 10 years there was carried out the stochastic simulation and obtained Markov transfer matrixes, allowing the calculation of global solar radiation for the area thereof in MJ/m^2 [9].

The data on the solar radiation in Malaysia for the period of 10 years was used in the work [10] to get mathematical description. There were considered the simulation outcomes applying the models of beta distribution for 4 regions of the country with meteorological stations.

There is known the research work [11], which systematizes the latest data on solar radiation resources in Brazil. It describes geographical distribution of solar radiation in Brazil.. It demonstrates geographical distribution of solar power and those resources dependences on the local climatic conditions. Average annual level of the solar radiation in Brazil is within $18 \pm 2 \text{ MJ}/(\text{m}^2 \cdot \text{day})$. Maximum monthly average level of the solar radiation is in Rio Grande state, located in the south of the country, in December and January ($\sim 24 \text{ MJ}/(\text{m}^2 \cdot \text{day})$), and minimum value of the solar radiation is in June and July in the south coast of the same state and amounts to $8 \text{ MJ}/(\text{m}^2 \cdot \text{day})$.

The work [12] reports the outcomes of experimental researches concerning the measurement of average monthly hourly diffused solar radiation in two cities of Nigeria: Lagos, a coastal town in the south of the country and Zaire, the town, located in savanna in the north ($11, 10^\circ$ north latitude.) of the country. Experimental data have been compared with prognosis, obtained by means of statistical models, developed for high latitudes. Comparison has shown that the models thereof are incorrect for Nigeria conditions.

Methods. We have offered a complex approach. Unfortunately, it does not grasp all necessary parameters and apart from that, it is schematic, large-scale due to shortage of actinometrical stations.

Multitude of natural factors conditions the task of their correct account upon the sun power plants development. Nevertheless, the work is recommended to be fulfilled based on radiation-climatic zoning of the republic, which seems a complex process. At that, the methodological base is detecting the main climatic elements criteria, account and assessment of radiation regime on the territory being considered.

To use the solar power effectively in combination with other climate components for the needs of the solar heating, the criteria for zoning are the solar intensity, climate meteorological parameters (outside air temperature, wind regime and other atmospheric phenomena). As the base of all solar system factors calculations while assessing solar power resources on the territory of Kazakhstan there were accepted quantitative characteristics of direct solar radiation on the horizontal surface, from which it is possible to perform recalculation from the horizontal to inclined plane of any orientation (table 13). Proceeding from the results of statistical treatment of the direct, total radiation and sunshine duration average values in compliance with the figures 19 and 20 there were differentiated five zones and drawn up a histogram, characterizing the possibilities of introducing the solar stations along the territory of Kazakhstan. Zone 1 occupies forest-steppe zones, located in the Northern Kazakhstan with an average June totals of the direct and global radiation of $11-14$ and $20-22 \text{ MJ}/\text{v}^2$, i.e. $350-400$ and $600-700 \text{ MJ}/\text{m}^2$ a month. According to the main features the solar power usage in this region is possible for practical aims of CCTC systems, but it is limited with a climatic, meteorological factor, wind and frequent sharp decrease in temperature in spring-autumn period. Sunshine duration in the year fluctuates from 1900 to 2200 hours.

Zone 2 is on the territory of Turgai valley, southern suburbs of Western-Siberian lowlands. Daily there is 22-24 MJ/m² of global radiation, but the most part of it is in the form of direct one, 13-15 MJ/m². Monthly amount is 600-700 and 400-500 MJ/m². The region thereof is characterized with sufficient amount of sunshine hours, i.e. 2200-2500 approximately, comparing to the Zone 1. But meteorological factors are not favorable either. In spring-autumn period there is stable cold air in Turgai lowlands, conditioning frequent, lasting ground frost.

Zone 3 is moderately-favorable for the solar power usage, which includes Precaspian lowland, Mugodzhary upland, Kazakh hummocky topography, Altai mountain uplift. Daily amount of average total radiation here is in July 23-26 MJ/m², whereof 15-18 MJ/m² is in the form of the direct radiation, monthly total amounts - to 700-800 and 400-550 MJ/m². Annual sunshine duration fluctuates within 2500-2700 hours.

Zone 4 includes Kyzyl Kum, Turan lowland, plain of Balkhash-Alakol basin, Tarbagata, Junggar and Zailiisky Ala Tau mountain ranges. Daily average total solar radiation here is 23-26 MJ/m², at that, the big amount is in the form of direct one, 15-18 MJ/m². Thus, correspondingly the monthly solar power amount is 700-800 and 500-600 MJ/m². Annual sum of direct radiation is higher here, especially in the mountains. Sunshine duration is 2700-2900 hours and the region is characterized as favorable for the solar power usage.

Zone 5 is the deserts Ak-Kum, Betpak-Dala with an average daily solar power intensity totals of correspondingly 18-22 and 25-28 MJ/m², and monthly sums 550-700 and 750-900 MJ/m². The region is also favorable for using the solar power, and as we can see, in general, grasps the south of the republic. Sunshine duration in summer is about 390 hours, annual – 2900-3200 hours at minimal amount of dull days.

As it is shown with analysis a wide range of quantitative characteristics, reflecting the solar radiation regime peculiarities, sunshine duration and cloudiness confirms that the separating having been done.

Results. Structural temporary features of the supposed days of “sunny” and “electric” solar plants heating are given for all the zones. The greatest interest from the energy point of view is the amount of days with the sun and electric water heating in the solar plants within a year. It is typical for the 1st zone to

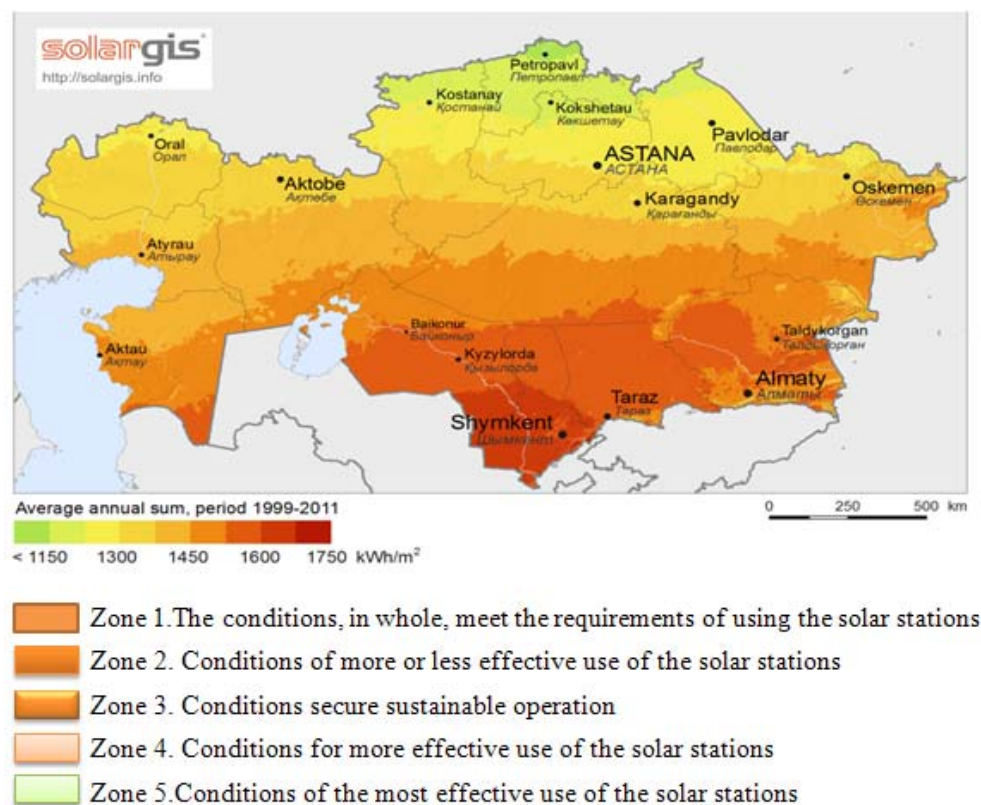


Figure 1 – Solar power resource of the Republic of Kazakhstan

use the solar power during 180 days, the rest 180 days there is the electric heating. For the 2nd, 3rd and 4th zones the number of days when the solar energy is used grows up to 270, and amount of days while using electric water heating decreases to 94. In the 5th zone it is possible to use the solar power more efficiently within a year. Criterion for such evaluation is an average time period, when the radiation amounts to minimum 0,4 kW/m² and exceeds 6 hours per day.

Radiation regime characteristics definition has been conducted as exemplified by Almaty hydro-meteorological station (HMS). The solar radiation is the main source for the heat conductor process in the solar station. For that purpose, firstly, it is necessary to get an average background mode of the solar radiation according to available data, many years of observation for Almaty city.

The big city's radiation regime has Almaty HMS, situated at Zailiisky Ala Tau foothills. Along with the area's height increase the solar radiation grows at the expense of atmosphere's transparent zing. Usually in the summer time's first part the atmosphere is more clear, than in the second part, which is connected with the atmosphere dust content increase, and convective clouds.

Solar power and meteorological zonal characteristics of Kazakhstan's territory

Region appropriate for practical usage	Total direct irradiation onto the horizontal surface (S'), MJ/m ²								
	days		min max		winter	spring	summer	fall	year
	1	7	1	7	12,1,2	3,4,5	6,7,8	9,10,11	
1	2	3	4	5	6	7	8	9	10
1. Conditions, in whole, meet the requirements of the solar plants usage Kostanai, Astana)	1,2 1,4	11,2 13,5	37,7 41,9	347,7 419,0	138 276	842 771	1064 1185	322 339	2367 2509
2. Conditions more or less effective for the solar plants usage Dzhanibek, Semipalatinsk)	1,2 2,3	13,9 14,5	37,7 71,2	431,6 448,4	150 243	880 1018	1252 1315	440 490	2723 3067
3. Conditions secure sustainable operation of the solar plants (Atyrau, Aktobe Aktau)	1,9 1,75 1,6	17,4 15,8 15,8	58,7 54,5 50,3	540,5 490,2 490,2	230 197 192	1127 934 1009	1596 1446 1454	662 553 636	3616 3129 3293
4. Conditions for more effective usage of the solar stations (Aralsk Sea, Zhezkazgan, Buran)	2,7 3,1 2,9	17,9 15,9 17,0	83,8 96,4 92,2	557,3 494,4 528	276 297 293	1156 1043 1152	1650 1462 1546	708 632 662	3791 3435 3653
5. Conditions for the most effective usage of the solar plants (Barsa-Kelmes, Ak-Kum, Kuigan)	2,9 4,19 3,6	17,4 21,3 19,7	92,2 129,8 113,1	540,5 662,0 611,7	272 360 347	1169 1210 1122	1713 1965 1751	699 972 825	3854 4508 4047

Table continuation

Region appropriate for practical usage	Total of global irradiation on the horizontal surface, (Q), MJ/m ²								
	days		min max		winter	spring	summer	fall	year
					12,1,2	3,4,5	6,7,8	9,10,11	
1	11	12	13	14	15	16	17	18	19
1. Conditions, in whole, meet the requirements of the solar plants usage Kostanai, Astana)	3,6 4,5	20,1 22	113,2 138,3	624 683	389 473	1520 1529	1839 1935	662 733	4412 4671
2. Conditions more or less effective for the solar plants usage Dzhanibek, Semipalatinsk)	4,0 5,3	22,6 22,8	125,7 163,4	699 708	414 817	1525 1730	2002 2065	775 863	4717 5191
3. Conditions secure sustainable operation of the solar plants (Atyrau, Aktobe Aktau)	5,1 5 4,19	25,5 24,5 23	159,3 155 129,9	792 758 716	469 532 452	1780 1634 1646	2300 2191 2099	1047 905 997	5664 5262 5195
4. Conditions for more effective usage of the solar stations (Aralsk Sea, Zhezkazgan, Buran)	6,0 6,0 5,9	25,4 23,7 24,5	188,5 188,5 184,4	787 737 762	624 607 607	1872 1726 1784	2317 2149 2208	1076 993 1013	5891 5476 5614
5. Conditions for the most effective usage of the solar plants (Barsa-Kelmes, Ak-Kum, Kuigan)	5,9 7,3 7,3	24,6 27,9 26,7	184,4 226,3 226,3	762 867 829	578 695 720	1822 1851 1826	2312 2543 2384	1030 1324 1206	5744 6414 6138

Table continuation

Region appropriate for practical usage	Sunshine duration, hours							Solar and electric heating duration (hours)	
	days		winter	spring	summer	fall	yr	annual	
	1	7	12,1,2	3,4,5	6,7,8	9,10,11		solar	electric
1	20	21	22	23	24	25	26	27	28
1. Conditions, in whole meet the requirements of the solar plants usage (Kostanai, Astana)	2,3 2,7	10,2 10,2	241 266	664 640	861 876	371 404	2137 2186	1900 2000	6900 6800
2. Conditions more or less effective for the solar plants usage (Dzhanybek, Semipalatinsk)	2,0 3,6	10,9 10,4	215 339	714 737	996 937	499 507	2424 2523	2200 2300	6600 6500
3. Conditions secure sustainable operation of the solar plants (Atyrau, Aktobe, Aktau)	2,4 3 2,2	11,3 11,3 11,4	249 301 257	724 712 701	1021 1032 1021	585 548 584	2579 2593 2563	2400 2400 2400	6400 6400 6400
4. Conditions for more effective usage of the solar stations (Aralsk Sea, Zhezkazgan, Buran)	3,7 3,3 4,5	11,9 11,2 11,1	350 350 395	799 750 793	1090 1014 1003	624 589 587	2863 2703 2778	2700 2600 2700	6100 6200 6100
5. Conditions for the most effective usage of the solar plants (Barsa-Kelmes, Ak-Kum, Kuigan)	3,3 4,3 4,7	12,2 13 12	324 391 420	813 770 761	1132 1160 1102	648 758 695	2917 3079 2978	2800 2900 2900	6000 5900 5900

Table continuation

Region appropriate for practical usage	Cloudiness, total number of clear and dull days		Average daily air temperature, 0C								Frostless period duration, days in a year
	annual		monthly								
	in points	clear	dull.	4	5	6	7	8	9	10	
1	29	30	31	32	33	34	35	36	37	38	39
1. Conditions, in whole meet the requirements of the solar plants usage (Kostanai, Astana)	5,9 6,2	48 37	88 123	2,5 2,1	12,7 12,4	18,7 17,8	20 20	18 18	12 11	2,7 2,5	113..156 98...123
2. Conditions more or less effective for the solar plants usage (Dzhanybek, Semipalatinsk)	6 5,7	43 44	119 106	7,4 3,8	15,9 13	21,1 19	23 21	22 18	15 12	6,5 3,8	139..161 85...129
3. Conditions secure sustainable operation of the solar plants (Atyrau, Aktobe, Aktau)	5,1 5,9 5,2	68 52 65	98 110 91	8,6 10,6	17,4 17,6	22,8 22,6	25 25	24 24	16 19	7,6 12,2	190..172 126..176
4. Conditions for more effective usage of the solar stations (Aralsk Sea, Zhezkazgan, Buran	4,8 4,8 5,2	75 86 40	78 71 118	8,3 6,2 6,2	17,4 15,5 14,4	23,6 21,6 20,1	26 24 22	24 22 20	17 14 13	7,8 4,8 4,7	170...213
5. Conditions for the most effective usage of the solar plants (Barsa-Kelmes, Ak-Kum, Kuigan)	4,1 4 4,7	119 117 97	60 77 64	6,5 8,8 9,1	15,3 17,3 17,2	22 23,3 20,5	25 26 24	24 24 22	19 16 15	3,5 7,2 7,2	165...201 85...183

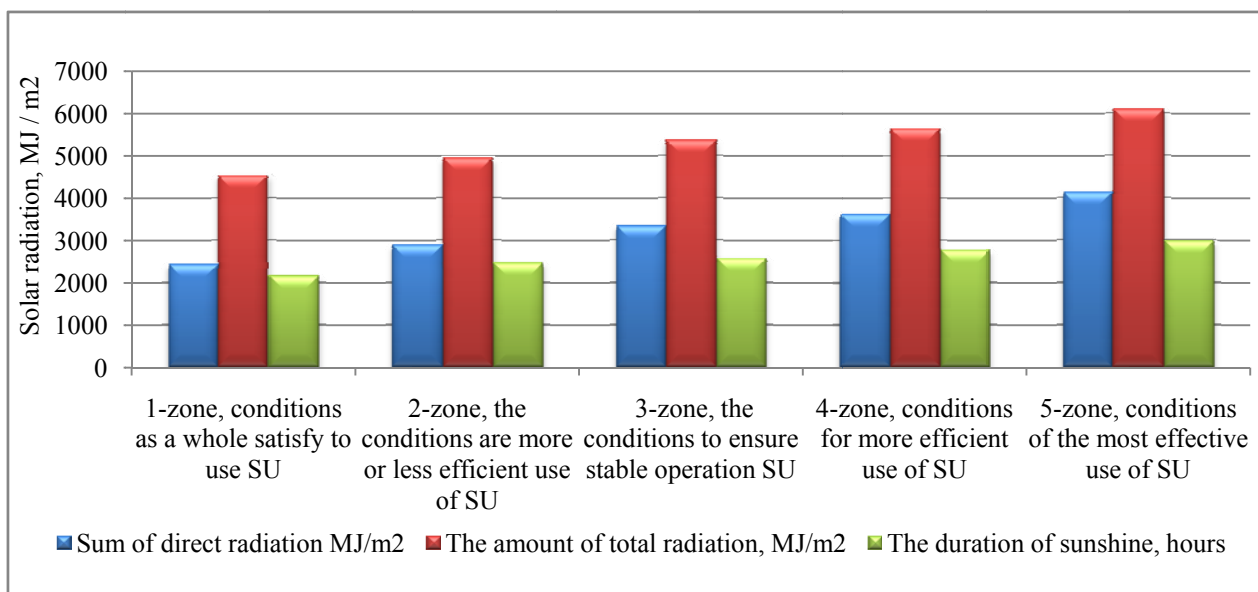


Figure 2 – Histogram of the solar stations usage dependence from average values of direct, total radiation and duration of the sunshine

We have studied actinometric and climatic characteristics, used in the methodology of the solar energy usage assessment for the following Hydro Meteorological Stations, located on the territory of Kazakhstan:

1. Araljsk Sea (Kyzyl-Orda oblast).
2. Barsa-Kelmes (Kyzyl-Orda oblast).
3. Ak-Kum (Kyzyl-Orda oblast).
4. Almaty, GMO (Almaty oblast).



Figure 3 – Average daily solar radiation intensity in Kyzyl-Orda oblast, settlement Barsa-Kelmes



Figure 4 – Average daily solar radiation in Araljsk sea



Figure 5 – Outside air average temperature in Araljsk Sea

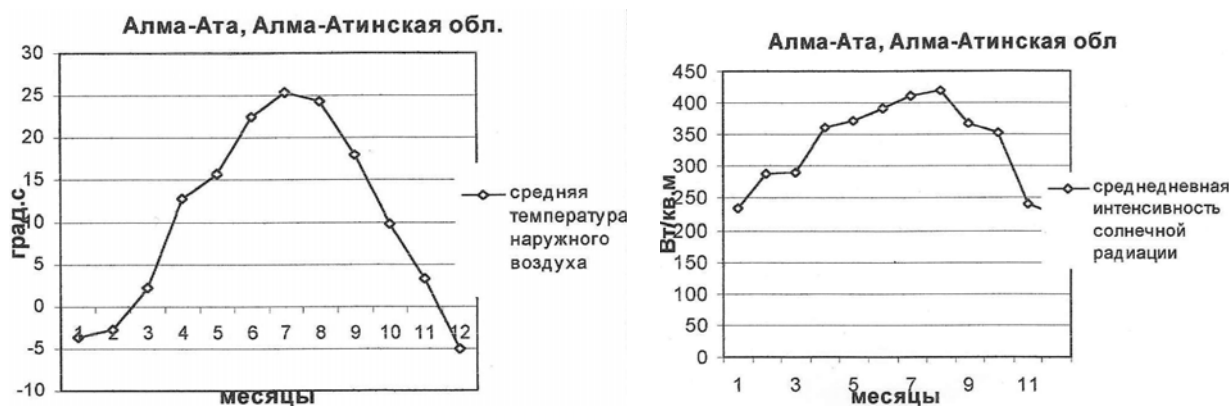


Figure 6 – Outside air average temperature and average intensity of the solar radiation in Almaty and Almaty oblast

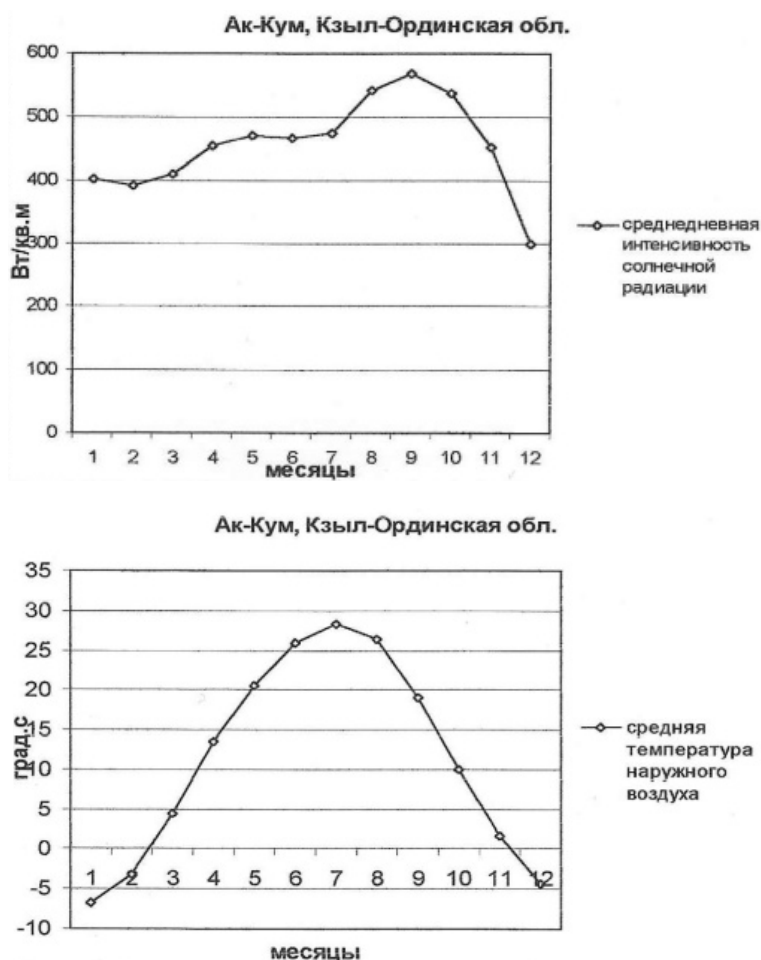


Figure 7 – Outside air average temperature and average daily solar radiation intensity in the settlement Ak Kum, Kyzyl-Orda oblast

Cloudiness increase decreases the direct and increases the diffused radiation. Diffused radiation flow, though partially, compensates the direct solar radiation weakening in the atmosphere but the compensation is not complete. Therefore the total radiation flow under cloudiness conditions, if the sun is not covered with clouds, will be bigger comparing to the clear sky conditions.

Apart from transparency and cloudiness the big influence at diffused radiation is exerted with the nature of underlying surface. Upon the snow cover there is increased the reflection of the direct solar radiation, secondary diffusion of which in the atmosphere brings to the diffused radiation growth.

Along with the elevation increase the direct solar radiation flow is growing, which is explained by lessening the optical width of the atmosphere. Hereupon the solar radiation flow maximum values in mountainous regions are bigger, than on the flat topography. Value of the diffused radiation flow with elevation over sea level decreases at clear sky, as the thickness of atmosphere's scattering layers decreases. Upon cloudiness the diffused radiation flow in the layers lower than the clouds increases according to the elevation. Appearance of direct and global radiation decreases in the areas, located in the floors of valleys or pits due to the closed horizon. Direct, diffused and total solar radiation has well defined annual motion, which is distinctly seen on the figures 1 and 2.

Conclusion.

Criterion 1. Average time duration. When radiation is no lower than $0,4 \text{ kW/m}^2$ and exceeds 6 hours per day. The table 2 demonstrates averaged long-term data of total daily accumulated radiation.

Criterion 2. Average number of clear days shall be no less than a half of an average number of dull days. With account of that the provision of daily totals of accumulated radiation is $4,6 \text{ kW}\cdot\text{h/m}^2$ and higher and according to long-term data of Almaty station amounts to (%):

Table 2 – Averaged daily global radiation

Month	1	2	3	4	5	6	7	8	9	10	11	12
	–	8	20	50	72	83	79	60	55	40	15	–

The most favorable period to use the solar energy in Almaty is from March to November, according to provision of daily totals of global radiation from April to September (table 2).

According to the data on long term observations of the sunshine duration in compliance with the sunshine recorder we differentiate the periods of the solar continuous shining 5,6,7, etc. At that, we exclude the time during one hour after and till the sun up. Results in Almaty city are given in the tabular form.

Table 3 – Solar station operational capacity (hour) depending on the solar continuous shining (for 10 years period)

	2	3	4	5	6	7	8	9	10	11	12
Almaty	4	4,8	7	8,2	8,4	8,3	8	6	5	4,8	4

Analysis of Table 3 demonstrates, that it is inappropriate to use the solar plants in Almaty city in March and November, much more successfully they will operate from April to October.

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ҚАЗАҚСТАН РЕСПУБЛИКАСЫНЫҢ ГЕЛИОЭНЕРГЕТИКАЛЫҚ РЕСУРСТАРЫ

Аннотация. Мақалада Қазақстан Республикасының гелиоэнергетикалық ресурстары қарастырылады. Белгілі бір аумақтағы территорияға түсетін күн энергиясының потенциалын бағалау үшін күн энергиясының потенциалы туралы деректер болу қажет. Іс жүзіндегі бақылаулар мен теориялық есептеулерді жалпылау негізінде, келесі мәліметтер алынды: ашық аспан кезінде перпендикуляр бетке түсетін тікелей күн радиациясының мүмкін болатын ай сайынғы және жыл сайынғы қосындыларының жылдық және ендік мөлшері, күн сәулесінің ұзақтығы туралы мағлұмат, жылдың ерекше күндеріне арналған күн радиациясының тәуліктік мөлшері, маусым және желтоқсан айлары үшін радиацияның орташа айлық қосындысының территория бойынша үлестіру картасы, сонымен қатар «техникалық түрде қолданылатын және экономикалық тиімді күн қуаттылығының» үлестірілу картасы туралы, осы тұжырымдаманы анықтау критеріі әзірленді. Қазақстандағы күн энергетикалық ресурстарын бағалаудағы күн жүйелерінің барлық есептік көрсеткіштерінің негізінде, кез келген бағыттан көлденең жазықтыққа дейін қайта есептеуге болатындай, көлденең бетке тікелей күн радиациясының сандық сипаттамалары қабылданды. Күн сәулесінің тікелей, қосынды радиациясының және ұзақтығының орташа мәнін статистикалық өңдеу нәтижелері бойынша бес аймақ белгіленді және ҚР территориясы бойынша гелиоқондырғыларды енгізу мүмкіндіктерін сипаттаушы гистограмма құрылды.

Түйін сөздер: күн энергиясы, гелиоколлектор, гелиоэнергетикалық ресурстар, күн радиациясы.

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ГЕЛИОЭНЕРГЕТИЧЕСКИЕ РЕСУРСЫ РЕСПУБЛИКИ КАЗАХСТАН

Аннотация. В статье рассматриваются гелиоэнергетические ресурсы Республики Казахстан. Для оценки потенциала солнечной энергии падающей на территорию в том или ином районе необходимо иметь данные о потенциале солнечной энергии. На основе обобщения фактических наблюдений и теоретических расчетов, имеются данные: годового и широтного хода возможных месячных и годовых сумм прямой солнечной радиации поступающей на перпендикулярную поверхность при условиях ясного неба, сведения о продолжительности солнечного сияния, суточный ход солнечной радиации для характерных дней года, карты распределения по территории средних месячных сумм радиации за июнь и декабрь, а также карты распределения «технически применимой и экономически выгодной солнечной мощности», разработанные им критерий определения этого понятия. В основу всех расчетных показателей гелиосистем при оценке гелиоэнергетических ресурсов территории Казахстана приняты количественные характеристики прямой солнечной радиации на горизонтальную поверхность, с которой можно произвести перерасчет с горизонтальной на наклонной плоскость любой ориентации. По результатам статистической обработки средних значений прямой, суммарной радиации и продолжительности солнечного сияния выделены пять зон и составлена гистограмма характеризующих возможности внедрения гелиоустановок по территории РК.

Ключевые слова: солнечная энергия, гелиоколлектор, гелиоэнергетические ресурсы, солнечная радиация.

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WAYS TO INCREASE OPERATIONAL EFFICIENCY OF BUSHINGS OF LEVER-HINGED MECHANISM OF MINING MACHINES

Abstract. In this article, ways to increase operational efficiency of bushings of lever-hinged mechanism of mining machines. Reliable operation of braking device of mine elevating machines, throughout the service life, is dictated by regulatory safety requirements. The research task is to determine the presence of significant changes on the surface of the mating parts of the hinged joints under different conditions. The friction surfaces of the hinge and their physical-mechanical and tribological characteristics are compared. Using a special measuring system basic regularities of interaction elements articulation parameters for establishing the wear in the contact surfaces were studied. Research changes of the friction coefficient and wear quantity in mating parts was conducted. Research carried out for various materials and various designs Bush-finger pairs of articulation. The experimental study of stress-strain states of the various designs of hinges possible to determine the parameters of the bore inner surface of the bush with the lowest voltage in the contact zone of the sleeve and the pin. The best tribotechnical characteristics are hinges with bronze bushes. Steel bushes with a bronze coating have wear of greater than 10% compared to bronze ones. Increasing the contact area of the bush with the pin due to the conical boring reduces the wear of the hinge, allows increasing the resistance to physical wear.

Key words: mine hoisting machines, hinged mechanism, friction machine, coefficient of friction, bushing.

Introduction. Rope mine elevating machines are the most important element in transport chain of mineral resources movement from the lower horizons of mine to the surface, and also provide transportation of personnel and equipment. Service life of mine elevating machine, generally, is equal to the service life of the mining enterprise. At the present time, in the mining industry elevating machines are used, mostly commissioned in the 60-80s of the last century. Complete replacement of this equipment does not provided. Braking device, which performs control and protection functions, is one of the most responsible elements of mine elevating machines [1-3].

Reliable operation of braking device of mine elevating machines, throughout the service life, is dictated by regulatory safety requirements.

Operational efficiency of braking device mechanism of mine hoisting machines depends from work reliable of its main elements, particularly hinged joints. During the intensive use of elevating machine there are damages in elements of lever-hinged mechanism, which associated with the appearance of gaps due to wear of the contact surfaces of bushings [4-7]. It leads to changing of operating parameters of braking device and consequently to increasing the time of its operation.

Meanwhile, does not use possibilities of increasing hinged joints reliability due increasing the area of contact surfaces, changes in lubrication conditions, deposition on the metal surfaces of the bushes of the most durable protective coatings, which reduce their wear during operation. Based on the foregoing, establishing rational design parameters of elements hinged joints and the development of methods to increase the reliability of their work is an urgent task.

Definition of the research task. Design parameters of the different variants of the research object are established (figure 1). We perform initial diameter measurement d_1 ; d_2 ; d_3 of lengths L_2 in order to establish the parameters of conic bore. Bore depth of the inner conical surface of the sleeve is selected as a part of the total length L_3 , the remainder of the length L_4 is bent to a cylindrical shape, provided that the inner diameter of the new hole d_7 is increased to the value $d_2 + 2\Delta_{in}$ (Δ_{in} is the amount of radial wear of the inner diameter of the sleeve) at a length L_4 , while the outer diameter of the bushing d_1 remains unchanged. Finger Length Ratio: L_8 is equal to L_2 , length L_5 is the difference between L_2 and L_{11} ; diameter of the larger base of the resulting truncated cone d_5 is d_8 ; diameter of the hole and smaller base of the truncated cone d_7 is equal to diameter of the finger of new repair size d_4 with the condition $d_2 + 2\Delta_{rel}$.

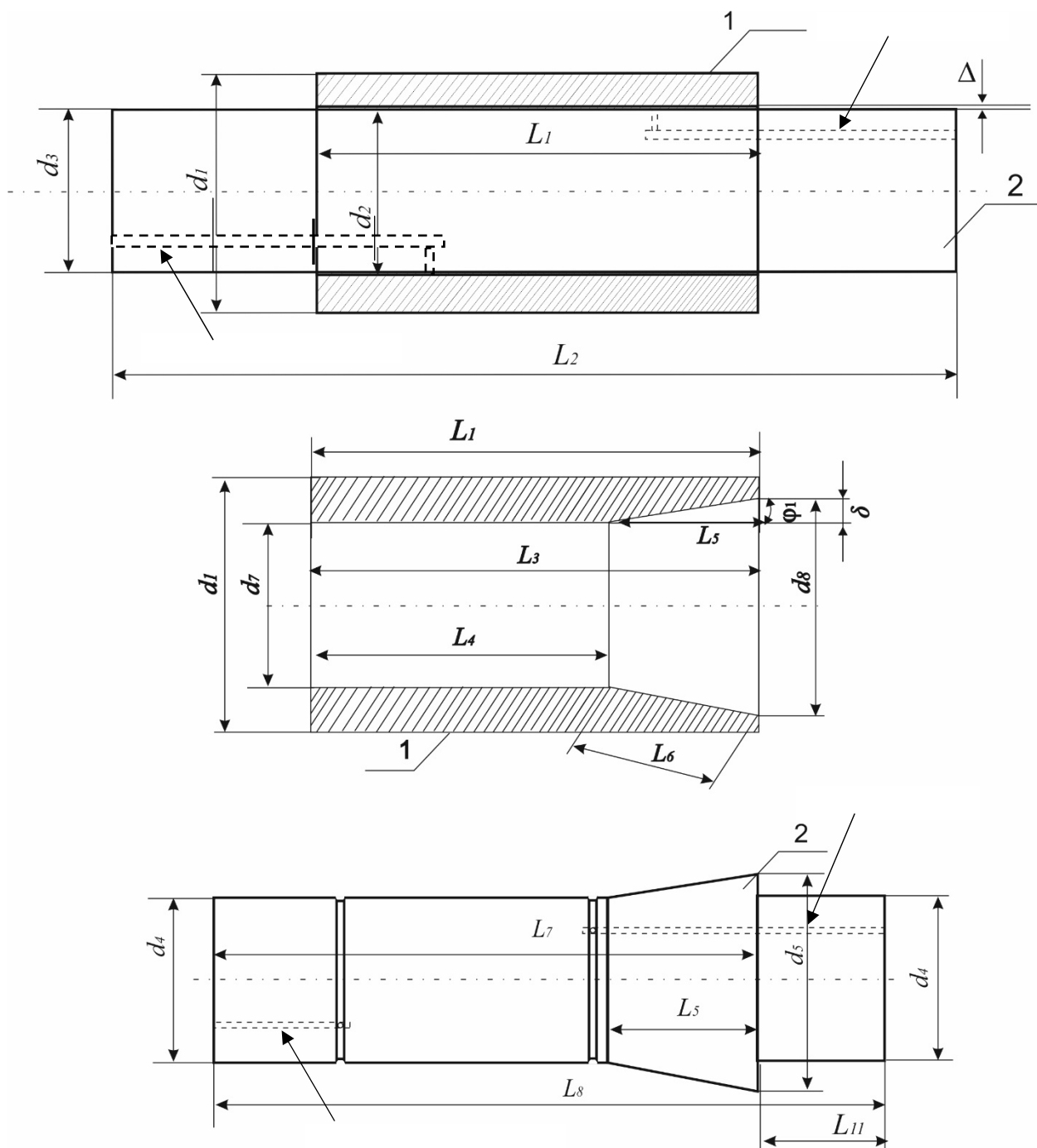


Figure 1 – Settlement scheme of the hinge

1) boring angle:

$$\operatorname{tg} \varphi_1 = \delta / L_5, \quad (1)$$

where φ_1 – bore angle, °; δ – value of increment to diameter d_7 at bore, mm; L_5 – the depth of the bore inner conical surface of the sleeve is HL₃, mm; X – ratio of the length of the bored part to the total length of the bushing.

2) length of the lateral line of the cone:

$$L_6^2 = L_5^2 + \left(\frac{d_8 - d_7}{2} \right)^2, \quad (2)$$

where L_6 – length of the lateral line of the cone, mm; d_8 – larger inner diameter of the bushing after boring, mm; d_7 – inner diameter of the bushing, mm.

3) contact surface area:

$$S_k = \pi L_6 + \left(\frac{d_8 + d_7}{2} \right)^2 + \pi d_7 L_4, \quad (3)$$

where S_k – contact surface area, mm; L_4 – length of the lateral line of the cylinder of the non-doped part of the inner surface of the sleeve, mm.

The maximum angle of conical bore of the bushing is limited by its outer diameter and the collapsing condition. The minimum angle of conical bore is limited in accordance with GOST 8593-81 [8], GOST 25557-82 [9]. At angles of bore less than 70, grasping of the mating surfaces and jamming of the hinge may appear, since the coefficient of friction in this case may be more than one.

The research task is to determine the presence of significant changes on the surface of the mating parts of the hinged joints under different conditions. The friction surfaces of the hinge and their physical-mechanical and tribological characteristics are compared [10, 11].

Using a special measuring system (figure 2) basic regularities of interaction elements articulation parameters for establishing the wear in the contact surfaces were studied.

Research changes of the friction coefficient and wear quantity in mating parts was conducted. Research carried out for various materials and various designs Bush-finger pairs of articulation. Various lubricants and different lubrication regimes were used (GOST 9490-75) [12].

Tests were carried out on a SMC-2 friction machine with hinges of various design versions. The analysis of obtained results for further realization in the actuating mechanisms of brake device of mine hoisting machines is carried out [11].

The friction machine SMC-2 (owned by Ugleservis of JSC ArcelorMittal Temirtau) is designed for testing materials for friction and wear during rolling, rolling with slip and sliding. Tests can be carried out on three different contact patterns of samples that simulate work of parts in friction units. The samples are loaded by a spring mechanism, and the carriage is balanced by a counterweight, which makes it possible to carry out tests with loads on a pair of friction.



Figure 2 – The friction machine

Figure 2 – The friction machine consists of:

- three-phase asynchronous AC motor;
- worm reducer;
- crank-slider mechanism with interchangeable eccentrics;
- friction unit with mandrels for samples of different types and sizes;
- removable bath for testing in a liquid medium;
- two tensor beam, installed in the friction unit of the stand and outside it (standard);
- a block for recording the analog output signal from the strain gages, consisting of a power supply, a digital oscilloscope PCS-500 and a computer [13].

Technical characteristics of the friction machine are presented in table.

Technical characteristics of the friction machine

Technical characteristics	Value
Power of the electric motor of the drive, kW	2.2
Rotational speed of the lower sample, s ⁻¹	5; 8.3; 16.7
Slippage of samples, %	0, 10, 15, 20, 100
Maximum load on a friction pair P, MPa	5

The object of research is a hinge, which consists of a bush and pin. Gray cast iron and bronze are used for making bushings. Bronze bushings are limited in use because of their high cost, an alternative variant is a bush made of steel with an antifriction coating. The pin is made of steel CT45 X18N. An important condition for testing is the correct choice of the value of the load on the friction pair, since its values directly affect wear.

An important factor in the wear of contact surfaces of bushings is the area of mating contact surfaces. The lubrication mode depends on type of lubricant and design of the bush-pin pair. The studies were carried out at an ambient temperature of + 22 ° C [14-20].

Conducting experiments. A set of experiments was performed, which made it possible to identify groups of friction pairs with minimum values for the coefficients of friction, wear, relative roughness, etc.

Further, dependencies connecting the coefficient of friction and wear value were constructed and analyzed with factors such as the relative slip velocity and pressure for the most widely represented material used for manufacturing friction pairs. The experimental data were processed by a statistically determined method of constructing models using a computer.

Determination of the friction coefficient as a function of slip speed when testing hub bushings made of different materials.

The first stage of the experiment consists in investigating the coefficient of friction of the "bushing-finger" pair, with different slip velocities in the interval from 0.1 to 0.6 m/s. The object of investigation in this experiment is the hinge, which consists of a bushing and a connecting pin.

The purpose of this experiment is to establish tribotechnical parameters of three variants of bushings with different physical and mechanical properties.

The first version of the hinge, when the bushing is made of cast iron; the second variant, when the bushing is made of steel with a coating of the inner working surface of the bushing with a bushing; the third option, when the bushing is made of bronze. Inside the sleeve, a finger is made of hardened steel grade ST45H18N2M, which is used in all experiments with three variants of bushings. The condition for carrying out this experiment is a predetermined slip speed interval from 0.1 to 0.6 m/s.

The construction of the investigated bushings is shown in figure 3. The graphs of the dependences constructed from the experimental results are shown in figure 4.



Figure 3 – Construction of the bushings

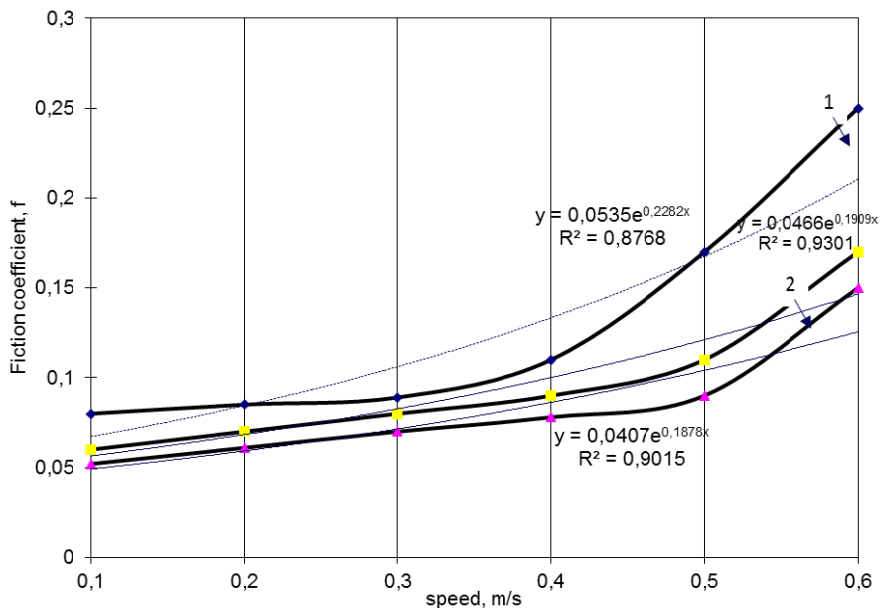


Figure 4 – Graphs of friction coefficient variation as a function of slip speed when testing hub bushings made of different materials:
1 – for the cast iron bushing; 2 – for a steel bush with a bronze coating; 3 – for the bronze bush

Determination of the wear of the inner surface of the bushes as a function of the load when testing the hub bushings made of various materials. We will determine the wear value of three different versions of hinge bushes made of different materials, depending on the applied pressure. The object of investigation in this experiment is a hinge bush with a connecting pin. Inside the bushing, a pin is installed, which is made of hardened steel grade ST45H18N2M. We will establish the value of wear, provided that the specified range of the pressure value lies in the range from 1 to 5 MPa. The graphs of the dependencies constructed from the results of the experiment are shown in figure 5.

Analysis of the dependencies in figures 4 and 5 shows that the hinges with bronze bushings have the best tribotechnical characteristics.

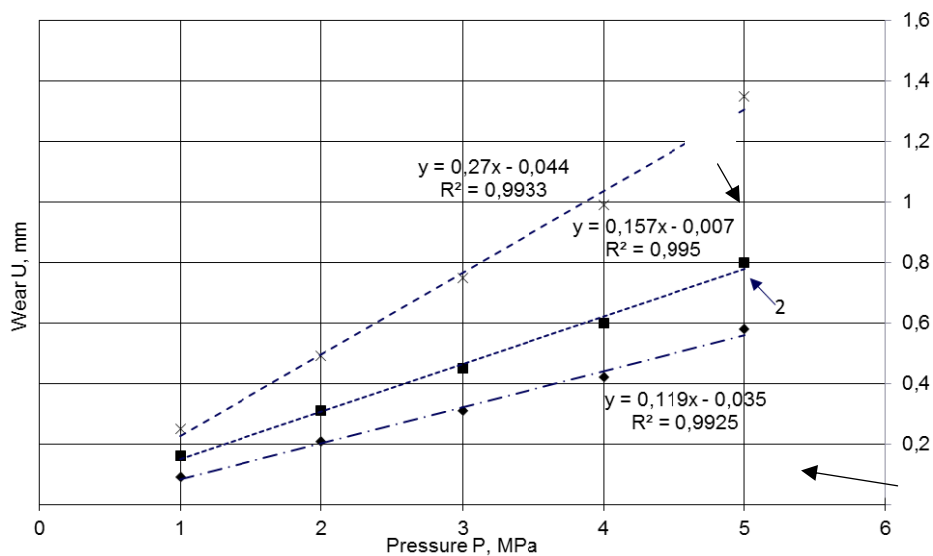


Figure 5 – Graphs of changes in wear of the inner surface of bushings depending on the load when testing hinge sleeves made of different materials:
1 – for the cast iron bushing; 2 – for a steel bush with a bronze coating; 3 – for the bronze bush

The proposed steel bushings with a bronze coating have excellent wear characteristics of about 10% compared to bronze ones, but considering the economic aspects of their production, we can talk about the advisability of using them.

The following single-factor dependencies are obtained with the condition that the output parameter is wear of the bush (U), and the input parameter is the pressure (P), depending on the applied pressure from 1 to 5 MPa, for the investigated bushings 1 - for the cast iron bush; 2 - for a steel bush with a bronze coating; 3 - for the bronze bush.

Determining the wear of hinge bushes with different geometric parameters depending on the load

At the second stage of the experiment, the wear values of hinge bushes with different geometric parameters are determined depending on the loading value. The object of investigation in this experiment is a hinge bush with a connecting finger. Inside the bushes, a finger is installed, which is made of hardened steel grade ST45H18N2M.

Wear values are established provided that the specified pressure range is in the range of 1 to 5 MPa. The graphs of the dependencies constructed from the results of the experiment are shown in figure 6.

The following single-factor dependencies with the condition that the output parameter is the wear of the sleeve (U), and the input parameter is the pressure (P), from 1 to 5 MPa are obtained.

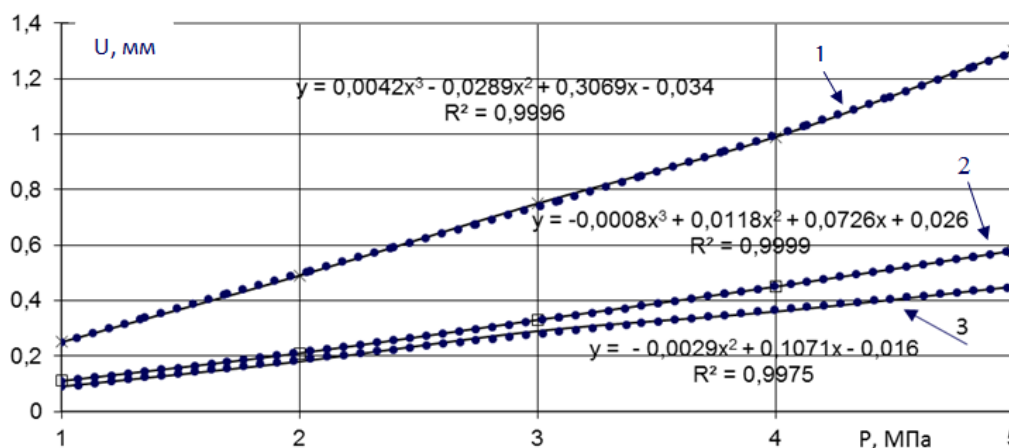


Figure 6 – Graphs of changes in the wear of the inner surface of the bushes as a function of the load when testing the hinge with different bushings:

- 1 – a cylindrical bush; 2 – bush with a partial conical boring of the inner cylindrical surface by 0.35 length;
3 – bush with a partial conical boring of the inner cylindrical surface by 0.7 of its length

According to the geometric shape of the inner surface of the cast iron bush: cylindrical; with a partial conical boring of the inner cylindrical surface by 0.35 of its length; with a partial conical boring of the inner cylindrical surface by 0.7 of its length.

Determination of the change in the friction coefficient as a function of slip speed when testing hinges with different lubrication regimes. The third stage of the experiment is the establishment of the friction coefficient of the pair, depending on the sliding speed, under different lubrication regimes. Different lubrication regimes can be obtained by applying different design versions of the grease nipples of the swivel joint. The object of investigation in this experiment is a sleeve made of cast iron and fingers with different arrangement of channels for lubrication of the hinge (figure 1). For the first variant, a typical cylindrical pin with one lubrication channel; for the second variant, the finger is cylindrical with two through lubrication channels. The first option is typical and is performed at the factory, we made changes to the lubrication system and equipped the pin with an additional lubrication channel (figure 1).

Determining the wear of hinge sleeves with different lubrication regimes depending on the load. The object of investigation in this experiment is a sleeve made of cast iron and pins made of hardened steel grade ST45H18N2M with different arrangement of channels for greasing the hinge (figure 1).

The condition for this experiment is a predetermined slip speed interval from 0.1 to 0.5 m/s. The loading is constant and is 1 MPa. The graphs of dependencies constructed from the results of the experiment are shown in figure 7.

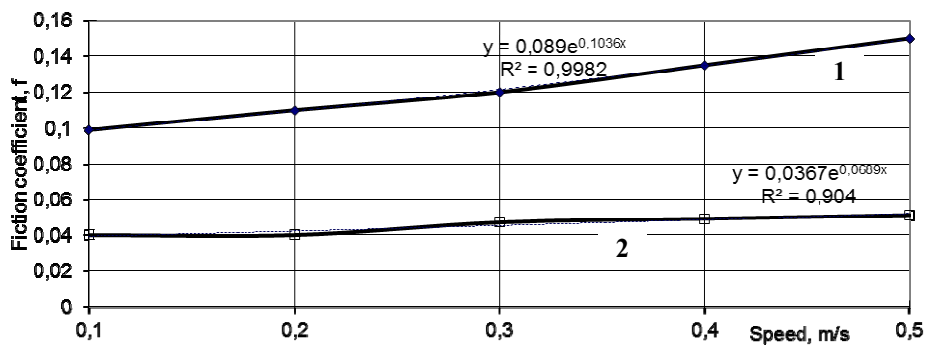


Figure 7 – Graph of the change in the coefficient of friction as a function of sliding speed when testing hinges with different lubrication regimes:

1 – cylindrical pin, single-channel lubricant; 2 – cylindrical pin, two-channel lubricant

Analyzing the graph of the dependencies shown in figure 7, we can draw the following conclusion: the proposed design changes of lubricating channels allow about more than three times, depending on the speed, to reduce the coefficient of friction of the conjugate surfaces, and thereby significantly increase the tribotechnical performance of the hinges.

Conclusions. The experimental study of stress-strain states of the various designs of hinges possible to determine the parameters of the bore inner surface of the bush with the lowest voltage in the contact zone of the sleeve and the pin. The spacing of the bushing is 0.35 to 0.7 times its length. The best tribotechnical characteristics are hinges with bronze bushes. Steel bushes with a bronze coating have wear of greater than 10% compared to bronze ones. But, given the economic aspects, we can talk about the advisability of using them. Increasing the contact area of the bush with the pin due to the conical boring reduces the wear of the hinge, allows increasing the resistance to physical wear, and also opens the possibility of reusing the bush due to its boring. Design changes lubricating channels improve joint lubrication regime and use of additional lubrication channel can significantly reduce wear and reduce the coefficient of friction of the mating surfaces 3 times.

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ТАУ-КЕН МАШИНАЛАРЫНЫҢ ТЕЖЕГІШ-ШАРНИРЛІ МЕХАНИЗМДЕРІНІҢ ТИІМДІЛІГІН АРТТЫРУ ЖОЛДАРЫ

Аннотация. Берілген мақалада иіктіректік-топсалы механизмдегі төлкенін жұмыс істеу тиімділігін арттыру жолдарын қарастырады. Шахтылы көтергіш машинаның тежегіш құрылғысының сенімді қолданылуы жұмыс істеу барысы нормативтік қауіпсіздік талаптарына сай бағынады. Зерттеудің мақсаты әр түрлі шарттарда топсалы қосылыстардың бетіндегі жанасатын бөлшектердің маңызды өзгерістерін анықтау. Топсаның үйкеліс беттерін салыстыру және олардың физика-механикалық және трибологиялық сипаттамаларын зерттеу жүргізіледі. Арнайы өлшеу кешенінің арқасында байланыс беттерінің аймағындағы тозу параметрлерін белгілеу үшін топсаның элементтері арасындағы өзара әрекеттесу үрдісінің негізгі заңдылықтары зерттелді. Үйкеліс коэффициентінің өзгеруін және жұпар бөліктеріндегі тозу мөлшерін зерттеу жүргізілді. Зерттеу әртүрлі материалдар мен хаб-түйіспелі жұптас жұптың түрлі жобалық нұсқалары үшін жүргізілді. Әр түрлі топсалы конструкциялардың стресс-штамм күйін өткізген эксперименталдық зерттеулер төлке пен саусақты байланыстыру аймағындағы ең төменгі кернеулі төлкенің ішкі бетінің бұрғылау параметрлерін анықтауға мүмкіндік берді. Үздік триботехникалық сипаттамалары қола бұталары бар ілмектер. Қола жабындысы бар болат жандер қоламен салыстырғанда 10% артық тозуға ие. Тұтқаны конустық бұрғылаумен байланысты саусағымен байланыстыру аймағының жоғарылауы топсаның тозуын азайтады, физикалық тозуға төзімділікті арттырады.

Түйін сөздер: шахталық көтергіш машиналар, топсалы механизм, үйкеліс машинасы, үйкеліс коэффициенті, төлке.

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ПУТИ ПОВЫШЕНИЯ ЭФФЕКТИВНОСТИ ЭКСПЛУАТАЦИИ ВТУЛОК РЫЧАЖНО-ШАРНИРНОГО МЕХАНИЗМА ГОРНЫХ МАШИН

Аннотация. В статье рассматриваются пути повышения эффективности эксплуатации втулок рычажно-шарнирного механизма. Надежная эксплуатация тормозного устройства шахтных подъемных машин, на протяжении всего срока эксплуатации, диктуется нормативными требованиями безопасности. Задача исследования состоит в определении наличия значимых изменений на поверхности сопрягаемых деталей шарнирных соединений при различных условиях. Проведено сравнение поверхностей трения шарнира и изучения их

физико-механических и трибологических характеристик. С помощью специального измерительного комплекса проведено исследование основных закономерностей процесса взаимодействия элементов шарнирного соединения для установления параметров износа в области контактных поверхностей. Было проведено исследование изменения коэффициента трения и величины износа в сопрягаемых деталях. Исследование проводилось для различных материалов и различных конструктивных исполнений втулочно-пальцевой пары шарнирного соединения. Проведенные экспериментальные исследования напряженно-деформированного состояния различных конструкций шарниров позволили определить параметры расточки внутренней поверхности втулки с наименьшим напряжением в зоне контакта втулки и пальца. Наилучшими триботехническими характеристиками обладают шарниры с бронзовыми втулками. Стальные втулки с бронзовым покрытием имеют износ больший на 10% по сравнению с бронзовыми. Увеличение площади контакта втулки с пальцем за счет конической расточки уменьшает износ шарнира, позволяют повысить сопротивление физическому износу.

Ключевые слова: шахтные подъемные машины, шарнирный механизм, машина трения, коэффициент трения, втулка.

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RESEARCH TO IMPROVE THE QUALITY OF FOOD PRODUCTS

Abstract. The article presents the results of research to improve the quality of food products, namely the results of the study of the restructured meat product. It is established that preliminary processing of raw materials by starter cultures promotes an increase in proteolytic activity and active accumulation of amine nitrogen, thus accelerates the ripening of meat. Adding to experimental samples raw plant materials, balanced carbohydrate and vitamin composition, has a positive effect on the balance of the finished product and increases their biological value. The findings are promising trend in improving meats technology.

Key words: meat, beef, mutton, restructure meat product, lactic acid bacteria, propionic acid bacteria, starter cultures, grain crops, corn, proteolytic activity.

Introduction. Supplying the population with high quality meat products is one of the main and urgent task facing the processing industry. To solve this problem a great role belongs to intensification of technological processes, using modern achievements of biochemistry and meat industry, using enzyme preparations [1].

In the Republic of Kazakhstan, the production of meat and meat products is traditionally considered one of the priority. The modern conditions of production associated with the transition to low-waste processing of raw materials, the desire to reduce the cost of finished products, to define the constant expansion of the range by improving meat production technology. The solution to this problem is connected with control of biochemical, physical, chemical and microbiological processes in the technology of production of meat products, which are formed as a result of qualitative indicators of the finished product [2].

It is known that beef is different from meat of other species of animals by quality and technological parameters. At the same time, the process of production of beef products, characterized by a fairly rigid consistency, is long. In this regard, there is a need to find ways to intensify production and develop new recipes for beef meat products [3].

One of the promising directions of production of meat products is the creation of technologies for restructured products, the advantage of which is the ability to recreate the structure of whole-piece raw materials, by the organoleptic properties close to whole-muscle meat (i.e. compound by a variety of individual pieces of meat components into one solid, which, when cutting into slices will have a uniform shape and size) [4].

Great interest for industrial applications represents culture of propionic acid and lactic acid bacteria. It was proved that certain strains of propionic acid bacteria have a high biotechnological potential and adaptive properties, which is important when salting and maturation of meat from the intact cell structure, where the processes are associated with a high concentration of salt and low temperature [5].

It is proved that cultures of lactic acid bacteria have antagonistic activity against pathogenic and opportunistic pathogens of various diseases, as well as capable of forming biologically active substances (vitamins, essential amino acids, hydrolytic enzymes) regulating metabolic processes in the body. Some of their representatives in the process of vital activity produce substances that impart a specific taste and aroma to the product, promote the acceleration and stabilization of the process of its maturation, improve the sanitary and hygienic conditions of production. The available data of the using of lactic acid bacteria in the meat processing industry indicate the possibility of their using in the technology of production of meat products in order to increase production by reducing the time of the ripening process with raw material salting, as well as improving the quality of finished products and increasing their yield [6].

One of the ways to improve the quality of products and improve the structure of the population's nutrition is the introduction of new non-traditional types of plant raw materials into the diet. The products created must contain a balanced complex of proteins, lipids, minerals, vitamins, ballast substances and have high nutritional and taste properties.

One of these directions is the possibility of using cereal crops in the composition of meat products subjected to various modification methods due to their high nutritional value and functional and technological properties. These cultures, being a source of dietary fiber, significantly contribute to increasing the human body's resistance to harmful environmental influences. Grain contains almost all the basic substances necessary for normal human life. Research local and foreign authors have shown promising using in the technology of combined meat products processed grain products that provide high nutritional and biological value of the product, enhance the flexibility of formulations, sustainable and uniform distribution of the ingredients, to minimize losses in the manufacturing process, which ultimately leads to create a product of stable quality.

The using of plant raw materials in meat can be considered as one of the ways to produce high-quality meat products with controlled properties. For example, tocopherols contained in cereals and oilseed plants, are natural fat-soluble antioxidants possess vitamin E activity, and are widely used in the meat industry as antioxidants. To increase the amount of antioxidants in plant raw materials, the method of germination of grains [7].

Germinated grain is a useful, easily digestible product containing vitamins A, C, B₁, B₂, B₆, PP, E, as well as dietary fibers necessary for normal digestion. When germination in grains increases the content of certain B vitamins (for example, vitamins B, B₂ and PP - an average of 1.5-2 times), vitamin E, appears in the germ and vitamin C, which does not contain in ungerminated grain. The germinated seeds are partially destroyed phytates that block the absorption of calcium, magnesium, zinc and other mineral elements. Also in the germinated grains are a lot of sugar and fiber, which in this form is easily digested [8].

Ready-made meat products are rarely considered as a basic source of vitamins, because In the process of processing most of the vitamins are destroyed, and the remaining quantities do not satisfy the physiological needs of the human body. In the meat there is no vitamin C, and vitamin E is contained in it in trace amounts. In the regulation of carbohydrate and fat metabolism involved vitamins: B₁ (thiamine), B₂ (riboflavin), B₃ (pantothenic acid), H (biotin). An effective way to solve this problem is to develop affordable meat products of a functional purpose, which is expedient to carry out based on the enrichment of plant materials. The using of plant raw materials is considered very relevant and timely, because this is accompanied by enrichment of products dietary fiber, minerals, vitamins [9].

In connection with the improvement of meat production technology using bacterial starter and cereal is actual and perspective.

Materials and methods. As objects of research have been chosen lamb and beef of 1st category of fatness in the ratio of 1:1, to ensure rational using of the resources provided for the using of meat chopped germinated corn, to accelerate the ripening process and stabilization using starter cultures.

Technological process. *Preparation of a control sample.* Raw meat was ground on a top with a hole diameter of 25-35 mm. Further, dry salt was produced by salt at the rate of 3.0 kg of salt per 100 kg of raw material. Stirring was carried out in a minced stirrer for 5-10 min. Then the raw material was left in the refrigerator for 20 h at + 5 °C. After 20 hours, the raw materials were fed to a stirrer by adding the necessary spices according to the recipe. Stir until cooked for 10 minutes. Then raw meat materials are injected. The formulation of the control and experimental samples is given in table 1.

Table 1 – Main components of a control and experimental meat products

Name of raw materials, spice and materials	Restructure meat product
Unsalted raw materials, kg on 100 kg	
Mutton of 1 category	51,0
Beef of 1 category	49,0
Spices and materials, g on 100 kg	
Sodium salt	3000
Granulated sugar	120
Black pepper	120

Preparation of experimental sample. Meat raw was ground on a top with a hole diameter of 25-35 mm. To activate the growth of propionic acid bacteria *Propionibacterium freudenreichii* and lactic acid bacteria *Leuconostoc lactis* in a ratio of 1:1 in meat, a preliminary exposure of the meat chopped to slices at a temperature of $(20 \pm 2) ^\circ\text{C}$ for 2 hours, 4 hours, 8 hours, 12 hours, 16 and 20 hours adding 1 unit of activity and 5 units of activity selected dose of starter cultures.

For the enrichment of the meat product, germinated corn was used, which improves the moisture-binding properties of meat raw materials. The germination technology was based on the existing patented technology of germination of wheat, as well as scientific research on processing maize.

After aging the sliced meat in the serum, plant raw materials were added in a ratio of 1% and the above spices.

The objects of research were 3 samples:

No. 1 - control sample;

No. 2 – experimental sample processed with 1 UA of pure cultures;

No. 3 - experimental sample processed with 5 UA pure cultures and enriched with 1% plant material.

In research were determined the following indices: Amine nitrogen content by the method of titration; Determination of the protein in accordance to Kjeldahl on the device "UDK-129" (Italy), Determination of fat on the device Soxhlet "SER-148" (Italy), Determination of carbohydrates in accordance with State standard 10574-91, The content of fat-soluble vitamins in accordance with State standard 32307-2013 on the high-performance liquid chromatograph "Agilent-1200" (USA); The content of water-soluble vitamins by the method of capillary electrophoresis using the capillary electrophoresis system "Kapel" (RF), on the device M-04-38-2009; Determination of the content of vitamins B1 and B2 - fluorimetric method on the analyzer "Fluorate-02-3M" (RF).

The definition of fat-soluble vitamins were conducted in "V.M. Gorbатов Federal Research Center for Food Systems of RAS" in Moscow, the rest of the research was carried out at the Scientific Research Institute of Almaty Technological University "Food Safety".

Results and discussion. The importance of meat is determined by the chemical composition and biological value of muscle tissue, primarily the protein content and essential amino acids, their ratio, the balance of the composition, compatibility with other food substances [10].

The taste qualities of meat products depend in many respects on the products of hydrolytic splitting of milk protein and fat, as a result of which various soluble nitrogenous compounds, free amino acids and fatty acids, which are the precursors of many flavors and aromatic substances, accumulate. In the formation of these compounds, the decisive role is played by enzymes of lactic acid bacteria.

With the development of our knowledge in the field of the mechanism for the formation of organoleptic properties of restructured meat products, the role of proteolytic processes carried out by propionic acid bacteria in the formation of its qualitative indices, biological value as a food product and intensification of the maturation process.

It is widely known that lactic acid and propionic acid microorganisms play an important role in most fermentation processes. Many strains are used in the production of dairy, meat, vegetable and bakery products. These microorganisms can suppress undesirable microflora by synthesizing various antibacterial metabolites, such as organic acids (lactic and propionic acid), carbon dioxide, hydrogen peroxide, diacetyl and bacteriocins [11].

The development of biochemical processes that contribute to the maturation and tenderization of meat during fermentation can be judged from the dynamics of proteolytic processes.

The proteolytic activity is one of the most important properties of lactic and propionic acid bacteria, which characterizes their ability to break down proteins to form more simple nitrogenous compounds. However, information concerning the proteolytic enzyme system in propionic acid bacteria during cultivation in the meat substrate and the influence of various factors on their activity is extremely scarce, therefore further studies have been devoted to the study of the influence of the conditions of biotechnological processing on the proteolytic activity of starter cultures. An informative indicator of protein proteolysis can be amine nitrogen. It is scientifically justified that the content of amine nitrogen, which contributes to the ripening of meat is 0.2 mg [5,12].

The obtained results, shown in figure 1, show that in the experimental samples a faster accumulation of amine nitrogen is observed in comparison with the control sample. Thus, in the experimental sample No. 3 the accumulation of amine nitrogen is observed 4 hours after ripening, in the experimental sample No. 2 of the same value reaches 16 hours, and in the control sample after 20 hours.

Thus, due to the introduction of starter of lactic acid and propionic acid bacteria, where the dose of the ferment is 5 units of activity, physico-chemical and biochemical processes are accelerated substantially, as a result of which the duration of salting is shortened to 16 h.

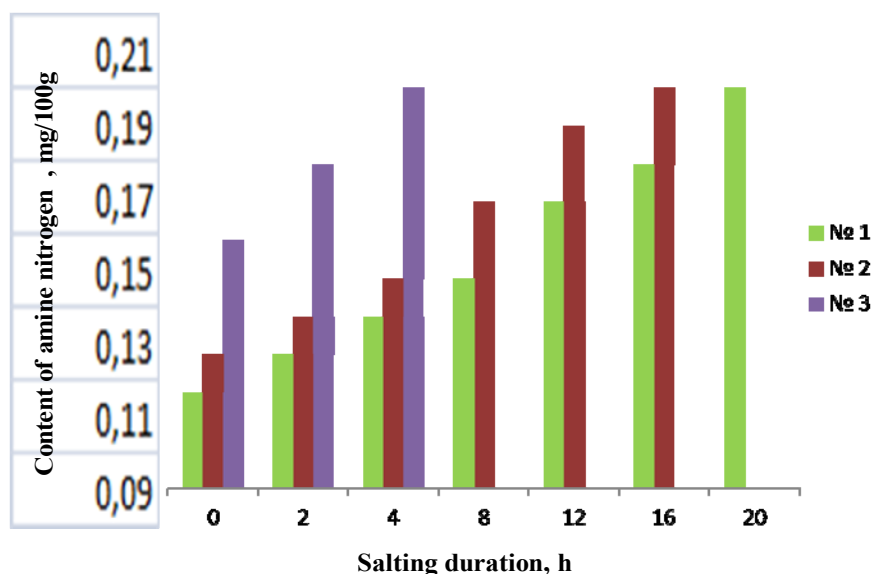


Figure 1 – Dynamics of accumulation of amine nitrogen in the process of salting

Analysis of published data on the chemical composition showed that the processing of meat products of bacterial starter culture and the enrichment of milled corn germ leads to increased concentrations of nutritional value, i.e. carbohydrates and vitamins. The results of the control and experimental samples are given in table 2.

Table 2 – Nutritional value of experimental samples of meat products

#	Nutritional value, %	The experimental samples		
		# 1	# 2	# 3
1	Mass fraction of protein	10,64±0,04	9,56±0,02	10,07±0,02
2	Mass fraction of fat	4,49±0,01	5,17±0,02	6,24±0,01
3	Mass fraction of carbohydrates	It isn't revealed	It isn't revealed	0,75±0,01
n=10.				

Based on the results of the studies, it can be judged that the presence of protein in the control and experimental samples remains unchanged. fat concentration in experimental samples is increased to 2% compared to the control. The results of the experimental sample No. 3 in which the carbohydrate content is increasing shows that the enrichment of meat with plant raw materials leads to the presence of carbohydrates in the composition of the finished meat product.

It is widely known that vitamins are irreplaceable substances necessary for growth, development and vital activity of a person. They contribute to the regulation of the metabolism in the human body. Vitamins are not formed in the body, so a person should receive them with food.

Further research was directed to the study of the vitamin composition of finished meat products. The results of the control and experimental samples are given in table 3.

Table 3 – Vitamin composition of samples of meat products

#	Vitamins, mg/100 g	The experimental samples		
		# 1	# 2	# 3
1	E (tocopherol)	0,84	0,91	1,88
2	C (ascorbic acid)	It isn't revealed	It isn't revealed	0,06
3	B1 (thiamin)	4,2	6,1	19,1
4	B2 (riboflavinum)	0,2	0,4	1,4
5	B6 (pyridoxine)	0,96	0,47	0,63
6	B3 (pantothenic acid)	5,53	5,94	38,28
7	B5 (nicotinic acid)	0,154	0,183	1,306
8	Bc (folic acid)	0,0266	0,0272	0,0269

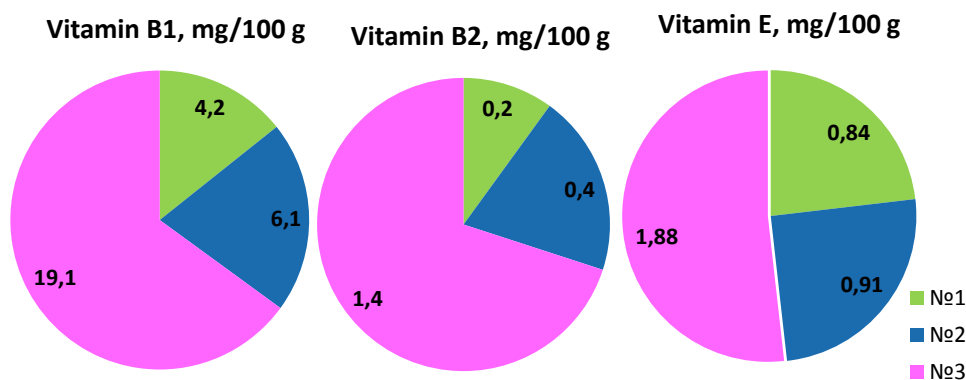


Figure 2 – Diagram of vitamins B1, B2 and E in the samples of meat products

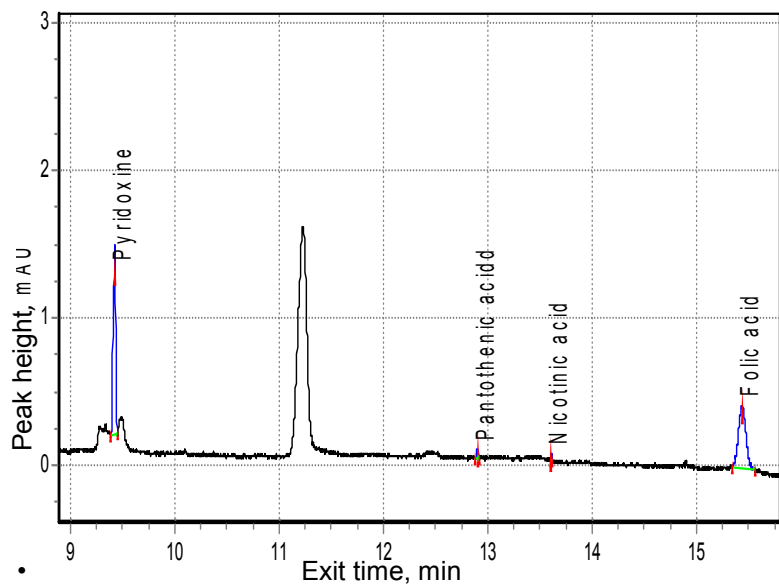


Figure 3 – Chromatogram of water-soluble vitamins in the control sample meat product № 1

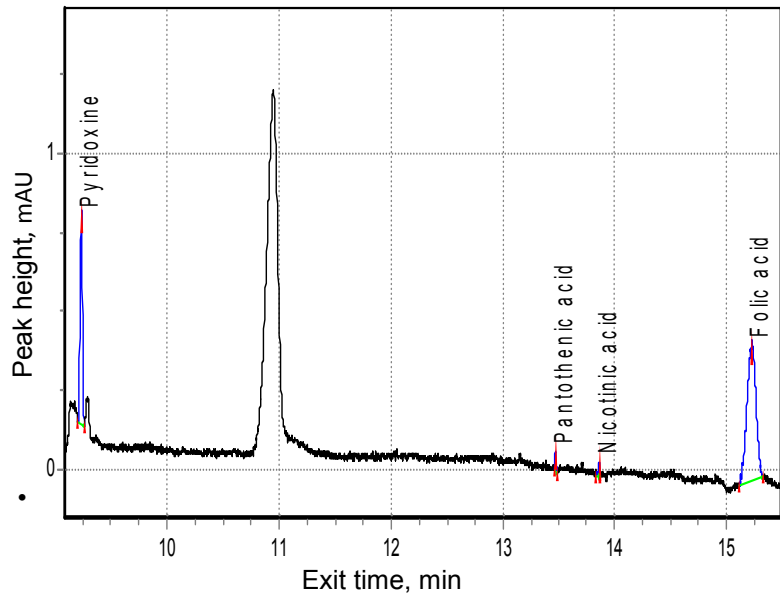


Figure 4 – The chromatogram of water-soluble vitamins in experimental sample meat product № 2

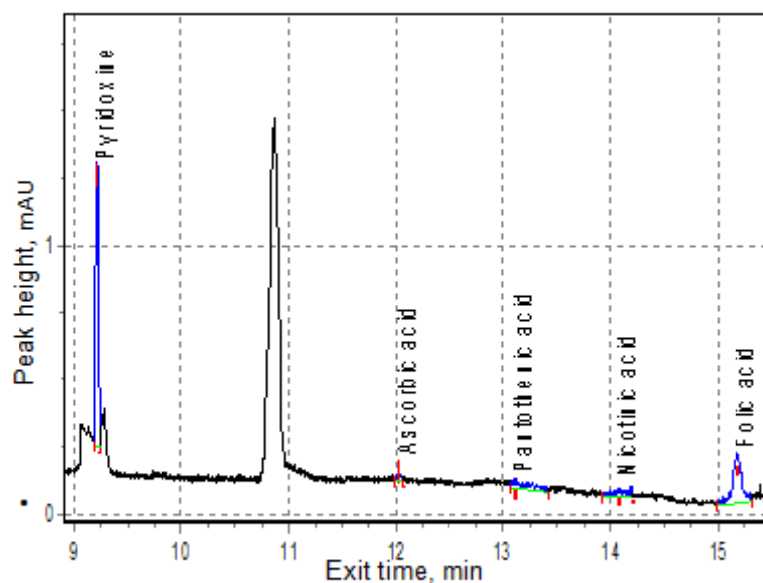


Figure 5 – The chromatogram of water-soluble vitamins in experimental sample of meat product № 3

According to the results of the vitamin composition of the studied meat samples, it can be judged that the presence of fat-soluble vitamin E in the experimental samples is significantly higher compared to the control one. If in the control samples the concentration of tocopherol is 0.84 mg/100 g, in experimental samples it is 0.91 and 1.88 mg/100 g. It has been proven that tocopherol is present in large quantities in green plants and germinated grain. This causes an increase in the concentration of vitamin E in the experimental sample number 3 with the addition of germinated corn. The importance of tocopherol in the human body plays a huge role. Vitamin E is characterized by high antioxidant activity, which promotes immunity and disease prevention.

The experimental data show that the concentration of vitamin B1 in the experimental sample №3 4.5 times, and in the experimental sample №2 1.4 times higher compared to the control. If the content of vitamin B3 in the control sample is 38.28 mg/100 g, in experimental samples it is 5.53 and 5.94 mg/100 g. In experimental sample №3 the concentrations of vitamins B5 is 8.48 times and Bc is 1.01 times higher than in control sample. In experimental sample №2 the concentration of vitamins B5 is 1.18 times, and Bc is 1.02 times higher than in control sample.

In addition, in the experimental sample №3, the concentration of vitamin C increased by 0.06% compared to samples №1 and №2 in which this vitamin is absent. It is widely known that vitamin C plays an important role in the oxidation-reduction processes in the body. Ascorbic acid has a specific impact on capillary walls, on the regeneration processes in the functional state of the central nervous system, cholesterol metabolism, immune biological reactions.

The vitamin B2, if in the control sample it is 0.2 mg/100 g, then in the experimental samples 0.4 and 1.4 mg/100 g. Only vitamin B6 concentration in the control sample №1 equal to 0.96 mg/100 g, whereas in the experimental samples №2 – 0.47 and №3- 0.63 mg/100 g.

Summarizing the results obtained, it can be concluded that adding 1 unit activity of starter cultures contributes to a slight increase in the concentration of vitamins, and the addition 5 units activity of starter cultures and 1% of crushed germinated maize contributes to the enrichment of meat products and has a positive effect on balanced vitamin content.

Conclusions. Based on the studies carried out to improve the quality of meat used as the main raw material for improving the technology of restructured meat products, the following technological solutions have been established:

- Using of starter cultures in a ratio of 1: 1, with a selected dose of starter - 5 units of activity, contributes to the intensification of physicochemical and biochemical processes of salting, maturation of meat and creation of optimal functional and technological properties in a shorter period;

- It is proved that the enrichment of meat with cereals with 1% of crushed germinated corn, leads to the presence of carbohydrates in the finished meat product and to an increase in the concentration of such vitamins as E, C, B₁, B₃, B₅ and B₆;

- The possibility of using of plant raw materials for the creation of restructured semi-smoked meat products has been substantiated.

Thus, revealed high biochemical activity of bacteria contributing to an increase in the proteolytic activity and the accumulation of the active amine nitrogen. It is established that preliminary processing of raw materials by the leaven of starter cultures and enrichment with crushed corn germ allows not only to intensify the salting process, but also to increase the biological and nutritional value of the finished product.

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ТАҒАМ ӨНІМДЕРІНІҢ САПАСЫН АРТТЫРУ БОЙЫНША ЗЕРТТЕУЛЕР

Аннотация. Мақалада тағам өнімдерінің сапасын арттыру бойынша зерттеулер нәтижесі, нақтылап айтқанда, қайта құрылымдалған ет өнімдерінің зерттеулер нәтижесі берілген. Шикізат алдын-ала бактериялды старттық дақылдармен өңделсе, протеолиттік белсенділік артып, аминді азоттың белсенді жинақталуына себеп болады, нәтижесінде еттің жетілуін жылдамдатады. Зерттеу үлгілеріне дәрумендік және көмірсу құрамы бойынша байытылған өсімдік шикізатын енгізу – дайын ет өнімінің теңгерімділігіне оң әсер

беріп, биологиялық құндылығын арттырады. Болашақта алынған нәтижелерді ет технологиясын жетілдіру кезінде пайдалануға болады.

Түйін сөздер: ет, қой еті, сиыр еті, қайта құрылымдалған ет өнімі, сүтқышқылды бактериялар, пропионқышқылды бактериялар, старттық дақылдар, дәнді дақылдар, жүгері, протеолиттік белсенділік.

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ИССЛЕДОВАНИЯ ПО ПОВЫШЕНИЮ КАЧЕСТВА ПРОДУКТОВ ПИТАНИЯ

Аннотация. В статье приведены результаты исследований по повышению качества продуктов питания, а именно результаты исследования реструктурированного мясного продукта. Установлено, что предварительная обработка сырья стартовыми культурами способствует увеличению протеолитической активности и активному накоплению аминного азота, соответственно ускоряет созревание мяса. Введение в опытные образцы растительного сырья, хорошо сбалансированного по углеводному и витаминному составу, оказывает позитивное влияние на сбалансированность готового продукта и повышает их биологическую ценность. Полученные данные являются перспективным направлением при совершенствовании технологии мяса.

Ключевые слова: мясо, говядина, баранина, реструктурированный мясной продукт, молочнокислые бактерии, пропионовокислые бактерии, стартовые культуры, зерновые культуры, кукуруза, протеолитическая активность.

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**DEVELOPMENT OF TECHNOLOGY
FOR PRODUCING SORBITOL
FROM WHEAT STRAW CELLULOSE**

Abstract. The aim of the work is to develop an enzymatic technology for processing wheat straw cellulose for the production of sorbitol by means of hydrolytic hydrogenation based on the use of a hybrid process.

Enzymatic hydrolytic hydrolysis and hydrogenation of wheat straw cellulose research have been carried out and optimal process parameters have been developed. As a result, a combined (hybrid) hydrolysis-hydrogenation process for production of sorbitol have been implemented. In this process, enzymes have been developed and tested for their activity. The influence of the process time, the temperature of the test and the pH on the conversion of cellulose and selectivity for sorbitol have been studied.

The developed technology will allow us to improve the traditional processes in terms of eliminating the numerous stages of purification and isolation of intermediate products. It enables the realization of a single-reactor combined (hybrid) process for the production of such a valuable chemical as sorbitol.

Key words: cellulose, wheat straw, hydrolysis, hydrogenation, polysaccharides, hydrolytic hydrogenation, glucose, sorbitol, enzyme.

Introduction. The growing interest in the use of carbohydrate-containing agricultural plant waste, rich in polysaccharides, determines the search for optimal methods for its processing [1, 2]. The main criterion for processing these wastes is their cost, volume, availability and localization, as well as their chemical composition and technological properties. At the same time, the possibilities of using directly microorganisms, enzyme complexes, chemical hydrolyzing agents for effective conversion of non-food raw materials into digestible sugars [3].

The main factor restraining the processing of polysaccharides of wheat straw is the low profitability of these industries, due to shortcomings in the preparation of raw materials, highly energy inputs and low yield of the target product. This problem can be overcome when solving the problem of maximizing the use of raw materials.

At present, there are no such industries in the Republic of Kazakhstan, which makes it difficult to solve the problems of determining the prospects for introducing the scientific results obtained into production. Therefore, the development of an acceptable technology for the depolymerization of carbohydrate-containing plant raw materials is an extremely urgent task. Modern technologies for processing cellulose-containing raw materials are extremely diverse. They differ in the type of feedstock, processing processes, end products, and, therefore, are specific for use in different economic and regional conditions. Direct combustion is the most widely used method of processing biomass (wood and wood waste, urban solid waste, straw, etc.). It should be noted that even well-known technologies for the use of cellulosic raw materials are being improved. The authors of [7-20] investigated the process of joint hydrolysis and hydrogenation of cellulose.

According to the statistical data of the Ministry of Agriculture of the Republic of Kazakhstan, wheat is the leader among crops in terms of yield. Despite the fact that to date a number of measures developed and implemented for the processing and utilization of wheat straw, most of them are unclaimed. In most cases, it is used for feeding cattle and as litter to animals, the rest of it is plowed into the ground or burned in the fields. Thus, this waste is a large-capacity, affordable and promising secondary agricultural production resources in the Republic of Kazakhstan. The development of an integrated technology for the processing of wheat straw to produce sorbitol will not only improve the ecological situation, but also will provide raw materials and additional products for the industry.

Thus, the analysis of the literature showed that a significant increase in the number of scientific publications devoted to the one-stage processing of biomass components, especially polysaccharides over the last ten years, indicates the high relevance of the problem of its transformation into valuable chemical substances.

The goal of this work is to develop a technology for enzymatic hydrolytic hydrogenation of wheat straw pulp, in order to obtain sorbitol necessary for the food, pharmaceutical and chemical industries.

The development of such an efficient technology for processing wheat straw, with the possibility of obtaining sorbitol, is an extremely urgent task.

Materials and methods. In the present work, studied wheat straw, which formed as waste in the agricultural sector of the Republic of Kazakhstan. Previously investigated plant raw materials crushed and sorted. For chemical analyzes, raw materials were used, were fractionated through a sieve with a particle size of 2-3 mm.

The ash contents determined by burning the sample of raw materials followed by calcination in a muffle furnace at a temperature of 600°C, the content of easily and hardly hydrolysable polysaccharides determined by the method of Kiesel and Semiganovsky, lignin determined by the Koenig method in the Komarov modification using 72% sulfuric acid, pentosans - determined on the content of pentoses in hydrolysates of easily and hardly hydrolysable polysaccharides.

The analysis of the sugars carried out by the method of Bertrand and Maken-Shoorl, individual sugars were determined on a liquid chromatograph HPLC; Shimadzu LC10-ATVP, Differential Digital Detector TEST-900, Luna Column Investigation of the process of enzymatic hydrolytic hydrogenation of wheat straw in the presence of a complex enzyme preparations.

In this case, enzymatic hydrolytic hydrolysis and hydrogenation of each wheat straw cellulose sample carried out in an aqueous medium (the active acidity regulated with phosphoric acid and was within the range of 4.8-4.9 pH units).

The substrate concentration in all the experiments was 45.0 g/l. As catalysts, a composition of enzyme preparations used, introduced in an amount of 0.03 g of enzyme per gram of substrate at the start of fermentation. To carry out the hydrogenation-hydrolysis process, the amount of wheat straw, enzymes, phosphoric acid weighed accurately on the analytical scales and the necessary amount of water placed in the fermenter. After a specified period of time, the process was terminated and analyzes were carried out for the content of sugar alcohols and the degree of conversion of cellulose was determined by means of liquid chromatography.

Results and discussion. Studies of the processes of enzymatic hydrolytic hydrogenation of wheat straw cellulose in the presence of complex enzymes carried out. Dependences of the rate of enzymatic hydrolytic hydrolysis and hydrogenation of wheat straw cellulose on the process time showed in table 1.

Table 1 – Dependence of the rate of enzymatic hydrolytic hydrolysis and hydrogenation of wheat straw cellulose on the time of the process

#	τ , min	Conversion degree, %	Selectivity on sorbitol, %	Selectivity on mannitol, %	Total output, %	Selectivity on glucose
1	80	32.0	1.9	1.0	21.4	19.1
2	160	37.1	2.9	1.4	33.5	21.8
3	240	54.0	3.6	1.8	46.1	35.0
4	320	45.7	3.0	1.6	40.0	33.3
5	400	44.6	2.3	1.3	36.7	31.1

Table 1 shows the experimental data on the study of the regularities of the change in the rate of enzymatic hydrolytic hydrolysis and the hydrogenation of wheat straw from the time of the reaction. The reaction time varied from 80 to 400 minutes. The optimal time for the process of catalytic conversion of wheat straw in the conditions chosen by us is 240 minutes. Before this moment of reaction, the conversion of wheat straw gradually increases, and after this index its values are within the margin of error. The same pattern observed with the selectivity index for sorbitol. However, the selectivity for sorbitol and mannitol is much lower than in chemical hydrolytic hydrolysis and hydrogenation. This explained by the prevalence of the rate of the hydrolysis reaction over the rate of the hydrogenation reaction. This evidenced by the high values of the selectivity on glucose (from 19.1 to 35.0%).

When studying the effect of the temperature of the process of enzymatic hydrolytic hydrolysis and hydrogenation on the conversion of wheat straw cellulose and selectivity on sorbitol and mannitol, it showed that, with an increase in temperature from 30 to 50°C, the conversion of wheat straw increased from 12.7 to 42.7% (table 2). Selectivity on sorbitol with increasing temperature (30-50°C) increased from 7.7 to 17.8% and decreased to 7.0% with an increase in temperature to 70°C. The decrease in selectivity for sorbitol due to the fact that at temperatures above 70°C the process of inactivation of the enzymes in use takes place.

Table 2 – Experience temperature influence on enzymatic hydrolytic hydrolysis and hydrogenation process of wheat straw cellulose

#	T, °C	Conversion degree, %	Selectivity on sorbitol, %	Selectivity on mannitol, %	Total output, %
1	30	12.7	7.7	1.8	10.2
2	40	28.3	14.3	2.0	16.1
3	50	42.7	17.8	1.1	18.9
4	60	34.3	12.1	1.1	14.8
5	70	19.7	7.0	1.2	9.0

Table 2 shows the optimal temperature for experience is 50°C, as soon as in this temperature we obtained maximum selectivity on sorbitol and mannitol.

During the study of the effect of pH (Table 3) on the process of enzymatic hydrolytic hydrolysis and hydrogenation of wheat straw cellulose on conversion and selectivity for polyols, it was established that the highest selectivity values for sorbitol-17.8% and conversion-42.7% were observed in when using a pH value of 5.0. The change in the pH of the medium leads to a change in the degree of ionization of the acidic and basic groups as the active center of the enzyme, and the substrate itself.

Table 3 – Effect of pH on the process of enzymatic hydrolytic hydrolysis and hydrogenation of wheat straw cellulose

#	T, °C	Conversion degree, %	Selectivity on sorbitol, %	Selectivity on mannitol, %	Total output, %
1	4.0	15.2	7.5	1.2	9.3
2	4.5	30.0	11.3	1.2	12.5
3	5.0	42.7	17.8	1.1	18.9
4	5.5	35.8	10.5	2.9	11.7
5	6.0	19.1	5.5	2.4	8.1

Consequently, a change in pH affects the affinity of the substrate to the active center of the enzyme and to the catalytic mechanism of the reaction. The dependence of the rate of the enzymatic reaction on the pH of the medium has the form of an extremum, since for each enzyme there is an optimum pH value at which the enzyme exhibits the greatest catalytic activity (the optimum pH of the enzyme). The pH value in the optimum corresponds to the best binding of the substrate by the enzyme and the highest catalysis rate. In our case, this value is 5.0.

Thus, we determined the optimal conditions for the enzymatic hydrolytic hydrolysis and hydrogenation of wheat straw pulp: pH 5.0, temperature 50°C, reaction time 3 hours.

Conclusion. Thus, we determined that the resource of wheat straw waste that we are interested in is quite sufficient for further implementation of the task. The effectiveness of a complex of enzymes for carrying out the process of enzymatic hydrolytic hydrogenation of cellulose of wheat straw substantiated and experimentally confirmed for the first time. The optimal conditions for the enzymatic hydrolytic hydrolysis and hydrogenation of wheat straw: pH 5.0, temperature 50°C, reaction time 3 hours are determined.

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БИДАЙ САБАНЫ ЦЕЛЛЮЛОЗАСЫНАН СОРБИТТІ АЛУ ТЕХНОЛОГИЯСЫН ЖАСАУ

Аннотация. Жұмыстың мақсаты – үйлестірілген (гибридті) тәсіліне негізделген бидай сабаны целлюлозасынан сорбитті гидролитикалық гидрлеуді қолдана отырып ферментативті өңдеу арқылы алу технологиясын жасау. Ферментативті гидролитикалық гидрлеу және бидай сабаны целлюлозасын гидролитикалық гидрлеу үрдістері зерттелді, үрдістің тиімді параметрлері жасалып алынды. Нәтижесінде біз сорбитті алудың үйлестірілген (гибридті) гидролиз-гидрлеу әдісін іске асырдық. Осы үрдіс үшін ферменттер жасалды, олардың белсенділіктері анықталды. Үрдіске уақыттың әсері, температура және целлюлоза конверсиясына рН әсері, сорбит бойынша таңдама жасалынды. Біз жасап шығарған технология дәстүрлік үрдіс барысында, көптеген тазалаулар мен бөліп алуларда пайда болатын аралық өнімдерді болдырмайды. Ол біз үшін, бір реакторлы үйлестірілген (гибридті) үрдісті қолданып сорбит секілді құнды химиялық затты алуға мүмкіндік береді.

Түйін сөздер: бидай сабаны, гидролиз, целлюлоза, гидрлеу, полисахаридтер, ферментативті гидролитикалық гидрлеу, глюкоза, сорбит, ферменттер.

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РАЗРАБОТКА ТЕХНОЛОГИИ ПОЛУЧЕНИЯ СОРБИТА ИЗ ЦЕЛЛЮЛОЗЫ СОЛОМЫ ПШЕНИЦЫ

Аннотация. Цель работы – разработка ферментативной технологии переработки целлюлозы соломы пшеницы для получения сорбита посредством гидролитического гидрирования, основанного на использовании совмещенного (гибридного) процесса. Проведены исследования по изучению процесса ферментативного гидролитического гидролиза и гидрирования целлюлозы соломы пшеницы, разработаны оптимальные параметры процесса. В результате чего нами реализован совмещенный (гибридный) гидролиз-гидрирование процесс получения сорбита. Разработаны ферменты для данного процесса, исследована их активность. Изучено влияние времени процесса, температуры опыта и рН на конверсию целлюлозы и селективность по сорбиту. Разработанная нами технология позволит усовершенствовать традиционные процессы в плане ликвидации многочисленных стадий очистки и выделения промежуточных продуктов. Она дает возможность реализации одnoreакторного совмещенного (гибридного) процесса получения такого ценного химического вещества, как сорбит.

Ключевые слова: солома пшеницы, гидролиз, целлюлоза, гидрирование, полисахариды, ферментативное гидролитическое гидрирование, глюкоза, сорбит, ферменты.

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**THE ANALYSIS OF HEAT AND MASS PROPERTIES
OF THE FIRE EXTINGUISHING POWDER
IN EFFECTIVENESS CRITERIA**

Abstract. The given research presents the classification of fire extinguishing and explosion suppression compositions. The effect on the combustion reaction is possible with the help of physical and chemical methods of gas mixture components concentration reducing, cooling the combustion zone and slowing down of chain reactions with the help of a phlegmatizing or inhibiting substances, of which the most universal and perspective are powder materials. In view of the high toxicity and environmental hazard of inhibitors (halides), the most promising search and development of effective powder compositions based on chlorides and substances with pronounced endothermic properties (easy-boiling, easy-decomposing, easy-melting) causing a sharp cooling of the combustion zone. The general laws of the effectiveness of extinguishing powders from their composition was considered in the scope of literature. There are proposed only some unsystematic series of dependence of the studied mineral compounds. Therefore, a necessary condition for solving the problems of developing effective flame arresters is to find common indicators and properties of substances that can become criteria for their phlegmatizing ability.

Keywords: fire extinguishing powders, explosion suppression composition, spread materials, burning reagents, efficiency of powder, heat and mass properties.

Classification of fire extinguishing and explosion suppression compositions. One of the modern means of fires fighting and explosions are fire extinguishing and explosion suppression powders, which are finely powdered mineral salts with various additives preventing caking and balling. Powders are differed with universal actions, providing the extinguishing of even such materials that cannot be put out by water and other means.

Powders used to extinguish most of the fires classes [1, 2]. Class A - burning solids, accompanied by decay (wood, paper, textiles, coal etc.) and not followed by decay (plastic, rubber); B - burning liquids (gasoline, petroleum products, alcohols, solvents, etc.); C - combustion of gas- and vaporous substances (ammonia, methane, propane, and others.); D - burning metals and metal-containing compounds (magnesium, aluminum, potassium, sodium, etc.); E - combustion of materials in electric installations under voltage.

Therefore, the powder can be used to extinguish of any substances and materials. Powder compositions depending on the class of fire that they can extinguish, divide:

- powders of ABCE type - active main component - phosphorus-ammonium salts;
- powders of BCE - the main component of these powders can be sodium and potassium bicarbonate; potassium sulfate; potassium chloride; alloy urea with salts of carbonic acid, etc.;
- powders of D type - main component - potassium chloride; graphite, etc.

There are distinguished powders of general and special purpose. Powders of common purpose (ABCE, BCE types) is used to extinguish fires of ordinary (organic) easy-flammable combustible materials (EF) and combustible liquids (CL), for example various liquefied gases, solid material - wood, rub-

ber, plastics, etc. The extinguishing of these materials is reached by creating a powder cloud that envelops the hearth burning.

The powders of special purpose are produced for the particular class of fire, for example for B, C and D classes. Cessation of combustion in this case is achieved by isolating the burning surface from the ambient air.

The advantages of powder include the possibility of their application for the deterrent and explosion suppression. In this regard, by applying powders fall into two groups: fire-extinguishing and explosion suppression. The largest group consists of extinguishing powders used for charging, manual and mobile fire extinguishers, fixed installations and special fire vehicles.

Fire extinguishing of powders ability of the general purpose is increased with rising of their dispersion (size reduction of particles), powders of a special purpose - almost does not depend on the degree of their dispersion. From literature data [3, 4] it is known that some mineral powders are active inhibitors of the chain gas-phase combustion reactions and can be used as explosion suppression agents.

So, in the USA, Germany, England, France developed and uses automatic systems of protection of curb, as a rule, commercially available fire-extinguishing powder or finely divided salts of phosphoric salts and carbonic acid.

Fire extinguishing powders properties and compositions characteristics. There are widely used various substances to prevent ignition and explosion of methane - air mixtures at mining industry at the present time. Beginning from simple deterrents (inert dust and water with the addition of 5-7% surfactants), the restraining effect of which is to reduce the temperature to a level at which terminates combustion. And finishing with the highly efficient flame retardants based on easy-decaying salts are treated with a special water-repellent additives and disintegrating, can extinguish the flame of the flash (explosion) at relatively low unit costs, about 0.01 to 0.10 kg/m³ of protected volume [5].

The extinguishing with powder method can be used to explain the physical-chemical properties of the powder (table 1) and the effect of the following factors:

- dilution of the combustible environment with gaseous products of powder decomposition or directly by a powder cloud;
- cooling of the combustion zone as a result of the heat cost for powder particles heating its partial evaporation and decomposition in flame;
- effect of fire-resistance achieved by passing the flame through the narrow channels, as if created by a powder cloud;
- inhibition of chemical reactions that lead to the development burning, gaseous products of evaporation and powders decomposition or heterogeneous open circuits on the powders surface or solid products of their decomposition.

The working life of agents is limited to 5-10 years and depends largely on the conditions of fire extinguishing compositions service.

So, powders, working in the conditions of transport are subject to additional vibration, which leads to the seal structure, the so-called effect of "pepper".

Standard GCST 26952-97 is spread to fire-extinguishing powders for general purposes, and establishes requirements for the indicators of technical level and quality as well their test methods.

Universal fire-extinguishing powders, such as P-2AP and P-4AP are checked on quality indicators according to the TC 113-08-597-86 [6].

Powder P-2A1T is used for filling powder fire extinguishers and installations and P-4AP for volume distant extinguishing of underground fires in coal mine workings and can be used for equipment of explosion-protection automatic machines.

Extinguishing powders are complex heterogeneous systems, so they have specific properties and characteristics which depend on their fire-extinguishing ability. Chemical composition of powders also determines their fire extinguishing action and performance properties.

There is presented information about the applied powder flame retardant compositions in the reviews [7-10].

The basis for fire extinguishing powder is phosphorus- salt (mono- and di-ammonium phosphates) such as: $(\text{NH}_4)_2\text{HPO}_4$, $\text{NH}_4\text{H}_2\text{PO}_4$; potassium chlorides KCl and others. In the composition of the powders also enter special additives that prevent the balling and caking.

Table 1 – Basic physical-chemical data of fire extinguishing powders

Class of fires	The combustible material	The required physical-chemical properties of powder	Spread components
A	Carbon-containing (wood, coal, rubber-technical products, plastic and other)	Viscous polymer film formation at the temperature 200-250°.	Phosphorus-ammonium salt; a sodium salt of boric acid
B	Flammable liquids (gasoline, alcohol, paints, solvents and others)	The ability of the surface particles and products of its evaporation (decomposition) sharp slowdown the chain reaction of combustion; the ability of the powder substances quickly decompose at $T > 200^{\circ}\text{C}$	Phosphorus-ammonium salts; bicarbonates and chlorides of potassium (sodium)
C	Combustible gases and vapors (hydrogen, methane, ammonia, propane - butane mixture, vapours of acetone, and others)	Same	Same
D	Light metals and their alloys (magnesium, aluminium, potassium, sodium)	The formation of melting film which stable at the temperatures of 2000-3000 °C	Potassium chloride (sodium); Melamine; graphite; cryolite
E	Electrical equipment and cables up to 1000-1200 V (at the latest international standards this class is absent)	The absence of electric-conductivity of powder layer and powder-air stream	From foresaid components-of all, besides graphite, but good dried (till humidity no more than 0,5%)

The powders based on bicarbonate and carbonates of alkaline materials (KHCO_3 , NaHCO_3) are widespread. To improve the yield and sustainability of the structure the additives of silicon organic compounds are entered. These powders are resistant to caking and have good performance properties.

One of the directions in solving the problem of phlegmatizing of explosive atmospheres is the use of special chemical compounds, relatively small additions of which greatly reduce the possibility of ignition from heat source. For this purpose, the authors of [11] were investigated substances: sodium bromide, sodium chloride and sodium bicarbonate with a particle size, a predominant fraction (87%) 0,2-0,5 mm.

Thus, the PSB powder made from bicarbonate of sodium has good performance properties, low-cost, and the main component of it available. Powder PSB is designed to extinguish fires of B, C and E classes. It is widely used for extinguishing liquefied gases large quantities of petroleum products (for example during an emergency landing of the aircraft), alcohols and other polar GL.

Currently available powder brand PSB-3 (TU 6-18-139-93) characterized by a higher dispersion and, consequently, increased fire-extinguishing ability.

Sodium bicarbonate and aerosol enters into powder PSB-3 as well nepheline concentrate is used to improve the fluidity.

Powder brand of PSB-3M is designed for extinguishing fires of B, C and E classes. It represents by itself a mechanical mixture of 87-90% of sodium bicarbonate (bicarbonate); 7-10% of nepheline concentrate; 3-5% flowing additives. The rate of fire extinguishing ability when extinguishing fire of B class is no more than 0,8 kg/m² (TU - 2149-017-19968286-95).

In addition, there are copyright certificates and patents for a number of fire extinguishing powder formulations, although not exploited commercially, but is of interest. In particular, to enhance fire-extinguishing efficiency of the composition added salts of organic acids - sodium carbonate [A. S. 1142128 (USSR)], trilon B [us Pat. 2118834 (UK)] and other salts.

There is a tendency to apply active fire-extinguishing salts (solution) in porous media. As inorganic salts - vermiculite, aerosil, zeolite, or organic - polystyrene (patent 4226727 USA; patent 77537 NDP). Along with effective powder type "Monex" is underway on the preparation of ternary alloys of the type urea (melamine) phosphate - bicarbonate.

485742 A. S. (USSR) invited the inhibitor of ignition of combustible gases consisting of inorganic salts of potassium stearate and talc for suppression of ignition improvement and the flame of a mixture of acetylene with air extinguishing. Components: 93-96% sulfide; 3-5% of potassium stearate and talc 1-2%.

In a.s. 563503 (USSR) to improve the efficiency of preventing dust explosions, and the prevention of caking as the ammonium salts, the composition contains ammonium bromide (97-98%) and calcium stearate. The mixture is ground until full passage through a sieve of 0.075.

The authors of [12] were investigated the combustion of explosive substances under conditions similar to the conditions in the mine, and also the effect of various reagents added to explosives to prevent them from burning. It was established experimentally that the most effective action have inorganic compounds with a high content of water of crystallization such as: $Al_2(NO_3)_3 \cdot 9H_2O$; $Al_2(SO_4)_3 \cdot 18H_2O$.

The authors of [13, 14] were experimentally investigated the inhibitors following the explosion of a coal - air mixture: rock dust, crushed limestone (both calcium carbonate), a conventional composition for fire extinguisher (sodium bicarbonate), "Monex". Sevrikov and others [15] suggest to use as fire-extinguishing powder industrial dust cement plants, especially dust Bakhchisaray cement plant the extinguishing capability of which is equal to 0,7-0,8 kg/m² (i.e. as at PSB).

To obtain fusible powders it is advisable to search among complex multi-component compositions that form a eutectic [16]. The eutectic is a thin mixture of solids, is simultaneously crystallized from the melt at a temperature lower than the melting components or other mixtures thereof. For example, in the ternary diagram of fusibility of the system CaO - SiO₂ - Al₂O₃ used for finding low-melting compositions metallurgical slag, the melting point of pure oxide is 2570, 2040, and 1728°C, respectively, and a eutectic mixture consisting of: 24% CaO + 62% SiO₂ + 14% Al₂O₃ starts to melt already at 1170 °C.

Considering the economic aspect of the problem, effective fire extinguishing powder compositions are supposed to look for on the basis of cheap natural materials and industrial wastes, among which the perspective can be slag, the chloride technology of nonferrous metallurgy. Examples of this are the reference data that the double eutectic mixture of 35% KCl + 65% CuCl₂ is melted at 150 °C, while pure KCl and CuCl₂ - at 770°C and 630 °C, respectively, and the triple eutectic melting separate ZnCl₂, NaCl and KCl are respectively 320 °C, 800 °C and 770 °C.

The perspective direction from an economic point of view is obtaining fire extinguishing powder based on mixtures of chlorine-containing effluents, rolling mills and iron mill scale rolling mills with the aim of iron chlorides crystal-hydrates obtaining, the effectiveness of which is conditioned by low temperature flowing of endothermic reactions decomposition and melting.

So according to I. T. Granovsky [17], FeCl₂·4H₂O is decomposed at a temperature of 76 °C, FeCl₃·6H₂O melts at 37°C and boils at 285°C. Anhydrous iron (II) chloride melts at 677°C, the iron chloride (III) at 309°C and sodium chloride, which melts only at 800°C is considered as a good enough antipirogen.

Thus, the chlorides of alkali metals are one of the most effective flame arresters. They are considered most promising for the development of new powder formulations because they are low-toxic and widely available. At the same time, Baratov noted that on the basis of these salts, fire-extinguishing powders, such as PGS-M (mixture NaCl and KCl) is recommended for metals extinguishing by the method of isolation from the air, and the possibility of their application as flame retardants has not been reported.

Thus, the research [18] revealed that the most efficient inert for lignite dust is the powder of NaCl, phlegmatizing ability of which is 3,5 times is higher than in dust CaCO₃.

The authors of [19] are proposed already as an inhibitor composition based on NaCl additives as a promoter of 0,1-5% FeCl₂.

There are claimed the ways of coal dust suppression in the mine atmosphere by blowing fine CaCl₂ and prevent its explosion of composite powders on the basis of chlorides (CaCl₂, MgCl₂, NaCl) with the addition of 0,1-3% hydrophilic organic wetting agent and 0,1-2% anti-corrosion agent (chromium, silicate, phosphorus and aluminate).

In several works of [19-23] are noted effectiveness of the suppression with fine powders of chlorides, including AlCl₃, NaCl, KCl - explosions of methane and KCl - the hybrid mixtures of methane with coal dust.

A review of the scientific-technical and patent literature allowing to conclude that the most promising components for the manufacture of powders are phosphor-ammonium salt, sulfide- ammonium and aluminium- ammonium crystal-hydrates of alum type, chlorine and fluorine-containing compounds such

as "Monex", salts of alkali metals, salts of carbonic acid, bicarbonate and sodium or potassium carbonate.

Fire-extinguishing capacity and efficiency of powders. Nowadays more and more preference is given to powder products due to their high fire extinguishing efficiency. They are also the most cost-effective means of extinguishing based on the indicator as "the ratio of the cost of extinguishing to the area of extinguishing".

Comparing the technical data of domestic and foreign fire extinguishing powders, which are presented in table 2, it can be seen that they have approximately the same fire extinguishing capacity and close in performance properties are. As the main component in fire extinguishing powders are used:

- bicarbonate and sodium and potassium carbonate;
- ammophos (ammonium phosphate);
- sodium and potassium chlorides;
- carbamide (urea);
- ammonium, potassium and sodium sulfates.

Table 2 – The characteristic of fire-explosion-danger dispersion wastes

Appellation of test-tube	Compound, % weight	Group of combustibility	Temperature, °C		
			Tn	Tk	Ignition of air suspension
Blast furnace slag	SiO ₂ - 36,72; CaO - 39,13; MgO - 7,51; Al ₂ O ₃ - 13,64	NG	no	No	
Open-hearth slag	SiO ₂ - 18,72; CaO - 45,25; MgO - 9,84; P ₂ O ₅ - 1,65; Al ₂ O ₃ - 4,15; FeO - 12,26; MnO - 6,98	NG	No	No	No
Dust of open-hearth gas-cleaning	Fe ₂ O ₃ - 54,5; Ca - 3,14; SiO ₂ - 1,9; MgO - 2,28; S - 2,75	NG	No	No	No
Convertor slag	SiO ₂ - 8,45; CaO - 44,03; Al ₂ O ₃ - 2,14; MgO - 5,24; MnO - 4,35; FeO - 15,34; P ₂ O ₅ - 6,34	NG	No	No	No
Dolomite slag	CaO - 44,50; SiO ₂ - 3,71; MgO - 26,36; MnO - 0,25; Fe ₂ O ₃ - 0,22; Al ₂ O ₃ - 1,74	NG	No Endo-effect 420-640 750-	Notill 1000	No
Limestone dust	CaO - 81,75; SiO ₂ - 1,20; MgO - 0,77; Al ₂ O ₃ - 0,61; S - 0,02	NG	Noendo-effect 430-580 720-830	Notill 1000	sparks
Graphite-containing dust of ventilation system	C - 97	TG	420	760	900 sparks

The general dependence of explosion-suppressing and fire-extinguishing powders efficiency on their chemical composition (at their identical dispersion) in the scientific and technical literature is not revealed by us. There are disclosed fragmentary according to the different composition of groups of substances. Some regularity of the effectiveness of powders with the composition of compounds present only in the last fourth and fifth cases:

1) $J \rangle Br \rangle Cl \rangle F$ (halogens, halons)

2) $NaHCO_3 \langle NaF \langle Na_2C_2O_4 \langle Na_2Cl_3 \langle K_2CO_3 \langle KCl \langle K_2Cr_2O_7 \langle NaCl \langle K_2C_2O_4 \cdot H_2O$

3) $SiO_2 \langle NaCl \langle melting KCl : NaCl : FeCl_2 - 55 : 44,8 : 0,2 \langle NaCl : KOH - 99 : 1 \langle$
 $\langle melting NaCl : MgF_2 - 98 : 2$

4) Hydrates of Salts > Hydroxides > Anhydrous Salts > Oxides

5) Salts: Chlorides > Carbonated > Sulphates and moreover: $FeR \rangle MgR \rangle CaR$, where R- acid residue - $SO_4^{-2}, CO_3^{-2}, Cl^{-1} or OH^{-1}$

The aim of our study is to find fire-extinguishing powders, in which the main part would be non-combustible (table 2) dusty metallurgical wastes of JSC "Arcelor Mittal Temirtau". The emphasis is powder flame-suppressing compositions development for the effective suppression of ignition and explosion, which would have been made from abundant raw materials by simple technology.

Therefore, the physical-chemical evaluation of metallurgical wastes by JSC "Arcelor Mittal Temirtau" is relevant both for the development of technological options for their use and for the search for new materials for the production of fire-extinguishing compositions [24, 25]. The large-tonnage dispersed waste of metallurgical plant, which have a phlegmatizing or inhibitory properties are:

- calcareous, limestone and dolomite dust of products of limestone burning shops which contains carbonates, hydroxides and calcium and magnesium oxides;
- blast furnace and steelmaking slags consisting of calcium, magnesium, aluminum, silicon and iron oxides in free state and bound in various compositions;
- neutralized acid runoff of rolling mills;
- iron oxide formed during regeneration of spent etching solution.

There is performed a review of scientific-technical and patent literature on the endothermic properties of powder materials and compositions, similar in composition to waste, as explosion suppression substances.

The efficiency of powder phlegmatizers can be combined into three groups [26].

The first group is substances that act as inert when heated. These include dispersed wastes consisting mainly of oxides:

- SiO_2 -spent foundry molding mixtures;
- Fe_2O_3 -dust generated during the regeneration of spent pickling solutions of rolling mills;
- CaO , MgO , SiO_2 , Al_2O_3 - oxides, contained in very stable silicates of CaO-SiO_2 , MgO-SiO_2 , $\text{Al}_2\text{O}_3\text{-SiO}_2$ in metallurgical slag. These substances do not undergo structural, mineralogical or chemical transformations when heated even above 1000°C . Fire-extinguishing properties of oxides are the weakest. The effect of phlegmatization by inertia increases with the use of substances with endothermic melting processes.

To them are related commonly magnesium, potassium, calcium and sodium chlorides, which have a melting point of $700\text{-}800^\circ\text{C}$.

The effect of oxides is due only to the physical absorption of the heat of the combustion reaction, which leads to a decrease in its thermal effect, a slowdown in the rate of combustion and an increase in the ignition temperature.

The second group is substances in which the heating occurs endothermic decomposition reaction with the transition to a substance of a different composition. These include:

- carbonates ($\text{CaCO}_3\text{-MgCO}_3$) contained in the limestone and dolomite dust, as well as calcined lime and dolomite dusts and bulk materials steel mills;
- hydroxides $\text{Ca}(\text{OH})_2$ and $\text{Mg}(\text{OH})_2$ formed upon contact with water during granulation of blast furnace slag and absorption of moisture from the air by lime and dolomite dust;
- iron hydroxides $\text{Fe}(\text{OH})_2$, $\text{Fe}(\text{OH})_3$ contained in the neutralized acid runoff of steel rolling mills;
- hydrates of iron and calcium salts, containing in its composition crystal-hydrates, i.e. chemically bound water, which are formed in acidic and neutralized effluents of steel-making shops, and are in the form of a solution or suspension, and after drying - in a dispersed state.

The third group is substances that have chemical effect on the reaction of oxidation and ignition in a combustible environment (chlorides).

Considering both efficiency, and ecological safety, search and development of compositions among substances with pronounced endothermic properties is the most perspective, i.e. preference, it is necessary to give to the materials causing sharp cooling of a zone of burning or capable to create the environment which is not supporting burning.

To these materials are related carbonates, crystal hydrates and other fusible salts. For example, as anti-pirogen are recommended the following: urea (CH_4ON_2), which melts at 132°C ; dolomite ($\text{CaCO}_3\text{-MgCO}_3$) decomposes at 350°C with the release of carbon dioxide; alum $\text{KAl}(\text{SO}_4)_3\cdot 12\text{H}_2\text{O}$ -above 100°C decomposes with the release of water vapor.

Recent studies have established [27] that one of the main factors determining the fire extinguishing capacity of powder wastes is the temperature of endothermic processes occurring in them during heating. The explosive action of powders with equal dispersion increases in a number of:

Oxides < Salt Anhydrous < Hydroxides < Hydrates Of Salts, Including Sulfates < Carbonates < Chlorides, And $\text{CaR} < \text{MgR} < \text{FeR}$ (R - acid residue - SO_4^{-2} , CO_3^{-2} , Cl^{-1} or OH^{-1}).

The authors of some scientific papers [28] noted that the efficiency of powder inhibitors is significantly influenced by the way of their spraying and delivery to the flame front. There are three ways to feed powders into a fire or explosion zone: pneumatic, explosive and combined.

Pneumatic method is carried out in several ways:

- the charge and case of the fire extinguisher are constantly under pressure of the displacing inert gas (air, nitrogen, carbon dioxide) or steam of the extinguishing agent;
- presence in the fire extinguisher with powder of the spray can with the compressed or liquefied gas located in the case of the fire extinguisher or outside;
- presence in the powder container of excess pressure created by the release of gas in the course of a chemical reaction between the components of the charge of a special pyrotechnic gas-generating element of the fire extinguisher;
- supply of extinguishing agent is carried out as a result of the thermal effect on electric current or chemical reaction products of components of a special element;
- ejection supply of fine powder in the air satellite stream (volumetric remote extinguishing powder in the mine, cable channels).

Explosive (pulse) method is implemented by placing before or in the mass of the explosive charge a detonator, the mass is selected experimentally. Explosive method has a number of advantages compared to the pneumatic method: instantaneous response, fast powder cloud formation, activation and dispersion of fire extinguishing powder by explosion energy, small inertia of the method. However, there are drawbacks: there are restrictions in the use of explosives require special accounting and storage. Burning explosives during blasting in coal mines can cause gas or coal dust explosion.

The combined (pneumatic impulse) method of feeding the powder into the fire or explosion is carried out by the energy of the gas compressed in the cylinder, the unlocking of which occurs with the help of an instantaneous micro-explosion.

The widespread use of powder-filled fire extinguishers and with an integrated pressure source, with regard to pulsed fire extinguishers and explosives is a new generation of firefighting equipment.

The successful and timely suppression of ignition and explosion of a gas-air mixture depends on the speed of introduction of an effective inhibitor into the ignition zone or flame front. For this purpose, high-speed automatic systems of active suppression [29] are used, the designs of which have recently been intensively developed. Typically, such systems include: explosion detection sensors that react to light, UV-radiation, static pressure, thermal radiation, smoke; control and amplifying device of the signal coming from the sensor and sending a command to the fuse; explosive devices, triggered by the charge of explosives and powder inhibitors, sprayed into the combustion zone or explosion.

Generators of volumetric aerosol fire extinguishing or volumetric extinguishing system (VES) are the most modern means of fire extinguishing.

They are designed to extinguish fires of flammable liquids and combustible liquids (gasoline and other oil products, organic solvents, etc.) and solid materials (wood, insulated materials, plastics, etc.) and electrical equipments (power and high voltage installations, consumer and industrial electronics, etc.)

Volumetric quenching systems (VES) are suitable for extinguishing alkaline and alkaline earth materials, as well as substances whose combustion takes place without the presence of air.

The VES generators are divided into: manual (VES-5M) and stationary (VES-1). The protected volume in case of fire by VES-5M generator up to 40m^3 and VES-1 generator is up to 60m^3 .

To actuate the VES-5 generator it is necessary: remove the cap from the start node, then sharply pull the cord and throw it into the burning room.

To start the VES-1 generator, special thermo-chemical or electrical start-up units are used.

The use of thermo-chemical start-up units, triggered when the temperature reaches 90°C in the protected volume, allows each generator, if there are several, to work completely autonomously. Gene-

rators with thermal nodes run, installed under the ceiling of the room in the area of the most likely ignition.

The use of electric start-up units allows the use of VES-1 generators at sites with fire alarms. Installation of the VES-1 generator in the protected area is performed using a special bracket. The operating position of the generator is horizontal or vertical by the injector downwards. Generators with electric start node are placed at random.

VES-1 generators operate in a temperature range from minus 55°C to plus 55° and 100% humidity.

In case of fire and tripping of generators, persons in this moment in a secure room need to quickly leave it firmly closed doors and not to take any action to extinguish the fire and calling the fire brigade.

Generators VES it is recommended to equip the following objects: industrial enterprises, power installations, household enterprises, public buildings, educational institutions, research institutes and establishments, banks and offices, shopping bases and warehouses, entertainment enterprises, administrative and residential buildings and vehicles.

In particularly hazardous conditions using automatic systems, as in the former Soviet Union developed the system explosion-suppression "Rainbow" and "Underbar", German firm "Total" designed "ACHEMA", a relatively new (2003), the Russian development of ASVP-LV explosion-suppression [30].

ASVP-LV includes:

a) explosion localization device (ELD) is a device, spraying the flame retardant powder and explosion creating a barrier in the form of clouds of flame retardant powder in suspension in underground mines;

b) autonomous command device (ACD) is a device that provides actuation of ELD.

The explosion localization device consists of a cone-shaped hopper and an intermediate chamber filled with flame retardant powder, inside of which is the working cavity of the device filled with compressed high-pressure air. Autonomous command device is docked with the device triggering of ELD and consists of extension rods, couplings, receiving shield and mounting nuts.

To protect the conveyor workings must be installed automatic systems ASVP-LV throughout the mine workings, at a distance apart of not more than 300 m. In the workings of the conveyor that transports only one kind, such systems are not installed.

For isolation of fire sites automatic systems of ASVP-LV are placed on all adjacent to them developments.

The systems are placed on the incoming and outgoing air streams in the production of monorail-equipped. The system by means of suspension and supports is attached to the elements of the fortress under the roof of the mining reception of acceptance board to the direction of expected spread of the shock wave front and the flame front formed as a result of the explosion of methane-air mixture and (or) coal dust. Unfortunately, this device has not been widely used.

Nowadays as we do here, and abroad, sufficient experience of creation of automatic system of explosion suppression. To develop, numerous variants of the basic elements and nodes of such systems were created, and their improvement continues.

So in Germany serially produced various modifications of the complex explosion suppression BVS complex [31], this is an automatic explosion device, developed by an experienced drift Westphalia mining partnership (BVS) especially for protection from explosions in the mine degasification systems. It is already for several years is an integral part of the means of explosion-protection mine degasification systems, and has justified itself in practice. According to the results of the experiments the most effective means for suppression of explosions is a powder based on ammonium phosphate sold under the brand name of tropolar.

In the [32] the powder efficiency of inhibitors was estimated by the lowest extinguishing concentration of powder in the detonation chamber g/l. Spraying device (suppressor) consisted of a polyethylene shell of spherical shape of the powdery inhibitor and an explosive charge. The authors noted that the effectiveness of powder inhibitors significantly affected by the method of atomization and delivery to the flame front. Testing of the restraining devices was successful.

Combustion, as is known, is a set of complex chemical and physical processes, such as chemical reactions, combustible oxidizer, diffusion, heat transfer and others. Due to the process of flame propagation in the combustible gas mixture heat transfer and the diffusion of the active centers of flame (ACF). If the flame propagation velocity is significantly less than the velocity of sound propagation in a

given medium, it is deflagration combustion, if is more this is detonation combustion or explosion. However, between deflagration combustion, when the shock wave is absent and detonation combustion, when the flame front and the shock wave front are combined, there is an area of "double non-stationary discontinuities". This is when the shock wave front propagates with a speed greater than the speed of propagation of the flame front and between them there is the explosion.

At suppression of deflagration burning powder fire equipment with pneumatic powder supply - manual and mobile fire extinguishers, stationary installations, cars can be used. In the case of explosive processes in the field of "double non - stationary explosions" - needed explosives with a spraying charge BB. In the case of the transition of the explosive process in detonation, when the flame front is combined with the shock wave front, - all available to date powder technology is unsuitable.

Application and long-term of the use of fire extinguishing powder. According to TC 113-08-597-86 on acceptance and standard tests the parameters of powders on points are checked to the following scheme: 7 (index of fire extinguishing ability), 9 (index of caking capacity), 10 (resistance to thermal influence), 11 (resistance to vibration and shaking), 12 (term of persistence) and parameter on 8 point (fluidity) on acceptance, standard, periodic and certification tests.

The application of powders (their durability) is taken to be equal to the number of years during which the values of fire extinguishing ability and fluidity correspond to the values of GCST.

Long-term of powders also depends on additives. To reduce the traceability and moisture absorption, as well as to increase vibration resistance are the next additives to powders: modified aerosils, amines of fatty acids, stearates of metals, various organic-silicon liquids [68], as well as inert powdering additives such as phlogopite, talc, fireclay - kaolin dust and vermiculite. It is noted that in each case it is necessary to find the optimal ratio of powdery additives in the powder, since their insufficient share will lead to deterioration in the performance properties of the powder (moisture absorption, flow traceability, vibration-stability) and to reduction in the guaranteed period of storage. Their excess will lead to the deterioration of its fire-extinguishing efficiency (especially on class - A, so aerosils, and inert additives impede the melting film formation on the smoldering surface). The excess in the powder of liquid hydro-phobizing additives can also lead to deterioration its fluidity and fire extinguishing efficiency on the following classes: B and C - too dense coating of powder particles with the film leads to increased adhesion, and to a decrease in inhibitory efficiency.

In addition, overly expensive aerosol increases the cost of the powder. A literature search yielded no information on the possibility of extending the operating period of overdue (non-conforming) fire extinguishing powder.

Conclusions:

1. The effect on the combustion reaction is possible with the help of physical and chemical methods of gas mixture components concentration reducing, cooling the combustion zone and slowing down of chain reactions with the help of a phlegmatizing or inhibiting substances, of which the most universal and perspective are powder materials.

2. There have been tested a wide range of inorganic and organic compounds in laboratory conditions in different countries as powder phlegmatizers and inhibitors of ignition and explosion of gas-air mixtures. However, a number of formulations are unacceptable because of the release of toxic products (freons), scarcity, and high cost of raw materials and complexity of technology.

3. In view of the high toxicity and environmental hazard of inhibitors (halides), the most promising search and development of effective powder compositions based on chlorides and substances with pronounced endothermic properties (easy-boiling, easy-decomposing, easy-melting) causing a sharp cooling of the combustion zone.

4. The analysis of scientific and technical literature did not reveal the general laws of the effectiveness of extinguishing powders from their composition. There are proposed only some unsystematic series of dependence of the studied mineral compounds. Therefore, a necessary condition for solving the problems of developing effective flame arresters is to find common indicators and properties of substances that can become criteria for their phlegmatizing ability.

5. The following conditions are taken into account in the development of new flame retardants:

- not deficiency and cheapness of the raw materials (at first it is industrial waste);
- low toxicity and environmental safety;
- simple manu facturing technology.

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ТИІМДІЛІК ӨЛШІМІ БОЙЫНША ӨРТСӨНДІРГІШ ҰНТАҚТАРДЫҢ ЖЫЛУЛЫҚ ЖӘНЕ САЛМАҚТЫҚ ҚАСИЕТТЕРІН ТАЛДАУ

Аннотация. Берілген зерттеу жұмысында өрт сөндіру мен жарылыс қауіпсіздігі құрамының классификациясы көрсетілген. Жану реакциясына ықпалды физикалық және химиялық газдардың қоспалар компоненттерінің концентрациясын төмендету әдістері, флегматикалық және ингибиторлық заттар көмегімен жану аумағын азайту және тізбекті реакцияны баяулату арқылы жасауға болады. Флегматикалық және ингибиторлық заттардың ішінде ең тиімді және перспективтісі болып ұнтақ тәріздем материалдар болып табылады. Ұйттылығы мен экологиялық қауіпсіздігі жағынан жоғары болып келетін ингибиторлардың (галогенидтердің) ішінде тиімді ұнтақ тәріздес композицияларды дайындау үшін жану аумағын лезде мұздату тудыратын эндотермиялық қасиеттері айқын (оңай қайнайтын, оңай ыдырайтын, оңай балқитын) хродиттер негізінде ұнтақтар болып табылады. Әдебиет шолуында өртсөндіруші ұнтақтардың құрамына байланысты олардың тиімділігінің жалпы заңдылықтары қарастырылды. Зерттелген минералды қосылыстыр тәуелділігінің кейбір жүйесіздік қатарлары ұсынылды. Тиімді өртсөндіргіштерді жасап шығару үшін қажетті шарттар ретінде флегматикалық қасиеттерінің критериясы бола алатын заттардың жалпы көрсеткіштері мен қасиеттерін іздеу болып табылады.

Түйін сөздер: өрт сөндіргіш ұнтақтар, жарылысты төмендеткіш қабілеті, спрейлер, жаңғыш реагенттер, ұнтақ тиімділігі, жылу және массалық қасиеттері.

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АНАЛИЗ ТЕПЛОВЫХ И МАССОВЫХ СВОЙСТВ ОГНЕТУШАЩИХ ПОРОШКОВ В КРИТЕРИЯХ ЭФФЕКТИВНОСТИ

Аннотация. В данном исследовании представлена классификация составов пожаротушения и взрывобезопасности. Воздействие на реакцию горения возможно с помощью физических и химических методов снижения концентрации компонентов газовой смеси, охлаждения зоны горения и замедления цепных реакций с помощью флегматизирующих или ингибирующих веществ, из которых наиболее универсальными и перспективными являются порошкообразные материалы. Ввиду высокой токсичности и экологической опасности ингибиторов (галогенидов) наиболее перспективными для разработки эффективных порошковых композиций являются порошки на основе хлоридов и веществ с выраженными эндотермическими свойствами (легкокипящие, легкоразлагающиеся, легкоплавкие), вызывающие резкое охлаждение зоны горения. Общие закономерности эффективности огнетушащих порошков в зависимости от их состава были рассмотрены в обзоре литературы. Предложены некоторые несистематические ряды зависимости изученных минеральных соединений. Необходимым условием для разработки эффективных пламегасителей является поиск общих показателей и свойств веществ, которые могут стать критериями их флегматизирующей способности.

Ключевые слова: огнетушащие порошки, взрывоподавляющая способность, спрей, горючие реагенты, эффективность порошка, тепловые и массовые свойства.

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DEVELOPMENT OF METHODS FOR MEASURING LINEAR PARAMETERS OF MOVING DIELECTRIC FILAMENTS

Abstract. Methods and devices for contactless and continuous measurement of linear parameters (drawing speed and diameter) of thin and ultra-thin dielectric filaments and optical fibers (10–125 microns) are developed on the basis of impulse characteristics of a unipolar corona discharge in the process of their manufacture. The developed devices differ from those known for high accuracy and reliability of measurements and are immune to changes in the electrical characteristics of discharge gaps and the state of ambient air. In both cases, the device for measuring the speed of drawing and the diameter of the dielectric thread uses the initial portion of the current-voltage characteristic of the positive corona discharge in the electrodes when the corona discharge is in the "waiting" mode, and the charging by ions of the surface of the moving dielectric filament is performed by applying additional pulses of negative polarity to the electrodes.

Key words: transfer speed, fiber diameter, corona discharge, pulse corona, ions, pulse signal generators, charging, discharging, "waiting" mode.

Introduction. Thin and ultra-thin wire (5-100 microns) made of various metals and alloys (tungsten, molybdenum, nichrome, copper, etc.) is widely used in the vacuum and electronics industries. Parameters homogeneity and the reliability of the operation of the electric and radio tubes depend on a large extent on the quality of the wire, the electrical characteristics of which, with a constant composition of the metal, are determined mainly by the geometric dimensions of its cross-section. Therefore, the development of new methods and devices for precise control of the dimensions of micro wire in production conditions is of great practical importance. In most cases, micro-wires of metals and alloys are produced by hot or cold wire drawing through diamond dies.

Equally important is the development of methods for measuring linear parameters (drawing speed and diameter) of moving dielectric filaments in the form of thin resistance wires with glass insulation of thin enamel wires and optical fiber filaments. In this case, for example, one of the main stages of the process of manufacturing optical fiber (OF) is pulling it on the drawing unit. It is established that oscillation of the diameter along the length of the fiber rod, in many respects, determines the optical - physical properties of the OF (optical losses in the propagation of the signal, bandwidth, dispersion, etc.), and the scatter of the exhaust velocities of the OF also significantly affect its strength and optics - physical properties [1].

A wide variety of electrode shapes and their location relative to each other, as well as the possibility of a corona discharge in atmospheric air, created the prerequisites for the development of a whole series of new methods and corona discharge transducers designed to measure the parameters of micro wires and linear dimensions of various objects [2].

Device for measuring the speed of pulling of dielectric filaments [3]. The main purpose of developing a device for measuring the speed of drawing dielectric threads is to ensure high accuracy and reliability of measurement when the indications of results are independent of changes in the electrical characteristics of the discharge gaps, the state of atmospheric air and the values of the geometric parameters of the dielectric filaments.

Previously, a method has been developed for measuring the speed of pulling a micro wire [4], which contains two additional ring electrodes identical in shape and size located coaxially on both sides of the main electrode, and a balance circuit with an output device, containing the main ring electrode surrounding the monitored wire. In this device, due to the appearance of an electro-gas dynamic effect near the surface of a moving wire, processes of entrainment and the introduction of space charges into the discharge zones of additional electrodes arise, which ultimately allows us to judge the values of the speed of wire drawing. In this device, it is noted that the use of a balanced measurement scheme significantly reduces the errors in measuring the speed of wire drawing with changes in electrical characteristics of discharges and geometric parameters of the corona wire. Meanwhile, due to the different location of the additional electrodes, which are essentially measuring, the changes in temperature and pressure of the ambient air can have a significant effect on the accuracy of the measurement. In addition, the proposed device also does not take into account the effect of difference in edge effects in two additional electrodes. In addition, because of the impossibility of replacing the corona wire with a dielectric thread, this device is not suitable for our purposes.

The measurement of the speed of drawing dielectric threads is based on the principles of measuring velocities by the method of marks, which are preliminarily applied to moving objects, and then the speeds of their passage through various measuring instruments are determined [5]. However, there are significant technical difficulties with marking when measuring the speed of movement of micro-objects, such as a dielectric thread or a micro wire with enamel coating (10-100 microns).

The proposed device for applying labels to a dielectric thread uses an outer corona discharge region that occurs when a sufficiently high voltage is applied between the corona wire and the outer plane-parallel electrode. In the outer corona discharge region, unipolar ions are usually present, which charge the surface of the dielectric filament. One of the best ways to get a clear picture of electronic labels on the surface of a dielectric filament is to supply the discharge chamber with additional clock pulses of sufficient magnitude with a certain duration and frequency. In this case, the dielectric filament is located parallel to the corona wire and in the middle of the discharge gap between the wire and the flat electrode. Next, a dielectric filament with electronic marks passes through a second measuring electrode, located some distance from the first electrode. When the filament passes through the measuring electrode, there are processes of discharge of the filament and accordingly, electric signals with a clock frequency appear on the electrode load. Now, choosing the duration of the reference signals, in other words, choosing the counting time of the clock pulses during this time, the number of pulses determines the speed of thread pulling.

To improve the accuracy of measurement and reliability of results, as well as to increase the noise immunity of the measurement to changes in the characteristics of the corona discharge and the geometric parameters of the measured dielectric filament, a positive corona discharge is used in both electrodes, its initial section of the current-voltage characteristic when the corona discharge is in the " " or a small discharge current flows (not more than 1 μ A). The choice of a positive corona discharge is due to the fact that it has a high stability of the characteristic and there are no electron avalanche processes that form the random pulses of Trichel [6]. As clock pulses for the application of electronic tags, rectangular pulses in the form of a "meander" shape are chosen for the filament, which close the discharge gap with a positive half-wave, and in the other half-wave create pulsed discharges that charge the moving dielectric filament.

Figure 1 shows functional diagram of the device for measuring the speed of pulling the dielectric thread during its manufacturing. The device contains two identical flat-parallel electrodes 1,2 shown in figure 2(a), which coaxially surround the corona wire 3 and are located at some distance from each other. Controlled dielectric thread 4 passes through the discharge zone of the corona discharge. In our case, a high voltage power supply 5 with negative polarity at the output is used, which allows obtaining a positive corona discharge in the discharge gaps between the electrodes 1 and 2 and the wire 3. Stabilization of the corona discharge characteristics in two discharge chambers 1 and 2 and creation of the "waiting" mode

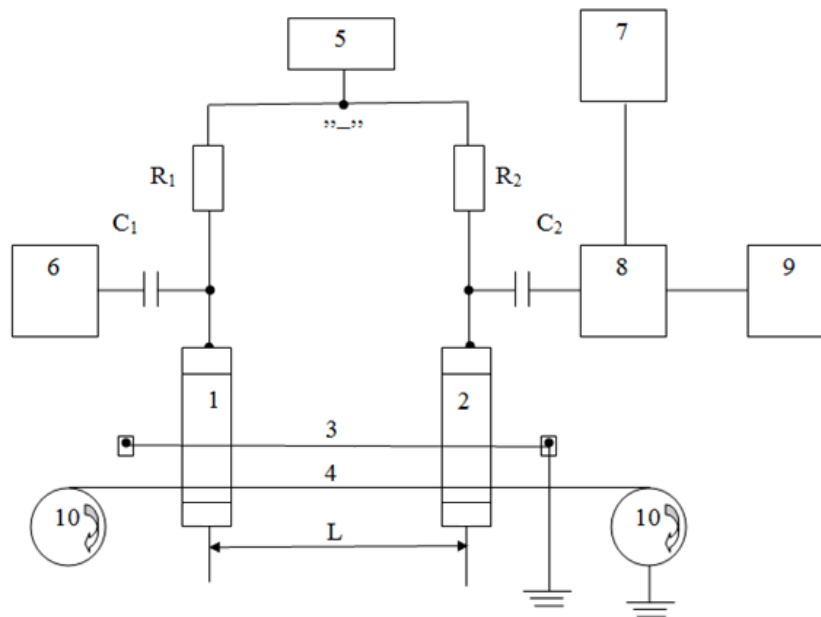


Figure 1 – Functional diagram of the device for measuring the speed of pulling the dielectric thread, where 1,2 is two identical planar-parallel electrodes, 3 is the corona wire, 4 is the dielectric thread, 5 is the power source, 6 is the high-frequency clock generator, 7 is the low-frequency reference pulse generator, 8 is the electronic unit, 9 is the pulse counter, 10 – rewind unit

conditions are achieved with the help of high resistance resistors $R1$ and $R2$. In addition, the device contains two pulse signal generators: one high-frequency clock generator 6, and the other low-frequency pulse generator - of the reference pulses 7. The supply and removal of pulse signals to the high-voltage points of the circuit are carried out by high-voltage capacitors $C1$ and $C2$. The output signal from the electrode 2 goes to the electronic unit 8 and, after conversion, is transmitted to the pulse counter 9. The electronic unit 8 shown in Figure 2(b) consists of the pulse former 1 and the electronic switch 2. The distance between 1 and 2 is denoted by L .

When a sufficiently high negative voltage is applied to the parallel-parallel electrodes 1 and 2, conditions are created for the occurrence of a positive corona discharge between them and wire 3. With two high-resistance resistors $R1$ and $R2$, and adjusting the high-voltage value 5, a "waiting" mode is established in two discharge gaps 1 and 2. Then, on the electrode 1 from the clock pulse generator 6, square pulses are transmitted through $C1$, in the form of a "meander" and for a negative half-wave it flows through the discharge gap imp corona discharge, which provides charging of the dielectric thread 4 located in the discharge zone. In the "waiting" discharge mode, the operating point is at the initial portion of the volt-ampere characteristic of the corona discharge, and therefore, a positive half-wave of the clocks closes the discharge gap, which makes it possible to purge the discharge zone and the surface of the dielectric filament from foreign charged particles. When pulling, the dielectric thread with electronic labels enters the second measuring electrode 2, where it discharges and at the same time, pulse signals with a clock frequency appear on the load of the electrode $R2$. These pulses through $C2$ are fed to the input of the electronic unit 8, consisting of the pulse former 1 and the electronic key 2 (figure 2(b)). They in the pulse former 1 are converted into a convenient form for the pulse counter and enter the electronic key 2. The electronic key 2 passes them only when the reference signal from the generator 7 is applied to it and for a time equal to the duration of the reference signal. The pulse counter 9 shows the number of pulses transmitted through the electronic key, which will be proportional to the speed of the thread. Thus, it becomes possible to perform the calibration of the pulse counter according to the previously known values of the dielectric filament pulling speed, measured in stationary conditions by control devices with a higher measurement accuracy.

Due to the fact that the method of electronic tags usually works by the algorithm "0 or 1", which means the signal is there or not, in principle, it is possible to exclude the influence on the measurement

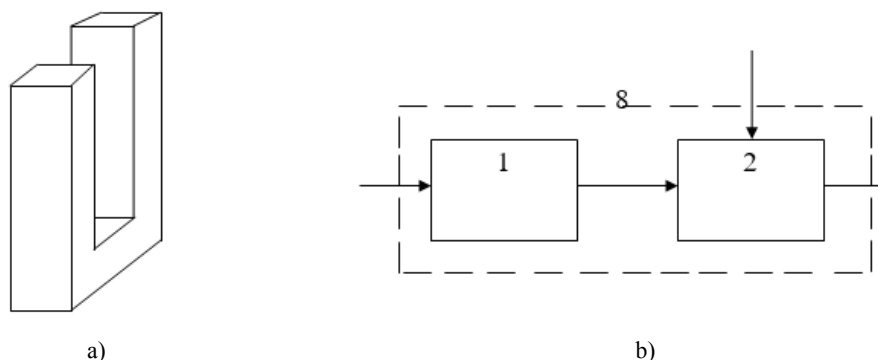


Figure 2 – The shape of the electrodes and the electronic unit:
a) form of electrodes, b) the electronic unit, where 1 – pulse shaper, 2 – electronic key

accuracy of changes in a number of parameters of the measuring device, for example, changes in the electrical characteristics of the corona discharge, The state of the ambient atmospheric air and the geometric dimensions of the controlled filament. If this methodological error of measurement is minimized, the rest of the measurement error will be determined by the instrumental error of the measuring instruments used in the device. Somewhat simplifies the task is that the measurement accuracy of the standard equipment used is known in advance or it is possible to select them.

The device has the following parameters: the plane-parallel electrodes have a width of 1.5 cm, the working length is 1 cm, the gap between them is $L = 2$ cm, the diameter of the corona wire from tungsten is 100 microns. The controlled filament is located at a distance of 0.3 cm from the surface of the outer electrode. The ballast resistances $R1$ and $R2$ were 1 m Ω , the capacitors $C1$ and $C2$ were 1 μ F. A high-voltage voltage source of the VS-22 type was used to power the discharge chambers. The sources of the pulse signals were generators G5 - 88 ($f = 1$ kHz, $U = 100$ V) and Г5-72 ($f = 1$ Hz, $U = 10$ V).

Experimental tests of the device were carried out on a rewinding unit 10 (figure 1) with a rate of change in the speed of winding up to 30 m/min. Copper wires with enamel coatings in the range of diameters of 20-100 microns have been tested as dielectric strands. Experimental measurements have shown that changes in atmospheric air pressure within ± 20 kPa and wire diameter by ± 10 microns do not affect the accuracy of measuring the dielectric filament pulling speed, which is about 1-2% of the measured velocity. The obtained accuracy of the measurement of the speed of pulling the dielectric yarn corresponds to a calibration curve constructed from the values of the drawing speeds in the range 1-30 m/min, measured under stationary conditions.

Device for measuring the diameter of moving dielectric filaments [7]. Close to the technical essence, the proposed device is a known device for controlling the inhomogeneity of moving dielectric threads [8], containing two ring electrodes concentrically surrounding the common corona wire electrode, high voltage power supplies with a constant stabilized output voltage, a load resistance and a voltmeter constant current, the controlled dielectric filament being pulled through the outer corona discharge zone, where the uniformity of the distribution volume charge is the highest. In this device, due to the presence of the discharge current stabilization effect when the two corona discharge zones are connected in series, the effect of the change in the state of atmospheric air on the accuracy of the object control will be negligible. In fact, the effects of the change in the state of atmospheric air on the discharge currents in the two electrodes can differ substantially. Since, at identical voltages on the electrodes, the negative corona discharge proceeds more efficiently and besides it is established that when the microelectrodes of negative polarity are corrupted there is always a pulsed discharge regime [2]. The proposed device also does not take into account the effect of the difference in the edge effects of the two electrodes. All this can greatly reduce the accuracy of measuring the device.

The main distinguishing feature of the proposed device is that in all three electrodes, the initial portion of the volt-ampere characteristic of the positive corona discharge is used, when the corona discharge is in the "waiting" mode, and the charging by ions of the surface of the moving dielectric filament occurs when additional pulses of negative polarity are fed to the middle electrode the form of half-waves of sinusoidal voltage. In this case, the middle electrode is covered on both sides by electrodes of similar

shape and size, which excludes the effect of edge effects on this electrode when pulsed charging of the thread.

Figure 3 shows the functional diagram of the device for measuring the diameter of the dielectric thread during its drawing. The device comprises three plane-parallel electrodes 1, 2, 3 (figure 2(a)) identical in shape and size and located at predetermined distances, a corona wire 4, a controlled dielectric yarn 5, a high voltage power supply with negative polarity at the output 6, a source of unipolar pulses 7, amplitude detector 8 and a DC voltmeter 9. The supply of pulse signals to the high-voltage points of the measuring circuit is carried out by high-voltage capacitors $C1$ and $C2$, and their removal also through capacitor $C3$. The stabilization of the electrical characteristics of the corona discharge in the electrodes and the creation of the "waiting" regime are provided by using high resistance resistors $R1$, $R2$, $R3$ and by selecting the high voltage value. Figure 4 shows the unipolar pulse source, consisting of a step-up transformer T_p with an average point in the second winding and two amplitude converters ($D1$, $R4$ and $D2$, $R5$). It produces two types of unipolar pulses for additional supply of electrodes 1 and 2.

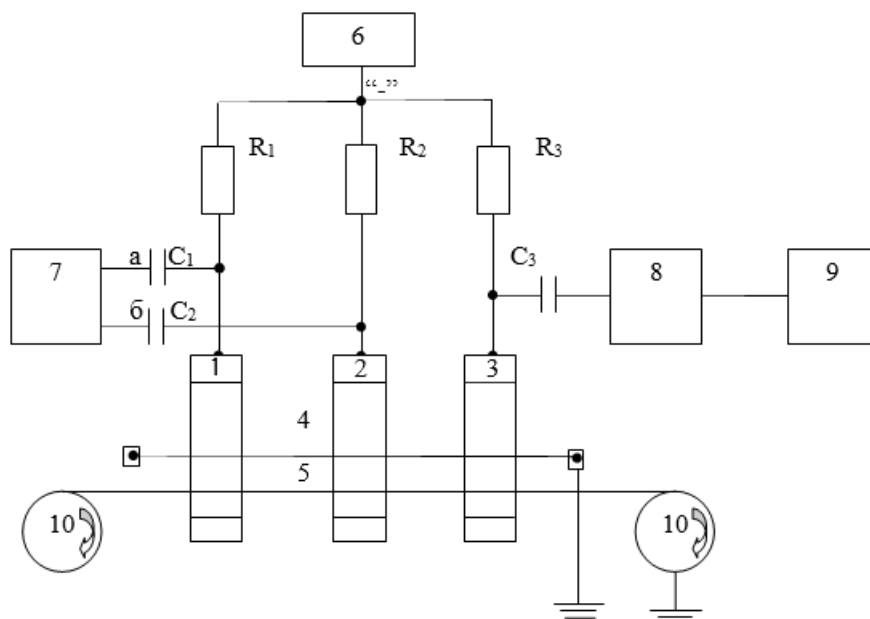


Figure 3 – Functional diagram of the device for measuring the diameter of the dielectric thread, where 1,2,3 are three identical planar-parallel electrodes, 4 is the corona wire, 5 is the dielectric thread, 6 is the power source, 7 is the unipolar pulse source, 8 is the amplitude detector, 9 is the DC voltmeter, 10 is the rewinder

When a sufficiently high negative voltage is applied to the external electrodes, conditions are created for the occurrence of a positive corona discharge between them and the wire 4. Then, adjusting the high voltage values 6 and achieving high-resistance resistance $R1$ - $R3$ obtain a "waiting" mode in all discharge gaps. After that, from a source of unipolar pulses, pulses of negative polarity are fed through $C1$ to the middle electrode 2 in the form of half-waves of sinusoidal voltage. In this case, an impulse corona discharge arises in the discharge gap of the electrode 2, which charges the surface of the dielectric filament 5, which is located in the outer zone of the discharge, with positive ions. In view of the transient nature of the transition of the ions in the discharge gap ($20 \pm 30 \mu s$), during a half-wave of the sinusoidal voltage, the dielectric filament succeeds in charging up to the "limiting charge" in accordance with the theory of Portenier [9]. According to this theory, it is established that the "ultimate charge" of a moving filament with constant dielectric constant of the material will, in the first place, depend on the dimensions of the surface area of the filament, i.e. from its diameter. The charged dielectric filament enters the electrode 3, which is in the "waiting" mode and is discharged there. When the thread is discharged at the load $R3$ of the electrode 3, impulse signals appear proportional to the "limiting charge" of the filament.

Pulsed signals are converted into an amplitude detector into a constant voltage, which is measured by a voltmeter. Graduation of the voltmeter scale is carried out in advance according to known standard diameters of the dielectric thread. One of the differences of the device is that simultaneously with a half-

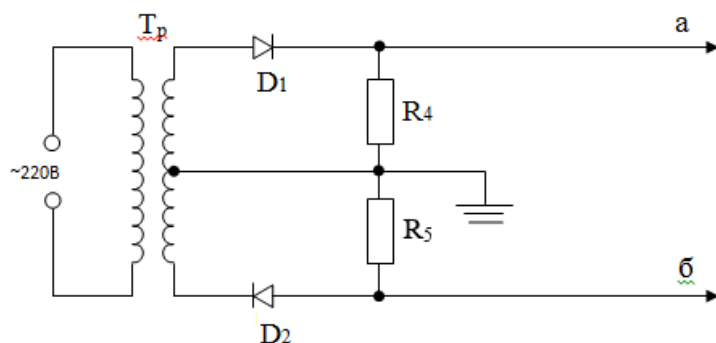


Figure 4 – Schematic of the source of unipolar pulses,
where T_p is a step-up transformer, D1 R4 and D2 R5 are amplitude converters, a is the output of a half-wave of a sinusoidal voltage of positive polarity, б is the output of a half-wave of a sinusoidal voltage of negative polarity

wave of negative polarity of the sinusoidal voltage applied to the electrode 2, a half-wave of positive polarity is fed to the electrode 1, while the discharge gap of the electrode 1 is closed and the filament charging by the "dark" corona discharge current in "Standby" mode.

The device has the following parameters: the plane-parallel electrodes have a width of 1.5 cm, the working length is 1 cm, the gap between them is 0.1 cm, the diameter of the corona wire from tungsten is 100 microns, the controlled filament is located at a distance of 0.3 cm from the surface of the outer electrode, the ballast resistances R1, R2, R3 were equal to 1 mΩ, capacitors C1, C2, C3 – 1 μF. As a high-voltage power source of voltage type VS-22.

Experimental measurements have shown that changes in the state of the ambient air and the speed of the moving filament do not significantly affect the accuracy of measuring the diameter of the filament, which amounted to about 1-2% of the measured diameter. The resulting accuracy in measuring the diameter of the filament corresponds to a calibration curve constructed from known standard diameters in the range 20-100 microns.

Conclusions. Methods and devices for contactless and continuous measurement of linear parameters (speed of drawing and diameter) of dielectric threads of optical fiber are developed, the application of which provides automatic control and control of the technological process of manufacturing of OB.

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ДИЭЛЕКТРЛІК ЖІПТЕРДЕ ҚОЗҒАЛАТЫН СЫЗЫҚТЫ ПАРАМЕТРЛЕРДІ ӨЛШЕУ ӘДІСТЕРІН ӨНДЕУ

Аннотация. Дайындау процесінде, бір тасымалды тәжді (каронды) разрядтың импульсті сипаттамасының негізінде жұқа және өте жұқа диэлектрлік жіптердің және оптикалық талшықтардың (10–125 микрон) сызықты параметрлерін (жылдамдық, тартажонғыштар және диаметр) үздіксіз, шексіз өлшеу әдістері мен құрылғылары өңделген. Өңделген құрылғының белгілі құрылғылардан айырмашылығы дәлдігі жоғары, өлшеудің сенімділігімен, разряд аралығындағы электр сипаттамасының өзгерісіне және қоршаған орта атмосфера ауасының өзгерісіне қарсы тұра алатындығында. Осы және басқа жағдайларда жіптерді тарту жылдамдығын өлшеуге және диэлектрикалық жіптердің диаметрі үшін электродтағы оң тәжді разрядының вольтамперлі сипаттамасының бастапқы аймағы қолданылады. Бұл жағдайда тәжді разряд «күту» режимінде болады, сонымен қатар диэлектрлік жіптердің үстінде қозғалатын иондармен зарядтау электродтарға қосымша теріс полярлы импульстерді беру арқылы орындалады.

Түйін сөздер: тартажонғыштар жылдамдығы, талшықты-оптикалық диаметр, тәжді разряд, импульстік тәж, иондар, импульстік сигналдардың генераторлары, зарядтау, разрядтау, «күту» режимі.

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РАЗРАБОТКА МЕТОДОВ ДЛЯ ИЗМЕРЕНИЯ ЛИНЕЙНЫХ ПАРАМЕТРОВ ДВИЖУЩИХСЯ ДИЭЛЕКТРИЧЕСКИХ НИТЕЙ

Аннотация. На основе импульсных характеристик униполярного коронного разряда разработаны методы и устройства для бесконтактного и непрерывного измерения линейных параметров (скорость протяжки и диаметр) тонких и сверхтонких диэлектрических нитей и оптических волокон (10–125 микрон) в процессе их изготовления. Разработанные устройства отличаются от известных высокой точностью и надежностью измерений и обладают помехоустойчивостью к изменениям электрических характеристик разрядных промежутков и состояния окружающего атмосферного воздуха. В том и другом случае устройство для измерения скорости протяжки и диаметра диэлектрической нити используется начальный участок вольтамперной характеристики положительного коронного разряда в электродах, когда коронный разряд находится в «ждушем» режиме, причем зарядка ионами поверхности движущейся диэлектрической нити производится подачей на электроды дополнительных импульсов отрицательной полярности.

Ключевые слова: скорость протяжки, диаметр оптоволокна, коронный разряд, импульсная корона, ионы, генераторы импульсных сигналов, зарядка, разрядка, «ждущий» режим.

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TECHNOLOGIES OF INFORMATION MONITORING BIOGENS LAKES OF KAZAKHSTAN

Abstract. Data on mineral substances on basis of nitrogen and phosphorus for the years 2007-2013 were analyzed based on statistics. Dynamic characteristics and seasonal features of changes were identified in the concentrations of substances. Seasonal factor plays a substantial role in changing nutrient concentrations. In the averaged year dynamics of substances concentrations are more diverse in the spring and early summer compared with the second half of the year. Spring effects may be related to the intensive development of phytoplankton. Autumn is also an outbreak of phytoplankton biomass, which can affect the concentrations of ammonium and phosphorus. In general, the concentration of phosphorus compounds is more stable, which may favorably affect the life of phytoplankton species which are fond of phosphorus.

Keywords: hydrobiology, hydrochemistry, trend, statistical analysis, correlation matrix, classification of lakes.

Introduction. Hydrobiological studies of the reservoirs of Kazakhstan (lakes Ashykol and Kumkol, Burabai and Ulken Shabakty, the Ural River, etc.) were carried out by a number of scientists: Khusainova N. [1], Akbaeva L., Zhamangar A. [2], Maikanov B. [3], Burlibaev M. [4], Zaitsev V.F. [5] and others.

Nitrogen and phosphorus have basic value for an aquatic ecosystem functioning. They provide phytoplankton with food during photosynthesis and play an important role in the ecosystem of the reservoir. Phytoplankton is indicator of aquatic ecosystem state. We investigate a dynamics of nitrogen and phosphorus contents in two lakes of important recreational area of Kazakhstan [6].

Thanks to the enrichment of nutrients in water bodies, the productivity of not only phytoplankton increases, but also the productivity of aquatic communities, including fish, which is considered an economically advantageous process. However, in many cases spontaneous anthropogenic enrichment of reservoirs with primary nutrients occurs on a scale that overloads the water body as an ecosystem with biogens. As a result, there is a very rapid development of phytoplankton («flowering» of water), the decomposition of which leads to the release of hydrogen sulphide or other toxic substances. This leads to the death of the animal population of water

Lake Burabai and lake Ulken Shabakty are located in Shchuchinsk-Borovoye resort area. This area has great recreational and tourist value. At the same time, the ecological status of the region is quite complicated. Pollution exceeding maximum permissible concentration (MPC) is captured in a village Borovoye. Major complexes of recreation institutions, fixed on the coast lakes Burabai, Ulken Shabakty and extends along the highways. As a result of irretrievable water intake for industrial and drinking and sanitary needs, plowing on the slopes, deforestation in the catchment area pollutants and organic substances are washed away, which increases the processes of lake siltation [7].

Study of mineral substances on base nitrogen and phosphorus allows to identify patterns of condition and dynamics of hydrobiological indicators. This leads to an assessment of the environmental condition of the reservoir [8].

Materials and methods. Lake Burabai - located within Kokshetau Highland, at the eastern foot of Kokshe, north of Lake Shchuchye. Area of water surface is approximately 11 square kilometers. The average depth of the lake is 3.4 m, maximum depth is observed in the north and makes up to 7 m. Water surface of the lake is mostly open, only the western and north-western coasts covered with reeds and rushes.

Lake Ulken Shabakty - the largest lake among Burabai group which is located 16.5 km to the north of Schuchinks. Water surface area is about 23 square kilometers. The average depth of the lake is 11.1 m, maximum - 33.3 m. The lake is open without aquatic vegetation, which is explained by the presence of the great depths [9].

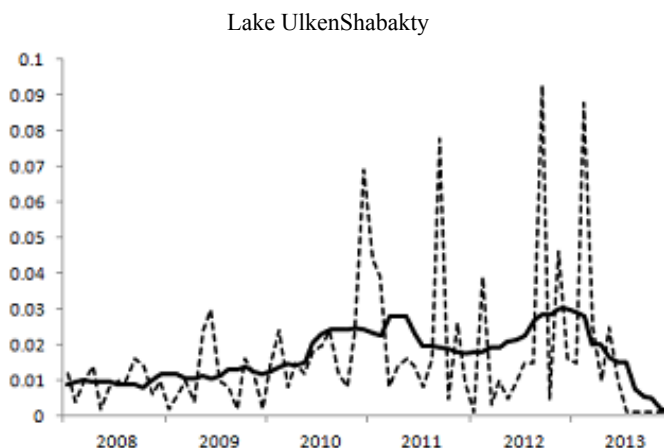
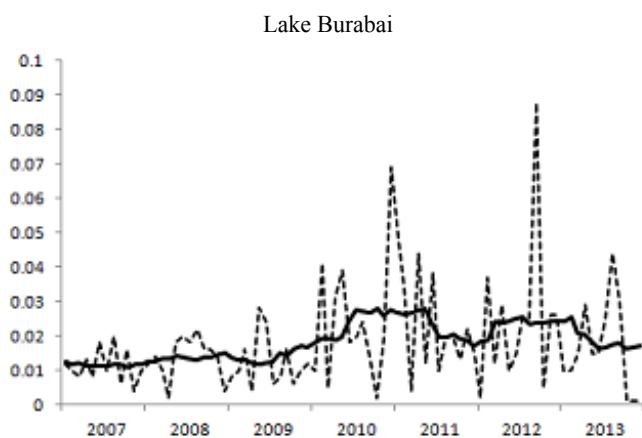
By the degree of pollution, the Lakes Burabai and Ulken Shabakty can be currently classified as between "clean" and "moderately polluted". All indicators of the lakes belonged to the "pure" in 2009 year, and in subsequent years, such parameters as dissolved oxygen, ammonia nitrogen and pH indicate some water pollution..

Results and discussion. The nitrogen is presented the nitrite compounds, nitrates and ammonium salts. Under phosphorus we mean the total phosphorus. These substances on basis nitrogen and phosphorus we mean here as mineral substances. We have data from 2007 to 2013 years for Lake Burabai and from 2008 to 2013 years for Lake Ulken Shabakty [10].

Trend analysis of mineral substances with averaging of 12 months (figure) show an increasing of pollutions in 2010 - 2011 years. These trends show interannual variability for concentration of mineral substances. The concentrations of all substances have bigger values in second half of time period. This fact is shown that the pollution in both lakes increased in this period. But the seasonal fluctuations are large enough compared to the interannual variability. Seasonal factor plays a significant role in changing

Trends (solid lines) of concentrations of total phosphorus on basis data of measures (dashed lines).

On vertical axis is the concentration of substance in mg/l, on horizontal axes years are specified



mineral substances concentrations too. Trend analysis showed that seasonal oscillations of concentrations of substances are sufficiently large.

Data on phosphorus load presented in figure show that in 2007-2008 lakes were close to oligotrophic and in 2012-2013 have already approached the mesotrophic reservoirs. Currently, according to the classification of the content of total phosphorus, both lakes relate to mesosaprobic type [11-14].

The application of methods of statistical processing of environmental research results makes it possible to obtain quantitative characteristics of the distribution of organisms that are suitable for comparison, to carry out the very procedure of comparison, and to establish the dependence between the individual variables characterizing the habitat [15].

Statistical data analysis was begun from test of the hypothesis about lognormal distribution for data. The presence of the lognormal distribution provides to use traditional criteria Student, Pearson, Fisher, etc. to analyze the data in a logarithmic scale. Data from all four substances are tested on the lognormal distribution for each lake. [16]. We use Pearson criterion for this test. Nitrate, ammonia and phosphorus have lognormal distribution with significance level 0.05. Nitrite has this distribution for Lake Ulken Shabakty but it has not for Lake Burabai.

In the averaged year dynamics of substances concentrations are more diverse in the spring and early summer compared with the second half of the year, although "outbursts" do happen in the ammonium and phosphorus in the fall and early winter. Spring effects may be associated with the arrival of melt water and intensive development of phytoplankton. Flashes also occur in autumn in the phytoplankton biomass, which can affect the concentrations of ammonium and phosphorus.

Data which are not included in the confidence intervals were allocated. When data were reanalyzed it is revealed that there are indicators, the absolute values of which lie outside the boundaries of the confidence intervals. The proportion of such points varies from 0.083 to 0.286. These deviations do not have any natural character of manifestations; that is they do not depend on the season or on the reservoir in which they are recorded. Number of such points is almost always within 20%. In our view, this indicates a satisfactory quality of data collection and a good reliability.

The correlation matrix for substances concentrations
the lakes Burabai (above the main diagonal) and Ulken Shabakty (below the main diagonal)

	Nitrite nitrogen	Nitrate nitrogen	Ammonia nitrogen	Total phosphorus
Nitrite nitrogen	1.000	0.465	0.072	0.233
Nitrate nitrogen	0.154	1.000	0.216	0.137
Ammonia nitrogen	0.116	0.157	1.000	-0.123
Total phosphorus	0.134	0.236	0.204	1.000

Rigid links between the concentrations of substances in each lake are not separately identified, substances behave relatively independently. Only nitrates and nitrites of Burabai lake have significant connections (table). This may mean that their delivery to the lake and phytoplankton consumption are not synchronized, that is substances come from various sources and converted with independent to each other speeds.

The obtained results on trends indicate that seasonal variations are large enough compared to the interannual. Seasonal factor plays a substantial role in changing nutrient concentrations. Testing for normal distribution of the substance concentration logarithms shows that the lake Burabai "lives" mainly due to natural factors or many small artificial factors. In the lake Ulken Shabakty there are probably artificial sources of nitrites and nitrates, "concealing" lognormal distribution patterns.

In the averaged year dynamics of substances concentrations are more diverse in the spring and early summer compared with the second half of the year, although there are "outbursts" in the ammonium and phosphorus which occur in the fall and early winter. Spring effects may be related to the intensive development of phytoplankton. Autumn is also an outbreak of phytoplankton biomass, which can affect the concentrations of ammonium and phosphorus. In general, the concentration of phosphorus compounds is more stable, which may favorably affect the life of phytoplankton species which are fond of phosphorus [17, 18].

Refilling the database on lakes would enhance data processing, including statistical data processing. It is anticipated that there is a possibility of using a dynamic mathematical model for the joint analysis of hydrobiological and hydrochemical information [19-21]. These models give us the possibility for analysis of functioning of aquatic ecosystems in seas and lakes.

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ҚАЗАҚСТАН КӨЛДЕРІНДЕГІ БИОГЕНДЕРДІҢ АҚПАРАТТЫҚ МОНИТОРИНГ ТЕХНОЛОГИЯЛАРЫ

Аннотация. Статистикалық деректер бойынша 2007-2013 жылдарға арналған азот пен фосфорға негізделген минералды заттар туралы мәліметтер талданды. Өзгерістердің динамикалық сипаттамалары мен маусымдық ерекшеліктері заттардың шоғырлануында анықталды. Маусымдық фактор коректік заттардың

концентрациясын өзгертуде маңызды рөл атқарады. Орташа жылда заттардың шоғырлану динамикасы көктемде және жаздың басында жылдың екінші жартысымен салыстырғанда әртүрлі. Көктем әсерлері фитопланктонның қарқынды дамуымен байланысты болуы мүмкін. Күздегі фитопланктон биомассасының жарқылы аммоний мен фосфордың концентрациясына әсер етуі мүмкін болып табылады. Жалпы, фосфор қосылыстарының концентрациясы әлдеқайда тұрақты, бұл фосфорды жақсы көретін фитопланктон түрлерінің өміріне жағымды әсер етуі мүмкін.

Түйін сөздер: гидробиология, гидрохимия, тренд, статистикалық талдау, корреляциялық матрица, көлдердің жіктелуі.

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ТЕХНОЛОГИИ ИНФОРМАЦИОННОГО МОНИТОРИНГА БИОГЕНОВ ОЗЕР КАЗАХСТАНА

Аннотация. Данные по минеральным веществам на основе азота и фосфора на 2007-2013 годы были проанализированы на основе статистики. Динамические характеристики и сезонные особенности изменений были выявлены в концентрациях веществ. Сезонный фактор играет существенную роль в изменении концентрации питательных веществ. В усредненном году динамика концентраций веществ более разнообразна весной и в начале лета по сравнению со второй половиной года. Весенние эффекты могут быть связаны с интенсивным развитием фитопланктона. Осень также является вспышкой биомассы фитопланктона, которая может влиять на концентрации аммония и фосфора. В общем, концентрация соединений фосфора более стабильна, что может благоприятно влиять на жизнь видов фитопланктона, которые любят фосфор.

Ключевые слова: гидробиология, гидрохимия, тренд, статистический анализ, корреляционная матрица, классификация озер.

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**SOIL COVER OF THE "ZAOVRAZHNY" MICRO-DISTRICT,
CHEBOKSARY, AND ITS ECOLOGICAL STATE**

Abstract. In July-August 2017, soil and agrochemical investigations of the territory of the Zaovrazhny micro-district in Cheboksary city were carried out.

The territory of the new Zaovrazhny micro-district in Cheboksary is located to the west of the north-western residential area of Cheboksary; it is bounded from the north by the coastal fortifications of the Cheboksary storage reservoir, and on the southern side by the M-7 highway (Cheboksary-Moscow).

Light gray forest heavy loam soils are widespread in the micro-district, in the middle and lower parts of the slope altered by water erosion. The undistorted soils are characterized by the following morphological features: a sod horizon A_d of 5-10 cm in thickness, a humus-eluvial horizon A₁ up to 15-20 cm. Below it, a transitional horizon A₁A₂ with a thickness of 5-15 cm is located. Gradually, A₁A₂ passes into the eluvial-illuvial horizon A₂B up to 20 cm thick. Illuvial horizon B consists of several subhorizons: B₁ – dark brownish-brown color with spots of humic substances and pseudopodzolic siliceous powder; it gradually shades into a more clarified B₂, followed by the transitional horizon BC and the soil-forming rock C (loess-like loam).

The content of heavy metals in the humus horizon and soil-forming rock, oil products, radio nuclides and benzo(a)pyrene corresponds to the background values and does not exceed the MPC.

The soil cover of the Zaovrazhny micro-district and its ecological state were studied for the first time.

Keywords: agrochemical properties, water erosion, humus horizon, soil-forming rocks, gray forest soils, heavy metals.

Introduction. The territory of the Zaovrazhny new micro-district in Cheboksary city is located to the west of the north-western residential area of Cheboksary; it is bounded from the north by the coastal fortifications of the Cheboksary storage reservoir, and on the southern side by the M-7 highway (Cheboksary-Moscow). The soil cover of the Zaovrazhny micro-district has not been studied, and its study and determination of the ecological state were studied for the first time.

Materials and methods. Soil research was carried out in accordance with GOST 17.4.2.03-86. When diagnosing the soil covering of the Zaovrazhny micro-district, the "Classification and Diagnostics of Soils of the USSR" (1977) was used. The content of labile phosphorus and exchangeable potassium was determined by the Kirsanov method, pH – ionometrically. Chemical, bacteriological, helminthological analyses of soil samples were carried out at the Federal State-Funded Budgetary Public Health Facility of the Hygienic and Epidemiological Center No 29 of the Federal Medical-Biological Agency of Russia, No. 2637, and also at the Federal State Institution of SCAS "Chuvashky".

The results of the research and their discussion. The territory of the Zaovrazhny micro-district is located in the North-Western part of Cheboksary and covers an area of 41 hectares. Until 2002, the territory of the micro-district was used as arable land.

In 2017, it was an idle field covered with sow-thistle, tansy and reed grass with young forest groups of 10-15 years of age, sometimes built up by cottages, with engineering networks (electricity, water supply) along the streets.

The site of the real surveys in geomorphological terms is confined to the right bank of the valley of the Volga river with a genetic type of surface – denudation, 300-350 m southeast of the site is the Shupashkarka river, the right feeder of the Volga river, from the northeast and partly from the southeast, the territory borders the allotment gardens, from the northwest - the forestry of the State Forest Fund.

The relief of the built-up area is gently-sloping, with a decrease to the north-east, towards the river Volga. The geological section before the studied depth of 10 m by drilling is mainly represented by Upper Permian and Middle Jurassic rocks, which are covered with quaternary sediments – loess-like loams. Covering loamy loess-like loams are heavy, hard, semisolid, hard-brown and light-brown, macroporous, with humus stains and streaks of calcification, ferruginous, with thin interlayers of sand [6].

Ground waters of a permanent aquifer are opened in the southern part of the site in boreholes at depths of 2.6-7.2 m in the upper fractured zone of Upper Permian sediments.

According to the chemical composition, groundwater is fresh ($M = 0.3-0.5$ g/l), hydrocarbonate, magnesium-calcium, from weakly acidic to slightly alkaline, lime, moderately hard, with pH 6.3-6.4.

As a result of the real soil studies, it was revealed that the soil cover on the territory of the Zaovrazhny micro-district in Cheboksary is represented by washed-away types (lightly washed, medium- and heavily washed) of light gray forest soil.

Not washed-away soils are characterized by the following morphological features: a sod horizon of 5-10 cm in thickness, a humus-eluvial horizon A_1 of light-gray or gray color, of low thickness (up to 15-20 cm).

The transitional horizon A_1A_2 is light-gray in color, a finely-nutty-lumpy structure, 5-15 cm of thickness. Gradually, A_1A_2 passes into the eluvial-illuvial horizon A_2B up to 20 cm thick, which is characterized by a finely-nutty structure, the silica powder on the faces of structural separates in combination with washing away stains of humus and other substances.

The illuvial horizon B consists of several subhorizons: B_1 is a dark brownish-brown color with spots of humic substances and pseudopodzolic silica powder; it gradually transforms into a more decolorized horizon B_2 , followed by the transitional horizon BC and the soil-forming rock C (loess-like loam).

In the investigations, soils with upper plowed up part of the horizon A_2B were attributed to light washed types; to the medium-washed ones – when a large part or the whole of the A_2B horizon is involved in the plowing layer and its absence; and to heavily washed ones - soils, in the profile of which there were no horizons A_2B and B_1 .

The morphological features of the reservoir soils are characterized by the fact that the former homogeneous arable Ap horizon was divided into two genetic horizons – A_1 and A_1A_2 , which are presented in virgin soils.

Description of the profile of light washed light-gray forest hard loamy medium-thick soil on loess-like loam (section 1), laid on a reservoir covered with birch and aspens with a thinned herb layer (brome grass, chicory, milfoil, dandelion) is shown in table. 1.

Table 1 – Description of the profile of light washed light-gray forest soil

A_1	0-20 cm	Wet, gray, heavy loamy, lumpy, loose. There may be roots, worm channels, earthworms, grub worm, clear transition.
A_1A_2	20-25 cm	Wet, whitish-gray, heavy loamy, lumpy, dense, there are roots, spangles of silica, worm channels, clear transition.
A_2B	25-38 cm	Humidified, brownish-gray, heavy loamy, lumpy, finely-nutty, does not boil up from 10% hydrochloric acid.
B_1	38-49 cm	Humidified, brownish-brownish, heavy loamy, nutty, with spangles of silica and humus stains, does not boil up from 10% hydrochloric acid.
B_2	49-91 cm	Humidified, brown, heavy loamy, large-nutty, with humus stains, does not boil up from 10% hydrochloric acid.
BC	91-130 cm	Moistened, brown, with root channels, rare humus stains, heavy loamy, structureless, does not boil up from 10% hydrochloric acid.
C	130-180 cm	Humidified, light-brown, heavy loamy, structureless, in the lower part slightly boil up from 10% hydrochloric acid.

In medium-washed light-gray forest soils on reservoirs with densely mixed herbs, the processes of water erosion are sharply weakened, in place of the former grayish-brown color of the arable layer, a sod horizon of A_d and humus-eluvial horizon A_1 or transitional A_1A_2 was formed. They are uniformly gray with inclusions of brownish-brown clayey lumps, sometimes with light silica powder.

Below them the transitional horizon A_2B lies, the depth of the upper boundary of which the degree of soil erosion is determined (table 2). In heavily washed light-gray forest soils bordering the lower part of the slope, the processes of water erosion under mixed grass also became weaker, and in the place of the former arable layer, a sod horizon A_d was formed, that was underlain by the illuvial horizon B .

Table 2 – Description of the profile of the medium-washed light-gray forest soil

A_d	0-8 cm	Wet, gray, with separate brownish-brown lumps, heavy loamy, lumpy, loose. The roots are densely interwoven, there are worm channels, earthworms, rare – the grub worm, the transition is clear.
A_1A_2	8-23 cm	Wet, whitish-gray, with separate whitish-brown lumps, heavy loamy, finely-nutty-lumpy, pressed, there are roots, silica spangles, worm channels, clear transition.
A_2B	23-26 cm	Humidified, brownish-gray, heavy loamy, lumpy, finely-nutty, dense, does not boil up from 10% hydrochloric acid.
B_1	26-36 cm	Moistened, brownish-brownish, heavy loamy, nutty, with spangles of silica and humus stains.
B_2	36-85 cm	Humidified, brown, heavy loamy, large-nutty, with humus stains.
BC	85-110 cm	Humidified, light-brown, heavy loamy, structureless, does not boil up from 10% hydrochloric acid.

In consequence of the weakening of the eluvial-eluvial soil-forming process due to the low water resistance of aggregates, strong lateral water flow, the profile of heavily washed light-gray forest soils is shortened (table 3).

Table 3 – Description of the profile of the heavily washed light-gray forest soil

A_d	0-7 cm	Wet, grayish-brown, heavy loamy, lumpy, loose. The roots are densely interwoven, there are worm channels, earthworms, grub worms, the transition is clear.
AB	7-16 cm	Wet, grayish-brownish-brown, heavy loamy, pressed,
B_2	16-59 cm	Humidified, brown, heavy loamy, large-nutty, with humus stains.
BC	59-82 cm	Humidified, light-brown, heavy loamy, structureless, does not boil up from 10% hydrochloric acid.

As a result of the soil investigations, a soil map of the Zaovrazhny micro-district was drawn upon a scale of 1:500 (GOST 17.4.2.03-86).

Soil studies have revealed that the total area of eroded soils on the territory of the micro-district is 86.7%, which corresponds to the conclusions obtained as a result of monitoring the soils of the Chuvash Republic - it was eroded more than 80% of the arable land [2, 5].

On the total area of 41 hectares, the following soil types of light-gray forest soils were formed (table 4).

Table 4 – Areas of soil types in the territory of the Zaovrazhny micro-district in Cheboksary

#	Name of the soil	Soil index	Area	
			ha	%
1	Light-gray forest heavy loamy medium-thick soils on loess-like loam	$\Pi_1\text{c}/\Pi$	5.1	12.4
2	Light-gray forest heavy loamy medium-thick light washed soils on loess-like loam	$\Pi_1\text{c}/\Pi\downarrow$	20.7	50.6
3	Light-gray forest heavy loamy, medium-thick, medium-washed on loess-like loam	$\Pi_1\text{т}/\Pi\downarrow\downarrow$	11.1	27.0
4	Light-gray forest heavy loamy, medium-thick, heavily washed on loess-like loam	$\Pi_1\text{т}/\Pi\downarrow\downarrow\downarrow$	4.1	10.0
	Total		41	100.0

The results of agrochemical analyses of soil samples characterize them as typical for light-gray forest soil of the northern natural-agricultural zone of Chuvashia [3, 4, 7].

The humus content in the soils of the site is low - from 1 to 3% (very low and low). The sum of exchange bases (S) in the upper soil horizon is 16.7-21.3 mg-e / 100 g, hydrolytic acidity (Ng) – 1.03-4.43 mg-e/100 g of soil. The content of labile phosphorus and exchangeable potassium is characteristic of light-gray forest soils: mainly medium and high. The saturation degree with soil bases is 82-94%. The reaction of soils varies from a medium to a neutral.

A study of the content of radionuclides (cesium-137 and strontium-90) in the upper horizon of the soil (B1) showed a low content of 8.6-12.20 and 3.3-4.4 Bq/kg, respectively.

According to the GOST 17.5.3.06-85 indices and calculations, the thickness of the fertile soil layer on the total area of the construction site with the area of 41 hectares is on average 20 cm. The total mass of the fertile soil layer with an average bulk density of 1.14 g/cm³ is 2280 tons.

The total mass of a potentially fertile layer with the thickness of 25 cm and the average bulk density of 1.25 g/cm³, located beneath the fertile layer, averages 3125 tons/ha.

Conclusion. As a result of the studies, the soil cover of the Zaovrazhny micro-district was revealed. The current state of soil quality in the micro-district area corresponds to sanitary and epidemiological requirements. The results of the research unequivocally testify to the ecological well-being of the territory of Cheboksary city of the Chuvash Republic [1], considering the new buildings located next to the ravine system.

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ЧЕБОКСАРЫ ҚАЛАСЫНЫҢ «ЗАОВРАЖНЫЙ» МӨЛТЕК АУДАНЫНДАҒЫ ТОПЫРАҚ ҚҰРАМЫ МЕН ЭКОЛОГИЯЛЫҚ ЖАҒДАЙЫ

Аннотация. 2017 жылдың шілде-тамыз айларында Чебоксары қаласындағы «Заовражный» мөлтек ауданындағы топырақтың агрохимиялық құрамы зерттелді.

Чебоксары қаласындағы жаңа «Заовражный» мөлтек ауданы территориясы Чебоксары қаласының солтүстік-батысында орналасқан; ол солтүстігінен Чебоксары су қоймасының жағалаулық су бекіністерімен, ал оңтүстік жағынан «М-7» көлік жолымен шектелген (Чебоксары-Москва).

Мөлтек ауданы территориясында ашық-сұр түсті орманның ауыр батпақты топырағы таралған, ал орта және төменгі тұстарында ол су эрозиясына ұшырап өзгерген. Сумен шайылған топырақтар келесідей морфологиялық белгілерімен сипатталады: А_д дерналық қабатының қалыңдығы 5-10 см, қарашірікті-элювиальды

А₁кабаты 15-20 см дейін. Олардың астында қалыңдығы 5-15 см құрайтын А₁А₂өтпелі қабаты орналасқан. Біртіндеп А₁А₂ қалыңдығы 20 см дейін жететін А₂В элювиальды-иллювиальды қабатына өтеді. В –иллювиальды қабаты бірнеше қабат қатпарларынан тұрады: В₁ – кара-қоңыр түсті қарашірікті заттардық теңбілдері бар және лессивировты кремни реңді себінделерден құралады; ол біртіндеп ақшыл тартқан В₂ қабатына, содан кейін өтпелі ВС және топырақ құраушы С (лессогоұқсас суглинок) қабаттарына айналады.

Топырақ құраушы қарашірікті қабаты құрамындағы ауыр металдардың, мұнай өнімдерінің, радионуклеидтер мен бензапирендер мөлшерлері фондық мәндеріне сәйкес келеді және ШРК аспайды.

«Заовражный» мөлтек ауданындағы топырақ қабаты мен оның экологиялық жағдайы алғаш рет зерттелінді.

Түйін сөздер: агрохимиялық қасиеті, су эрозиясы, қарашірікті қабат, топырақ құраушы породадар, сұр түсті орман топырағы, ауыр металдар.

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ПОЧВЕННЫЙ ПОКРОВ МИКРОРАЙОНА «ЗАОВРАЖНЫЙ» Г. ЧЕБОКСАРЫ И ИХ ЭКОЛОГИЧЕСКОЕ СОСТОЯНИЕ

Аннотация. В июле-августе 2017 г. проводились почвенно-агрохимические исследования территории микрорайона «Заовражный» г. Чебоксары.

Территория нового микрорайона «Заовражный» г. Чебоксары расположена к западу от северо-западного жилого района г. Чебоксары; она с севера ограничена береговыми укреплениями Чебоксарского водохранилища, а с южной стороны автотрассой «М-7» (Чебоксары-Москва).

На территории микрорайона распространены светло-серые лесные тяжелосуглинистые почвы, в средней и нижней части склона измененные водной эрозией. Несмытые почвы характеризуются следующими морфологическими признаками: дерновый горизонт А_д мощностью 5-10 см, гумусово-элювиальный горизонт А₁ до 15-20 см. Под ним расположен переходный горизонт А₁А₂ мощностью 5-15 см. Постепенно А₁А₂ переходит в элювиально-иллювиальный горизонт А₂В мощностью до 20 см. Иллювиальный горизонт В состоит из нескольких подгоризонтов: В₁ – темно-буровато-коричневой окраски с пятнами гумусовых веществ и лессивированной кремнеземистой присыпки; он постепенно переходит в более осветленный В₂, сменяющийся переходным горизонтом ВС и почвообразующей породой С (лессовидный суглинок).

Содержание тяжелых металлов в гумусовом горизонте и почвообразующей породе, нефтепродуктов, радионуклеидов и бензапирена соответствует фоновым значениям и не превышают ПДК.

Почвенный покров микрорайона «Заовражный» и его экологическое состояние изучались впервые.

Ключевые слова: агрохимические свойства, водная эрозия, гумусовый горизонт, почвообразующие породы, серые лесные почвы, тяжелые металлы.

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NEWS

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kazecoanalysis@mail.ru k.gapparova@gmail.com**INTERPHASE DISTRIBUTION OF BORIC ACID
BETWEEN AQUEOUS SOLUTIONS
AND MODIFIED CELLULOSE**

Abstract. Regarding the need for processing of hydromineral raw materials, many researchers have an increased focus on core and applied problems of producing organic sorbents based on natural materials, in particular, different kinds of cellulose modified by mercerization methods (treatment with alkali solutions) and chemical change of functional groups.

The research addresses the interfacial distribution of boric acid on a mercerized, then chemically modified crushed kernel of common apricot, *Prunus armeniaca* (apricot).

It was found that the sorbent material has selective properties for boric acid, extracting it from the aqueous phase and concentrating H_3BO_3 in the solid phase of the sorbent (modified cellulose). On the basis of carried out elemental chemical and mass spectrometric analyzes, along with IR spectrum of sorbents, the structure of sorbents was identified, and a mechanism for the absorption of boric acid by the phase of modified cellulose (CM) was proposed.

Keywords: boric acid; modification; interphase distribution.

Nomenclature of user. In this work rational nomenclature for naming organic compounds was applied. The extra-system units (%) and the amount of the solute in a liter of solution) were used to specify the concentration and the rate of extraction. Abbreviations were spelled out in full at their first occurrence in the text.

Introduction. Spectrophotometric analysis and acid-base titration in the presence of polyhydric alcohols of mannitol, xylitol, sorbitol, etc. were applied in order to analyze the amount of boron (the relative error of the analysis is $\pm 3.5\%$) [1-3].

The literature describes the use of cellulose and polyhydric alcohols as components for the synthesis of various sorbents. For example, the works [4-6] describe methods for preparing composite sorbents using cellulose fibrillated fibers together with compounds of iron and calcium to extract inorganic ions from aqueous solutions, but do not consider the extraction of boric acid.

In the invention [7], it is proposed to obtain an effective sorbent for wastewater treatment from metal ions by immobilizing finely dispersed $MgCO_3$ and $Mg(OH)_2$ onto fibrillated cellulose fibers.

In the patent of the Russian Federation No. 2528696 [8] in order to extract silver and phosphorus it is proposed to obtain a sorbent by treating fibrillated cellulose fibers in a salt solution of zinc and sodium sulfide.

According to the patent of the Russian Federation No. 2520457 [9] a composite sorbent consisting of polyvinyl alcohol and nanophasic oxyhydroxide separated from waste from groundwater deironing stations is used to purify aqueous environment from arsenic.

In the work [10], carboxymethylcellulose (CMC) containing layered double hydroxides was synthesized by the ion exchange method [10]. Experiments have shown that on such CMC, the adsorption of boron increases with increasing contact time, boron concentration and pH.

A study of the removal of boron from simulated and real water systems in the northern part of Chile using ultrafiltration reinforced with a polymer in water, for example, polyglycidyl methacrylate-N-methyl-D-glucamines, which was used to form complexes with boron, is presented in the work [11]. The retention capacity of the polymer membrane was maintained at a level of 2-4 mg per gram of polymer.

For producing adsorbents obtained from natural polymer [12] two forms (powder and fiber) of cellulose derivatives and N-methylglucamine [12] were synthesized. The sorption capacity of the cellulose derivatives by boron was the same as that of commercially available polystyrene resin with N-methylglucamine type groups. It was found that cellulose derivatives are superior to a polystyrene resin as the adsorbent for boron (III) in the processing of large amounts of wastewater.

It should be noted that the general shortage of sorbents obtained using glucomine is due to a significant biodegradation of glucomine, since the latter is a nutrient for bacteria.

Thus, there is no information in the literature on neither on chemical modification of mercerized cellulose, by "sewing" of chlorinated derivatives of polyhydric alcohols to its polymeric carbon skeleton (matrix), nor the structure and sorption properties of these compounds. Nevertheless, the interest of researchers in the study of cellulose derivatives as sorbents remains [3].

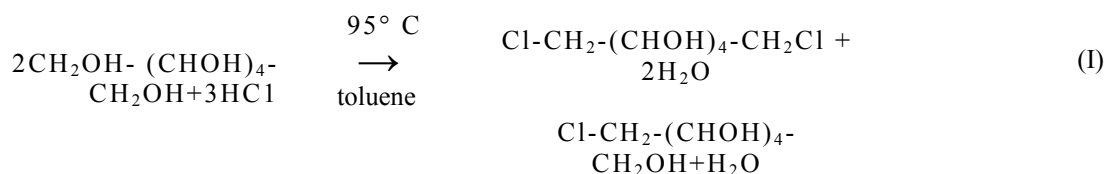
The purpose of this research was to study the redistribution of the initial boron content in the form of H_3BO_3 between the phases of the aqueous solution and the sorbent in time, on chemically modified cellulose (CM).

In order to achieve this goal, the following tasks were set:

- chemical processing of cellulose in order to improve its operational, physical and chemical properties;
- establishment of the mechanism of the sorption process on (CM);
- examination of regularities of interphase distribution of boron in the solution-solid phase system for the development of practical recommendations.

Experimental part. To improve the capacity of the CM sorbent, it was additionally modified by chemically "sewn" molecules of hexahydric alcohol (sorbitol). The synthesis was carried out in two stages.

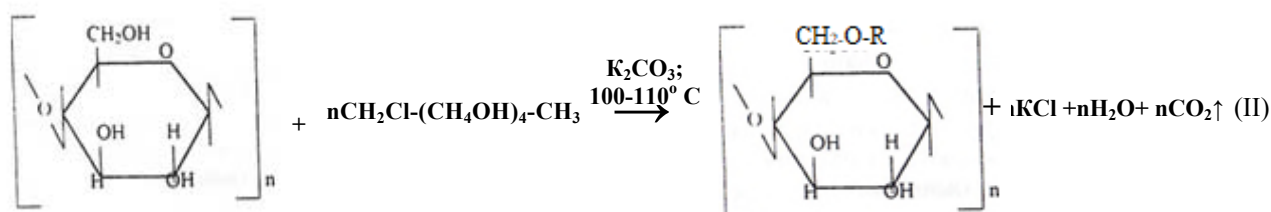
The first stage is the synthesis of 1-chloro or 1,6-dichlorosorbitol. Six-atom alcohol-sorbitol is treated with hydrogen chloride at 95 °C in toluene during 6 hours.



Chlorination in reaction (I) proceeds by the mechanism of nucleophilic substitution. The reaction product is treated with a solution of sodium carbonate until neutral, and then washed with water. After separation of the aqueous layer, the mixture of the chlorine derivatives of sorbitol is purified by distillation.

The chlorinating agent – hydrochloric acid was prepared by the known reaction of a mixture of sulfuric acid and sodium chloride when heated.

II stage – chlorinated sorbitol is "sewn" chemically to mercerized cellulose at 100-110 °C by 10% solution of K_2CO_3 during 5 hours:



where R is the residue of a polyhydric alcohol "sewn" to the cellulose monomer.

The reaction product is filtered off, washed with water, alcohol and again with water until neutral, then it is brought to an air-dry state. The composition of the substance was determined by independent IR spectroscopy, elemental chemical and mass spectrometric analyzes. A chromatography-mass spectrometer Clarus SQ 8 was used for this work.

IR spectra of absorption of reaction products are recorded on an IR-20B spectrophotometer in potassium bromide tablets in the range of 600-3800 cm^{-1} .

The percentage of carbon and hydrogen was equal: C - 78.86%, H - 9.66%. According to these data, the calculated ratio of carbon to hydrogen atoms is 1: 1.41 and it practically coincides with their theoretical ratio in a monomer.

The calculation was made using the well-known method for determining the formula of a chemical compound based on its percentage and element composition:

$$\text{C: H} = 78.85 / 12.0: 9.65 / 1.0 = 6.57: 9.65 = 1: 1.47$$

In figures 1 and 2, IR spectra of chlorinated sorbitol and modified cellulose are presented for comparison.

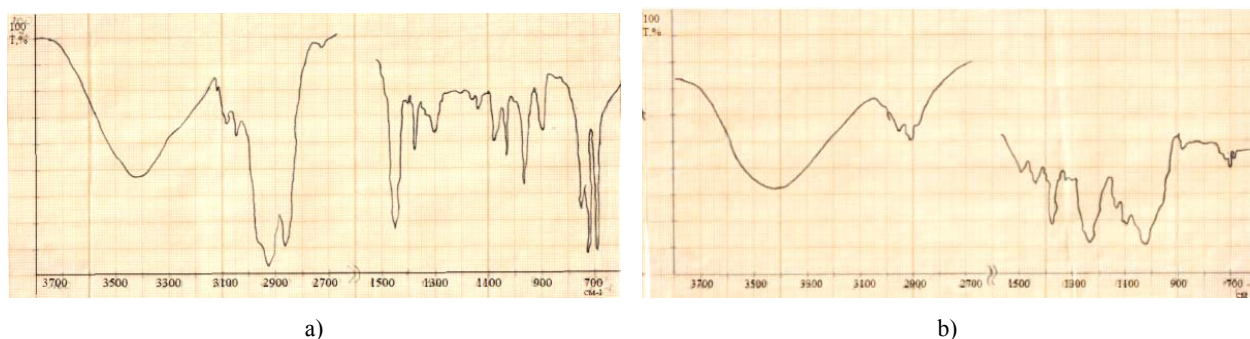


Figure 1 – IR spectra of a) chlorinated sorbitol, b) modified cellulose

In the IR spectra in the range of 3400-3200 cm^{-1} , there is an intense wide band of valence vibrations ν that arise when intermolecular hydrogen bonds-polyassociates are formed.

In the spectra of chlorinated sorbitol, based on the significantly increasing of the intensity of the vibrational bands with the participation of the bond (C-Cl), the substitution of two primary (OH) groups for chlorine atoms can be suggested.

Sewing chlorinated sorbitol proceeds quite fully, which is proved by the minimization of the band of stretching vibrations $\nu_{\text{C-Cl}}$ in the range of 700 cm^{-1} .

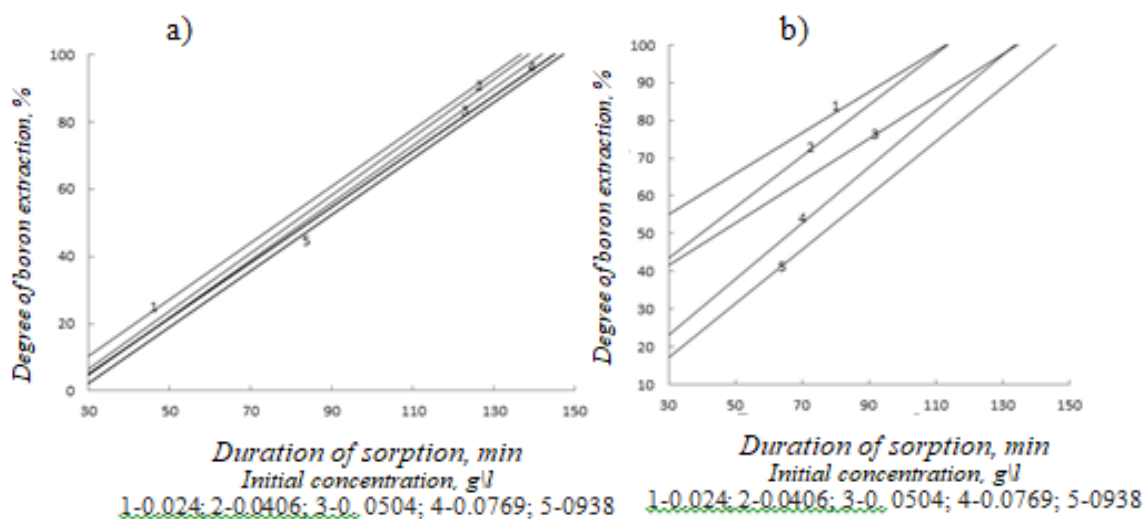


Figure 2 – The influence of time on the amount of boron sorption
a) unmodified cellulose b) modified cellulose

In the range of 970-900 cm^{-1} , average low-density absorption bands characteristic of deformation vibrations of methane groups (CH) are observed.

In the 750-700 cm^{-1} range, intense narrow bands characteristic of the bond (C-Cl) appear both in the mixture of the chlorinated derivatives of sorbitol and in the finished product.

Results and discussions. The extraction of boron from water in both types of CM is studied depending on the initial boron concentration, contact time and phase ratio (S: L).

Under static conditions, in a state of equilibrium on a modified CM the degree of extraction reaches 95-97%. The modified CM is more efficient compared to the unmodified one. The sorption capacity of the CM reaches more than 6mg per gram of sorbent, which is at the level of the best existing boron selective ion exchangers. In order to obtain more information, the data of the experiments were processed using the program Excel Microsoft (figures 3, 4). Figures contain a quantitative characteristic of the influence of time and boron concentration on the degree of its sorption.

The regression equations for the dependence of the degree of boron extraction on the time factor on unmodified and modified cellulose at different initial concentrations of boron in the solution were approximated by linear dependence for computer processing (table).

Dependence of the degree of boron extraction on the initial concentration

Unmodified cellulose			Modified cellulose		
initial concentration of boron, g/l	$y = ax + b$ type of equations	coefficient of approximation R^2 (correlation)	initial concentration of boron, g/l	$y = ax + b$ type of equations	coefficient of approximation R^2 (correlation)
0.024	$y = 0.8433x - 15.08$	0.8845	0.024	$y = 0.5437x + 38.7$	0.8643
0.0406	$y = 0.862x - 19.3$	0.8668	0.0406	$y = 0.678x + 23.2$	0.9018
0.0504	$y = 0.853x - 20.87$	0.8524	0.0504	$y = 0.5597x + 24.91$	0.8884
0.0769	$y = 0.853x - 20.87$	0.8524	0.0769	$y = 0.7453x + 0.62$	0.8804
0.0938	$y = 0.8363x - 22.82$	0.8485	0.0938	$y = 0.7173x - 4.48$	0.8785

Note: a – tangent of the slope of the line to the axis of the abscissa, b – the segment cut off by the straight line along the ordinate axis.

It can be seen from the table that the coefficient of approximation achieves values greater than 0.85, which indicates the reliability of the results obtained.

Figure 3 shows the information obtained by calculation, describing the influence of the time factor on the amount of boron sorption on two types of cellulose.

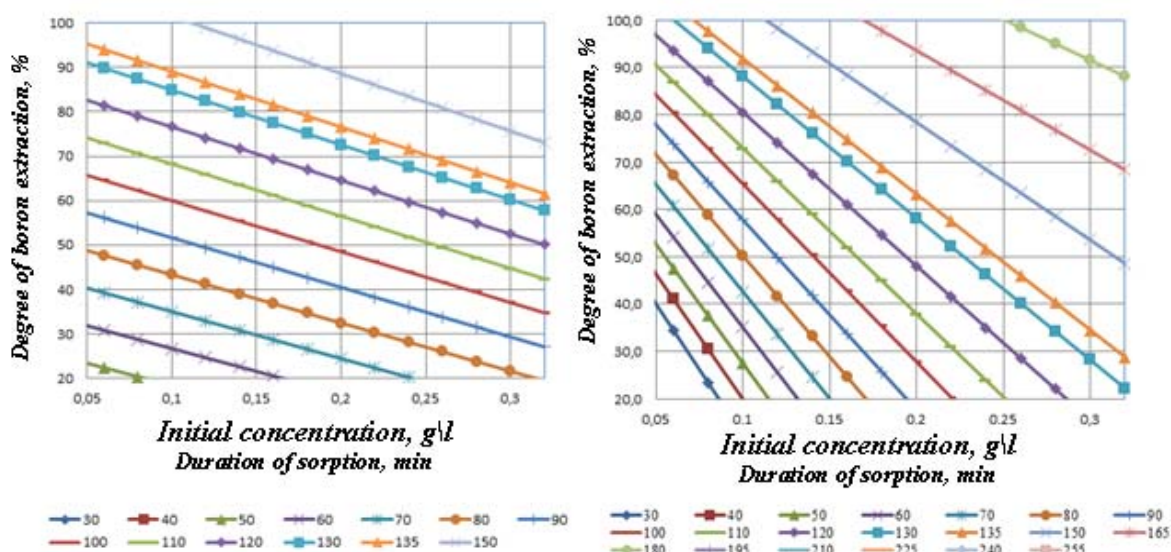


Figure 3 – The diagram of the dependence of boron sorption on the initial concentration and time of sorption on a) unmodified cellulose, b) modified cellulose

It can be seen from the graph (figure 3) that as the time and concentration increase, the degree of the extraction rate of H_3BO_3 decreases. This is due to the gradual saturation of the sorbent phase with boron, which leads to an increase in diffusion difficulties in the transportation of H_3BO_3 molecules in nano- and micro-dimensional pores of sorbents.

A sufficiently complete extraction occurs in all cases with a sorption time of more than 130 minutes, and the modified sorbent is much more efficient than the unmodified one.

Based on the Microsoft Excel program calculation a combined empirical equation is obtained, that relates the dependence of the influence of the initial boron concentration and sorption time on the extraction value:

$$Y = (0.86 - 0.3 \cdot X) \cdot \tau - 85.2 \cdot X + 14.7 \quad (1)$$

where: Y is the boron sorption, (% of the initial content), X is the initial concentration in the solution, g / l; τ is the time of the sorption process, min.

In a graphical form, this dependence is shown in Figure 3a in the form of a diagram.

As can be seen from the diagram of the combined dependence of the degree of sorption on the initial boron concentration for different sorption times (30 to 150 min or more), the degree of increase of the target substance decreases with an increase of the initial boron concentration and a decrease of the phase contact time. As noted earlier, this type of dependence is associated with an increase in the degree of boron saturation of the sorbent phase and diffusion difficulties.

Since the obtained dependences are linear, this allows extrapolating the results of sorption to other values of the variables: the time of the process and the initial content of the extracted substance, without conducting new experiments.

Experiments were carried out using modified mercerized cellulose with "residues" of chlorine derivatives of polyhydric alcohols sewn to it (The results are given in figure 2b).

As it is shown on this figure in comparison with unmodified cellulose, the recovery of H_3BO_3 on this sorbent is also more effective.

The degree of sorption of boron on modified cellulose is described by the empirical equation, which we obtained using the above described calculation method.

$$Y = (2.54 X + 0.5) \cdot \tau - 630.2 \cdot X + 52.6 \quad (2)$$

From the analysis of the diagram obtained by visualizing this equation (Figure 3b) it follows that the general pattern of the change in the magnitude of the dependence of sorption on the variable factors will remain the same as for the unmodified sorbent. However, the efficiency and speed of extraction is much higher. This is confirmed by a very significant relative increase of the tangent in the slope of the majority of straight lines (about 0.60-0.75 percent of extraction per minute). The tangent of the slope of the straight line to the abscissa axis graphically represents the speed of the process, which was used to estimate the speed of the process.

Figure 2b shows that in the case of long process duration and a large percentage of boron extraction, irrespective of its initial concentration, the straight lines converge at one point. This is obviously due to the almost complete saturation of the sorbent with boron over time. The saturation of the sorbent for all solutions occurs in this case with a shorter sorption time of about 100 minutes.

It is convenient to use the diagram (figure 3) proposed by us to determine the efficiency of sorption of a substance at given concentrations of boron and the sorption time, for example at a boron concentration of 0.2 g / l in 165 minutes 95% of the substance is extracted and 150 min less than 80% (figure 3 b). The proposed methodology for drawing up such diagrams can be used to visualize a wide range of other processes of interphase redistribution and concentration of matter in heterogeneous systems.

Thus, it can be concluded that the mercerization of the studied cellulose species and the subsequent "sewing" of chlorine derivatives of polyhydric alcohols to it led to a significant increase in the sorption capacity of cellulose.

With an increase in the background salt, the extraction of the substance is significantly improved as a result of the salting out effect. For example, it was found that, other things being equal, an increase in the NaCl concentration from 0.005 N to 1.00 N increases the coefficient of interphase distribution of boron

(K_c) 226 times between the sorbent phase and the aqueous solution from 3350 to 7640, respectively, (initial concentration of 1.40 g / l, S: L = 1: 50). The values of K_c for different concentrations of salting out agent (NaCl) are given below:

K _c	3350	4800	5515	6230	7640
[NaCl] _н	0.005	0.050	0.250	0.500	1.00

The free energy of the isochoric process ΔF is related to K_c, the equilibrium constant of the chemical reaction or the chemisorption process by the following formula:

$$-\Delta F_{298}^0 = 2,3 \cdot RT \cdot \lg K_c$$

where: T is the absolute temperature, K; R is the universal gas constant.

Calculation using this formula using the values of K_s for the smallest and largest concentration of the salting out agent NaCl (0.005 and 1.00 N) showed that the free energy of sorption for a more concentrated salting out solution with respect to the less concentrated salting out solution increases 1.31 times (almost 30%). This is due to a decrease in water activity with an increase in the salt background as a result of the binding of water molecules to hydrated ion shells.

Further, the influence of the ratio of the solid and liquid phases (S: L) on the process was studied. Studies have shown that under comparable conditions, a change in S: L ÷ 1: 100; 1:75; 1:50; 1:25 significantly increases the extraction of boron in modified cellulose by (30-50%) compared to unmodified cellulose.

Data on the sorption capacity of sorbents allow us to conclude that the CM exhibits a static capacity of 6.02 mg/g dry sorbent, i.e. at the level of synthetic boron selective anion exchangers (ANB).

We have noticed that CM is not susceptible to biocorrosion, unlike ANB since it does not contain glucose derivatives in its structure.

Practical interest is the extraction of boron at its small (milligram) concentrations and a large salt background, modeling the composition of natural and man-made mineral raw materials.

Under dynamic conditions more closely approximated to real technological conditions, the CM also does not concede by its effectiveness to ANB [3], purifying the water from the boron below the MRL (0.5 mg / l) [3, 21, 22].

The equation (II) shows that the mechanism of boron absorption is analogous to polycondensation reactions with the splitting of water and the formation of heteropolymers in inorganic, colloidal chemistry and biochemistry, as well as technologies for processing hydromineral raw materials. The thermodynamic evaluation of this reaction, taking into account the salting out effect according to the formula given above for free energy, showed that ΔF_{298}^0 is in the range from -10.5 to -20.0 kJ / mol. The free energy of Gibbs calculated by us in the reaction: $2 \text{ OH} \rightarrow \text{H}_2\text{O} + \text{O}$ equals -19.0 kJ / mol which means it is in the same interval. It is interesting that the energy of hydrogen bond widely distributed in nature is also in the range of 12.6÷33.6 kJ / mol [23].

Other things being equal, the CM is significantly cheaper than synthetic ANB type sorbents, because it is obtained from cellulose waste, and when modified, non-defective materials are used. The CM after use is easily regenerated by washing with a 3% solution of hydrochloric acid. The recovery of boron-containing waters after the regeneration of sorbents is sufficiently effective in the form of components of fertilizers [18, 19, 20], while simultaneously obtaining purified water, which will help solve the problem of complex use of mineral raw materials and ecology [24, 25].

Study of the interphase distribution of boric acid between aqueous solutions and the solid phase of chemically modified cellulose, the development of non-waste technologies for processing and utilization of natural and man-made boron-containing hydromineral raw materials.

Conclusion. Based on the work done, the following conclusions can be drawn:

- a method for obtaining an efficient boroselective sorbent by chemical "sewing" to mercerized natural cellulose (CM) of chlorinated derivatives of polyhydric alcohols has been developed;
- CM is a more affordable and inexpensive sorbent and, other things being equal, does not concede to the best boron elective ion exchangers of the ANB type (boron-selective anionite) by its sorption characteristics;

– in heterogeneous systems it is proposed to depict data on the interphase distribution of matter in analytical (mathematical) and graphical interpretation (in the form of diagrams), taking into account three variables (time, concentration and recovery percentage), which allows obtaining results without conducting additional experiments.

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МОДИФИКАЦИЯЛАНҒАН ЦЕЛЛЮЛОЗА МЕН СУ ЕРІТІНДЕРІНІҢ АРАСЫНДАҒЫ БОР ҚЫШҚЫЛЫНЫҢ ФАЗААРАЛЫҚ БӨЛІНУІ

Аннотация. Гидроминералды шикізатты өңдеу қажеттілігіне байланысты көптеген зерттеушілер табиғи материалдар негізінде органикалық сорбенттерді алудың іргелі және қолданбалы мәселеріне, атап айтқанда, мерсеризация әдістерімен модификацияланған әртүрлі целлюлозаға (сілтілі ерітінділерімен өңдеу) және функционалдық топтардың химиялық модификациясына қызығушылық танытады.

Бор қышқылының фазаралық бөлуді нақтылы, *Prunus armeniaca* (абрикос) мерсеризденген, содан кейін химиялық түрде модификацияланған ұсақталған өрік сүйегіне зерттеу жүргізілді.

Сорбент материалында бор қышқылына арналған селективті қасиеттері бар, оның су фазасынан алынып, H_3BO_3 -ні сорбент (өзгертілген целлюлоза) қатты фазасында шоғырландыратыны анықталды. Элементтік химиялық және масс-спектрометриялық талдау жүргізілді, сорбенттердің ИК-спектрлері түсірілді, олардың негізінде құрылымдар берілді және бор қышқылын модификацияланған целлюлоза (МЦ) фазасы арқылы жұту механизмі ұсынылды.

Түйін сөздер: бор қышқылы; өзгерту; фазаралық таралуы.

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МЕЖФАЗОВОЕ РАСПРЕДЕЛЕНИЕ БОРНОЙ КИСЛОТЫ МЕЖДУ ВОДНЫМИ РАСТВОРАМИ И МОДИФИЦИРОВАННОЙ ЦЕЛЛЮЛОЗЫ

Аннотация. В связи с необходимостью переработки гидроминерального сырья многие исследователи проявляют интерес к фундаментальным и прикладным проблемам получения органических сорбентов на основе природных материалов, в частности к различным видам целлюлозы, модифицированной методами мерсеризации (обработкой растворами щелочей), а также химическим изменением функциональных групп.

В работе изучено межфазное распределение борной кислоты на мерсеризованной, затем химически модифицированной дробленой косточке абрикоса обыкновенного, *Prunus armeniaca* (урюка).

Установлено, что вещество сорбента обладает селективными свойствами к борной кислоте, извлекая ее из водной фазы и концентрируя H_3BO_3 в твердой фазе сорбента (модифицированной целлюлозе). Проведены элементный химический и масс-спектрометрический анализы, сняты ИК-спектры сорбентов, на основании которых дана их структура, а также предложен механизм поглощения борной кислоты фазой модифицированной целлюлозы (ЦМ).

Ключевые слова: борная кислота; модификация; межфазовое распределение.

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CALCULATION AND VISUALIZATION OF A BODY MOTION IN A GRAVITATIONAL FIELD

Abstract. The article presents the program for calculation and visualization of a material particle motion trajectory in a gravitational field of two motionless objects M1 and M2. The system of differential equations of the particle motion is solved using the ode45 procedure of the MATLAB system. At first the m-file under the title «f=fini2(t,x)», is created and then it is connected from a command line. Experiments with change of mass of the second motionless object are made, i.e. at M1=50 for M2=0; 0.2; 1; 2; at M1=49 for M2=0; 1; 2; at M1=47 for M2=0.5; 1.0. The movement of a point in the field of one motionless object happens along an ellipse, and introduction of other motionless object of small mass leads to perturbation of an orbit and the trajectory isn't closed. Initial parameters are introduced as global. By changing initial parameters it is possible to get various models of the particle's motion in the gravitational field. The results of this study can be used on theoretical mechanics classes of the higher school.

Key words: gravitational field, trajectory, perturbation, ode45 procedure.

Nowadays all educational institutions of Kazakhstan are provided with computer hardware and software, interactive boards and internet. Almost all teachers have completed language and computer courses of professional development. Hence the educational institutions have all conditions for using computer training programs and models for performing computer laboratory works. In recent years we conduct work on organization computer laboratory works on physics with use of resources of the Fizikon Company [1] and [2], developed at Al-Farabi Kazakh National University by V. V. Kashkarov and his group. Some of worksheet templates for computer laboratory works are introduced in educational process of our university and schools of the Southern Kazakhstan [3-29]. Students of the specialties 5B060400 and 5B011000-physics successfully study the discipline “Computer modeling of physical phenomena” which is the logical continuation of the disciplines “Information technologies in teaching physics” and “Use of electronic textbooks in teaching physics”. The aim of this discipline is to study and learn the program language of the MATLAB [30] system, acquaintance with its huge opportunities for the modeling and visualization of physical processes. The MATLAB system is widely applied for calculating and visualization of problems of applied mechanics which are studied by students of specialties 5B070600-Geology and exploration of mineral deposits, 5B071200-Mechanical engineering, 5B072900-Construction, 5B072400-Technological machines and the equipment, 5B071300-Transport, transport equipment and technologies, 5B070800-Oil and gas business, 5B090100-Organization of transportations, movement and operation of transport.

This article is devoted to calculation and visualization of a body motion in a gravitational field using MATLAB software package.

Laboratory work “Calculation and visualization of a body motion in a gravitational field of two motionless objects”.

Aim of the work: to work out the program for calculation and visualization of a body motion in a gravitational field of two motionless objects.

Formulation of the problem: A particle of mass m moves in a gravitational field of two motionless objects with masses M_1 and M_2 (figure 1).

The motion of the particle with mass m is described by the following equation

$$m\ddot{\vec{R}} = -G \frac{mM_1}{|\vec{R} - \vec{r}_1|^3} (\vec{R} - \vec{r}_1) - G \frac{mM_2}{|\vec{R} - \vec{r}_2|^3} (\vec{R} - \vec{r}_2) \quad (1)$$

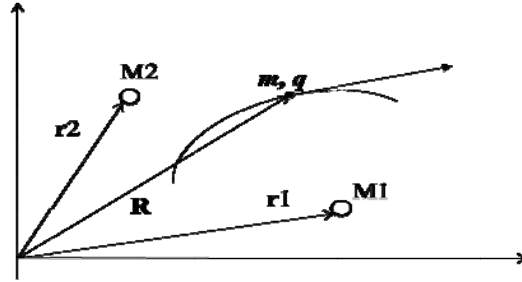


Figure 1 – The diagram of a location of the particle with mass m in gravitational field of two motionless objects with masses M_1 and M_2

The equation (1) is the second-order differential equation. It can be reduced to the first-order equation:

$$\begin{aligned} \dot{\vec{R}} &= \vec{V} \\ \dot{\vec{V}} &= -G \frac{M_1}{|\vec{R} - \vec{r}_1|^3} (\vec{R} - \vec{r}_1) - G \frac{M_2}{|\vec{R} - \vec{r}_2|^3} (\vec{R} - \vec{r}_2) \end{aligned} \quad (2)$$

We suppose that motion occurs on the plane and introduce the following denotations:

$$\vec{R} = (x1, x2), \quad \vec{r}_1 = (c1x, c1y), \quad \vec{r}_2 = (c2x, c2y), \quad \vec{V} = (x3, x4) \quad (3)$$

Using these denotations we rewrite the equation (2) as the followings

$$\begin{aligned} \dot{x1} &= x3; \quad \dot{x2} = x4; \\ \dot{x3} &= -G \frac{M1(x1 - c1x)}{\left((x1 - c1x)^2 + (x2 - c1y)^2\right)^{3/2}} - \frac{M2(x1 - c2x)}{\left((x1 - c2x)^2 + (x2 - c2y)^2\right)^{3/2}}; \\ \dot{x4} &= -G \frac{M1(x2 - c1y)}{\left((x1 - c1x)^2 + (x2 - c1y)^2\right)^{3/2}} - \frac{M2(x2 - c2y)}{\left((x1 - c2x)^2 + (x2 - c2y)^2\right)^{3/2}}; \end{aligned} \quad (4)$$

Without impact on the solution of the problem, we take the value of a gravitational constant to be equal to $G=1$ and $M1=50$, $M2=0$ (their values can be changed). Also we suppose that coordinates of motionless objects are $c1 = (5,0)$, $c2 = (0,10)$. Then the system of the equations can be written as m. file under the title finit2.

Listing of the m. file

```
f=finit2(t,x)
global M1 M2 c1x c1y c2x c2y
f=[x(3);x(4);...
-M1*(x(1)-c1x)/(sqrt((x(1)-c1x)^2+(x(2)-c1y)^2))^3-...
M2*(x(1)-c2x)/(sqrt((x(1)-c2x)^2+(x(2)-c2y)^2))^3;
-M1*(x(2)-c1y)/(sqrt((x(1)-c1x)^2+(x(2)-c1y)^2))^3-...
M2*(x(2)-c2y)/(sqrt((x(1)-c2x)^2+(x(2)-c2y)^2))^3];
end
```

The program of the movement of a particle of mass m in the field of one motionless object with mass $M_1=50$. In the command line of MATLAB we write

```
>> global M1 M2 c1x c1y c2x c2y
>> M1=50; M2=0; c1x=5; c1y=0; c2x=0; c2y=10; % input of parameters
>> x0=0; y0=0; vx0=0; vy0=4.3; T1=4000; % input of parameter
>> [t,h]=ode45(@finit2,[0,T1],[x0,y0,vx0,vy0]); % solution of the differential equation
>> x=h(:,1); y=h(:,2); x1=c1x; y1=c1y; x2=c2x; y2=c2y;
>> plot(x,y) % drawing the motion trajectory
>> grid on % drawing the coordinate grid
>> hold on % drawing the next element
% drawing the location of motionless objects
>> plot(x1,y1,'r+',x2,y2,'r*','MarkerSize',15);
>> plot(x1,y1,'ro',x2,y2,'ro','MarkerSize',15);
>> gtext('M1=50') % input of the notation in the figure
>> gtext('M2=0') % input of the notation in the figure
```

The result is presented in the figure 2.

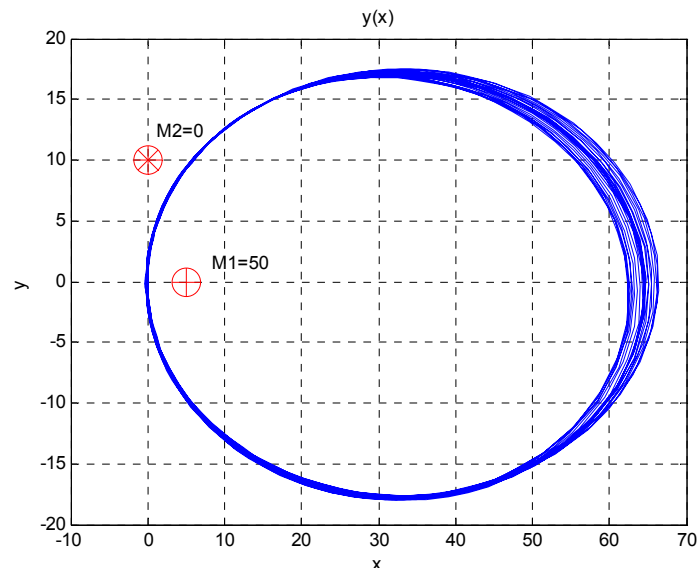


Figure 2 – The trajectory of a particle motion in a gravitational field of one motionless object with mass M_1

It is known that the particle in a gravitational field of one motionless object with a certain mass moves along an ellipse or a circle. In the figure 2 the line trajectory is indistinct. This is due to insufficient accuracy of the calculation. By default the accuracy of calculation of the ode45 procedure is $1e-6$ which isn't enough for the considered problem. Therefore, in the ode45 procedure the calculation accuracy is taken to be $1e-9$.

```
>> global M1 M2 c1x c1y c2x c2y
>> M1=50; M2=0; c1x=5; c1y=0; c2x=0; c2y=10; % input of parameters
>> x0=0; y0=0; vx0=0; vy0=4.3; T1=4000;
>> tol=1e-9;
>> [t,h]=ode45(@finit2,[0,T1],[x0,y0,vx0,vy0],odeset('RelTol',tol));
>> x=h(:,1); y=h(:,2); x1=c1x; y1=c1y; x2=c2x; y2=c2y;
>> plot(x,y) % drawing the trajectory of the motion
>> grid on
>> hold on % drawing the next element
% drawing the location of motionless objects
>> plot(x1,y1,'r+',x2,y2,'r*','MarkerSize',15);
>> plot(x1,y1,'ro',x2,y2,'ro','MarkerSize',15);
```

```
>>gtext('M1=50') % input of the notation in the figure
>> gtext('M2=0') % input of the notation in the figure
```

The result is presented in the figure 3.

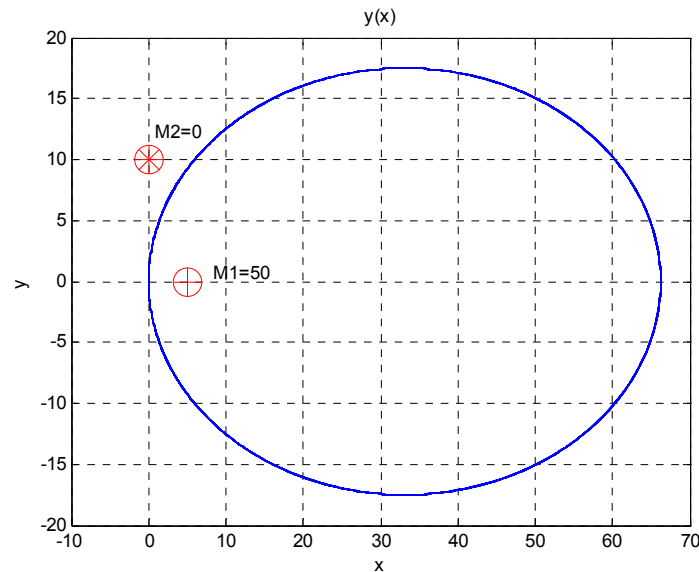


Figure 3 – The trajectory of a particle motion in a gravitational field of one motionless object with mass $M1$

Now we have got the perfect picture of the trajectory.

The program of the movement of a particle of mass m in the field of two motionless objects with masses $M1=50$ and $M2=0.2$.

```
>> M1=50; M2=0.2; c1x=5; c1y=0; c2x=0; c2y=10; % input of parameters
>> x0=0; y0=0; vx0=0; vy0=4.3; T1=1000; % input of parameters
>> [t,h]=ode45(@finit2,[0,T1],[x0,y0,vx0,vy0]); % solution of the differential equation
>> x=h(:,1); y=h(:,2); x1=c1x; y1=c1y; x2=c2x; y2=c2y;
>> plot(x,y); % drawing the motion trajectory
>> gtext('M2=0.2') % input of the notation in the figure
>> gtext('M1=50') % input of the notation in the figure
```

The result is presented in the figure 4.

Figure 4 shows that introduction of the second motionless object with a small mass of $M2=0.2$ leads to disturbance of an orbit and the orbit isn't closed.

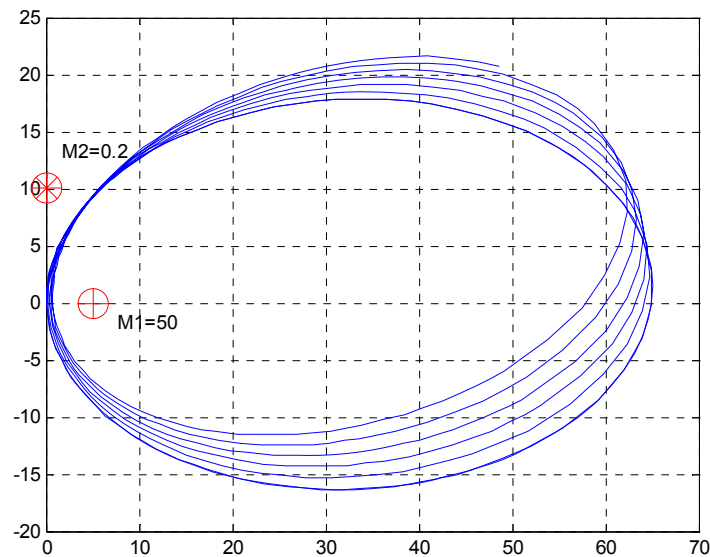


Figure 4 – The trajectory of a particle motion in a gravitational field of two motionless objects with masses $M1=50$ and $M2=0.2$

The program of the movement of a particle of mass m in the field of two motionless objects with masses $M_1=50$ and $M_2=1$.

```
>> global M1 M2 c1x c1y c2x c2y
>> M1=50; M2=1; c1x=5; c1y=0; c2x=0; c2y=10; % input of parameters
>> x0=0; y0=0; vx0=0; vy0=4.3; T1=1000; % input of parameters
>> [t,h]=ode45(@finit2,[0,T1],[x0,y0,vx0,vy0]); % solution of the differential equation
>> x=h(:,1); y=h(:,2); x1=c1x; y1=c1y; x2=c2x; y2=c2y;
>> plot(x,y); % drawing the motion trajectory
>> grid on % drawing the coordinate grid
>> hold on % drawing the next element
>> % drawing the location of motionless objects
>> plot(x1,y1,'r+',x2,y2,'r*','MarkerSize',15);
>> plot(x1,y1,'ro',x2,y2,'ro','MarkerSize',15);
>> gtext('M1=50') % input of the notation in the figure
>> gtext('M2=1') % input of the notation in the figure
```

The result is presented in the figure 5.

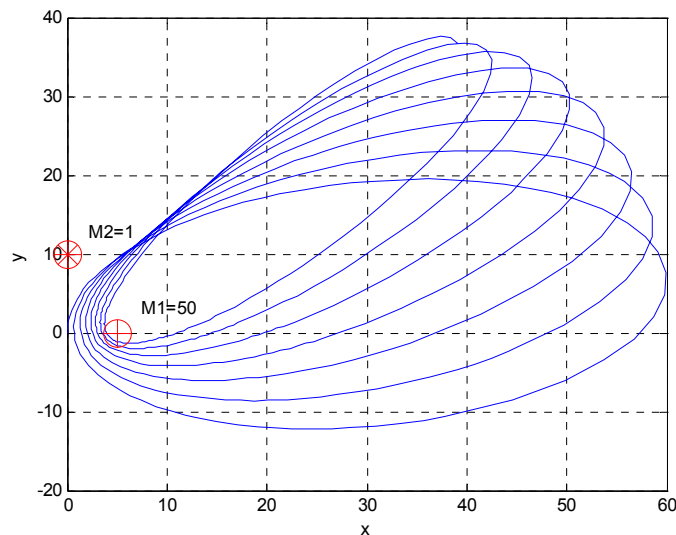


Figure 5 – The trajectory of a particle motion in a gravitational field of two motionless objects with masses $M_1=50$ and $M_2=1$

Figure 5 shows that the increase in mass of the second motionless object leads to a greater disturbance of the orbit.

The program of the movement of a particle of mass m in the field of two motionless objects with masses $M_1=50$ and $M_2=2$.

```
>> global M1 M2 c1x c1y c2x c2y
>> M1=50; M2=2; c1x=5; c1y=0; c2x=0; c2y=10; % input of parameters
>> x0=0; y0=0; vx0=0; vy0=4.3; T1=1000; % input of parameters
>> [t,h]=ode45(@finit2,[0,T1],[x0,y0,vx0,vy0]); % solution of the differential equation
>> x=h(:,1); y=h(:,2); x1=c1x; y1=c1y; x2=c2x; y2=c2y;
>> plot(x,y); % drawing the motion trajectory
>> grid on % drawing the coordinate grid
>> hold on % drawing the next element
>> % drawing the location of motionless objects
>> plot(x1,y1,'r+',x2,y2,'r*','MarkerSize',15);
>> plot(x1,y1,'ro',x2,y2,'ro','MarkerSize',15);
>> gtext('M1=50') % input of the notation in the figure
>> gtext('M2=2') % input of the notation in the figure
```

The result is presented in the figure 6.

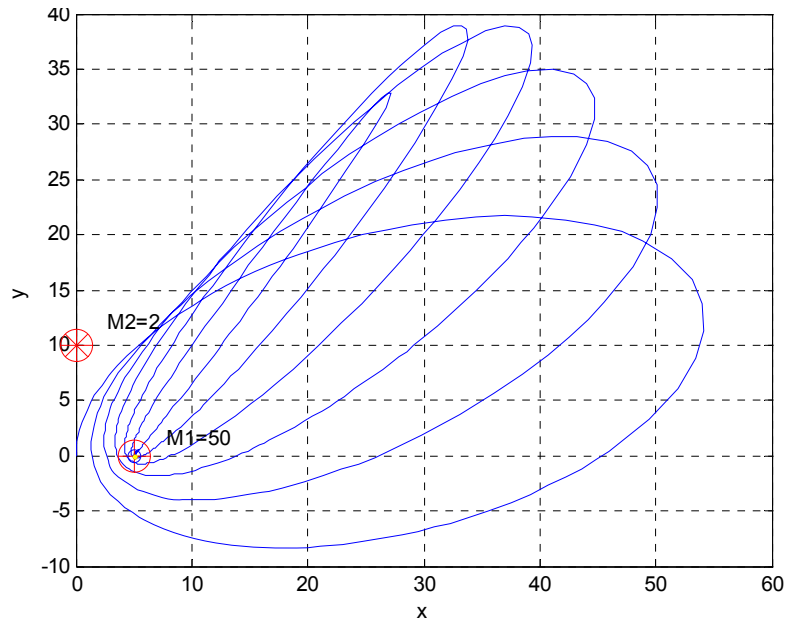


Figure 6 – The trajectory of a particle motion in a gravitational field of two motionless objects with masses $M1=50$ and $M2=2$

The program of the movement of a particle of mass m in the field of two motionless objects with masses $M1=49$ and $M2=0$.

```
>> global M1 M2 c1x c1y c2x c2y
>> M1=49; M2=0; c1x=5; c1y=0; c2x=0; c2y=10; % input of parameters
>> x0=0; y0=0; vx0=0; vy0=4.3; T1=300; % input of parameters
>> [t,h]=ode45(@finit2,[0,T1],[x0,y0,vx0,vy0]); % solution of the differential equation
>> x=h(:,1); y=h(:,2); x1=c1x; y1=c1y; x2=c2x; y2=c2y;
>> plot(x,y); % drawing the motion trajectory
>> grid on % drawing the coordinate grid
>> hold on % drawing the next element
% drawing the location of motionless objects
>> plot(x1,y1,'r+',x2,y2,'r*','MarkerSize',15);
>> plot(x1,y1,'ro',x2,y2,'ro','MarkerSize',15);
>> gtext('M1=49') % input of the notation in the figure
>> gtext('M2=0') % input of the notation in the figure
```

The result is presented in the figure 7.

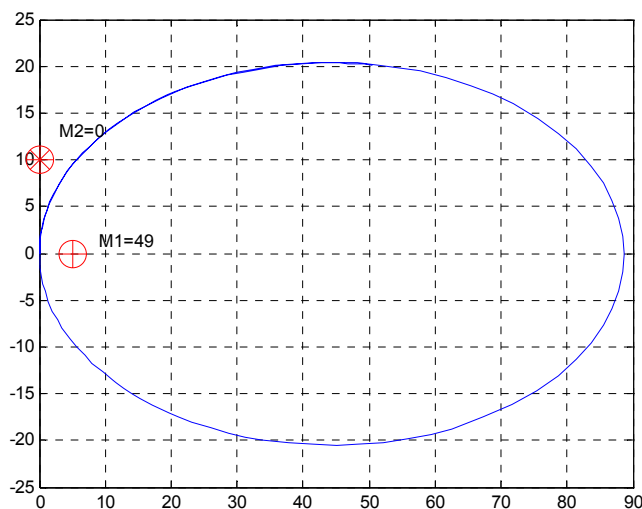


Figure 7 – The trajectory of a particle motion in a gravitational field of two motionless objects with masses $M1=49$ and $M2=0$

The program of the movement of a particle of mass m in the field of two motionless objects with masses $M_1=49$ and $M_2=1$.

```
>> global M1 M2 c1x c1y c2x c2y
>> M1=49; M2=1; c1x=5; c1y=0; c2x=0; c2y=10; % input of parameters
>> x0=0; y0=0; vx0=0; vy0=4.3; T1=1000; % input of parameters
>> [t,h]=ode45(@finit2,[0,T1],[x0,y0,vx0,vy0]); % solution of the differential equation
>> x=h(:,1); y=h(:,2); x1=c1x; y1=c1y; x2=c2x; y2=c2y;
>> plot(x,y); % drawing the motion trajectory
>> grid on % drawing the coordinate grid
>> hold on % drawing the next element
>> % drawing the location of motionless objects
>> plot(x1,y1,'r+',x2,y2,'r*','MarkerSize',15);
>> plot(x1,y1,'ro',x2,y2,'ro','MarkerSize',15);
>> gtext('M1=49') % input of the notation in the figure
>> gtext('M2=1') % input of the notation in the figure
```

The result is presented in the figure 8.

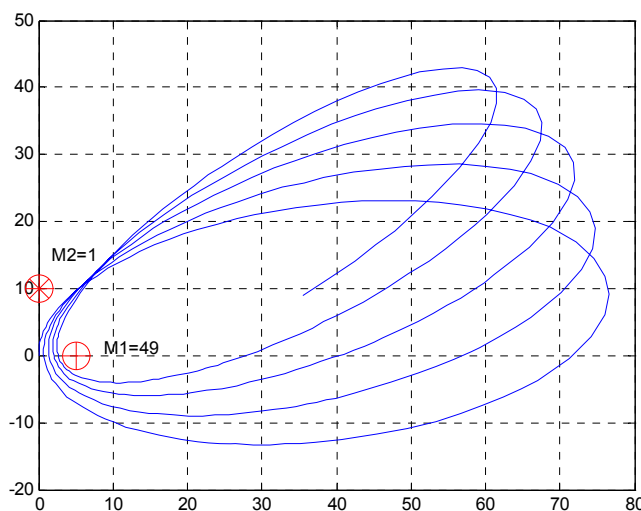


Figure 8 – The trajectory of a particle motion in a gravitational field of two motionless objects with masses $M_1=49$ and $M_2=1$

The program of the movement of a particle of mass m in the field of two motionless objects with masses $M_1=49$ and $M_2=2$.

```
>> global M1 M2 c1x c1y c2x c2y
>> M1=49; M2=2; c1x=5; c1y=0; c2x=0; c2y=10; % input of parameters
>> x0=0; y0=0; vx0=0; vy0=4.3; T1=1000; % input of parameters
>> [t,h]=ode45(@finit2,[0,T1],[x0,y0,vx0,vy0]); % solution of the differential equation
>> x=h(:,1); y=h(:,2); x1=c1x; y1=c1y; x2=c2x; y2=c2y;
>> plot(x,y); % drawing the motion trajectory
>> grid on % drawing the coordinate grid
>> hold on % drawing the next element
>> % drawing the location of motionless objects
>> plot(x1,y1,'r+',x2,y2,'r*','MarkerSize',15);
>> plot(x1,y1,'ro',x2,y2,'ro','MarkerSize',15);
>> gtext('M1=49') % input of the notation in the figure
>> gtext('M2=2') % input of the notation in the figure
```

The result is presented in the figure 9.

The program of the movement of a particle of mass m in the field of two motionless objects with masses $M_1=47$ and $M_2=0.5$.

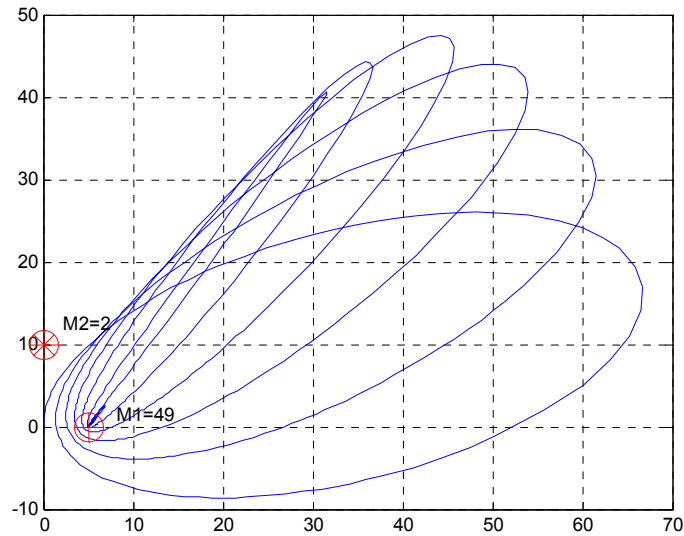


Figure 9 – The trajectory of a particle motion in a gravitational field of two motionless objects with masses $M_1=49$ and $M_2=2$

```
>> global M1 M2 c1x c1y c2x c2y;
>> M1=47; M2=0.5; c1x=5; c1y=0; c2x=0; c2y=10; % input of parameters
>> x0=0; y0=0; vx0=0; vy0=4.3; T1=4000; % input of parameters
>> [t,h]=ode45(@finit2,[0,T1],[x0,y0,vx0,vy0]); % solution of the differential equation
>> x=h(:,1); y=h(:,2); x1=c1x; y1=c1y; x2=c2x; y2=c2y;
>> plot(x,y); % drawing the motion trajectory
>> grid on % drawing the coordinate grid
>> hold on % drawing the next element
% drawing the location of motionless objects
>> plot(x1,y1,'r+',x2,y2,'r*','MarkerSize',15);
>> plot(x1,y1,'ro',x2,y2,'ro','MarkerSize',15);
>> gtext('M1=47') % input of the notation in the figure
>> gtext('M2=0.5') % input of the notation in the figure
```

The result is presented in the figure 10.

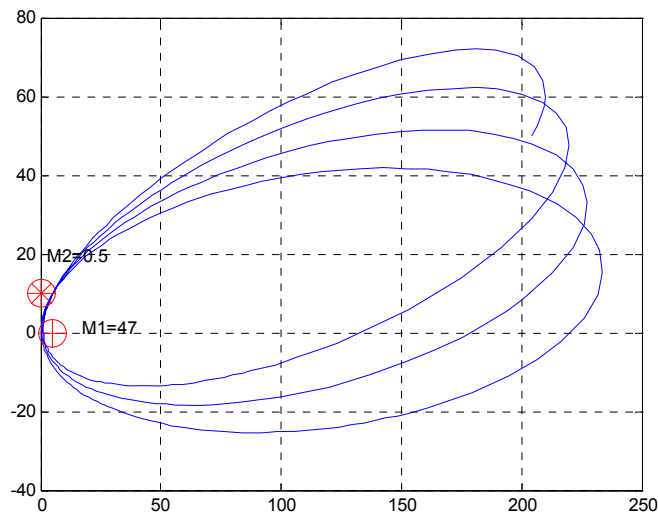


Figure 10 – The trajectory of a particle motion in a gravitational field of two motionless objects with masses $M_1=47$ and $M_2=0.5$

The program of the movement of a particle of mass m in the field of two motionless objects with masses $M_1=47$ and $M_2=1$.

```

>> T1=4000; M1=47; M2=1;
>> [t,h]=ode45(@finit2,[0,T1],[x0,y0,vx0,vy0]); % solution of the differential equation
>> x=h(:,1); y=h(:,2); x1=c1x; y1=c1y; x2=c2x; y2=c2y;
>> plot(x,y) % drawing the motion trajectory
>> grid on % drawing the coordinate grid
>> hold on % drawing the next element
% drawing the location of motionless objects
>> plot(x1,y1,'r+',x2,y2,'r*','MarkerSize',15);
>> plot(x1,y1,'ro',x2,y2,'ro','MarkerSize',15);
>> gtext('M1=47') % input of the notation in the figure
>> gtext('M2=1') % input of the notation in the figure

```

The result is presented in the figure 11.

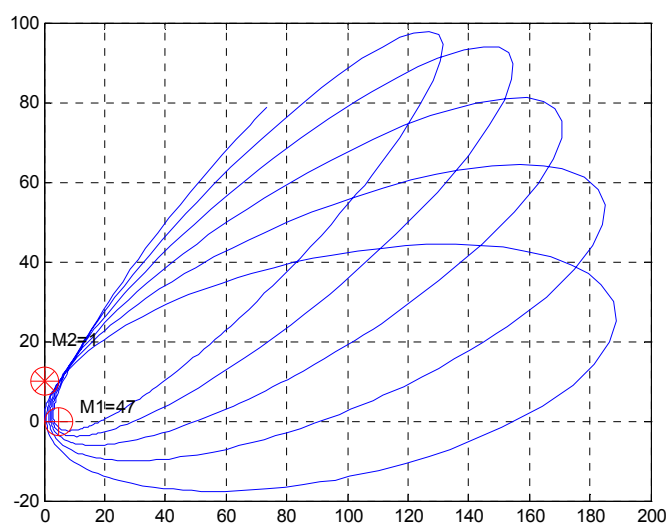


Figure 11 – The trajectory of a particle motion in a gravitational field of two motionless objects with masses $M1=47$ and $M2=1$

Conclusion. The program allows performing modeling at various initial parameters: for example at $M1=50$ and $M2=0; 0.2; 1; 2$; at $M1=49$ and $M2=0; 1; 2$; at $M1=47$ and $M2=0.5; 1.0$. Students are suggested to simulate independently for other various initial parameters by changing calculation accuracy using the command “odeset('RelTol', tol)”.

The use of the MATLAB language for simulation of the material particle motion in the gravitational field of two motionless objects with different masses helps greatly in study of the gravitational field influence on the particle's motion.

The movement of the particle in the field of one motionless object happens along an ellipse, and introduction of other motionless object of small mass leads to perturbation of an orbit and the trajectory isn't closed.

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ДЕНЕНІҢ ГРАВИТАЦИЯЛЫҚ ӨРІСТЕ ҚОЗҒАЛЫСЫН ЕСЕПТЕУ МЕН БЕЙНЕЛЕУ

Аннотация. Екі тыныштықтағы M_1 және M_2 объектілердің гравитациялық өрісінде материялық нүктенің траекториясын есептеу мен бейнелеу ұсынылған. Предлагается программа расчета и визуализации. Қозғалыстың дифференциалдық теңдеулер жүйесі MATLAB жүйесінде ode45 процедурасымен шешіледі. Ол үшін алдын-ала «f=fini2(t,x)» деп аталатын m-файл жазылады және ол MATLAB тың командалық строкасынан қосылады. Тыныштықтағы бірінші объектінің массасын өзгертпей $M_1=50$, тыныштықтағы екінші объектінің массасын $M_2=0; 0.2; 1; 2$ шамаларында өзгертіп эксперименттер жүргізілген;

Сонымен қатар $M_1=49, M_2=0, 1, 2; M_1=47, M_1=0.5, 1.0$ шамалар бойынша эксперименттер қайталанған. Тыныштықтағы бір объектінің өрісінде материялық нүктенің қозғалысы эллипс бойында, ал екінші объект қосылғанда нүктенің траекториясы шамалы өзгереді де траектория тұйықталмайды. Бастапқы параметрлер глобалды деп жарияланған. Бастапқы параметрлерін өзгерту арқылы материалдық нүктенің гравитациялық өрістегі қозғалысының әр түрлі моделін алуға болады.

Зерттеу нәтижелері жоғары оқу орындарындағы теориялық механика дәрістерінде қолдануға болады.

Түйін сөздер: гравитациялық өріс, траектория, өзгерту, ode45 процедурасы.

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РАСЧЕТ И ВИЗУАЛИЗАЦИЯ ДВИЖЕНИЯ ТЕЛА В ГРАВИТАЦИОННОМ ПОЛЕ

Аннотация. В статье приводится расчет и визуализация траектории движения материальной точки в гравитационном поле двух неподвижных объектов M_1 и M_2 . Решение системы дифференциальных уравнений движения проводится процедурой ode45 системы MATLAB. Сначала создается m-файл под названием «f=fini2(t,x)», который подключается с командной строки. Далее проводится моделирование с изменением массы второго неподвижного объекта при постоянной массе первого объекта: $M_2=0; 1; 2$ при $M_1=50; M_2=0, 1, 2$ при $M_1=49; M_1=0.5$ и 1.0 при $M_1=47$. Движение точки в поле одного неподвижного объекта происходит по эллипсу, а введение другого неподвижного объекта малой массы приводит к возмущению орбиты и траектория незамкнута. Исходные параметры объявлены как глобальные. Меняя исходные параметры можно получить разные модели движения материальной точки в гравитационном поле.

Результаты исследования могут быть использованы на занятиях по теоретической механике в высших учебных заведениях.

Ключевые слова: гравитационное поле, траектория, возмущение, процедура ode45.

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**INVESTIGATION OF THE KINEMATICS
OF ROLLING RIBS AND PIPES
ON A CONTINUOUS RADIAL-SHIFTING MILL
OF A NEW CONSTRUCTION**

Abstract. When using a continuous cast piece to press bars or pipes in a new mill, the deformation must be carried out in the most efficient way, so that a better structure of the metal can be obtained. For a new continuous pressing mill, a possible solution to this problem is to use helical rolls with rational geometric dimensions of the protrusions and hollows. The use of helical rolls with rational sizes of protrusions and hollows will intensively deform the metal of the workpiece within the required reduction of the workpiece. In the study of kinematics of pressing, helical rolls with different sizes of protrusions and hollows were used. Their use made it possible to establish the dependence of the rate of metal yield from the deformation center on the technological regimes of deformation in helical-shaped rolls and to determine the more effective geometric dimensions of the protrusions and hollows of these rolls. It is shown that the deformation of the metal during rolling on the radial-shear mill is realized with sliding of the workpiece relative to the rolls. Slip occurs due to the discrepancy between the speed of the screw movement of the workpiece in the area of deformation of the speed of rotation of the rolls. The quality of steel products depends on the magnitude of sliding, as well as other technical and economic indicators of production. It is established that when rolling on a radial-shear mill, the speed of the workpiece movement is less than the speed of the rolls. The kinematics of the process is analyzed analytically and formulas are derived to determine the rate of roll slippage relative to the workpiece in the zones of the hollow of the workpiece.

Keywords: helical-shaped rolls, matrix, process kinematics, rod, workpiece, slippage, tangential and axial components of slip and velocities.

Introduction. Rods and pipes are widely used in all industries. They are used, both in the form of finished products, and in the form of semi-finished products for the production of a number of metal products. It should be noted that at present there is a significant interest in ponds and pipes, which has ultrafine-grained (UFG) or nanocrystalline (NC) structure. This is due to the unique physical and mechanical properties of such materials, which are significantly higher than the similar properties of coarser polycrystalline materials [1-6].

One of the most promising ways to obtain a UFG or NC structure in metallic materials is the use of severe plastic deformation (SPD), when a combination of nonmonotonic and intense deformation breaks down the metal structure [1-6]. When using a nonmonotonic SPD, without changing the shape and geometric dimensions of the workpiece, the angle between the directions of deformation is changed consequently by 90° and 180°. Such deformation leads to the development of macro-shear deformations along its cross-section, which contributes to the intensive generation of new dislocations, the evolution of the dislocation structure, and the rearrangement of the small-angle boundaries of the structure fragments into high-angle structures [7]. Particularly widely used is the method of equal-channel angular (ECA) pressing [4-6]. It should be noted that to date, none of the methods of SPD, including ECA-pressing, does

not allow obtaining industrial products that are acceptable in shape and size [7]. First of all, this concerns the possibility of structuring metal in long products, such as bars, pipes and wires.

Of the SPD methods that allow to obtain long-length products with significant changes in microstructure and mechanical properties, it is necessary to note the cross-screw rolling, or rather its appearance, singled out by its authors in a separate way with the name "Radial Shear Rolling" (RSR) [8-12]. RSR is defined as a special case of stationary helical rolling in the region of large feeding angles (16–18 deg, and more), in rolls with special calibration for deformation of continuous workpieces of constant cross-section.

At the heart of the RSR method is the trajectory control of the motion of the deformable metal [9,13]. In the focus of deformation, a helicoidal outflow of metal is created with the braking of the outer layer of the preform and the acceleration of the internal layer. In this case, in the outer layer each element undergoes compression deformation along the radius of the workpiece and the direction of flow (along the screw path). Multidirectional flows cause intensive shearing movements in the volume of rolled metal, which leads to a considerable grinding of the structural structure. The metal acquires a characteristic finely dispersed structure that is practically not available for other stationary methods of metal processing. In terms of its morphological pattern, structure and properties, the metal after the RSR becomes a material of new quality. There is a complex increase and stabilization of the physico-mechanical and service properties of the metal at a level exceeding the traditional properties of the material [11].

In terms of the overall structure, the RSR mills are identical to the helical rolling mill used for the production of seamless hot-rolled pipes [13]. The main difference between these technological processes is that during the production of pipes, a "loosening" of the central zone of the circular billet (pipe piercing) is created, and during the process of the RSR, the metal of the billet is consolidated throughout the cross section. The theory, technology and equipment for the implementation of the RSR process are presented in [10-12].

The first industrial tests of radial-shear rolling technology were carried out at the Verkhne-Saldinsky metallurgical production association [11]. Using the results obtained, the RSR-130 radial shear rolling mill was designed and put into operation, designed to produce high-quality bars of titanium alloys. The design of the mill allows for reverse rolling. The working cage of the RSR-130 is made in the form of a cast die-cast frame, in cylindrical bores at which the drums with rigidly fixed roller assemblies are placed at an angle of 120°. The distance between them is changed by moving the drums into the guide rails by means of the roll setting mechanism. The rotation of the rolls to the required feed angle is achieved by rotating the drums in the cylindrical bores of the frame by the action of the rotation mechanisms of the drum. In the working position, the lid adjoins the base of the frame with support surfaces and is pressed with a tie, ensuring the integrity and high stiffness of the frame together with the hinged connection and screed.

As a way of conducting transshipment in the line of the RSR-130 mill, a scheme for changing the rolls is provided by tilting the lid of the stand with the drum in it [12]. When transshipment, the lower rollers with rolls openly located at the bottom of the frame are replaced by a crane. To replace the upper drum with the roller, a special stand is used.

It should be noted that the RSR mill consists of two stands [12]. The roughing stand works in reverse mode. It produces 9-11 passes with single draw coefficients of 1.15–1.25. Such a regime excludes the possibility of deformation heating, since the temperature range of deformation of titanium alloys is rather narrow. The maximum diameter of the blank for the roughing stand is 160, and the minimum rolling diameter after rolling is 75 mm. The design of the finishing stand is similar to roughing. It produces a single pass and ensures high accuracy of the produced bars, minimal curvature and a smooth surface. The maximum diameter of the roll for the finishing stand is 110, and the bar after rolling is 65 mm. That is, the deformation capabilities of the roughing stand in this case are not fully used.

The rod produced in the RSR-130 mill with a diameter of 75–90 mm is fed to the longitudinal rolling mill 450 and rolled onto bars of 18–65 mm in diameter [12]. The resulting bars have a homogeneous globular metal structure.

In work [12] the technical characteristics of working stands of the RSR are presented. On the largest of them, RSR-500 uses a maximum diameter 450 billet and a minimum diameter of 120 mm is rolled in a roughing mill and 150 and 90 mm respectively in a finishing stand. The rough cage is reversible, several passages are made in it, in the finishing is one pass.

Thus, the disadvantage of RSR mills is the impossibility of rolling bars by continuous mode, the relatively complex design of equipment and the use of a large number of passes to produce bars with precise geometric dimensions and ultrafine-grained structure.

In the present work, a new combined method for creating a stable submicrocrystal structure is proposed: intense plastic deformation by the method of radial shear rolling with a combination of pressing (figure 1) [14].

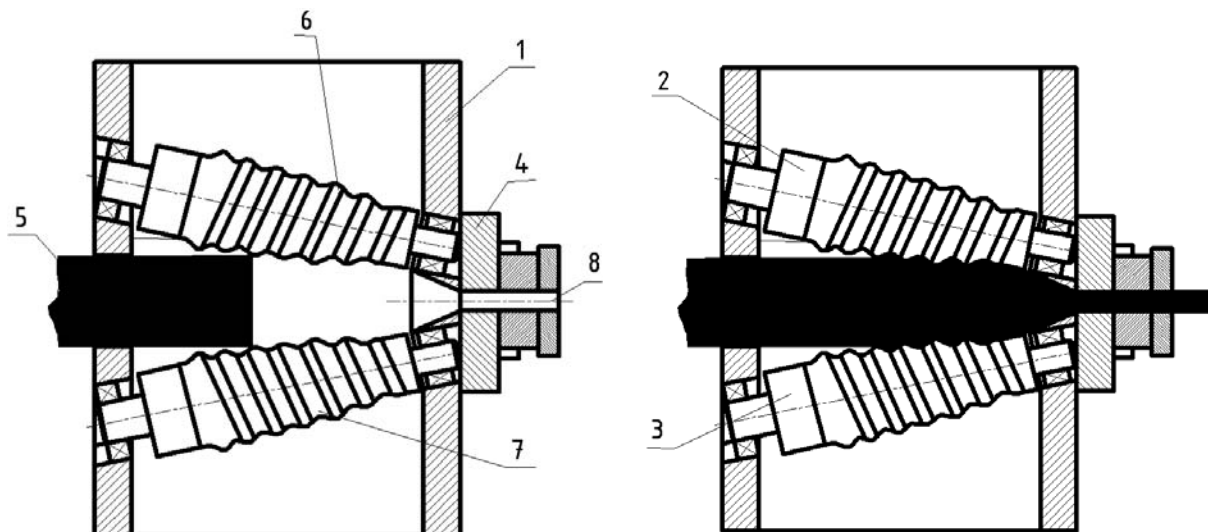


Figure 1 – Device for continuous pressing of rods: 1 - working stand, 2 and 3 - rolls; 4 - matrix; 5 - blank; 6 and 7 - are projection sand hollows of the rolls; 8 - aperture of a pressmatrix

The device for continuous pressing of rods comprises a main drive, a work stand, rolls rotating in one direction and a die. The rolls have smooth and undulating cone-shaped gripping and crimping portions, respectively, and calibrating cylindrical portions. The protrusions or hollows of wavy cone-like sections having the same width and corresponding height or depth are made along a helical line with an angle between the tangent to the helical line and a line passing through the point of tangency along the generatrix perpendicular to the base of the roll equal to 45° to 60° .

The rods are pressed in the following way. The workpiece is fed into the gap between the rolls, and is gradually deformed by the protrusions and valleys of corrugated cone-shaped areas. With this deformation, the workpiece rotationally translates in the direction of rolling and extruded through the aperture of a press matrix.

The use of this method and the pressing device ensures the rolling of the bars by a continuous mode, efficient grinding of the metal structure throughout the cross section of the workpiece due to the development of shear deformations and reduction of the rolling force. Effective grinding of the structure creates the conditions for obtaining high-quality products.

The purpose of the work is to study the kinematics of the deformation process and physical and mechanical phenomena in the process of continuous pressing of rods on a new plant and to obtain new scientific knowledge about the laws of the mechanics of rolling processes in screw-like rolls, depending on the specific features of the technologies used and the design of the tool, the development of techniques for searching for effective deformation modes, ensuring the production of quality rods.

Materials and the method of the experiment. When using a continuous cast piece for pressing bars or pipes on a new mill, the deformation must be carried out in the most efficient way so that a better structure of the metal can be obtained. For a new continuous pressing mill, a possible solution to this problem is to use helical rolls with rational geometric dimensions of the protrusions and valleys. The use of helical rolls with rational sizes of protrusions and valleys will intensively deform the metal of the workpiece within the required reduction of the workpiece. To determine the effective geometric dimensions of the protrusions and cavities of these rolls, the kinematics of the process of pressing the rods on a new mill was investigated.

It is known [15-17] that when the circumferential speed of the circular roll stock preparation is exceeded, rolling is carried out ahead of time, therefore, $\eta > 1$, and vice versa, when the circumferential speed of the peripheral speed rolls is exceeded, the rolling stock is lagged, therefore, $\eta < 1$.

It should be noted that when rolling ahead and behind, the flow of metal along the roll surface is carried out with sliding [16,17]. In this case, the slip, appearing when rolling in screw-like rolls ahead of time, does not affect the quality of the rods. However, when rolling in screw-like rolls with a lag in the bars, surface and internal defects may appear.

In general case the slip value can be determined by the speed coefficient during rolling in helical rolls in the absence of axial movement of the workpiece [15, 16]:

$$\eta_i = \frac{v_i}{v_i},$$

where v_i - circumferential velocity of the corresponding workpiece surfaces; v_i – circumferential roll speed corresponding to these surfaces.

It should be emphasized that the lower the speed coefficient, the greater the slip between the workpiece and the rolls [17].

The circumferential velocity of any point on the surface of a screw-like roll of diameter D_i can be determined from the formula [15, 16]:

$$v_i = \frac{\pi \cdot D_i \cdot n}{60}, \quad (1)$$

where n – rotational speed.

When investigating the kinematics of the radial shear rolling process, it is necessary to take into account the position of the helical rolls with respect to the rolling axis, i.e., the feed angle β . In this case, it is necessary to emphasize that the rotational-translational movement of the preform in the deformation region is divided into tangential and axial components [16-18]. The tangential components of the speed of the roll impart a rotational motion to the workpiece, the axial components are translational motion.

It has been established [16, 17] that the tangential and axial components of the slip more significantly affect the productivity of the process, the surface defects of the rods, and the intensity of the deformation effect of the rolls on the metal structure. Consequently, the tangential and axial components of the slip, respectively, influence the study of the structure of the peripheral and axial zones of the workpiece. With radial shear rolling, the tangential and axial velocity components are used to estimate the tangential and axial slip components. With the increase in these coefficients, the quality of the rod surface is increased. For the quantitative determination of the tangential and axial components of the slip in any section of the deformation center:

$$\eta_{ti} = \frac{v'_{ti}}{v_{ti}}, \quad (2)$$

$$\eta_{oi} = \frac{v'_{oi}}{v_{oi}}, \quad (3)$$

where η_{ti} , η_{oi} – coefficients of tangential and axial velocity components at different points of the workpiece surface; v'_{ti} , v'_{oi} and v_{ti} , v_{oi} – tangential and axial velocity components at various points of the surface of the workpiece and the roll.

When studying the kinematics of radial shear rolling, the velocity components at various points of the rod surface are usually determined by the following formulas [17]:

$$v_{ti} = v_i \cdot \cos \beta; \quad (4)$$

$$v_{oi} = v_i \cdot \sin \beta. \quad (5)$$

Using the law of constancy of seconds volumes [15], we express the axial rolling speed in the helical-shaped rolls in the examined cross-section through the bar speed at the exit from the deformation center.

The condition of the constancy of the seconds volumes for rolling in screw-like rolls can be written in the form:

$$v_{i,0}F_{i,0} = v_{i,1}F_{i,1} = v_{i,2}F_{i,2} = v_{i,3}F_{i,3} = \dots = v_{i,k}F_{i,k}, \quad (6)$$

where v_{ij} – axial flow velocities of the workpiece metal in the depressions or protrusions of the screw-like roll; F_{ij} – cross-sectional area of the workpiece, deformed in the corresponding sections of the screw-like roll and at the exit from the deformation center; $v_{ik}F_{ik}$ – the axial velocity and cross-sectional area of the workpiece at the exit from the deformation center, respectively.

From (6) we obtain the following formula:

$$v_{i,j+1} = (v_{ij}F_{ij})/F_{i,j+2} = v_{ij}\mu_{ij},$$

where μ_{ij} – coefficient of drawing the workpiece, deformable in the corresponding section of the screw-like roll.

It should be noted [15], that for any point lying on the surface of a helical-shaped roll and located in some section remote from one of the ends of the rolls, we can write the following equations (without gliding):

- circumferential speed of the roll:

$$v_{x6} = \omega_B \cdot R_x, \quad (7)$$

where R_x – the radius of the roll in the examined section; ω_B – angular velocity of the roll (without slip);

- circumferential rotational speed of the workpiece at the feed angle β :

$$v_{\tau3} = v_{x6} \cdot \cos \beta = \omega_B \cdot R_x \cdot \cos \beta; \quad (8)$$

- axial billet speed at feed angle β :

$$v_{03} = \omega_B R_x \cdot \sin \beta; \quad (9)$$

- the angular velocity of the billet in the considered section (without slip):

$$\omega_3 = \omega_B \cdot \cos \beta (R_x/r_x), \quad (10)$$

where r_x – radius of workpiece in the examined section.

In operation, the angle of elevation of the helical line β' of the screw-like roll was used as an additional parameter in determining the kinematic conditions of the deformation process in the mill:

$$\operatorname{tg} \beta' = \frac{S}{\pi \cdot d},$$

where S – pitch of helix; d – diameter of the workpiece.

The values of S and d were determined by specifying the dimensions of the screw line on the helical-shaped rolls. The speeds of the translational and rotational motion of the workpiece during the motion along the helical line were determined, using the relations (2) - (5) will be equal to:

$$v'_{oi} = v_i \cdot \eta_{\theta} \cdot \sin \beta' = \eta_{oi} v_{oi} = \eta_{oi} \cdot v_i \cdot \sin \beta; \quad (11)$$

$$v'_{ai} = v_i \cdot \eta_{\theta} \cdot \cos \beta' = \eta_{ai} v_{ai} = \eta_{ai} \cdot v_i \cdot \cos \beta, \quad (12)$$

where η_{θ} – coefficient of speed along the screw line of the helical roll.

From relations (11) and (12), we can establish the following relationship between the angles β and β' , which can later be used to determine the tangential velocity coefficient:

$$\operatorname{tg} \beta' = \frac{\eta_{oi}}{\eta_{ai}} \operatorname{tg} \beta \quad \text{or} \quad \eta_{ai} = \eta_{oi} \frac{\operatorname{tg} \beta}{\operatorname{tg} \beta'}. \quad (13)$$

In the method of continuous pressing, the extrusion of metal through the die aperture is effected by contact friction of the rotating screw-like rolls formed on the contact surface and by the deformable bar stock. In this connection, the value of the contact area of the workpiece with the tool largely determines the pressing pressure, the torque in the screw-like rolls and the power of the electric drive of the instal-

The points on the projecting roll surface have the following linear velocity:

$$v_{нв.і} = \omega_{і} \cdot R_{Hi} = \frac{R_{Hi}}{R_{oi}} v_i. \quad (16)$$

Slippage of the workpiece and the roll in the corresponding sections characterize the following difference in speeds:

$$\Delta V_i = v_{нв.і} - v_{вз.і} = \left(\frac{R_{Hi}}{R_{oi}} - \frac{r_{ei}}{r_{oi}} \right) \cdot v_i. \quad (17)$$

In this case, the relative rate of slippage in the hollows of the workpiece can be determined from formula:

$$g_i = \frac{\Delta V_i}{v_i} = \frac{R_{Hi}}{R_{oi}} - \frac{r_{ei}}{r_{oi}}. \quad (18)$$

On the basis of the analysis of the above formulas, we found that the slippage of blanks relative to the rolls depends on the position of the radii r_{oi} and R_{oi} of the circles, where the velocities are the same. The position of these circles depends on the shape of the hollows of the workpiece, the friction value, the temperature of the workpiece and rolls, and other factors. The locations of the circles were estimated using the coefficient.

$$k_i = \frac{h_i}{H_i}, \quad (19)$$

where h_i – the distance from the hollow of the workpiece to the point on the workpiece and the roll with identical speeds in the corresponding sections; H_i – the height of the workpiece protrusion in the corresponding sections.

In this case, the relative rate of slippage in the corresponding section can be determined from formula:

$$g_i = \frac{R_{Hi}}{R_{Hi} + k_i(R_{Hi} - R_{ei})} - \frac{r_{hi}}{r_{ei} + k_i(r_{hi} - r_{ei})}. \quad (20)$$

Results and discussion. In the study the calculation of the relative slip velocity in the valley of the rolls was performed. At the same time, the coefficient « k » was varied in the range of 0.3–0.8. Table and figure 3 present results of the calculations.

Analysis of the results shows that the relative slippage speed of the workpiece relative to the rolls depends on the coefficient k . With an increase of k , the relative speed of slip also increases. The calculated results showed that the lower the relative slip speed, the better the conditions for extruding the metal of the workpiece and the probability of cracks and peeling on the surface of the pressed bars decreases.

The results of calculating slip during rolling in helical rolls have shown that tangential and axial slip components are not very sensitive to the change in technological factors and mainly depend on the angle of rise of the helix line β' or the angle between the tangent to the helix and the line passing through the

Relative speed of sliding during rolling by screw-like rollers

k	r_{ei} , mm	r_{Hi} , mm	R_{ei} , mm	R_{Hi} , mm	r_{oi} , mm	R_{oi} , mm	g_i
0.3	15	24	71	80	17.7	73.7	0.476048
0.4	15	24	71	80	18.6	74.6	0.531868
0.5	15	24	71	80	19.5	75.5	0.580744
0.6	15	24	71	80	20.4	76.4	0.623652
0.7	15	24	71	80	21.3	77.3	0.661406
0.8	15	24	71	90	22.2	78.2	0.694684

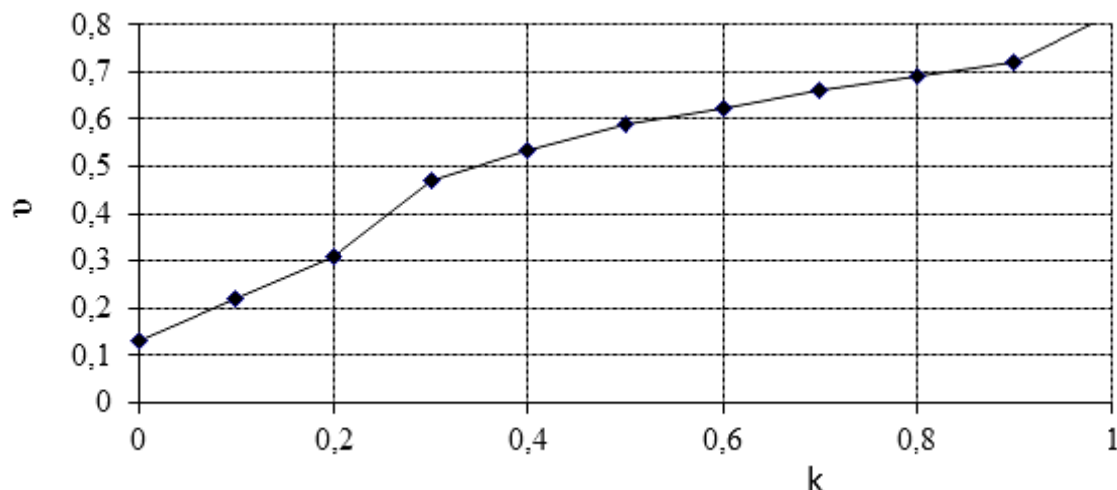


Figure 3 – Dependence of the relative slip velocity on the coefficient «k» when pressing by screw-like rollers

point of tangency along the generatrix perpendicular to the base felling. When the feed angle is not more than 1° and the helix line is not more than 45° , these component slides have equal values. As the angle of ascent decreases, the tangential component increases, and the axial component decreases. The reason for this distribution of tangential and axial slip components is the predominant metal flow along the valleys of the helical tool.

Various design and technological possibilities of the device for continuous pressing of rods are reflected in the kinematic conditions of deformation. Thus, for the considering device with screw-like rolls of tangential and axial velocity components at different points of the surface, the workpieces are equal at a feed angle of not more than 1° and lifting of the screw line 45° . As the angle of ascent decreases, the tangential velocity component increases, and the axial component decreases. At the same time, the circumferential velocities along the length of the deformation center are uneven.

Inequality of circumferential speeds during radial-shear rolling is caused by the influence of the design of the technological tool (helical-cone roller design). The ratio of the roll diameter D_i to the diameter d_i of the workpiece, and also the tangential slip along the length of the deformation center will be variable. Along with this, the screw movement of the metal in the deformation is realized with a constant angular velocity zone from the inlet to the exit from, if one does not take in to account the rolling with minor torsion of the rolled stock in screw-like rolls. In connection with this, further development of speed and slip between the helical rolls and the deformable workpiece can be used in the design of a radial-shear mill with screw-like rolls.

When the rods and tubes are pressed in the proposed device, rolling in a radial shear mill can be performed at large feed angles ($\beta > 20^\circ$) and large single compressions ($\varepsilon \geq 5\%$). Under such rolling conditions, the deformation center will be relatively short, and the axial movement of the metal in the feed step is large. Under such rolling circumstances, the tangential component of the frictional forces will not develop much, and the tangential component of the rolling speed will be smaller in value in comparison with the analogous value of the roll [2]. In connection with this, at the proposed radial-shear mill tangential sliding can be significant, in comparison with other known mills.

Analysis of the calculation results showed that when rolling in screw-like rolls, the most rational values of the tangential and axial velocity and slip components can be used for rolling with a feed angle of 15-20 degrees with the helix angle of the screw-like roll equal to 25 to 30 degrees.

When rolling the proposed radial-shear mill with screw-like rolls, the widest areas of the contact surface of the workpiece with rolls are the initial zones of the deformation center. Therefore, these zones are the dominant areas where high-speed deformation conditions develop in the process of metal reduction. In comparison with the rest of the contact surface, the tangential component of the frictional forces will develop more. These sections give the workpiece an angular velocity and the corresponding metal flow velocity, depending on the geometric dimensions of the helical tool. It can be noted that the speed of these sections over the entire rolling period will be constant, while the velocity and geometric conditions

of the metal flow will not coincide with other parts of the deformation center. For the rest of the pressed metal, the front zones of the deformation focus are the force and kinematic parameters. It should be noted that these sections adjust the velocity, geometric and other differences along the length of the deformation center to certain uniform boundary.

Thus, when rolling in a radial-shear mill with helical rolls, tangential sliding can be influenced by changing the feed angle and the angle of the helix. As the feed angle and the angle of elevation of the helical line increase, the tangential velocity coefficient increases. Changes in speed, boundary, dimensional and other conditions of rolling in screw-like rolls it is possible to adjust the coefficient of tangential velocity.

It should be noted that axial slip, in contrast to tangential sliding, has a more complex dependence on the design of the helical roll and technological factors. Axial slip varies in sufficiently wide intervals with a change in the feed angle and the angle of the helix and the geometric dimensions of the screw-like swath and the array of the device. From the above, the relationship of axial slip to rolling regimes, structural features of the radial-shear mill (cage) and, in general, to pressing technology, is not quite evident. On the basis of recent data, it can be noted that, unlike tangential slip, it is promising to find ways to control axial slip. Optimization of ways to control the values of axial slip can significantly improve the quantitative and qualitative performance of the equipment.

Axial slip occurs over the entire length of the deformation center, its magnitude increases in the direction of the matrix in accordance with the growing values of the extruded workpiece. It should be noted that for rolling slip is a natural process, without which it is impossible to carry out the pressing process. However, its presence, in the case of a significant delay in the speed of rotation of the workpiece from the speed of the rolls, can reduce the quality parameters of the rod surface and reduce the productivity of the installation. The results of the calculation showed that the smaller the height of the protrusion of the helical rolls, the greater the slip. However, in accordance with the law of constancy of seconds volumes, an increase in the rate of deformation in the initial sections of the workpiece will lead to an increase in the speed of axial displacement at the end of the deformation center and in the matrix.

The proposed design of the radial-shear mill allows wide variation of the value of the coefficients of tangential and axial velocities. When rolling on a radial-shear mill with screw-like rolls with a small angle of lift of the helical line, the tangential velocity coefficient is larger and the axial velocity coefficient is less than on the helical-shaped rolls with a large angle of the helix. It can be noted that when rolling in screw-like rolls with a large angle of elevation, the axial component of metal velocity predominates significantly in the kinematics of the process, rather than the tangential component, as in helical-shaped rolls with a small angle of ascent. Therefore, the process of pressing bars on the proposed device will be more dependent on factors that negatively affect the axial slip.

Analysis of the data obtained shows that tangential and axial slip are significantly influenced by factors that change the coefficient of friction at the contact surface of the metal with the tool. First of all, this refers to the roughness of the rolls and the presence of helical protrusions and depressions on their surfaces. With a smooth surface of the rolls, the axial velocity coefficient decreases, and in the presence of roughnesses or screw-like protrusions and depressions on the surface of the rolls, it increases and will be the greater, the larger the protrusions and depressions of the rolls.

According to the results of the research, it was established, in comparison with screw-like rolls, that rolls with smooth working surfaces can not provide high speed parameters of rolling. This is due to the fact that rolling in such rolls is carried out with a lag of the axial component of the speed of the rod from the speed of the rolls. The most noticeable effect on axial slip is the angle of the helix of the helical rolls. When the workpiece is deformed in screw-like rolls with a small angle of lifting of the helical line, the tangential component of the workpiece speed exceeds by two or more times the axial component of the speed of the rolls. On these rollers, with an angle of 45° , the tangential component approaches the axial component of the billet speed. When pressing rods using screw-like rolls, the productivity of the device also increases.

The presence of screw-shaped protrusions and valleys on the surface of the rolls does not allow the workpiece to rotate in the center of deformation and contributes to an increase in the pitch of the metal, and thus to its stretching by the feed step. It is known [17] that with a larger feed step, the single compressions increase and so do, the surface quality of the rod.

Large single compressions and metal movements along the helical line intensively deform the structure of the metal of the billet [19, 20]. Therefore, in comparison with the rollers, an even surface, the screw-like rolls at a high rolling speed will grind the metal structure well, both in the axial and peripheral zones of the rod. This is most important when pressing continuously cast billets, when the axial porosity of the rod can not be eliminated by the technological conditions of rolling due to an increase in the reduction of the metal. In this case, the use of screw-like rollers, which, due to the development of intense plastic deformation, provides a good study of the structure of the metal, an increase in the productivity of the installation and an improvement in product quality are achieved.

It is found that in the proposed tool the opposite arrangement of the projections or valleys of the rolls relative to each other also allows intensively deform the metal structure.

Conclusions.

1. Formulas have derived that allow to determine the slippage speed of the roll relative to the workpiece in the zones of the hollow of the workpiece.

2. An analysis of the results obtained showed that the low slippage speed of the workpiece relative to the roll takes place at small values of the coefficient k .

3. It is shown that when rolling in screw-like rolls, sliding occurs due to the discrepancy between the speed of the screw movement of the workpiece in the area of deformation of the rotation speed of the rolls.

4. It is established that the use of helical rolls with rational sizes of protrusions and valleys intensively deforms the metal of the workpiece within the required reduction of the workpiece.

5. Using the kinematics of the rolling process in a radial-shear mill, the dependence of the velocity of the metal exit from the deformation center on the technological deformation modes was established, and the more effective geometric dimensions of the protrusions and valleys of these rolls were defined.

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ҚҰРЫЛЫМЫ ЖАҢА ҮЗДІКСІЗ РАДИАЛЬДЫ-ЫҒЫСТЫРУ ОРНАҒЫНДА ШЫБЫҚ ПЕН ҚҰБЫРДЫ ИЛЕМДЕУ ПРОЦЕСІНІҢ КИНЕМАТИКАСЫН ЗЕРТТЕУ

Аннотация. Жаңа қондырғыда құбыр мен шыбықты баспақтап жасаған кезде үздіксіз дайындаманы қолдану, металл құрылымын жақсы өңдеуді қамтамасыз ететін нәтижелі тәсілмен деформация іске асыруды қажет етеді. Жаңа үздіксіз баспақтау қондырғысы үшін осындай мәселені шешудің жолы болып, шығынқылығы мен ойымдарында ұтымды өлшемдер бар бұрандалы пішінбіліктерді қолдану саналады. Шығынқылығы мен ойымдарында ұтымды өлшемдер бар бұрандалы пішінбіліктерді қолдан кезде, талап етілетін жаншу шегімен дайындаманың құрылымын қарқынды деформациялауға болады. Баспақтаудың кинематикасын зерттеген кезде шығынқылығы мен ойымдарында әртүрлі өлшемдер бар бұрандалы пішінбіліктерді қолданылды. Осы бұрандалы пішінбіліктерді қолдану, деформациялаудың технологиялық режимдеріне байланысты деформация ошағынан металдың шығу жылдамдығын және осы пішінбіліктердің шығынқылығы мен ойымдарының нәтижелі геометриялық өлшемдерін анықтауға мүмкіндік берді. Радиальды-ығысу орнағында илемдеген кезде металды деформациялау, дайындаманың пішінбілікке қатысты сырғанауымен іске асырылатындығы мақалада көрсетілді. Деформация ошағында дайындаманың бұрандалы қозғалысының жылдамдығы пішінбіліктің айналу жылдамдығымен сәйкес келмеуінен сырғанау пайда болатындығы жұмыста айтылды. Сырғудың мөлшерінен өнімнің сапасы және тағыда басқа өндірістің техника-экономикалық көрсеткіштерді тәуелді болатындығы мақалада анықталды. Радиальды-ығысу орнағында илемдеген кезде дайындаманың қозғалыс жылдамдығы пішінбілік жылдамдығынан кіші болатындығы жұмыста табылды. Жұмыста, дайындаманың ойым аймағында деформацияланатын дайындамаға қатысты пішінбіліктің сырғанау жылдамдығын анықтауға мүмкіндік беретін формулалар шығарылған.

Түйін сөздер: бұрандалы пішінбілік, ұяқалып, процестің кинематикасы, шыбық, дайындама, сырғанау, сырғанау мен жылдамдықтың тангенциалды және осьтік құраушылары.

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ИССЛЕДОВАНИЕ КИНЕМАТИКИ ПРОЦЕССА ПРОКАТКИ ПРУТКОВ И ТРУБ НА НЕПРЕРЫВНОМ РАДИАЛЬНО-СДВИГОВОМ СТАНЕ НОВОЙ КОНСТРУКЦИИ

Аннотация. При использовании непрерывнолитой заготовки для прессования прутков или труб на новой установке деформация должна осуществляться наиболее эффективным способом, чтобы можно было добиться лучшей проработки структуры металла. Для новой установки непрерывного прессования возможным решением такой задачи является использования винтообразных валков с рациональными геометрическими размерами выступов и впадин. Применение винтообразных валков с рациональными размерами

выступов и впадин, будет интенсивно деформировать металл заготовки в пределах требуемого обжатия заготовки. При исследовании кинематики прессования были использованы винтообразные валки с различными размерами выступов и впадины. Их использование позволило установить зависимость скорости выхода металла из очага деформации от технологических режимов деформирования в винтообразных валках и определить более эффективные геометрические размеры выступов и впадин данных валков. Показано, что деформация металла при прокатке на радиально-сдвиговом стане осуществляется со скольжением заготовки относительно валков. Скольжение возникает вследствие несоответствия скорости винтового перемещения заготовки в очаге деформации скорости вращения валков. От величины скольжения зависят качество металлопродукции, а также другие технико-экономические показатели производства. Установлено, что при прокатке на радиально-сдвиговом стане скорость перемещения заготовки меньше скорости валков. Аналитическим способом исследована кинематика процесса и выведены формулы, позволяющие определять скорость проскальзывания валка относительно заготовки в зонах впадины заготовки.

Ключевые слова: винтообразные валки, матрица, кинематика процесса, пруток, заготовка, скольжение, тангенциальные и осевые составляющие скольжения и скоростей.

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SIMULATION OF AUTOCATALYTIC SYSTEMS WITH CHEMICAL OSCILLATIONS WITH ALLOWING FOR REACTION STAGES REVERSIBILITY

Abstract. The paper deals with the simulation of two auto-catalytic system are remarkable for chemical oscillations in the case of some reactions stages reversibility. The methods for engineering calculations of kinetic characteristics and the residence time applying to the dynamical processes of mass transfer in cascades of chemical reactors for various model environments have been studied. The preferred model schemes for describing various systems with vibrational chemical reactions have been established. For bromate systems and systems with oxidation-reduction reactions containing metal ions, it is proposed to use a Belousov-Zhabotinsky model with irreversibility kinetic stages. For systems with organic reducing agents the suitable model is a model of the type of the Belousov-Zhabotinsky system, taking into account the reversibility of the reaction stages. For systems with enzymatic reactions and biochemical systems it is a model with autocatalysis or "Brusselator".

Grounded on the criteria equations for the known flow pattern in each of the cascade reactors, the following calculation sequence is recommended. First, the required average velocity of the phase flows in the section of the tubular reactor is calculated. Then, according to this average velocity, the diameter of the apparatus is calculated for a given consumption of the processed substance. Then, at a given degree of the conversion in the reactor and at a certain average flow rate, the required residence time in the reactor is calculated according to the offered method. If the length of the reactor is specified for design reasons, the calculated residence time can be used to determine the required number of reactors in the cascade. If the length of the reactor is not specified, it can be selected by iterative calculation according to the described procedure to ensure a given degree of the conversion.

Key words: modelling of chemical reactors, recycle, two-stage reactor, Belousov-Zhabotinsky reaction, "brusselator" system.

1. Introduction. Description of concentration wave fronts and oscillatory processes in reaction-diffusion systems is an extremely topical scientific problem, which also has great practical significance. Many known methods for modeling chemical reactors completely ignore the possibility of forming wave fronts in physicochemical systems. At the same time, the intensity of the processes of heat and mass transfer in the presence of moving frontal sections changes significantly and cannot be correctly calculated without accounting these phenomena.

In this paper, we consider some fairly simple models that make it possible to describe the general characteristic features of propagation of wave fronts in reaction-diffusion systems.

2. Analysis of model systems.

2.1. Belousov-Zhabotinsky reaction. The Belousov-Zhabotinsky (BZ) reaction is the process of oxidation of malonic or bromomalonic acid by bromate ions in an acidic medium, catalyzed by ions of

transition metals (cerium, iron). Under different conditions in a flow-type reactor with mixing, one can observe long-term self-oscillations, several stationary states and periodic regimes, chaotic behavior, and for distributed systems the propagating concentration waves of oxidation and restoration can be occurred. It is well-known that this reaction serves as a model for studying nonlinear phenomena in chemical kinetics. Field, Kőrsh and Noyes developed a detailed scheme for the mechanism of this reaction, consisting of eleven basic reactions between twelve components. Later, Field and Noyes proposed a simplified scheme, consisting of five main stages.

In our analysis, we will use the reduced scheme of Field-Noyes. Let us denote the components of the reaction as follows: $A = BrO_3^-$, $B = BrMA$, $P = HOBr$, $X = HbrO_2$, $Y = Br^-$, $Z = Ce^{4+}$. The appropriate scheme of the reaction reads



As a rule, the known papers in mathematical models of the kinetics of individual stages do not take into account the reversibility of the reactions. However, under real conditions, many reaction stages of the Belousov-Zhabotinsky type can be reversible [1, 2]. This circumstance substantially complicates the kinetic equations and their analysis.

Further we consider the case of reversibility of the fourth stage of the reaction, i.e. decomposition of the product X .

Then the scheme of chemical equations is supplemented by the equation:



Let us assume that the components A and B are in a large excess and that their concentrations do not change noticeable on time. For the convenience of numerical experiments and the data interpretation, all reaction rate constants k_i , transfer coefficients D_{ij} and time t were dimensioned with respect to the relaxation time of the first stage $\tau_p = 1/k_1$, i.e. the dimensionless characteristics were determined according to the scheme:

$$t \rightarrow tk_1, \quad k_i \rightarrow k_i/k_1, \quad D_{ij} \rightarrow D_{ij} k_1. \quad (7)$$

Then the time variation of the concentrations of the remaining components in a closed system can be described using the equations:

$$\begin{aligned} \frac{dX}{dt} &= k_1 AY - k_2 XY + k_3 AX - 2k_4 X^2 + 2k_6 AP, \\ \frac{dY}{dt} &= -k_1 AY - k_2 XY + hk_5 BZ, \\ \frac{dZ}{dt} &= 2k_3 AX - k_5 BZ, \\ \frac{dP}{dt} &= k_1 AY + 2k_2 XY + k_4 X^2 - 2k_6 AP \end{aligned} \quad (8)$$

The above balance equations do not take into account the input and output streams. Thus, it is assumed that only the Y (Br^-) component is fed into the flow-type reactor with mixing, and the reaction components X ($HbrO_2$) and Z (Ce^{4+}) are intermediate products arising during the reaction. The analytical solution of the obtained system (8) is impossible. Therefore, we carried out a numerical study using the Runge-Kutta method. For the numerical experiment, the following sets of control parameters were selected:

The first series of experiments:

$$k_1 = 1, k_2 = 1, k_3 = 1, k_4 = 1, k_5 = 1, k_6 = 1/2,$$

The second series of experiments:

$$k_1 = 1, k_2 = 1, k_3 = 1, k_4 = 1, k_5 = 1/2, k_6 = 1/2.$$

Some results of the experiments are depicted in figures 1, 2.

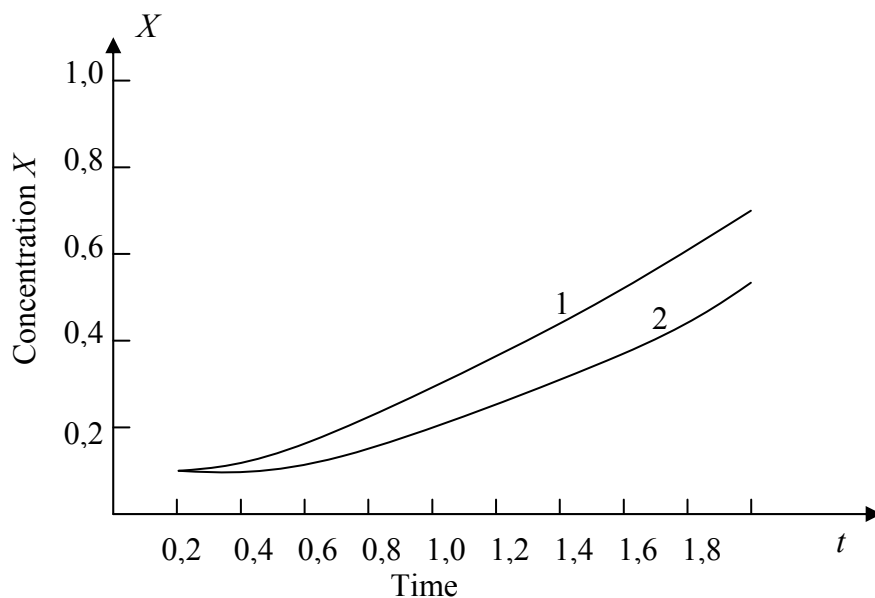


Figure 1 – The change in the concentration of intermediate reagent X in the reactor of flow type with mixing at $A = 1$; $B = 1,4$: 1 – reversible reaction; 2 – irreversible reaction

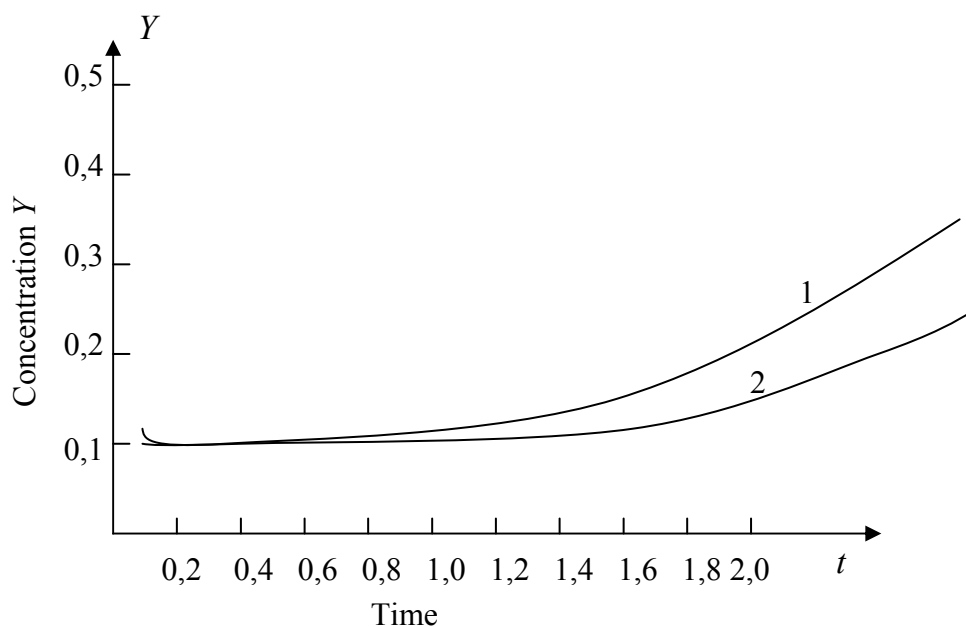


Figure 2 – The change in the concentration of intermediate reagent Y in the reactor of flow type with mixing at $A = 1$; $B = 1,4$: 1 – reversible reaction; 2 – irreversible reaction

Numerical investigation has shown that taking into account the reversibility of the reaction stages can be important in the simulation of the considered process. In particular, it can be seen that the reversibility of the fourth stage alters the yield of the product Z by 25%.

2.2. "Brusselator" system with accounting two reaction stages reversibility. When modeling nonlinear physical and chemical systems, a system of nonlinear kinetic equations of the "brusselator" type is often used. This system simulates many real complex multi-stage reactions occurring in industrial reactors.

In accordance with this model, the starting reagents A and B are converted to reaction products D and E with the appearance of intermediates X and Y , and the kinetics of the reaction can be described by the following system of equations:



In the presented form, the system of kinetic equations is rather complicated for analytical investigation. The nonlinearity of the kinetic equations leads to a multiplicity of stationary states that differ from one another in the type of stability. In addition, under real conditions, the individual reaction stages can be reversible, which stipulates the formation of feedbacks and also complicates the theoretical analysis of the dynamics of the process.

At the same time, as it has already been shown, the question of reversibility is extremely important and requires special research.

In our work, a numerical study of the solutions of the system of kinetic equations describing the dynamics of the process (9) has been carried out, taking into account the reversibility of the two reaction stages, namely corresponding to the decomposition of the substance A entering the reactor and the product of the reaction between X and the other substance B entering the reactor inlet.

In this case the system of chemical equations is supplemented as follows:



With a constant concentration of the initial substances A and B , and the given set of reaction rate constants, we obtain the following mathematical model of the process kinetics in the reactor:

$$\begin{aligned} \frac{dX}{dt} &= k_1 A - k_2 BX + k_5 YD + k_3 X^2 Y - k_4 X + k_6 E, \\ \frac{dY}{dt} &= k_2 BX - k_5 YD - k_3 X^2 Y, \\ \frac{dD}{dt} &= k_2 BX - k_5 YD, \\ \frac{dE}{dt} &= k_4 X - k_6 E. \end{aligned} \quad (11)$$

Numerical investigation of the system (12) is carried out with the following values of reaction rate constants:

$$k_1 = 1, k_2 = 1, k_3 = 1, k_4 = 1, k_5 = 1/2, k_6 = 1/2.$$

Some results of the numerical experiment are presented in figures 3, 4.

An analysis of the results of a numerical study shows that the reversibility of the individual stages of the reaction can lead to a significant change in the parameters of the stationary state. This circumstance can radically change the type of stability of a stationary point. Moreover, the influence of the irreversibility factor increases with time and it is more significant not in the initial transition period, but in a period process stabilization corresponding to a completely irreversible system. As the rate constant of the reverse reaction increases, the influence of the reversibility factor increases too.

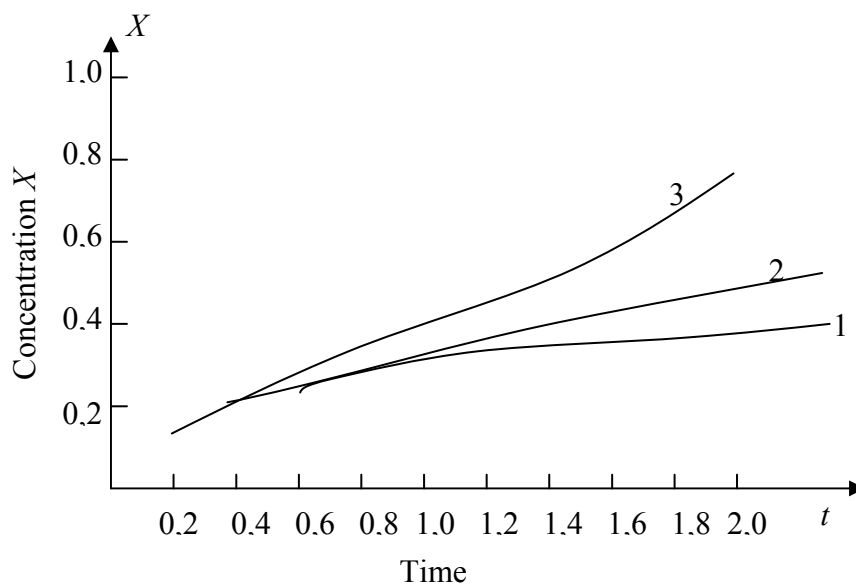


Figure 3 – The change in the concentration of intermediate reagent X in the reactor of flow type with mixing for "brusselator" at $A = 1$; $B = 1,4$:
1 – inversible reaction; 2 – reversibility of the one reaction stage; 3 – reversibility of two reaction stages

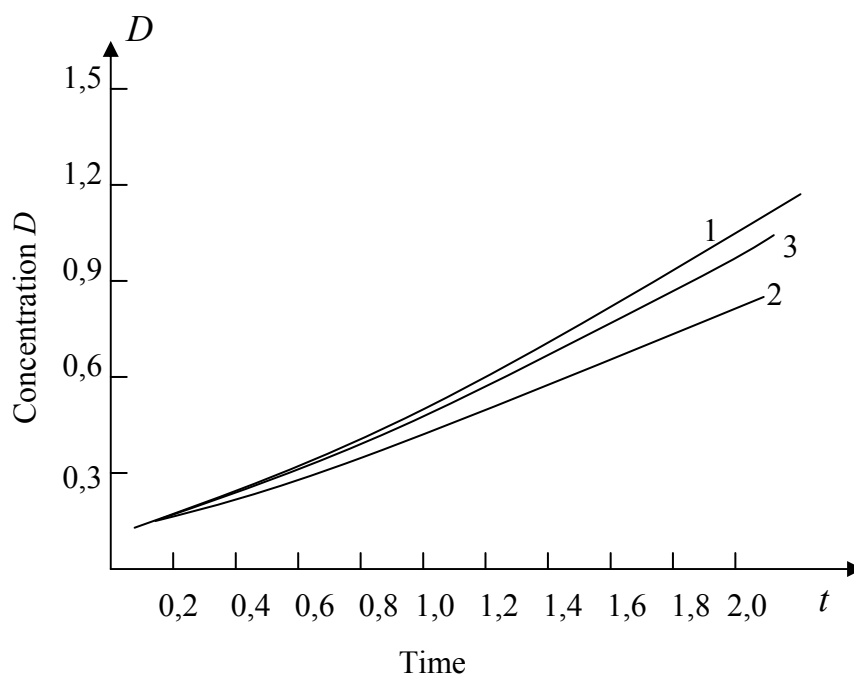


Figure 4 – The change in the concentration of intermediate reagent D in the reactor of flow type with mixing for "brusselator" at $A = 1$; $B = 1,4$:
1 – inversible reaction; 2 – reversibility of the one reaction stage; 3 – reversibility of two reaction stages

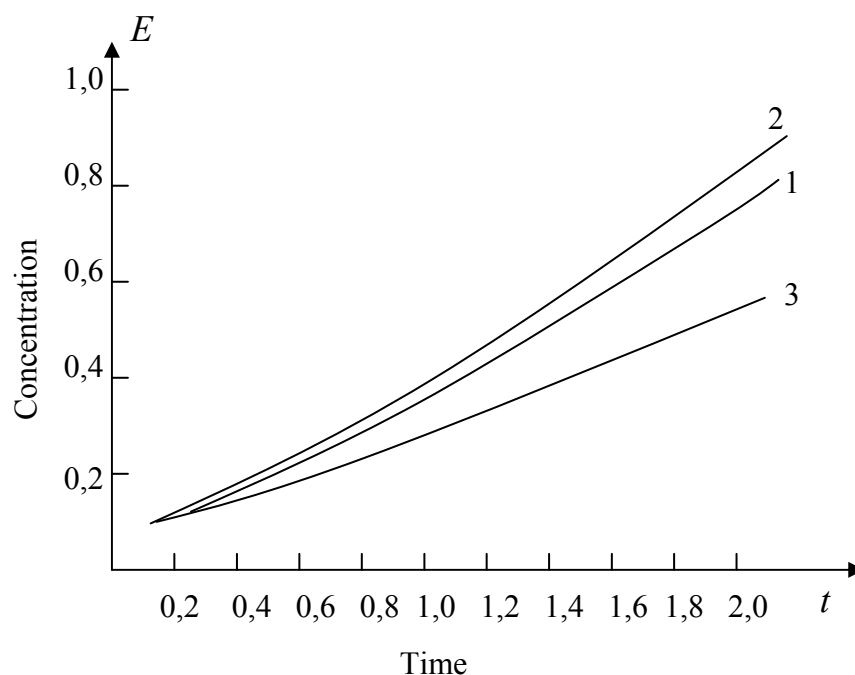


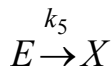
Figure 5 – The change in the concentration of intermediate reagent E in the reactor of flow type with mixing for "brusselator" at $A = 1$; $B = 1,4$:
1 – irreversible reaction; 2 – reversibility of the one reaction stage; 3 – reversibility of two reaction stages

Further studies should be aimed at assessing the influence of the flow structure in the reactor and of the reversibility of various stages of the "brusselator type" reactions on the kinetics of the process.

3. Methods of calculation and discussion of the results.

3.1. Simulation of a two-cascade reactor with a partially reversible reaction in the "brusselator" system. Simulation of chemical reactors for the implementation of complex physicochemical processes requires taking into account the specific features of the kinetics of chemical transformations and the conditions for the heat and mass transfer. at the same time, the correct choice of the model system allows often for greater generality of the conclusions and the possibility to create methods for calculating a wide class of systems and reactors.

In this section, a mathematical model of two cascade reactors with a brusselator type reaction is constructed, taking into account the partial decomposition of the final product, that is, the reversibility of the last stage of the reaction:



The numerical investigation of the developed mathematical model is carried out. The concentrations of the input substances A and B are assumed to be constant (that is, the assumption of their excess is assumed), and the reaction rate constants are assumed to be equal to the following values: $k_1 = 1$, $k_2 = 1$, $k_3 = 1$, $k_4 = 1$, $k_5 = 1/2$.

The structure of the streams is represented as a cascade of two fully agitated reactors with mutual mass transfer (figure 8).

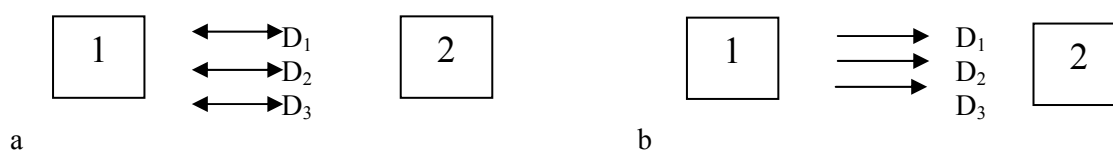


Figure 6 – Cascade of two fully agitated reactors with mutual mass transfer:

a) – cascade with recycles; b) – stream in one direction

The corresponding systems of kinetic equations, provided that the resulting inflow and outflow of intermediate products are zero, and the concentrations of incoming components are kept constant, have the form:

$$\begin{aligned}
 \frac{dX_1}{dt} &= k_1 A_1 - k_2 B X_1 - k_4 X_1 + k_3 X_1^2 Y_1 + k_5 E_1 + D_{11}(X_2 - X_1), \\
 \frac{dY_1}{dt} &= k_2 B X_1 - k_3 X_1^2 Y_1 + D_{21}(Y_2 - Y_1), \quad \frac{dE_1}{dt} = k_4 X_1 - k_5 E_1 + D_{31}(E_2 - E_1), \\
 \frac{dX_2}{dt} &= k_1 A_2 - k_2 B X_2 - k_4 X_2 + k_3 X_2^2 Y_2 + k_5 E_2 + D_{12}(X_1 - X_2), \quad (12) \\
 \frac{dY_2}{dt} &= k_2 B X_2 - k_3 X_2^2 Y_2 + D_{22}(Y_1 - Y_2), \quad \frac{dE_2}{dt} = k_4 X_2 - k_5 E_2 + D_{32}(E_1 - E_2),
 \end{aligned}$$

Two reactors with mutual mass transfer can also be considered in the case of a stream flowing in only one direction from the reactor 1 to the reactor 2.

Then the system of equations (12) takes the form:

$$\begin{aligned}
 \frac{dX_1}{dt} &= k_1 A_1 - k_2 B X_1 - k_4 X_1 + k_3 X_1^2 Y_1 + k_5 E_1, \\
 \frac{dY_1}{dt} &= k_2 B X_1 - k_3 X_1^2 Y_1, \\
 \frac{dE_1}{dt} &= k_4 X_1 - k_5 E_1, \\
 \frac{dX_2}{dt} &= k_1 A_2 - k_2 B X_2 - k_4 X_2 + k_3 X_2^2 Y_2 + k_5 E_2 + D_{12}(X_1 - X_2), \\
 \frac{dY_2}{dt} &= k_2 B X_2 - k_3 X_2^2 Y_2 + D_{22}(Y_1 - Y_2), \\
 \frac{dE_2}{dt} &= k_4 X_2 - k_5 E_2 + D_{32}(E_1 - E_2),
 \end{aligned} \quad (13)$$

The analytical solution of the obtained systems (12) and (13) is impossible. Therefore, we conducted a numerical study. The reaction rate constants in the numerical experiment are assumed to be equal to the following values: $A1 = 1$; $A2 = 1.2$; $D11 = 0.1$; $D21 = 0.1$; $D31 = 0.1$; $D12 = 0.05$; $D22 = 0.05$; $D32 = 0.05$. The initial conditions can be taken for $t = 0$ $X1 = X2 = Y1 = Y2 = E1 = E2 = 0$. Some results of the numerical experiment are shown in figures 9–12.

The analysis of the data of a numerical experiment showed that the concentration of the intermediate active complex Y arising during the reaction reaches a maximum value after the start of the process, and then decreases, trending to a stable value.

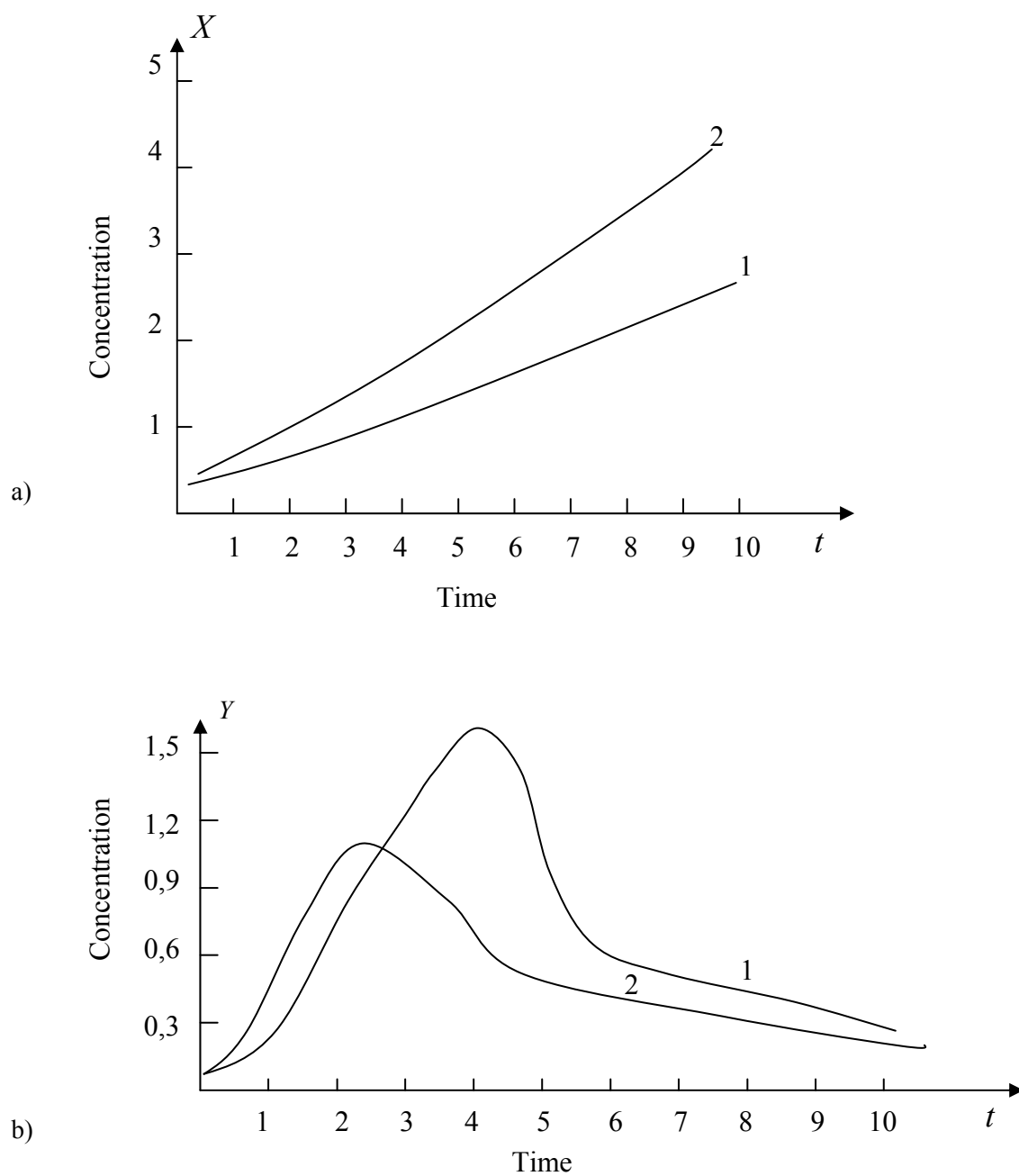


Figure 7 – The change in the concentration of intermediate reagents X - a) and Y - b) in the cascade with recycle ("brusselator");

1 – the first reactor of the cascade; 2 – the second reactor of the cascade

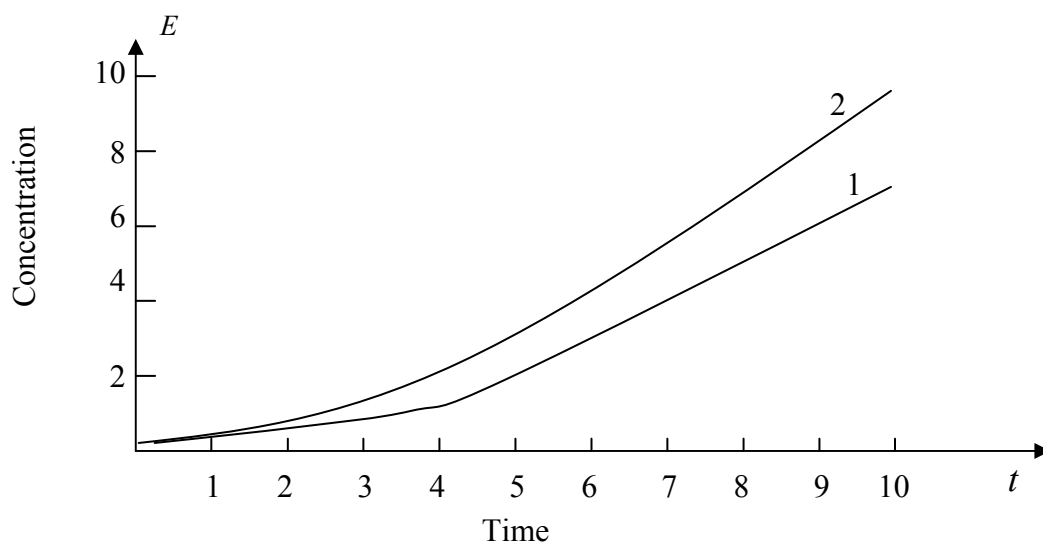


Figure 8 – The change in the concentration of the end-product E in the cascade reactors with recycle ("brusselator"): 1 – the first reactor of the cascade; 2 – the second reactor of the cascade

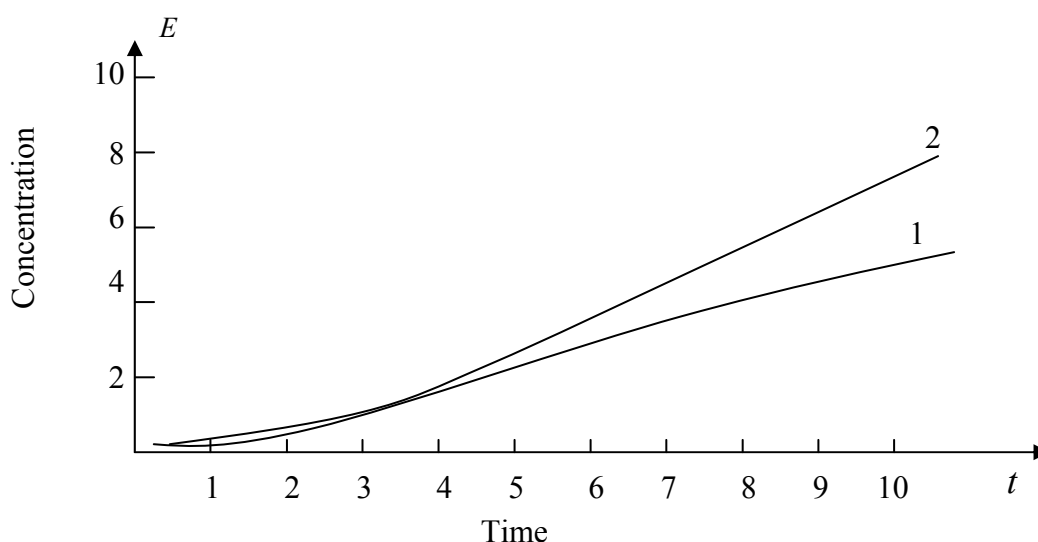


Figure 9 – The change in the concentration of the end-product E in the cascade reactors without recycle ("brusselator")

The dependencies of the concentration of the intermediate complex X and the final product E on time are monotonic and reach stable values after a long time. The partial decomposition of the final product in the case when the rate constant of the decomposition reaction is comparable with the constants of the other stages, can remove the oscillatory character of the concentrations of intermediate complexes characteristic to the "brusselator". A significant effect of recycling on the nature of the process was not found in the investigated range of parameters.

The results of the study show the importance of taking into account the reversibility of individual reaction stages in the analysis of the kinetics in cascades of chemical reactors.

3.2. Stages of modeling and calculation of cascades of through-flowing reactors. To obtain an approximate estimation of the necessary residence time of the reactants in the cascade of reactors operating in the dynamic regimes of the traveling concentration waves, we consider separately the cases of a model medium of the "Brusselator" type and a medium with three stationary states (to this case, a reaction-diffusion medium with the Belousov-Zhabotinsky system can be attributed).

For a model medium of the "Brusselator type", we use the expressions from [8] to characterize the concentration profile, since the numerical experiment confirms the qualitative agreement with such an approximation.

In estimating the minimum residence time, we take the waves front velocity to be equal to the critical propagation velocity of the traveling wave.

Then we can rewrite the mentioned expression in the form:

$$C \approx 3 \left(C_{01} - \frac{R_2}{R_1} \right) \text{sch}^2 \left(\sqrt{\frac{(C_{01}R_1 - R_2)}{4D}} (L - v^* \tau) \right), \quad (14)$$

where L – a reactor length; τ – residence time.

We introduce the degree of conversion in the reactor as the main initial criterion for the calculation

$$\eta = \frac{C_0 - C}{C_0}. \quad (15)$$

Then (14) can be rewrite as follows:

$$\eta = 1 - \frac{3}{C_0} \left(C_{01} - \frac{R_2}{R_1} \right) \text{sch}^2 \left(\sqrt{\frac{(C_{01}R_1 - R_2)}{4D}} (L - v^* \tau) \right). \quad (16)$$

Let us denote $S = \sqrt{\frac{(C_{01}R_1 - R_2)}{4D}} (L - v^* \tau)$ and rewrite (16) in the form:

$$\eta = 1 - \frac{3}{C_0} \left(C_{01} - \frac{R_2}{R_1} \right) \text{sch}^2(S) = 1 - \frac{3}{C_0} \left[\frac{2}{\exp(S) + \exp(-S)} \right]^2. \quad (17)$$

We now use the expansion of exponents in a Taylor series, restricting ourselves to a minimum estimation of the residence time by two terms of the expansion:

$$\exp(S) \approx 1 + S + \frac{S^2}{2}; \quad \exp(-S) \approx 1 - S + \frac{S^2}{2}.$$

After rearrangements the following expression linking the residence time in the reactor, its length and the given conversion can be obtained:

$$\tau \approx \left[L - \sqrt{\frac{D_{ef}}{C_0 k_1} \left(\frac{3}{\eta} - \frac{1}{g} \right)} \right] / v^*. \quad (18)$$

Here

$$g = \frac{R_2}{R_1 C_0}. \quad (19)$$

For a medium with three stationary states (or a reaction-diffusion medium with the Belousov-Zhabotinsky system), we use expression from [8] to estimate the necessary residence time of reagents in a dynamic mode, since numerical experiments and published data confirm the validity of such an approximation.

$$C = \frac{C_{01} + C_{02}}{2} + \frac{C_{01} - C_{02}}{2} \text{th} \left(-\frac{1}{2} \left[\sqrt{\frac{k}{2D_{ef}}} (C_{01} - C_{02}) (L - v^* t) + C(0) \right] \right). \quad (20)$$

Let us use the notation

$$S = -\frac{1}{2} \left[\sqrt{\frac{k}{2D_{ef}}} (C_{01} - C_{02}) (L - v^* t) + C(0) \right]. \quad (21)$$

Thus from the expression for hyperbolic tangent

$$\text{th}(S) = \frac{\exp(S) - \exp(-S)}{\exp(S) + \exp(-S)}. \quad (22)$$

and Taylor expansions we can offer the following calculation scheme for optimal residence time:

A) Calculation of the subsidiary parameter **M**:

$$\mathbf{M} = C_{01} + C_{02} - 2C_0(1 - \eta). \quad (23)$$

B) Calculation of the subsidiary parameter **N** from the equation:

$$\mathbf{M} \cdot \mathbf{N}^2 + \mathbf{N}(C_{01} - C_{02}) + 2\mathbf{M} = 0. \quad (24)$$

C) Obtaining the estimation of the residence time:

$$\tau \approx \frac{C_0 + 2\mathbf{N}}{\alpha(C_{01} - C_{02})v^*} + \frac{L}{v^*}. \quad (25)$$

For the cascade of reactors, the estimations of the necessary residence time in an individual diffusion cell for different systems with a lot of stationary states and self-oscillating dynamic regimes should be used in the general system of design equations, taking into account the known structure of the flows.

Conclusions. Thus, the following general scheme of simulation and calculation is proposed:

1. Choice of the model kinetic scheme.

For bromate systems and systems with oxidation-reduction reactions containing metal ions, the optimal model is the BZ type model.

For systems with organic reducing agents, the optimal model is the model of Belousov-Zhabotinsky type with allowing for the reversibility of the reaction stages.

For systems with enzymatic reactions and biochemical systems the optimal model is the model with autocatalysis or "Brusselator" type.

2. Modelling the flows structure and defining the number of cascades.

3. Analysis of the multiplicity of stationary states for each cascade.

4. Investigation of the stability of stationary states.

5. Analysis of conditions for the formation of wave regimes of mass transfer and estimation of the parameters of wave fronts.

6. Calculation of the conversions of reagents.

The calculation sequence is the same.

On the base of the criterial equations for the known flow structure in each of the cascade reactors, the required average flow rate of the phases in the section of the tubular reactor is calculated.

Then, at this average speed, the diameter of the apparatus can be determined for a given flow rate of the processed substance.

Then, at a given degree of conversion in the reactor and a certain average flow rate, the required residence time in the reactor is calculated according to the procedure described above.

If the length of the reactor is specified for design reasons or it is also specified, the calculated residence time is used to determine the required number of reactors in the cascade.

If the length of the reactor is not specified, it can be selected by iterative calculation according to the described procedure to ensure a given degree of conversion.

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РЕАКЦИЯНЫҢ ҚАЙТЫМЫН ЕСЕПКЕ АЛА ОТЫРЫП ХИМИЯЛЫҚ ОСЦИЛЛЯЦИЯМЕН АВТОКАТАЛИТИКАЛЫҚ ЖҮЙЕЛЕРДІ МОДЕЛЬДЕУ

Аннотация. Мақалада химиялық осцилляциямен екі автокаталитикалық жүйені модельдеу қарастырылады: Белоусов–Жаботинский реакциясы және «брюсселятор» жүйесі, қайтымды реакция жағдайында. Түрлі моделдік орта үшін химиялық реакторлар каскадында және келу уақытын анықтау әдістемесі жалпы тасымалдаудың динамикалық процестері үшін кинетикалық сипаттамалардың инженерлік есептеу сұлбасы ұсынылған. Тербелмелі химиялық реакциямен түрлі жүйелерді сипаттау үшін қолайлы модельдің сұлбасы орнатылған. Ионды металы бар броматты жүйе және тотығу – қалпына келтіру реакциясы үшін БЖ түріндегі модельді қолдану ұсынылады. Органикалық қалпына келтіру жүйесі үшін – Белоусов–Жаботинский жүйесі түріндегі модель реакциялардың қайтымды сатыларын есепке алу. Ферментативті реакциялар мен биохимиялық жүйелері үшін – автокатализ немесе «Брюсселятор» мен модель.

Әр каскад реакторынан белгілі ағындар құрылымында критериальды тендеуден шығатыны келесі есептеу тізбегі. Бастапқыда құбырлы реактордың қимасындағы фазалар ағындарының қажетті орташа жылдамдығы есептеледі. Ары қарай осы орташа жылдамдықпен өңделетін субстанциялардың берілген шығыны бойынша аппарат диаметрі анықталады. Сонан соң берілген айналдыру дәрежесінде реакторды және жоғарыда аталған әдіс бойынша ағындардың анықталған орташа жылдамдығымен реактордағы қажетті келу уақыты есептеледі. Егер реактор ұзындығы конструктивті тұрғыдан берілсе, онда есептелген келу уақыты каскадтағы реакторлардың қажетті санын анықтау үшін қолданылады. Егер реактор ұзындығы берілмесе, онда ол берілген айналдыру дәрежесін қамтамасыз ету үшін сипатталған әдіс бойынша итерациялық есептеу жолымен таңдала алады.

Түйін сөздер: химиялық реакторларды модельдеу, екі сатылы реактор, Белоусов–Жаботинский реакциясы, «Брюсселятор» жүйесі.

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МОДЕЛИРОВАНИЕ АВТОКАТАЛИТИЧЕСКИХ СИСТЕМ С ХИМИЧЕСКИМИ ОСЦИЛЛЯЦИЯМИ С УЧЕТОМ ОБРАТИМОСТИ РЕАКЦИЙ

Аннотация. В статье рассматривается моделирование двух автокаталитических систем с химическими осцилляциями: реакция Белоусова–Жаботинского и система «брюсселятор» в случае обратимости реакций. Предложена схема инженерного расчета кинетических характеристик для динамических процессов массопереноса в каскадах химических реакторов и методика определения времени пребывания для различных модельных сред. Установлены предпочтительные модельные схемы для описания различных систем с колебательными химическими реакциями. Для броматных систем и систем с окислительно-восстановительными реакциями, содержащих ионы металлов, предлагается использовать модель типа БЖ. Для систем с органическими восстановителями – модель типа системы Белоусова–Жаботинского с учетом обратимости стадий реакций. Для систем с ферментативными реакциями и биохимических систем – модель с автокатализом или «Брюсселятор».

Исходя из критериальных уравнений при известной структуре потоков в каждом из реакторов каскада рекомендована следующая последовательность расчета. Вначале рассчитывается необходимая средняя скорость потоков фаз в сечении трубчатого реактора. Далее по этой средней скорости при заданном расходе

обрабатываемой субстанции определяется диаметр аппарата. Затем при заданной степени превращения в реакторе и определенной средней скорости потоков по описанной выше методике рассчитывается необходимое время пребывания в реакторе. Если длина реактора задается из конструктивных соображений, то рассчитанное время пребывания используется для определения необходимого числа реакторов в каскаде. Если же длина реактора не задана, то она может подбираться путем итерационного расчета по описанной методике для обеспечения заданной степени превращения.

Ключевые слова: моделирование химических реакторов, двухкаскадный реактор, реакция Белоусова–Жаботинского, система «брюсселятор».

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METHODS OF DISTRIBUTION OF DATA PROCESSING SYSTEMS TO THE NODES OF COMPUTING SYSTEMS

Abstract. A new class of discrete programming problems - block-symmetric problems is considered in this paper. General formulation and solution of block-symmetric problems of discrete programming are presented.

The features and properties of this class of problems are given. The formulation and solution of the problem of optimal allocation of program modules and database arrays to the nodes of computing systems of a given topology is considered.

Key words: model, method, algorithm, variable, block-symmetric problem, discrete programming.

Introduction. Large-scale development and implementation of information systems is carried out on the basis of computer networks on which data processing systems are operated.

By data processing systems we mean a set of application software for the implementation of various applications and associated database arrays.

With the increase in the number of applications, there arises a problem of the optimal allocation of the set of application software and database arrays to the nodes of the computing system of a given topology. This allocation problem also arises when a node of computing system and communication channels between nodes fail.

The existing optimization methods for solving this problem are not effective because of the small dimensionality of the problems being solved.

Therefore, there is a need to develop new productions, models and methods for solving these problems.

One of the approaches is the application of a new class of problems of setting and solving discrete programming problems for block-symmetric problems.

1. General statement of block-symmetric discrete programming problems. The problems of discrete programming are widely used in the formulation and solution of applied scientific and technical problems.

At the same time, this section of applied mathematics is conservative for a number of reasons. The main ones being the exponential computational complexity of traditional statements of discrete programming problems, the difficulty of constructing effective algorithms for solving problems, the inadequacy of traditional problem statements for new applied problems that arise in various fields of science and technology, in particular in the field of information technology.

Therefore, one of the research areas is the development of new classes of discrete programming problems that most fully meet the modern requirements of setting and solving applied problems.

A number of applied problems: the design of modular software and database arrays of information systems, the distribution of program modules and database arrays to the nodes of computing networks, the choice of projects in conditions of limited resources can be formulated in the form of a new class of tasks -

block-symmetric models of discrete programming. Unlike traditional models, models of this class make it possible to formulate problems with several types of variables of different nature, to decompose complex problems into blocks with a single objective function and to develop efficient algorithms having polynomial computational complexity [1,2].

Let us consider the general formulation and solution of block-symmetric problems of discrete programming.

Problem statement. Let the set of objects $A = \{a_i; i = \overline{1, I}\}$ and the set of objects $B = \{b_j; j = \overline{1, J}\}$ are given with elements of different types, and also the interrelations between the elements of these sets that are defined by matrix $W = \|\omega_{ij}\|, i = \overline{1, I}, j = \overline{1, J}$, whose elements are integer or Boolean. It is necessary to combine the elements of the set A into disjoint subsets $A_n, n = \overline{1, N}$, and the elements of the subset B to disjoint subsets $B_m, m = \overline{1, M}$, in such a way as to deliver the extreme of the objective function $F(A_n, B_m)$.

For a formal formulation of the problem, we introduce the following variables. Let $X = \|x_{in}\|, i = \overline{1, I}; n = \overline{1, N}$ be a Boolean matrix, where $x_{in} = 1$ if the i -th element is distributed to the n -th group and $x_{in} = 0$ otherwise. Similarly, $Y = \|y_{jm}\|, j = \overline{1, J}; m = \overline{1, M}$, where $y_{jm} = 1$, if the j -th element is distributed to the m -th group and $y_{jm} = 0$ otherwise. In the general case of a matrix, the variables X and Y can be integer.

We define on the set $A \times B$ the function $F(X, Y)$, depending on the distribution of the elements of the sets A and B in the subsets A_n and B_m . Correspondingly, on the set of the A-function $\varphi_k(X), k = \overline{1, K}$, and on the set B - the functions $\psi_s(Y), s = \overline{1, S}$, defining constraints on the sets A and B.

The block-symmetric discrete programming problem is formulated as follows:

$$F(X, Y) \rightarrow \text{extr} \quad (1.1)$$

under constraints

$$\varphi_k(X) \leq \varphi_{ko}, k = \overline{1, K} \quad (1.2)$$

$$\psi_s(Y) \leq \psi_{so}, s = \overline{1, S} \quad (1.3)$$

In the set of constraints (1.2) and (1.3), depending on the statements of problems, the signs of the inequalities can be reversed.

In general, two-index matrices - the variables X and Y and a given matrix W can be integer-valued.

Consider the problem under the condition that the variables X, Y and W are Boolean matrices. As functions $F(X, Y)$, often use a function of the form $F(Z)$, where

$$Z = XWY \quad (1.4)$$

Consider the expression (1.4), which is the product of the matrices of the variables X and Y and the given matrix Z on which the objective function is defined. Unlike traditional statements of discrete programming problems, in this formulation there are two types of variables X and Y, the variables X and Y are symmetric with respect to the given matrix W.

In the problem (1.1) - (1.3) one can select the set of constraints of the form (1.2.) that depend on the variable X, and the set of constraints of the form (1.3) that depend on the variable Y.

A functional of the form $F(X, Y)$ can be represented as follows:

$$F(p(X), g(Y)) \rightarrow \text{extr} \quad (1.5)$$

$$p(X) \rightarrow \text{extr} \quad (1.6)$$

$$\varphi_k(x) \leq \varphi_{ko}, k = \overline{1, K} \quad (1.7)$$

$$g(Y) \rightarrow \text{extr} \quad (1.8)$$

$$\psi_s(Y) \leq \psi_{so}, s = \overline{1, S} \quad (1.9)$$

In the formulation of the problem (1.5) - (1.9), we single out a block of functions (1.6) - (1.7) depending only on the variable X , and a block of functions (1.8) - (1.9) depending only on the variable Y , united by a single functional of the form (1.5). Note that in a number of problem statements there can be a constraint block of the form

$$f_r(X, Y) \leq f_{ro}, r = \overline{1, R} \quad (1.10)$$

depending only on the variables X and Y .

In this case, we can select a block of the objective functional of the form (1.5), (1.10).

Thus, the problem (1.2.5-1.2.10) is called the block-symmetric discrete programming problem.

In a number of problem statements, the functional $F(X, Y)$ can be represented as a function vector. In this case, a multicriterial block-symmetric discrete programming problem is formulated.

Consider the features and properties of block-symmetric problems.

2. Analysis of features and properties of block-symmetric models. Basic algorithm for solving block-symmetric problems. Analysis of the general statement of the block-symmetric problem showed that the model of this class differs from the known models of discrete programming.

Consider the problem under the condition that the variables X , Y and W are Boolean matrices. As functions $F(X, Y)$, often use a function of the form $F(Z)$, where

$$Z = XWY \quad (2.1)$$

Expression (2.1) is the product of the matrices of the variables X and Y and a given matrix W on which the objective function is defined. Unlike traditional statements of discrete programming problems, in this formulation there are two types of variables X and Y , the variables X and Y are symmetric with respect to the given matrix W .

In the problem (1.1) - (1.3) one can select a set of constraints of the form (1.2) that depend on the variable X , and the set of constraints of the form (1.3) that depend on the variable Y .

We consider the expression (2.1.). It follows from this that the variables X and Y are symmetric with respect to the given matrix W , and the function (2.1) can be defined from left to right, and vice versa, i.e.

$$Z = XWY = YWX \quad (2.2)$$

On the basis of the general formulation, we define the basic properties of the formulated class of problems that distinguish it from the traditional statements of problems of discrete programming.

Property 1. The presence of two types of variables X and Y of different types, represented in the form of Boolean matrices, which are defined on the given matrix W .

Property 2. The blocking of the problem consists in isolating in the formulation of individual blocks functions of the form (1.2) and (1.3), depending on the corresponding variable X and Y .

Property 3. The symmetry of the problem consists in the possibility of computing (2.1) both in the forward and backward directions.

The solution of the problem. Analysis of the features and properties of the formulated problem allows us to propose effective algorithms for solving this class of problems. Consider the solution of block-symmetric discrete programming problems, provided that X , Y and W are Boolean matrices. It is easy to prove the following statement.

Statement. The distribution of the elements of the set A to the disjoint subsets A_n corresponds to the logical addition of the rows of the matrix W , $i \in n$, and the distribution of the elements of the set B with respect to disjoint subsets of B_m is the logical addition of the columns of the matrix W , $j \in m$. The results of this statement allow us to simply calculate the estimates and directions of the solution search for the development of effective algorithms.

We introduce the concepts of the basis for the solution of the problem. A basis is a predefined composition of the elements of the subset A_n and B_m .

In the matrix W the basis is found as a certain submatrix Z whose elements are defined. This submatrix can always be determined in the upper left corner by rearranging the row and column numbers

of the matrix and their renumbering. Such a representation simplifies the procedure for calculating estimates and determining the direction of the search for a solution.

To solve the block-symmetric discrete programming problem under the condition that, X , Y and W are Boolean matrices, an effective scheme for solving the problem is developed and proposed. The solution search scheme consists of the following main steps [3]:

1. In the Boolean matrix W , we select the matrix $Z = \|Z_{nm}\|$, $n = \overline{1, N}$; $m = \overline{1, M}$ and define it as the basis for the solution of the problem.

2. Define the matrix $D = \|d_{i^1 n}\|$, $i^1 = \overline{n+1, I}$; $n = \overline{1, N}$ of the direction of the search for the solution X by the logical addition of non-linear rows of the matrix W with rows basis and calculate the values of the estimates only for the positions of the basis.

3. In accordance with the estimates obtained, we realize the distribution of the elements of the set A with respect to the subsets A_n . As a result, we fix the solution X and the intermediate matrix $\Pi = \|\pi_{nj}\|$, $n = \overline{1, N}$, $j = \overline{1, J}$.

4. Define the matrix $D = \|d_{j^1 m}\|$, $j^1 = \overline{m+1, I}$; $m = \overline{1, M}$ of the direction of finding the solution Y by the logical addition of the non-spacing columns of the intermediate matrix $\Pi = \|\pi_{nj}\|$ with columns of the basis and calculate the values of the estimates only for the positions of the basis of the matrix Π .

5. In accordance with the estimates obtained for the matrix Π , we partition the elements of the set B with respect to the subset B_m . As a result, we fix the solution Y and the target matrix Z on which the value of the objective function $F(Z)$ is determined.

It should be noted that the search for the solution of the problem can be carried out both in the forward direction according to the scheme $DX \tilde{D}Y$, and in the reverse direction according to the scheme $\tilde{D}YDX$.

Thus, the basic model of a new class of problems - block - symmetric discrete programming problems is developed. In the future, we will consider the application of this model to solving applied problems in the design of information systems.

3. Development of methods for distributing application software modules and database arrays to nodes of computer systems. Designing information systems is a multi-stage and labor-intensive process and depends on the scale and class of the system.

The result of the design is a variety of applied data processing and control tasks, application programs and a database for the implementation of functional tasks. At the same time, one of the stages is the task of distributing tasks, program modules and a database on nodes of computer systems.

Depending on the purpose and characteristics of computing systems (local, corporate, global), the setting of tasks can also change. For example, in the process of designing information systems based on local computer networks of a homogeneous structure, it becomes necessary to distribute software modules and a database to nodes of computer systems in such a way as to minimize the number (time) of data arrays transmitted between nodes of the network. In a number of cases, it is necessary, with the given structure of the local network, to determine user functions by optimal distribution of program modules and database arrays. There are also tasks of redistribution of software and information resources in solving new tasks, various modifications of software systems, as well as damage to data transmission channels.

The developed models can be used in the process of distributing the application software and the database to the nodes of a computational system of a given structure, the synthesis of the structure (topology) of the computing system (CS) in conditions when the CS nodes and information resources (program modules and interrelated database arrays) are given.

The dynamic development of enterprises and firms in a highly competitive environment necessitates the introduction of information systems of various classes and purposes. At the same time, radical or evolutionary changes in the structure of enterprises (modernization, new technological process, commissioning of new capacities, etc.) invariably affect the information systems. The composition and number of information resources, the systems structure, the distribution of functional tasks and application programs to the nodes of the system are changing. CS nodes are remote computer systems of computing networks or points intended for data processing.

In the design process, the composition and number of application programs, the number and composition of the database, the purpose and number of nodes of the systems can change, which leads to a redesign of the structure of an operational information system.

Problem statement. Let us consider the problem of distributing software modules and database arrays to the nodes of the computer network. Let $A = \{a_i; i = \overline{1, I}\}$, - a set of applied programs for solving the functional problems of information systems. $\beta = \{b_j; j = \overline{1, J}\}$ - a set of database arrays (database fragments) used in the solution of applied problems. The matrix $W = \|\omega_{ij}\|$, ($\omega_{ij} = 1$, if the j -th database array is used to solve the i -th problem, otherwise $\omega_{ij} = 0$,) reflects the use of database arrays for solving application problems. The structure of a computer system or complex is specified by the matrix $G = \|g_{mn}\|$, $m, n = \overline{1, M}$, where $g_{mn} = 1$, if there is a data transfer channel between nodes m and n , $g_{mn} = 0$, if there is no communication channel between the nodes m and n .

It is necessary to distribute application programs and database arrays to nodes of the computer system in order to minimize the total number of transmitted arrays through communication channels under technological limitations. For the mathematical formulation of the problem, we introduce the following variables

$$x_{mi} = \begin{cases} 1, & \text{if } i - \text{th applied program is distributed in } m - \text{th network node;} \\ 0, & \text{otherwise} \end{cases}$$

$$y_{jn} = \begin{cases} 1, & \text{if } j - \text{th database array is distributed in } n - \text{th network node;} \\ 0, & \text{otherwise} \end{cases}$$

We also introduce auxiliary variables in the form:

$$a_{mj} = \begin{cases} 1, & \text{if } \sum_{i=1}^I x_{mi} \omega_{ij} \geq 1 \\ 0, & \text{if } \sum_{i=1}^I x_{mi} \omega_{ij} = 0 \end{cases} \quad (3.1)$$

The variable α_{mj} reflects the need to read the j -th database array by the m -th network node.

$$\beta_{in} = \begin{cases} 1, & \text{if } \sum_{j=1}^J \omega_{ij} y_{jn} \geq 1 \\ 0, & \text{if } \sum_{j=1}^J \omega_{ij} y_{jn} = 0 \end{cases} \quad (3.2)$$

The meaning of the variable β_{in} is that if the database array is located in the n -th node and it is needed to solve the i -th problem, the latter uses the n -th network node to read the database arrays.

We also define the derived variable

$$z_{mn} = \begin{cases} 1, & \text{if } \sum_{i=1}^I \sum_{j=1}^J a_{mj} \omega_{ij} g_{mn} \beta_{in} \geq 1 \\ 0, & \text{if } \sum_{i=1}^I \sum_{j=1}^J a_{mj} \omega_{ij} g_{mn} \beta_{in} = 0 \end{cases} \quad (3.3)$$

A variable z_{mn} reflects the transfer of data between m -th and the n -th nodes of the network.

The total number of transmission over the communication channels of the necessary data during the exchange of information is determined in the form

$$P = \sum_{m=1}^M \sum_{n=m+1}^M z_{mn} \quad (3.4)$$

We also introduce the following notation t_i - for the processing time of the i -th application program for the case of the same node performance in the implementation of programs, θ_{mi} - the processing time of the i -th application program in the m -th node of the computer network for the case of different node

performance, τ_{mj} – time of transfer of j -th array of data to a m -th node, V_i – the amount of memory occupied by the i -th application program, q_{mj} – the amount of j -th database that is sent to the m -th node.

The task of optimal allocation of software and information resources is formulated as follows

$$\sum_{m=1}^M \sum_{n=m+1}^M \sum_{i=1}^I \sum_{j=1}^J x_{mi} \omega_{ij} g_{mn} y_{jn} \rightarrow \min \quad (3.5)$$

subject to restrictions on:

duplication of tasks in nodes of computer networks

$$\sum_{m=1}^M x_{mi} = 1; \quad i = \overline{1, I}; \quad (3.6)$$

duplication of database arrays in nodes of computer networks

$$\sum_{n=1}^M y_{jn} = 1, \quad j = \overline{1, J}; \quad (3.7)$$

processing time of application programs and transfer of database arrays in the node of the computer network.

$$\sum_{i=1}^I t_i x_{mi} + \sum_{j=1}^J \tau_{mj} \alpha_{mj} \leq T_m, \quad m = \overline{1, M} \quad (3.8)$$

The amount of memory occupied by application programs and arrays of the database in the node of the computer network

$$\sum_{i=1}^I v_i x_{mi} + \sum_{j=1}^J q_{mj} \alpha_{mj} \leq V_m; \quad m = \overline{1, M} \quad (3.9)$$

and constraints of the form (1) - (4).

The problem (3.5) - (3.9) and (3.1) - (3.4) belongs to the class of block-symmetric problems of discrete programming [3].

To solve the formulated problem, an effective algorithm of iterative mappings is proposed [4].

Algorithm for solving the problem. 1. In the Boolean matrix, we select the submatrix $Z = \|Z_{ij}\|$, $i = \overline{1, N}$, $j = \overline{1, M}$ and define it as the basis for the solution of the problem.

The basis is defined in the form of a square matrix of the number of rows and columns, which is equal to the number of nodes of computing systems.

2. Define the matrix $D = \|d_{mi'}\|$, $i' = \overline{1, I}$, $m = \overline{1, M}$ directions of the solution search x by logical addition of the non-linear rows of the matrix W with the rows of the basis and calculate the values of the estimates only for the positions of the basis.

3. In accordance with the estimates obtained, we can distribute the elements of the set A over sets A_N . As a result, we fix the solution X and the intermediate matrix $\Pi = \|\pi_{mi}\|$, $m = \overline{1, M}$, $i = \overline{1, I}$.

4. Define the matrix $D = \|d_{j'm}\|$, $j' = \overline{1, J}$, $n = \overline{1, M}$, directions of the solution search Y by logical addition of the non-basis columns of the intermediate matrix $\Pi = \|\pi_{mi}\|$ with the columns of the basis and calculate the values of the estimates only from the positions of the Π basis of the matrix.

5. In accordance with the obtained estimates of the matrix Π we distribute the elements of the set B over the set B_m . As a result, we fix the solution Y and the target matrix Z on which the value of the objective function $P(Z)$ is determined.

The results of computational experiments showed high efficiency of the developed algorithm.

Conclusion. One of the actual tasks in the design and operation of information systems of various classes and purposes is the optimal distribution of data processing systems to the nodes of computing systems.

The problem of the optimal distribution of program modules and database arrays to the nodes of computing systems of a given topology was formulated and solved on the basis of the block-symmetric approach.

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КОМПЬЮТЕР ЖҮЙЕСІНІҢ ЖОЛ ТОРАБЫ (ТҮЙІНДЕРІ) АРҚЫЛЫ ӨТЕТІН ДЕРЕКТЕР ҚОРЫН ӨНДЕУ ЖҮЙЕСІН ТАРАТУ ӘДІСТЕРІ

Аннотация. Берілген жұмыста дискретті бағдарламалаудың жаңа классы – блок-симметриялық әдісі қарастырылған, оның жалпы тұжырымдамасы (қойылымы) жасалып, оны шешу жолы келтірілген. Бұл әдістің ерекше мүмкіндіктері мен қасиеттері көрсетілген.

Компьютер желісінің берілген желі топологиясының жол торабы (түйіні) арқылы өтетін деректер қорының массивін және бағдарламалық модульдерін желі арқылы таратудың оңтайлы әдісі қарастырылып, есептің қойылымы жасалған.

Түйін сөздер: модель, әдіс, алгоритм, айнымалы, блок-симметриялық мәселе, дискретті бағдарламалау.

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МЕТОДЫ РАСПРЕДЕЛЕНИЯ СИСТЕМ ОБРАБОТКИ ДАННЫХ ПО УЗЛАМ ВЫЧИСЛИТЕЛЬНЫХ СИСТЕМ

Аннотация. В работе рассматривается новый класс задач дискретного программирования – блочно-симметричные задачи. Приведена общая постановка и решение блочно-симметричных задач дискретного программирования.

Приведены особенности и свойства этого класса задач. Рассматривается постановка и решение задачи оптимального распределения программных модулей и массивов базы данных по узлам вычислительных систем заданной топологии.

Ключевые слова: модель, метод, алгоритм, переменная, блочно-симметричная задача, дискретное программирование.

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**ESTIMATE OF FORECAST RESOURCES
OF UNDERGROUND WATER IN NARYN SANDY AREA**

Abstract. To solve the problems related to water supply to rural population centers and cattle farms, irrigation of pastures within the territory, regional hydrogeology surveys were conducted in the territory of Naryn sand massif in Northern Pre-Caspian.

Hydrogeological justification of the underground water use prospectivity is in estimating its forecast resources. With the purpose of studying the current state of surface and underground water within the territory under study, regional studies were conducted. Underground water of sandy Aeolian deposits within borders of Naryn sands is caught mainly by wells excavated and equipped manually for non-centralized drinking water supply of cattle farms and small population centers, and also for cattle watering points. Previously explored underground water fields in Aeolian deposits are not operated.

Regional hydrogeological zoning with the purpose of estimating the resources of fresh and low-mineralized water is based on general geological and hydrogeological representations, results of regional route studies. It was carried out with account to the following characteristics of water-bearing formations: perspective water-bearing formation spread contour; underground water occurrence depth; water-bearing formation thickness; underground water mineralization.

To estimate forecast resources of Naryn sands underground water, identified were basic sources of their formation: natural (volumetric) reserves, natural (renewable) resources.

The estimate of forecast underground water resources was carried out using traditional and hydrodynamic methods. Methodology developed by scientists of the Institute of Hydrogeology and Geoecology named after U. M. Ahmadsafin was used as conventional estimate method.

In the process of scientific research, regional map of modules of Naryn sands underground water resources was built. Data was processed and maps were built with the use of up-to-date geoinformational software systems Geomatica 2016 and ArcGIS 10.5.

Key words: interstitial underground water, Naryn sands, Northern Pre-Caspian, hydrogeological parameters, natural reserves, natural resources, hydrogeological zoning, hydrodynamic method, forecast useful resources.

Introduction. The most acute problem in Kazakhstan is the supplying population with quality drinking water. The whole number of regions, including Western Kazakhstan experiences deficit in fresh water.

Hydrogeological conditions and the status of Western Kazakhstan level of water supply is characterized by highly intense water resources balance. This is first of all characteristic for Pre-Caspian oblasts (Atyrau, Mangistau and south-west of half of Western Kazakhstan oblast). Due to the absence of surface water, almost the only source of all types of water supply is the underground water. Hydrogeologically, underexplored until now territory of Naryn sands (interfluvium of Volga and Zhayyk (Ural)) [1, 2] is of significant interest.

Prospectivity of a vast sandy massif is estimated not only by multiple data about presence of fresh water lenses of considerable size, large dishes and estuaries, and also the development of large confluent macrotuberous ridges and massifs of barchans type. Aeolian sand are underplayed here with water-

permeable formations of Khvalynskiy age. These sands having relatively well filtering surfaces and interstitial reservoirs, created are favorable conditions for the filtration of precipitation and absorption of land runoff, drainage and driving of fossil saline water, which results in the formation of fresh lenses [3, 4].

One of the most important problems is the forecast of the prospects of using underground water resources for water supply, irrigation and watering. Such forecast must be hydrogeologically substantiated. Hydrogeological justification of the underground water use is in the estimate of their forecast useful resources.

Borders of the territory under study with the purpose of underground water resources estimate (figure 1) are identified by hydrogeological map having scale of 1:500 000 and are adjusted with the use of remote-sensed data (RSD) [5-8]. RSD processing was performed with the use of geoinformation software Geomatica 2016 (PCI Geomatics). Maps building and their further visualization was implemented in the software system ArcGIS 10.5 (ESRI).

When estimating forecast resources of Naryn sands underground water, identified were the key sources of its formation: natural (volumetric) reserves, natural (renewable) resources [9].

Conditions for underground water resources formation. Ground (nonartesian) water of the Northern Pre-Caspian are connected with different by lithologic-and-facies composition and genesis of Quarternary age rock occurring not deep from the day surface and exposed to direct impact of climatic and hydrological drug factors [1, 2, 4-10].

The major source of ground water resources replenishment in the territory under study are precipitations and in wellhead areas of rivers and their affluent - surface water (flood run-off). Favorable conditions of ground water resources replenishment and formation at account of precipitations are observed within the areas of Aeolian formations development. In the estuarine part of Mal and Bol. Uzen river

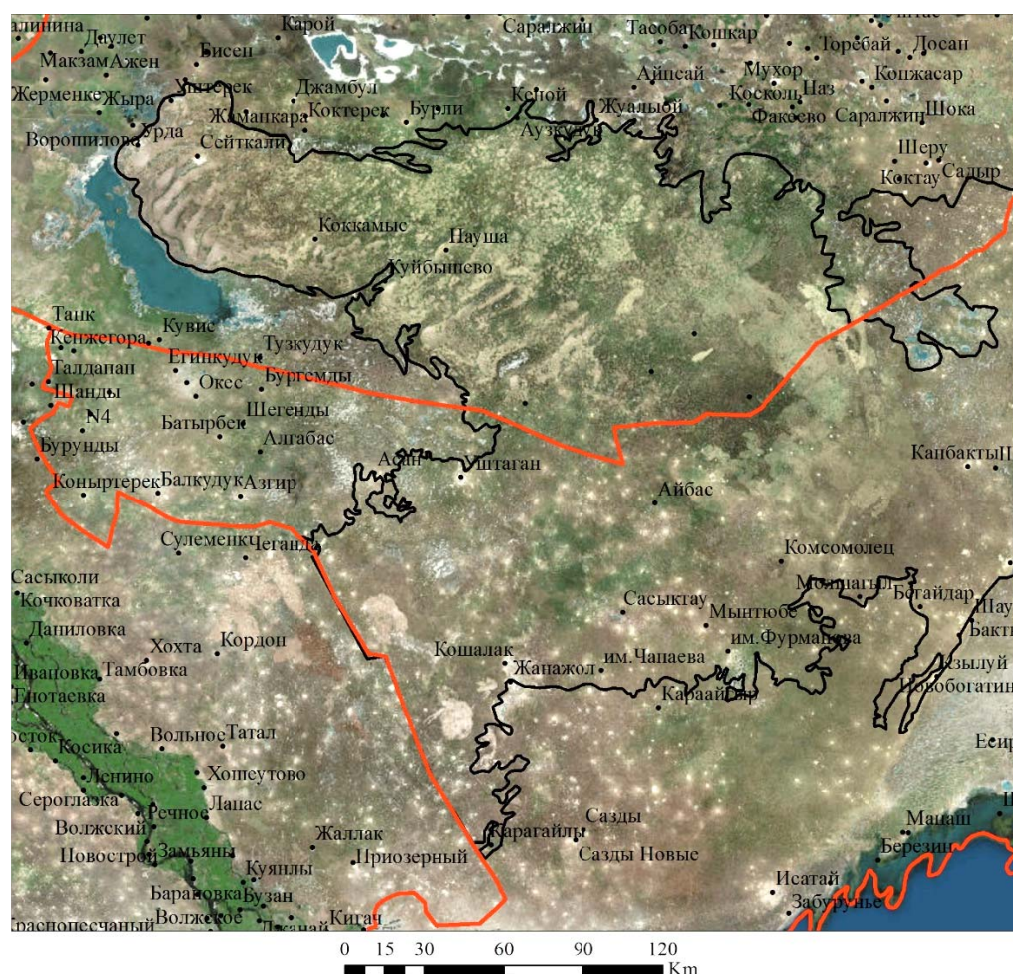


Figure 1 – Sketch map of Naryn sands location

valleys, favorable conditions are also noted for the underground water formation not only at account of precipitations, but filtration of river floodwater. Such conditions of groundwater feed within the areas of sand spread facilitate the formation of major reserves of fresh water.

In general, studies conducted previously within the territory of Naryn sands revealed fresh ground water [4]. Underground water here is desalted throughout the full thickness of water-bearing sand. This is explained by the fact that along with favorable fed conditions, water-bearing formations have a powerful discharge site - Khaki playa, spreading from north-west to south-east in the form of slightly curved horseshoe and embedded into the surrounding valley by 10-25 m.

The underflow is discharged into the basin of the Caspian Sea, and also by evaporation in case of its shallow occurrence. Local points of discharge are shut-ins and topographic lows.

Field studies were conducted with the purpose of studying the current state of surface and underground water of the territory under study (figure 2). Described were 34 observation points, were 26 water samples were taken for chemical analysis. The total length of routes – 1,160 km.



Figure 2 – Field route surveys within the territory of Naryn sands

Based on the results of the field routing surveys, the following can be noted:

1. Fresh underground water with mineralization of up to 1.0 g/dm^3 is 58 % of the sampled water. Their composition from bicarbonate and bicarbonate-sulphate to three-anionic with predomination of sodium cations, hardness within $2\text{-}10 \text{ mg-eq/dm}^3$, pH 6,9-8,2 (water from neutral to weakly alkaline).
2. Underground water with mineralization of more than $1,0 \text{ g/dm}^3$ has chloride-sulphate and sulphate-chloride sodium, sodium-magnesium chemical composition, with hardness of more than $10,0 \text{ mg-eq/dm}^3$ and faintly alkaline reaction.
3. Underground water of sand Aeolian formations within Naryn sands is mainly captured by wells made and equipped manually. Fresh underground water is used for non-centralized drinking water supply of cattle farms and small population centers, and also for cattle watering points. More mineralized underground water is taken for cattle drinking places on specifically equipped sites (manually or with pumps, drinking reservoirs etc.).
4. Explored underground water fields of Aeolian deposits are not operated. Previously drilled holes were plugged.
5. Results of route surveys confirm the presence of fresh underground water in Quarternary Aeolian deposits both in the form of lenses, as well as water-bearing formations perspective for development with the purpose of utility and drinking water supply.

Hydrogeological zoning of the territory under study was carried out for the further estimation of underground water forecast resources and separating perspective areas of underground water sources and is based on geological-hydrogeological representations, results of regional studies.

The zoning was carried out with the account to the following characteristics of water-bearing formations: contour of perspective water-bearing formation spread; underground water depth of occurrence; water-bearing formation thickness; underground water mineralization. The total area of the territory to be estimated within Northern Pre-Caspian (Naryn sands) was – 30,5 thousand km^2 . Zoning results are presented in table 1 and figure 3.

Table 1 – Hydrogeological zoning of Naryn sands

A. By underground water mineralization				
Research area	Areas of underground water spread (km ²) with mineralization, g/dm ³			
	to 1,0	1,0-3,0	more than 3,0	in all
Naryn sands	12115	16295	2089	30499
Б. По мощности водоносного горизонта				
Research area	Areas of water-bearing formations spread (km ²) with thickness, m			
	less than 5,0	5,0-10,0	more than 10,0	in all
Naryn sands	3876	14539	12084	30499

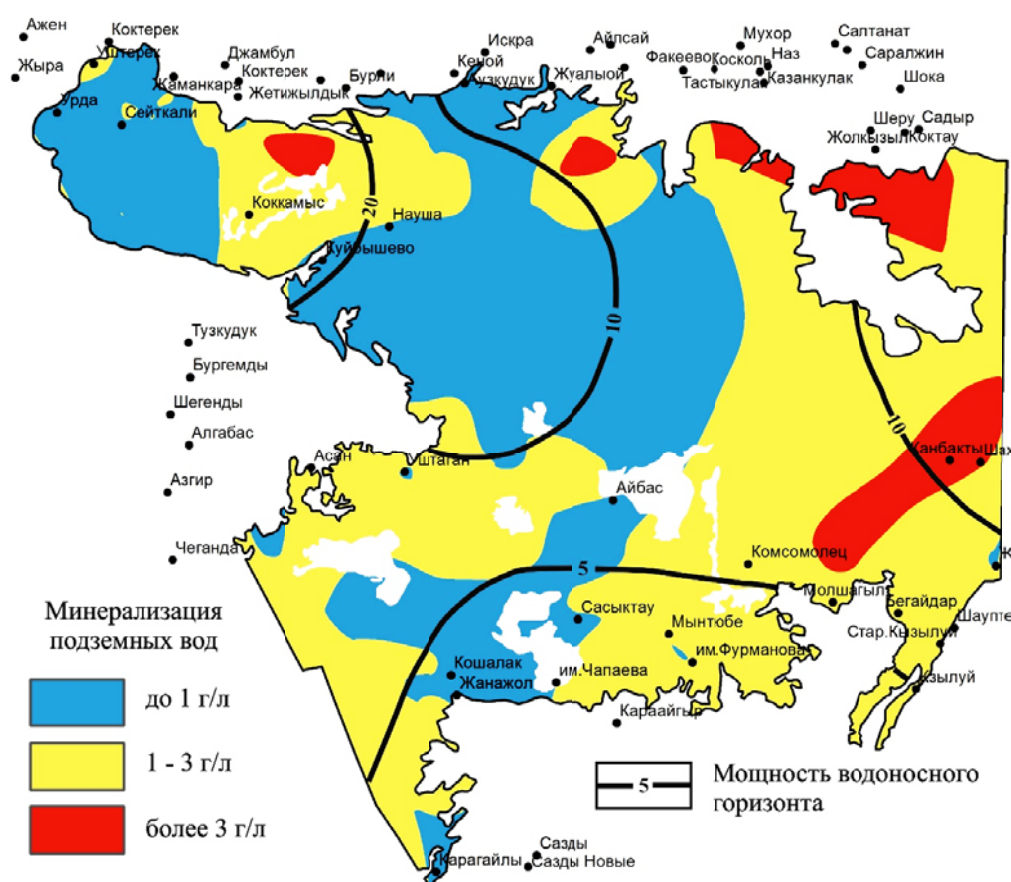


Figure 3 – Schematic map of Naryn sands territory zoning

The area of fresh underground water spread is estimated as 12,11 thousand km² or 39,7 %, and subsaline underground water with mineralization of 1-3 g/dm³ – 16,29 thousand km² or 53,4 %. By thickness of water-bearing formation, prevailing by the area is the value of less than 5,0-10,0 m (14,53 thousand km² or 47,6 %). The territory with water-bearing formation thickness of more than 10 m is estimated as 12,0 thousand km² or 39,6 %.

Natural reserves (V_e) of interstitial nonartesian underground water of Naryn sands were calculated by formula:

$$V_e = \mu \cdot m \cdot F, \quad (1)$$

where V_e – natural (volumetric) reserves of underground water, m³; μ – gravitation filtration-loss factor, as decimal fraction; m – average value of water-bearing formation thickness, m; F – area of water-bearing formation spread within the territory under study, m².

Values (m) and (F) are taken by schematic zoning map (figure 3). Value (μ) was determined by data of exploration within Naryn sands area and varies within 0,11-0,16, mean value being 0,13.

Natural reserves of interstitial underground water in Naryn sands territory is estimated as 42582,7 mln. m³, natural reserves module varies within 0,39-2,6 mln. m³/km² depending on water-bearing formation thickness, making on average in the territory under study – 1,39 mln. m³/km². Estimates are presented in table 2.

Table 2 – Natural reserves of Naryn sands interstitial underground water

Area of spread, km ²	Average thickness, m	Water loss factor, decimal fraction	Natural reserves, mln. m ³	Natural reserves module, mln. m ³ /km ²
3876	3,0	0,13	1511,64	0,39
14539	8,0	0,13	15120,56	1,04
8398	15,0	0,13	16376,1	1,95
3686	20,0	0,13	9583,6	2,6
30499	10,74	0,13	42582,7	1,39

Natural resources (Q_e) interstitial nonartesian Naryn sands underground water are estimated as annual feeding at account of precipitation infiltration under natural conditions. For the conditions of sand massifs, the value of effective precipitation infiltration was identified by meteorological method, which is based on long-term observations of precipitation in the territory used in calculation of infiltration.

The following equation serves a structural basis:

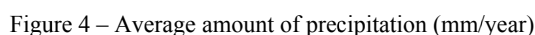
$$Q_e = \frac{H_{\text{эфф}} \cdot K_{\text{инф}} \cdot F}{31,536 \cdot 10^6}, \quad (2)$$

where Q_e – natural resources of underground water formed at account of precipitation infiltration, m³/s; $H_{\text{эфф}}$ – average annual total of effective precipitation, m; $K_{\text{инф}}$ – infiltration factor used by analogy; F – area of estimate, km²; Value $K_{\text{инф}}$, was identified by analogy for which engaged were the results of studies of Aeolian sand massifs underground water formation processes in arid regions.

So, a complex of observation works was performed by specialists of the State Hydrology Institute (SHI) on Khvalynskiy valley [11-14]. At similar site $K_{\text{инф}}$ decreases with the depth and at the level of 10-11 meters reaches the value of 0.10-0.12. For the conditions of Moynkum sand massifs, the value of feed for unfixed sand by data of observations of lysimeters installed at the depth of 4.5 m, was 0.1-0.38 of the total of effective precipitation. Besides, used were the results of review of published materials related to the issue of underground water feeding under conditions of arid climate. In particular, these included the works of Bindeman N.N., Wolfzung N.B., Ganiev K.G., Ostrovskiy N.S., and also the results of MSU laboratory studies. As the result of critical review of the listed materials, and also based on the results of previous estimates, with account to the fact that the depth of underground water occurrence at water points was less than 3,0 m, and the value of effective precipitation infiltration factor for Naryn sands was taken as equal to 0,2.

Design totals of precipitation were identified by data of long-term observations on the network of meteorological stations [15]. Average totals of precipitation in the territory of Naryn sands are presented in figure 4. Effective total of precipitation ($H_{\text{эфф}}$) of the cold season for the territory under study vary within 35-42%, making on average 39% of the annual level.

Natural resources of interstitial underground water within Naryn sands territory are estimated as 16,59 m³/s, and the module of natural resources varies within 0,43-0,65 l/s·km² depending on the level of effective precipitation making on average in the territory under study – 0,54 l/s·km². Results of calculations are presented in table 3.



Area of spread, km ²	Average annual amount of precipitation, mm		Infiltration factor, decimal factor	Natural resources, m ³ /s	Module of natural resources, l/s·km ²
	annual total	effective			
1851	175,0	68,25	0,2	0,80	0,43
6765	185,0	72,15	0,2	3,09	0,46
7811	195,0	76,05	0,2	3,76	0,48
4888	205,0	79,95	0,2	2,47	0,50
3475	215,0	83,85	0,2	1,84	0,53
2270	225,0	87,75	0,2	1,26	0,56
1100	235,0	91,65	0,2	0,64	0,58
791	245,0	95,55	0,2	0,48	0,60
795	255,0	99,45	0,2	0,50	0,63
750	265,0	103,35	0,2	0,49	0,65
30496	220,0	85,8	0,2	16,59	0,54

When estimating regional forecast resources used was the methodology developed by scientists of the Institute of Hydrogeology and Geocology named after U. M. Ahmedsafin, who for more than 50 years

had been dealing with the studies of Kazakhstan underground water formation and distribution regularities. In calculations, used was the formula proposed by U. M. Ahmetsafin [16-18]:

$$Q_3 = \frac{V_e}{2 \cdot 100 \cdot 31,536 \cdot 10^6} + 0,7Q_e, \quad (3)$$

where Q_3 – forecast regional useful resources of underground water, m^3/s ; V_e – natural reserves of underground water, m^3 ; Q_e – natural resources of underground water, m^3/s .

Design value of forecast regional useful resources of Naryn sands underground water is $18,36 m^3/s$. These values represent potential using possibilities of the territory under study.

Hydrodynamic methods of estimating forecast resources of underground water included a method of calculations applicable to the conventional even grid of wells [19, 20] throughout the Naryn sands area to be estimated. Grid size with account to geological-hydrogeological conditions and variability of the thickness of water-bearing sediments and underground water mineralization was taken as 5.0 and 10.0 km. Each single water intake structure is conditionally schematized as working in the closed circular block with impermeable boundaries at account of natural reserves included into such block, and also natural resources corresponding to its area (figure 4).

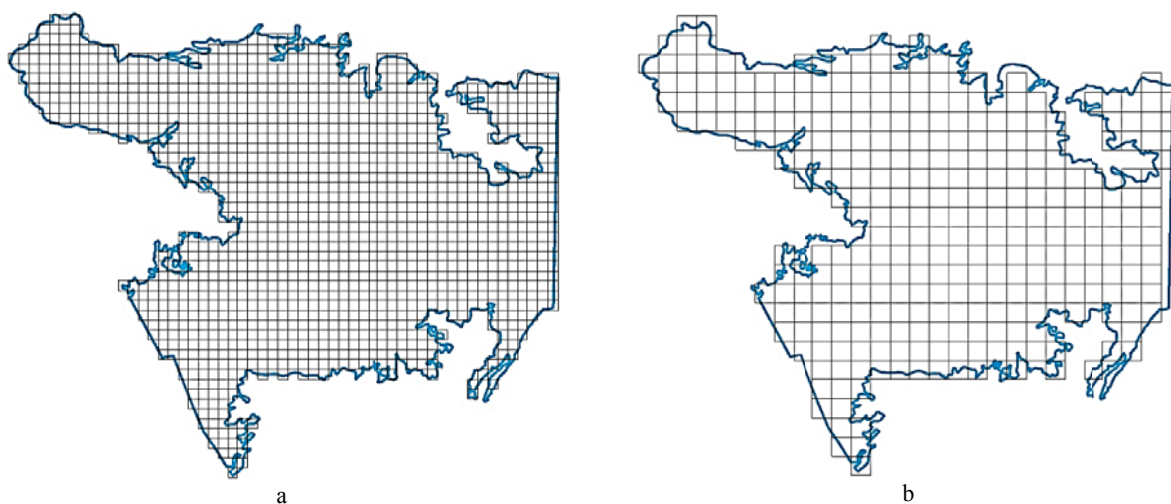


Figure 4 – Examples of model grids with block size of 5x5 km (a), 10x10 km (b)

Block radius (R_0), equal to circle radius of equal area with square block of the grid is determined from expression:

$$R_0 = \frac{\Delta x}{\sqrt{\pi}} = 0,565\Delta x, \quad (4)$$

where Δx – grid size, m.

A single water intake structure flow for free-flow interstitial water located in the center of the block, us found by formula:

$$Q_3 = \frac{\left[S(1 - \frac{S}{2m}) + Q_e \frac{T}{\pi \mu R_0^2} \right] \pi R_0^2}{\frac{T}{\mu} + \frac{R_0^2}{2km} \cdot \ln \frac{R_0}{r}} \quad (5)$$

where Q_3 – capacity of water intake structure, $m^3/daily$; Q_e – additional feeding at account of natural resources, $m^3/daily$; S – allowable level lowering, m; m – water-bearing formation thickness, m; k – filtration factor, m/daily; T – design life cycle, days; μ – gravitation filtration-loss factor, decimal fraction; R_0 – block radius, m; r – radius of water intake structure well, m.

In calculations, the following input data was used:

a) additional feed coming to a block area at account of precipitation infiltration, identified by module of natural resources from expression:

$$Q_e = 86400M_e, \quad (6)$$

where M_e – module of natural resources, $l/s \cdot km^2$.

b) the given radius of a single water intake structure is taken as equal to block radius (R_0) when calculating by even grid and is equal with the grid size of 5 km and 10 km, 2,825 m and 5,650 m accordingly. Radius of water supply well (r), by operating experience – 0,1 m.

c) useful reserves were calculated for 50-year period of operation, or 18,250 days with two options.

d) value of allowable decrease of level was identified provided natural reserves drawdown by half of thickness of water-bearing formation ($S=0.5t$).

e) design hydrogeologic parameters of water-bearing formations are determined by results of development works, performed previously on underground water exploration sites. Value (μ) is taken as 0,13. Value (k) in the area of Naryn sands varies within 5,8-20,7 m/daily and for forecast calculations is - 6 m/daily.

f) total forecast useful resources of underground water were estimated for sand water-bearing formations with mineralization of up to 1 and 1-3 g/dm^3 with account to the use of underground water for utility and drinking water supply and cattle drinking place, by formula:

$$Q_{\Sigma} = \sum_{i=1}^n Q_i, \quad (7)$$

where Q_i – intake facilities flow rate in i -block ($i = 1, 2, 3, \dots, n$); n – number of blocks in the area to be estimated.

Results of calculations of forecast useful resources by analytical method are presented in tables 4-7. With account to conventional even grid of wells throughout the Naryn sands area under study with grid size of 5 km, forecast useful resources of underground water were taken by the 2-nd option of calculation. Value of forecast useful resources of underground water for the Naryn sands territory to be estimated is 108,07 m^3/s , including: fresh water (up to 1 g/dm^3) – 54,27 m^3/s , and light subsaline (1-3 g/dm^3) – 53,8 m^3/s .

Table 4 – Forecast resources of fresh underground water (Δx – 10 km)

Underground water mineralization, g/dm^3	Area of spread, km^2	Number of blocks, pcs	Thickness, m	Module of natural resources, $l/s \cdot km^2$	Single intake facility capacity, m^3/day	Forecast useful resources		Module of forecast resources, $l/s \cdot km^2$
						thousand $m^3/daily$	m^3/s	
Fresh (to 1)	747	7	20	0,65	5412,52	37,89	0,44	0,59
	757	7	20	0,63	5260,48	36,82	0,43	0,56
	570	5	20	0,6	5032,42	25,16	0,29	0,51
	183	1	15	0,58	3652,27	3,65	0,04	0,23
	130	1	20	0,56	4728,33	4,73	0,05	0,42
	417	4	15	0,56	3535,68	14,14	0,16	0,39
	468	4	8	0,56	1877,36	7,51	0,09	0,19
	1824	18	15	0,53	3360,78	60,49	0,70	0,38
	505	5	8	0,53	1781,05	8,91	0,10	0,20
	2006	20	15	0,5	3185,89	63,72	0,74	0,37
	1298	12	8	0,5	1684,74	20,22	0,23	0,18
	154	1	15	0,48	3069,29	3,07	0,04	0,23
	1869	18	8	0,48	1620,54	29,17	0,34	0,18
	122	1	3	0,48	603,05	0,60	0,01	0,06
	101	1	8	0,46	1556,33	1,56	0,02	0,18
	897	8	3	0,46	578,40	4,63	0,05	0,06
	136	1	3	0,43	541,43	0,54	0,01	0,05
Total	12184	114				322,81	3,74	0,31

Table 5 – Forecast resources of subsaline underground water ($\Delta x - 10$ km)

Underground water mineralization, g/dm ³	Area of spread, km ²	Number of blocks, pcs	Thickness, m	Module of natural resources, l/s*km ²	Single intake facility capacity, m ³ /day	Forecast useful resources		Module of forecast resources, l/s*km ²
						thousand m ³ daily	m ³ /s	
Subsaline (1 – 3)	311	3	20	0,6	5032,42	15,10	0,17	0,56
	570	5	20	0,58	4880,37	24,40	0,28	0,50
	100	1	15	0,58	3652,27	3,65	0,04	0,42
	403	4	20	0,56	4728,33	18,91	0,22	0,54
	554	5	15	0,56	3535,68	17,68	0,20	0,37
	205	2	8	0,56	1877,36	3,75	0,04	0,21
	182	1	15	0,53	3360,78	3,36	0,04	0,21
	712	7	8	0,53	1781,05	12,47	0,14	0,20
	430	4	15	0,5	3185,89	12,74	0,15	0,34
	637	6	8	0,5	1684,74	10,11	0,12	0,18
	1074	10	15	0,48	3069,29	30,69	0,36	0,33
	4558	45	8	0,48	1620,54	72,92	0,84	0,19
	464	4	15	0,46	2952,70	11,81	0,14	0,29
	2451	24	8	0,46	1556,33	37,35	0,43	0,18
	1821	18	3	0,46	578,40	10,41	0,12	0,07
	794	7	8	0,43	1460,02	10,22	0,12	0,15
	872	8	3	0,43	541,43	4,33	0,05	0,06
Total	16138	154				299,92	3,47	0,22

Table 6 – Forecast resources of fresh underground water ($\Delta x - 5$ km)

Underground water mineralization, g/dm ³	Area of spread, km ²	Number of blocks, pcs	Thickness, m	Module of natural resources, l/s*km ²	Single intake facility capacity, m ³ /day	Forecast useful resources		Module of forecast resources, l/s*km ²
						thousand m ³ /daily	m ³ /s	
Fresh (to 1)	747	30	20	0,65	16785,38	501,55	5,80	7,77
	757	30	20	0,63	16280,93	492,99	5,71	7,54
	504	20	20	0,6	15524,26	312,97	3,62	7,19
	66	3	20	0,58	15019,81	39,65	0,46	6,95
	183	7	15	0,58	12072,66	88,37	1,02	5,59
	130	5	20	0,56	14515,37	75,48	0,87	6,72
	417	17	15	0,56	11664,54	194,56	2,25	5,40
	468	19	8	0,56	6925,36	129,64	1,50	3,21
	1824	73	15	0,53	11052,36	806,38	9,33	5,12
	505	20	8	0,53	6558,42	132,48	1,53	3,04
	2006	80	15	0,5	10440,18	837,72	9,70	4,83
	1298	52	8	0,5	6191,48	321,46	3,72	2,87
	154	6	15	0,48	10032,06	61,80	0,72	4,64
	1869	75	8	0,48	5946,86	444,59	5,15	2,75
	122	5	3	0,48	2427,05	11,84	0,14	1,12
	101	4	8	0,46	5702,23	23,04	0,27	2,64
	897	36	3	0,46	5654,85	202,90	2,35	2,62
	136	5	3	0,43	2175,45	11,83	0,14	1,01
Total	12184	487				4689,25	54,27	4,45

Table 7 – Forecast resources of subsaline underground water ($\Delta x - 5$ km)

Underground water mineralization, g/dm ³	Area of spread, km ²	Number of blocks, pcs	Thickness, m	Module of natural resources, l/s·km ²	Single intake facility capacity, m ³ /day	Forecast useful resources		Module of forecast resources, l/s·km ²
						thousand m ³ /daily	m ³ /s	
Subsaline (1 – 3)	37	1	20	0,63	16280,93	24,10	0,28	7,54
	274	11	20	0,6	15524,26	170,15	1,97	7,19
	570	23	20	0,58	15019,81	342,45	3,96	6,95
	100	4	15	0,58	12072,66	48,29	0,56	5,59
	403	16	20	0,56	14515,37	233,99	2,71	6,72
	554	22	15	0,56	11664,54	258,49	2,99	5,40
	205	8	8	0,56	6925,36	56,79	0,66	3,21
	182	7	15	0,53	11052,36	80,46	0,93	5,12
	712	28	8	0,53	6558,42	186,78	2,16	3,04
	430	17	15	0,5	10440,18	179,57	2,08	4,83
	637	25	8	0,5	6191,48	157,76	1,83	2,87
	1074	43	15	0,48	10032,06	430,98	4,99	4,64
	4558	182	8	0,48	5946,86	1084,23	12,55	2,75
	431	17	15	0,46	9623,93	165,92	1,92	4,46
	2451	98	8	0,46	5702,23	559,05	6,47	2,64
	1821	73	3	0,46	5654,85	411,90	4,77	2,62
	33	1	15	0,43	9011,75	11,90	0,14	4,17
	794	32	8	0,43	5335,29	169,45	1,96	2,47
	872	35	3	0,43	2175,45	75,88	0,88	1,01
Total	16138	646				4648,12	53,80	3,33

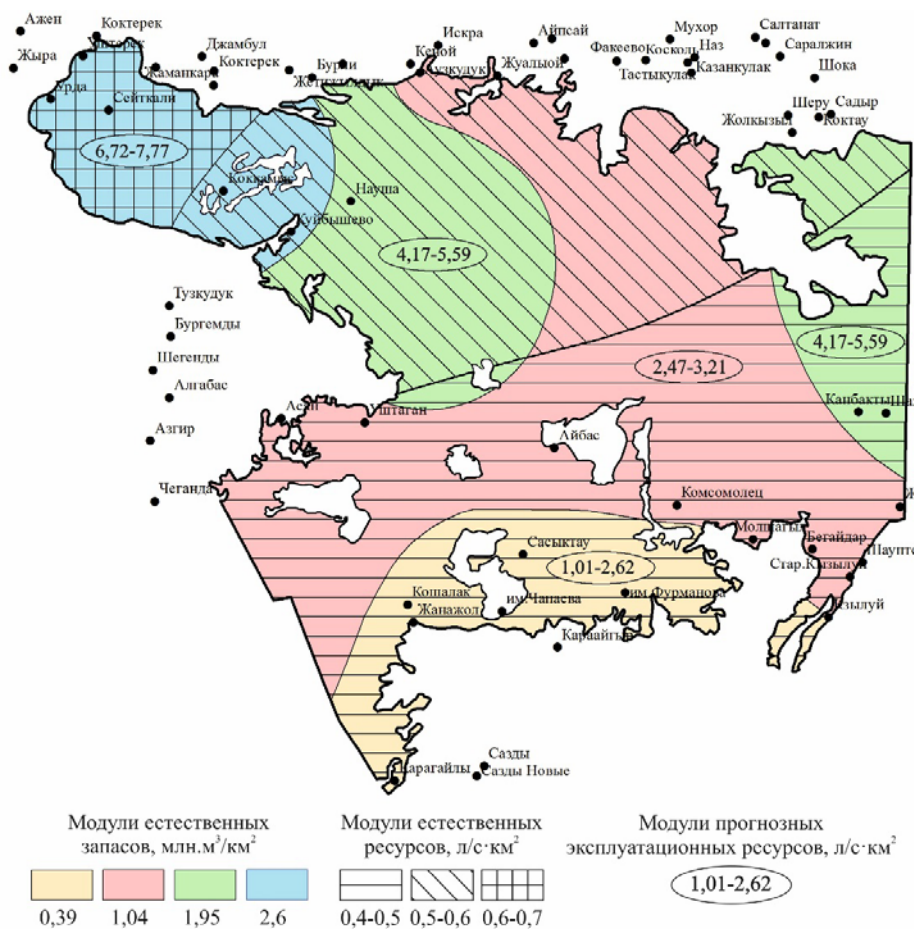


Figure 5 – Map of Naryn sands underground water resources

In the process of scientific studies, based on data of analysis of previously performed works, materials of RSD and field route surveys, regional map of Naryn sands underground water resources was made (figure 5). The map shows modules of natural resources (mln. m³/km²), natural and forecast useful resources (l/s·km²) of underground water.

Conclusion:

1. Based on data of hydrogeological zoning, the area of spread of fresh underground water was estimated as 12,11 thousand km² or 39,7 %, By thickness of water-bearing formation, prevailing by the area is the value of less than 5,0-10,0 m (14,53 thousand km² or 47,6 %). The territory with water-bearing formation thickness of more than 10 m is estimated as 12,0 thousand km² or 39,6 %.

2. Field studies allowed estimation of the quality of used water resources. Fresh underground water with mineralization of up to 1,0 g/dm³ make 58% of the taken water. Their composition from bicarbonate and bicarbonate-sulphate with predomination of sodium cations, hardness within 2-10 mg-eq/dm³, pH 6.9-8.2 (water from neutral to weakly alkaline). Underground water with mineralization of more than 1,0 g/dm³ has chloride-sulphate and sulphate-chloride sodium, sodium-magnesium chemical composition, with hardness of more than 10,0 mg-eq/dm³ and faintly alkaline reaction. Results of route surveys confirm the presence of fresh underground water in Quarternary eolian deposits both in the form of lenses, as well as water-bearing formations perspective for development with the purpose of utility and drinking water supply.

3. Calculations of natural reserves of free-flow Naryn sands underground water are estimated as – 42582,7 mln. m³, natural reserves module was on average – 1,39 mln. m³/km². Natural resources of Naryn sands underground water are estimated as 16,59 m³/s, module of natural resources – 0,54 l/s·km² on average.

4. The value of forecast useful resources of underground water for the Naryn sands territory under study is 108,07 m³/s, including: fresh water (up to 1 g/dm³) – 54,27 m³/s and light subsaline (1-3 g/dm³) – 53,8 m³/s. Major part of resources of fresh and light subsaline underground water is concentrated in the northern part of Naryn sands massif.

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НАРЫН ҚҰМДАРЫНЫҢ ЖЕРАСТЫ СУЛАРЫНЫҢ БОЛЖАМДЫ РЕСУРСТАРЫН БАҒАЛАУ

Аннотация. Ауылдық елді мекендерді, мал шаруашылығын және жайылымдық аудандарды суару сумен қамтамасыз етуге байланысты мәселелерді шешу үшін Солтүстік Каспий маңындағы Нарын құмды массив аумағында аймақтық гидрогеологиялық зерттеулері жүргізілген.

Жерасты суларын пайдалану тиімділігін гидрогеологиялық негіздемесі олардың болжамды ресурстарын бағалауы болып келеді. Жерүсті және жерасты суларының қазіргі заманғы жағдайын зерттеу мақсатында осы ауданда аймақтық экспедициялық зерттеулер жүргізілген. Нарын құмдары шегінде құмды эол шөгінділерінің жерасты сулары, негізінен, мал суғару, ұсақ елді-мекендерді және мал шаруашылығын орталықтандырыл-маған сумен қамтамасыз ету үшін, қолмен қазылған және жабдықталған құдықтар қолданылады. Эолды шөгінділердің жерасты суларының бұрын зерттелген кен орындары пайдаланбайды.

Аймақтық гидрогеологиялық аудандау, тұщы және сәл минералданған сулардың ресурстарын бағалау мақсатында, жалпы геология-гидрогеологиялық көзқарастарға аймақтық маршруттық зерттеу нәтижелеріне негізделген. Ол келесі сулы горизонттардың сипаттамаларын есепке ала отырып орындалған: тиімді сулы го-ризонттың таралған айналасы; жерасты суыларының жату тереңдігі; сулы горизонттың қалыңдығы; жерасты суыларының минералдылығы.

Нарын құмдарының болжамдық жерасты суларының ресурстарын бағалау үшін оның басты қалыптасу дереккөздері анықталды: табиғи (сыйымдылық) қорлары, табиғи (жаңғыртылмалы) ресурстары.

Ғылыми зерттеу жүрісінде Нарын құмдарының жерасты сулар ресурстарының аймақтық модулдер картасы жасалды. Деректерді өңдеу және карта салуда Geomatica 2016 және ArcGIS 10.5 заманауи геоақпа-раттық бағдарламалық комплекстері пайдаланды.

Түйін сөздер: кеуектік жерасты суы, Нарын құмдары, Солтүстік Каспий маңы, гидрогеологиялық көрсеткіштер, табиғи қорлары, табиғи ресурстары, гидрогеологиялық аудандау, гидродинамикалық әдіс, болжамды пайдалану ресурстары.

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ОЦЕНКА ПРОГНОЗНЫХ РЕСУРСОВ ПОДЗЕМНЫХ ВОД ПЕСКОВ НАРЫН

Аннотация. Для решения проблем, связанных с водоснабжением сельских населенных пунктов и жи-вотноводческих ферм, обводнением пастбищ территории проведены региональные гидрогеологические исследования на территории песчаного массива Нарын в Северном Прикаспии.

Гидрогеологическое обоснование перспективности использования подземных вод заключается в оценке их прогнозных ресурсов. С целью изучения современного состояния поверхностных и подземных вод терри-тории исследований проведены региональные экспедиционные исследования. Подземные воды песчаных эоловых отложений в пределах песков Нарын каптируются в основном колодцами, выкопанными и обо-рудованными вручную для децентрализованного питьевого водоснабжения животноводческих хозяйств и мелких населенных пунктов, а также водопоя скота. Ранее разведанные месторождения подземных вод эоло-вых отложений не эксплуатируются.

Региональное гидрогеологическое районирование с целью оценки ресурсов пресных и слабоминерализованных вод основано на общих геолого-гидрогеологических представлениях, результатах региональных маршрутных исследований. Оно выполнено с учетом следующих характеристик водоносных горизонтов: контур распространения перспективного водоносного горизонта; глубина залегания подземных вод; мощность водоносного горизонта; минерализация подземных вод.

Для оценки прогнозных ресурсов подземных вод песков Нарын определены основные источники их формирования: естественные (емкостные) запасы, естественные (возобновляемые) ресурсы.

Оценка прогнозных эксплуатационных ресурсов подземных вод производилась традиционным и гидродинамическим методами. В качестве традиционных методов оценки использована методология, разработанная учеными Института гидрогеологии и геоэкологии имени У. М. Ахмедсафина.

В процессе научных исследований выполнено построение региональной карты модулей ресурсов подземных вод песков Нарын. Обработка данных и построение карт выполнено с использованием современных геоинформационных программных комплексов Geomatica 2016 и ArcGIS 10.5.

Ключевые слова: поровые подземные воды, пески Нарын, Северный Прикаспий, гидрогеологические параметры, естественные запасы, естественные ресурсы, гидрогеологическое районирование, гидродинамический метод, прогнозные эксплуатационные ресурсы.

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ORGANIZATION OF COMPUTER LABORATORY WORK “CALCULATION AND VISUALIZATION OF SMALL FORCED OSCILLATIONS”

Abstract. In the article there are calculations and visualizations of forced oscillations of the system under the action of constant and variable forces: 1. $F = \text{const} = F_0$; 2. $F = at$; 3. $F = F_0 \exp(-at)$; 4. $F = F_0 \exp(-at) \cos(\beta t)$. The graphs of dependence of the above given forces on the time are drawn in one graphic window. The programs for calculation and visualization of the forced oscillations under the action of the given forces are presented. The graphs of dependence of the one-dimensional forced oscillations on the time are submitted. Formulas (1-4), describing the laws of oscillations, are difficult for understanding the features of oscillations. Their visualization makes the nature of the system oscillations more evident and clear.

For the solution of this task the MATLAB language is used. It is known that the MATLAB language has opportunities for modeling and visualization of physical processes. MATLAB allows presenting visually the complicated formulas in the form of graphs that considerably makes easier the comprehension of the nature of the process or the phenomenon.

Aim of the work: To work out the program for calculations and visualizations of forced oscillations of the system under the action of the force $F(t)$ if at the initial time $t = 0$ the system is at rest in an equilibrium state ($x(t=0)=0$, $v(t=0)=0$).

The results of this study can be used on theoretical mechanics classes of the higher school.

Key words: forced oscillations, visualization, oscillation graph, amplitude.

Introduction. Nowadays all educational institutions of Kazakhstan are provided with computer hardware and software, interactive boards and internet. Almost all teachers have completed language and computer courses for professional development. Hence the educational institutions have all conditions for using computer training programs and models for performing computer laboratory works. During several years we have been conducting the work on organization computer laboratory works on physics with use of resources of the Fizikon Company [1, 2] which are developed at Al-Farabi Kazakh National University by V. V. Kashkarov and his group. Some of worksheet templates for computer laboratory works are introduced in educational process of our university and schools of the Southern Kazakhstan [3–29]. Students of the physics specialties 5B060400 and 5B011000 successfully master the discipline “Computer modeling of physical phenomena” which is the logical continuation of the disciplines “Information technologies in teaching physics” and “Use of electronic textbooks in teaching physics”. The aim of this discipline is to study and learn the program language of the MATLAB system [30], acquaintance with its huge opportunities for modeling and visualization of physical processes. This article is devoted to organization of performance of the laboratory work "Calculation and visualization of the system undergoing one-dimensional small oscillations" using the MATLAB language.

The aim of the work is to work out the program for calculations and visualizations of forced oscillations of the system under the action of the force $F(t)$ if at the initial time $t = 0$ the system is at rest in an

equilibrium state ($x(t=0)=0$, $\alpha(t=0)=0$). (The problems are taken from [31]. They were solved at practical classes on classical mechanics).

Methods. The program for calculation and visualization of forces acting on the system:

```
>> F0=1; m=0.2; w=1; % input the parameters
>> t=0:pi/10:2*pi; % input the time vector
>> subplot(2,2,1);plot(t,F0,'k-') % plotting the graph in the first sub-window
>> a=1; F=a.*t; % input the parameters
>> subplot(2,2,2);plot(t,F,'k-') % plotting the graph in the second sub-window
>> grid on % drawing the coordinate grid
>> F0=1; alfa=0.5; %
>> F=F0.*exp(-alfa.*t); %
>> subplot(2,2,3);plot(t,F,'k-') % plotting the graph in the third sub-window
>> grid on % drawing the coordinate grid
>> beta=0.2; alfa=0.5; % input the parameters
>> F=F0.*exp(-alfa.*t).*cos(beta.*t); % calculation of the acting force
>> subplot(2,2,4);plot(t,F,'k-') % plotting the graph in the fourth sub-window
>> grid on % drawing the coordinate grid
```

Results and discussion. The result is presented in the figure 1.

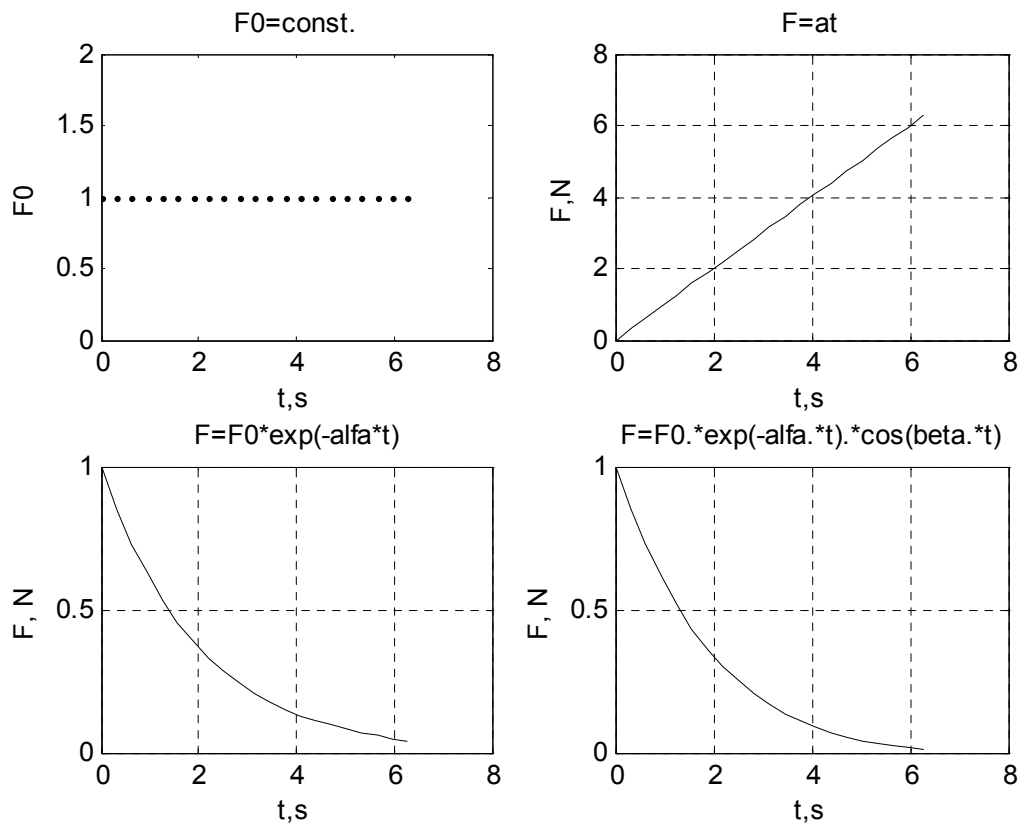


Figure 1 – The graphs of acting forces versus time in one graphic window

1. $F = \text{const} = F_0$. Under the action of a constant force the system is displaced from its equilibrium position and oscillates about this position according to the equation:

$$x = \frac{F_0}{m\omega^2} (1 - \cos \omega t), \quad (1)$$

where m is the mass of the system, ω is the oscillation frequency.

The program for calculation and visualization:

```
>> F0=1; m=0.2; w=1; % input the parameters
>> t=0:pi/10:2*pi; % input the time vector
>> x=F0.*(1-cos(w.*t))./m*w.^2; %
>> plot(t,x) % plotting the graph
>> grid on % drawing the coordinate grid
```

The result is presented in the figure 2.

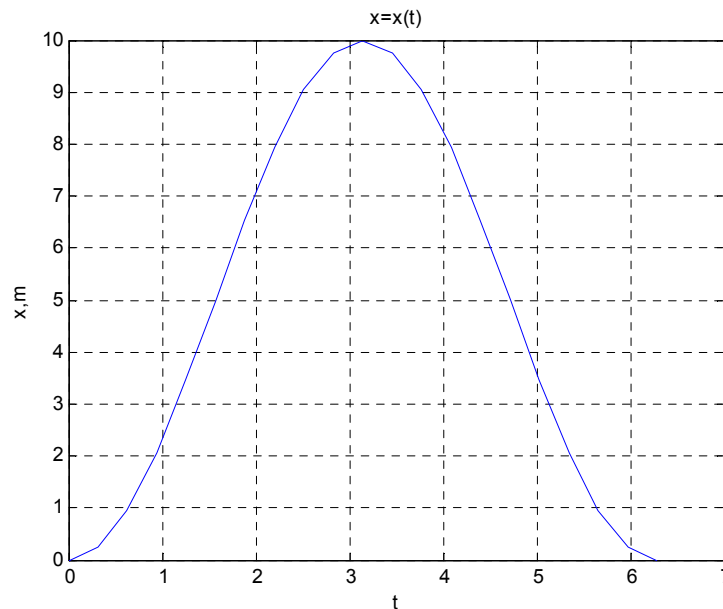


Figure 2 – The graph of displacement x versus time t

2. $F = at$, $a = 1$; The force is directly proportional to the time. Oscillation obeys the following law:

$$x = \frac{a}{m\omega^3}(\omega t - \sin \omega t) \quad (2)$$

The program for calculation and visualization:

```
>> a=1; % input the parameters
>> x=a.*(w*t-sin(w.*t))./m*w.^3; % calculation of the system oscillation
>> plot(t,x) % plotting the graph
>> grid on % drawing the coordinate grid
```

The result is presented in the figure 3.

3. $F = F_0 \exp(-at)$; The force exponentially decreases with time. Oscillation obeys the following law:

$$x = \frac{F_0}{m(\omega^2 + \alpha^2)} \left(e^{-\alpha t} - \cos \omega t + \frac{\alpha}{\omega} \sin \omega t \right) \quad (3)$$

The program for calculation and visualization:

```
>> F0=1; alfa=0.5; % input the parameters
>> F=F0.*exp(-alfa.*t); % calculation of the acting force
>> plot(t,F) % plotting the graph
>> grid on % drawing the coordinate grid
```

The result is presented in the figure 4.

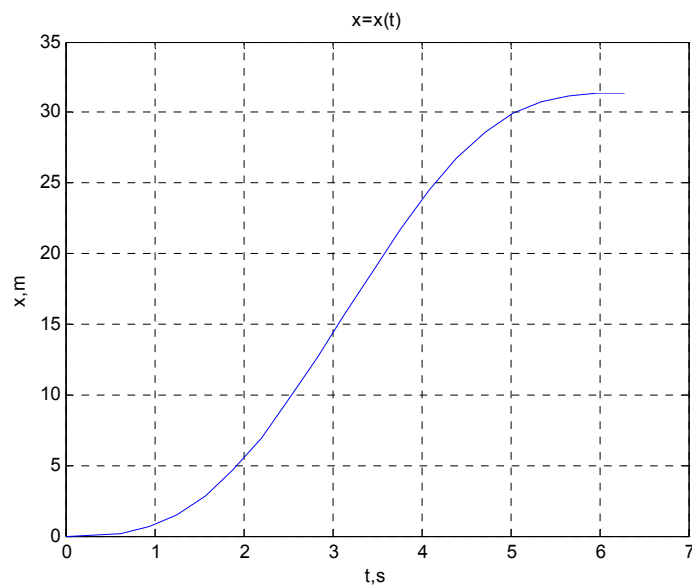


Figure 3 – Oscillation of the system under the action of the force proportional to time

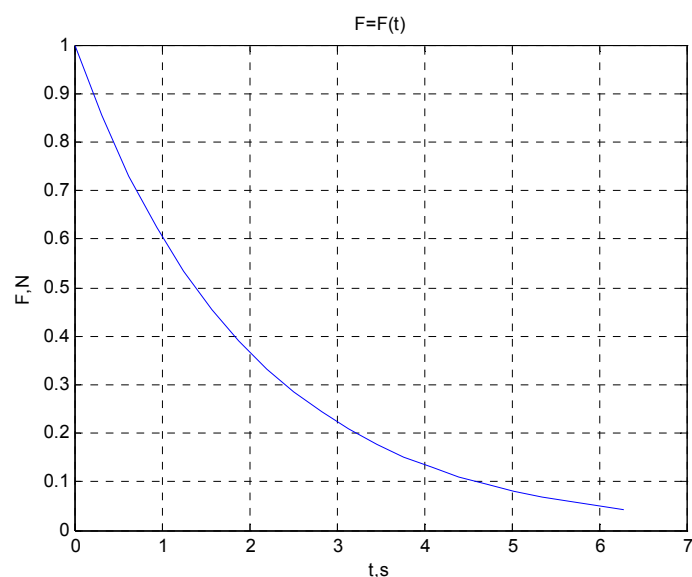
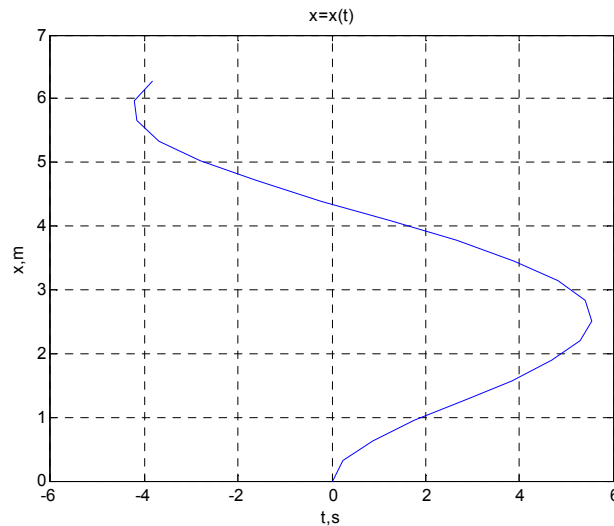


Figure 4 – The graph of the acting force versus time

```
>> A=F0/(m*w.^2+m*0.5.^2); % calculation of the first factor
>> B=exp(-0.5.*t)-cos(w.*t)+0.5*sin(w.*t)./w; % calculation of the second factor
>> x=A.*B; % calculation of the oscillation
>> plot(x,t) % plotting the graph
>> grid on % drawing the coordinate grid
```

The result is presented in the figure 5.

Figure 5 – Oscillation of the system under the action of the force $F=F_0 \exp(-\alpha t)$

4. $F=F_0 \exp(-\alpha t) \cos(\beta t)$. The solution of an inhomogeneous linear differential equation describing the oscillations under the action of such driving force is very complicated to understand its nature. It is easier to realize the solution in the form of graph using the following program for calculation and visualization:

```
>> beta=0.2;alfa=0.5; % input the parameters
>> F0=1; m=0.2; w=1; % input the parameters
>> t=0:pi/10:2*pi; % input the time vector
>> F=F0.*exp(-alfa.*t).*cos(beta.*t); % calculation of the acting force
>> plot(t,F); % plotting the graph
>> grid on % drawing the coordinate grid
```

The result is presented in the figure 6.

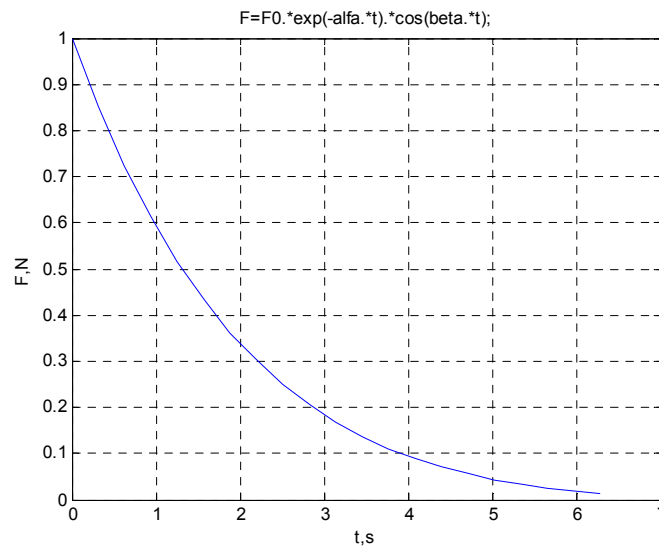


Figure 6 – The graph of the acting force versus time

Oscillation under the action of the given force obeys the following equation:

$$x = \frac{F_0}{m \left[(\omega^2 + \alpha^2 - \beta^2)^2 + 4\alpha^2 \beta^2 \right]} \left\{ -(\omega^2 + \alpha^2 - \beta^2) \cos \omega t + \right. \\ \left. + \frac{\alpha}{\omega} (\omega^2 + \alpha^2 + \beta^2) \sin \omega t + e^{-\alpha t} \left[(\omega^2 + \alpha^2 - \beta^2) \cos \beta t - 2\alpha\beta \sin \beta t \right] \right\} \quad (4)$$

Program for calculation and visualization:

```
>> beta=0.2;alfa=0.5; % input the parameters
>> A1=F0./m*((w.^2+alfa.^2-beta.^2).^2+4*alfa.^2*beta.^2);% calculation of factor
>> B1=-(w.^2+alfa.^2-beta.^2).*cos(w.*t); % calculation of the first term
>> C=alfa.*(w.^2+alfa.^2+beta.^2).*sin(w.*t); % calculation of the second term
>> D=exp(-alfa.*t).*((w.^2+alfa.^2-beta.^2).*cos(beta.*t)-2*alfa*beta.*sin(beta.*t));% calculation
of the third term
>> x=A1.*(B1+C+D); % calculation of the product of the factor and the sum of the terms
>> plot(x,t) % plotting the graph
>> grid on % drawing the coordinate grid
```

The result is presented in the figure 7.

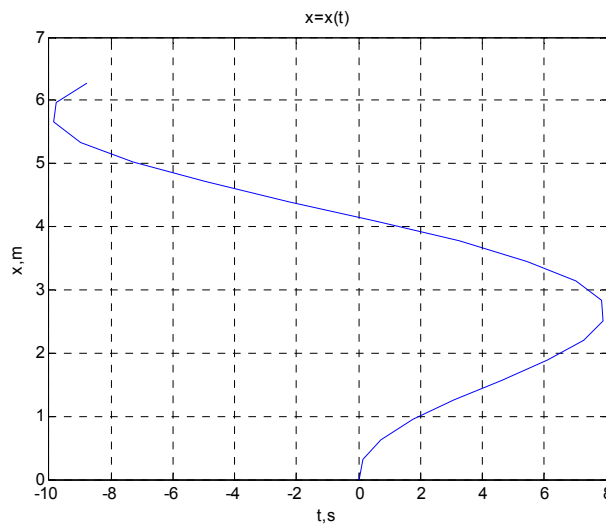


Figure 7 – Oscillation of the system under the action of the force $F=F_0 \exp(-\alpha t) \cos(\beta t)$

The graphs of oscillations of the system under the actions of forces $F=F_0 \exp(-\alpha t)$ and $F=F_0 \exp(-\alpha t) \cos(\beta t)$ for a longer time interval of oscillations are shown in figure 8. For comparison convenience the graphs are drawn in one graphic window. Below there is the program for calculation and visualization of oscillations in one graphic window:

```
>> t=0:pi/10:8*pi; input the time vector
>> A=F0/(m*w.^2+m*0.5.^2); % calculation of the first term
>> B=exp(-0.5.*t)-cos(w.*t)+0.5*sin(w.*t)./w; % calculation of the second term
>> x=A.*B; % calculation of the oscillation
>> subplot(2,2,1);plot(t,x);
>> grid on
>> beta=0.2;alfa=0.5; % input the parameters
>> A1=F0./m*((w.^2+alfa.^2-beta.^2).^2+4*alfa.^2*beta.^2);% calculation of the factor
>> B1=-(w.^2+alfa.^2-beta.^2).*cos(w.*t); % calculation of the first term
>> C=alfa.*(w.^2+alfa.^2+beta.^2).*sin(w.*t); % calculation of the second term
>> D=exp(-alfa.*t).*((w.^2+alfa.^2-beta.^2).*cos(beta.*t)-2*alfa*beta.*sin(beta.*t));%calculation
of the third term
>> x=A1.*(B1+C+D); % calculation of the oscillation
>> subplot(2,2,2);plot(t,x);
>> grid on
```

The result is presented in the figure 8.

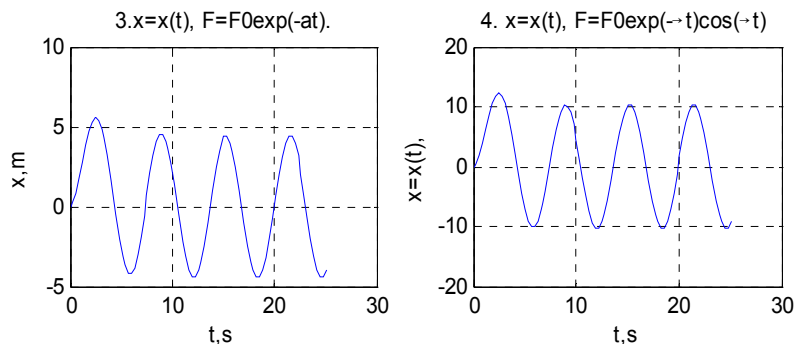


Figure 8 – The graphs of oscillations of the system under the action of forces $F=F_0 \exp(-at)$ and $F=F_0 \exp(-at) \cos(\beta t)$ in one graphic window

Here is the program for calculation and visualization of forces in one graphical window:

```
F0=1; alfa=0.5; % input the parameters
F=F0.*exp(-alfa.*t); % calculation of the acting force
>> plot(t,F) % plotting the graph grid on % drawing the coordinate grid
>> hold on
>> F=F0.*exp(-alfa.*t).*cos(beta.*t); % calculation of the acting force
>> plot(t,F,'-+'); % plotting the graph
```

The result is presented in the figure 9.

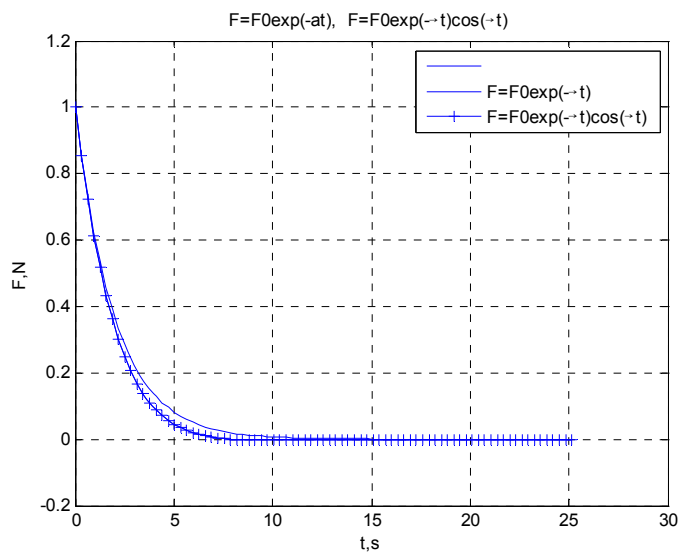


Figure 9 – The graphs of acting forces versus time

Conclusion. Formulas (1)-(4) describing the laws of oscillations are difficult for understanding the features of oscillations. Their visualization makes them more evident and clear.

Oscillations of the system under the actions of forces $F=F_0 \exp(-at)$ and $F=F_0 \exp(-at) \cos(\beta t)$ at first sight seem to be similar (see figures 5 and 7) since the graphs of these forces as a function of time are similar (see figures 4 and 6). However, if to draw the oscillations for a longer time (Fig. 8.), then it can be noticed that as the time goes on the oscillations begin to differ markedly from each other: under the action of the force $F=F_0 \exp(-at)$ the oscillation amplitude decreases considerably during the first 12 seconds, and further it decreases not so much; under the action of the force $F=F_0 \exp(-at) \cos(\beta t)$ the oscillation amplitude during the first 5 seconds increases and further practically doesn't change, i.e. the oscillation stabilizes.

So, the use of the MATLAB language for calculation and visualization of small forced oscillations shows that it is an effective tool for studying the complicated oscillations.

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**«АУЫТҚУЫ АЗ МӘЖБҮР ТЕРБЕЛІСТЕРДІ ЕСЕПТЕУ МЕН БЕЙНЕЛЕУГЕ»
АРНАЛҒАН КОМПЬЮТЕРЛІК ЗЕРТХАНАЛЫҚ ЖҰМЫСТЫ ОРЫНДАУДЫ
ҰЙЫМДАСТЫРУ**

Аннотация. Тербеліс жүйесіне тұрақты және айнаымалы күштер әсерінен туындаған мәжбүр тербелістерді есептеу мен бейнелеу программалары ұсынылады: 1. $F=const=F_0$. 2. $F=at$. 3. $F=F_0 \exp(-at)$. 4. $F=F_0 \exp(-at) \cos(\beta t)$. Берілген күштердің уақытқа тәуелділік графиктері бір терезеде салынған. Аталған күштердің әсерінен тербелген жүйенің бірөдшемді мәжбүр тербелісін есептеу мен бейнелеудің MATLAB жүйесіндегі программалары келтірілген. Мәжбүр тербелістердің уақытқы тәуелділік графиктері салынған. Мәжбүр тербелістерді сипаттайтын формулалар физика тұрғысынан түсініксіздеу, ал оларды график арқылы бейнелегенде тербеліс сипаты айқындалып, физика тұрғысынан түсінуге болады.

Бұл мәселені шешу үшін MATLAB тілі қолданылады. Физикалық процесстерді модельдеу және бейнелеу барысында MATLAB тілінің орасан зор мүмкіндіктері бар екені мәлім. MATLAB күрделі формулаларды график түрінде бейнелеуге мүмкіндік береді, бұл процестің немесе құбылыстың табиғатын түсінуін айтарлықтай жеңілдетеді түседі.

Мақаланың мақсаты $F(t)$ күштің әсерінен болған мәжбүр тербелісті есептеуге және бейнелеуге арналған MATLAB тілінде бағдарлама жасау. Зерттеу шарты бойынша бастапқы уақытта $t = 0$ жүйенің жылдамдығы тепе-теңдік күйде нольге тең деп аламыз, яғни жүйе тыныштық күйде болады ($(t = 0) = 0$, $v(t = 0) = 0$).

Зерттеу нәтижелері жоғары оқу орындарындағы теориялық механика дәрістерінде қолдануға болады.

Түйін сөздер: мәжбүр тербеліс, бейнелеу, тербелу уақыты, амплитуда.

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ОРГАНИЗАЦИЯ КОМПЬЮТЕРНОЙ ЛАБОРАТОРНОЙ РАБОТЫ «ВЫЧИСЛЕНИЕ И ВИЗУАЛИЗАЦИЯ МАЛЫХ ВЫНУЖДЕННЫХ КОЛЕБАНИЙ»

Аннотация. В статье рассматриваются вычисления и визуализации вынужденных колебаний системы под действием постоянных и переменных сил: 1. $F=const=F_0$; 2. $F=at$; 3. $F=F_0exp(-at)$; 4. $F=F_0exp(-at)cos(\beta t)$. Графики зависимости вышеупомянутых сил от времени представлены в одном графическом окне. Приведены программы для вычисления и визуализации вынужденных колебаний под действием данных сил. Представлены графики зависимости одномерных вынужденных колебаний от времени. Формулы (1-4), описывающие законы колебаний, являются трудными для понимания особенностей колебаний. Их визуализация делает природу колебаний системы более очевидной и ясной.

Для решения данной задачи использован язык MATLAB. Известно, что язык MATLAB обладает огромными возможностями для моделирования и визуализации физических процессов. MATLAB позволяет наглядно представить сложные формулы в виде графиков, что значительно облегчает понимание природы процесса или явления.

Цель данной статьи разработать программу на языке MATLAB для вычислений и визуализаций вынужденных колебаний системы под действием силы $F(t)$ если в начальный момент времени $t = 0$ система находится в покое в равновесном состоянии ($x(t=0)=0$, $\dot{x}(t=0)=0$).

Результаты исследования могут быть использованы на занятиях по теоретической механике в высших учебных заведениях.

Ключевые слова: вынужденные колебания, визуализация, график колебания, амплитуда.

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**DECISION-MAKING FOR CHOOSING
OF GEOLOGICAL AND ENGINEERING OPERATIONS:
CURRENT STATUS AND PROSPECTS**

Abstract. It is commonly known that great care is given to upgrading of the efficiency due to implementing of various new technologies and GTM during development of oil fields. Widespread introduction of GTM as well as enhanced oil recovery (EOR) and elaboration of their technologies raise the issues of relevant choice of the best methods ensuring proper technical and economical efficiency in particular conditions. Despite of the profound interest of the researches to the given question, major problems arise currently anyway at comparative evaluation of various types of GTM regarding particular conditions. The issue of upgrading of efficiency of GTM based on the integrated geological and physical and technological information is currently challenging and deserves relevant consideration. Deep analysis of the conditions for applying of various GTM using advanced techniques and corresponding software allows in its turn to give guidance to current possibilities in order to upgrade efficiency of field deposit. For many years the research focused on upgrading of the efficiency of field deposits had been conducted in various scientific and industrial organizations. The analysis of choosing and implementing of GTM at different deposits is of great interest. Review and analysis of up-to-date condition of problem of GTA choosing are illustrated in the article. Examples of application and performance evaluation of GTM are shown at different deposits. Development and upgrading of the analysis methods as well as forecasting of indicators and decision-making have been observed over the recent years. Their implementation allowed upgrading the efficiency of conducted geological and technical operations. As a result of conducted operations the researchers solved the issue of creating of integrated methodology and its mathematic, scheduled and information application for evaluating of efficiency and optimal scheduling of geological and technical operations at field deposits; structure of automated system of decision support and algorithm of its functioning have been created; by transforming the indicators characterizing the formation into the relevant factors, the equations (linear and multiplicative) were made expressing the dependence of the efficiency indicators of GTM from the formed factors; by variants calculation and analysis of comparative efficiency of any GTM in different conditions the directions were shown and the results of making decisions for choosing of the best GTM were obtained.

Key words: geological and technical measure (GTM), field development, decision-making, crude oil production, oil recovery.

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ПРИНЯТИЕ РЕШЕНИЙ ПО ВЫБОРУ ГЕОЛОГО-ТЕХНИЧЕСКИХ МЕРОПРИЯТИЙ: СОВРЕМЕННОЕ СОСТОЯНИЕ И ПЕРСПЕКТИВЫ

Аннотация. Как известно, повышению эффективности за счет применения различных новых технологий и ГТМ уделяется большое внимание при разработке нефтяных месторождений. Широкое внедрение ГТМ, а также с МУН и развитие их технологий ставит вопросы адекватного выбора наилучших методов, обеспечивающих должную технологическую эффективность в конкретных условиях. Несмотря на большой интерес исследователей к данному вопросу, все же в настоящее время серьезные затруднения возникают при сравнительной оценке различных видов ГТМ применительно к конкретным условиям. Проблема повышения эффективности ГТМ на основе комплексной геолого-физической и технологической информации в настоящее время является актуальной и заслуживает соответствующего внимания. Тщательный анализ условий применения различных ГТМ с использованием современных методов и соответствующего программного обеспечения позволит в свою очередь правильно сориентировать имеющиеся возможности с целью повышения эффективности разработки месторождения. На протяжении многих лет исследования, направленные на повышение эффективности разработки месторождений, проводились в различных научных и производственных организациях. Представляет интерес анализ опыта выбора и внедрения ГТМ на различных месторождениях. В статье приводится обзор и анализ современного состояния проблемы выбора ГТМ. Показаны примеры применения и оценки эффективности ГТМ на различных месторождениях. В последние годы наблюдается развитие и совершенствование методов анализа, прогнозирования показателей и принятия решений, реализация которых позволила повысить эффективность проводимых геолого-технических мероприятий. В результате проведенных работ исследователями решена задача создания комплексной методики и ее математического, программного и информационного обеспечения для оценки эффективности и оптимального планирования геолого-технических мероприятий на нефтяных месторождениях; разработана структура автоматизированной системы поддержки принятия решения и алгоритм ее функционирования; путем преобразования признаков, характеризующих пласт, в соответствующие факторы, построены уравнения (линейное и мультипликативное), выражающие зависимость показателей эффективности ГТМ от сформированных факторов; путем вариантных расчетов и анализа сравнительной эффективности того или иного ГТМ в различных условиях показаны пути и получены результаты принятия решений по выбору наилучшего ГТМ.

Ключевые слова: геолого-техническое мероприятие (ГТМ), разработка месторождений, принятие решений, добыча нефти, нефтеотдача.

Введение. В период эксплуатации нефтяного месторождения, как известно, проводятся работы на скважинах с целью регулирования его разработки и поддержания уровня добычи нефти. Этот комплекс работ называют геолого-техническими мероприятиями (ГТМ), за счет проведения которых нефтедобывающие компании обеспечивают достижение необходимых показателей разработки месторождений. Естественно, имеется производственная необходимость в оценке методов и критериев эффективности ГТМ.

Как известно, повышению эффективности за счет применения различных новых технологий и ГТМ уделяется большое внимание при разработке нефтяных месторождений. Широкое внедрение ГТМ, а также с МУН и развитие их технологий ставит вопросы адекватного выбора наилучших методов, обеспечивающих должную технологическую эффективность в конкретных условиях. Несмотря на большой интерес исследователей к данному вопросу, все же в настоящее время серьезные затруднения возникают при сравнительной оценке различных видов ГТМ применительно к конкретным условиям. Это связано с недостаточностью исследований, позволяющих дать прогнозную оценку эффективности ГТМ для тех условий, где по тем или иным причинам оно не применялось. Современный уровень развития методов анализа информации и принятия решений позволит это сделать при наличии комплексной геолого-физической и технологической

информации. В то же время опыт внедрения различных ГТМ на различных месторождениях подтверждает большое их значение в повышении показателей добычи нефти, а также обуславливает важность изыскания путей наиболее полного использования потенциальных возможностей имеющейся информации, хотя очень часто приходится сталкиваться с ее неопределенностью, как статистического, так и нестатистического характера. Отмеченное требует применения методов, позволяющих в зависимости от характера имеющейся информации строить соответствующие модели прогнозирования показателей эффективности и принимать решения в условиях многокритериальности.

Исходя из этого, проблема повышения эффективности ГТМ на основе комплексной геолого-физической и технологической информации в настоящее время является актуальной и заслуживает соответствующего внимания. Тщательный анализ условий применения различных ГТМ с использованием современных методов и соответствующего программного обеспечения позволит в свою очередь правильно сориентировать имеющиеся возможности с целью повышения эффективности разработки месторождения. На протяжении многих лет исследования, направленные на повышение эффективности разработки месторождений, проводились в различных научных и производственных организациях. Представляет интерес анализ опыта выбора и внедрения ГТМ на различных месторождениях.

Краткий обзор исследований, посвящённых геолого-техническим мероприятиям. В настоящее время на нефтяных месторождениях используются различные виды ГТМ, в частности обработка призабойной зоны (ОПЗ), гидроразрыв пласта (ГРП), бурение горизонтальных скважин, а также другие методы интенсификации добычи нефти, а также методы увеличения нефтеотдачи (МУН) пластов [1-3].

К настоящему времени предложены различные методики расчета эффективности применяемых ГТМ [4]. В целом, все мероприятия, проводимые на скважинах, по виду воздействия могут быть разделены на следующие виды: технические, ремонтные, МУН и интенсификация добычи нефти, ОПЗ.

Как показывает анализ литературы, с целью выбора наиболее эффективных ГТМ применяются различные модели для решения задач прогнозирования добычи нефти. Прогнозные показатели определяются сложившимися тенденциями добычи нефти и эффективностью планируемых ГТМ. Современные исследования, в том числе совершенствования существующих подходов к оценке эффективности ГТМ, позволяют осуществлять широкое внедрение новых систем программирования, автоматизации процесса оценки технологической эффективности применяемых методов повышения нефтеотдачи. Сюда следует отнести разработку программного комплекса EOR–Office, который представляет современный инструмент, предназначенный для автоматизации всего комплекса задач, стоящих перед специалистами, занимающимися повышением нефтеотдачи пластов [5, 6]. Одним из основных подходов к оценке технологической эффективности различных ГТМ в нефтяной промышленности является экстраполяционный. Суть экстраполяционных методов оценки технологической эффективности различных ГТМ состоит в построении базового уровня добычи нефти. Для этого фактическая добыча нефти при проведении ГТМ сравнивается с прогнозными данными, полученными при экстраполяции предыстории. При этом даже небольшие ошибки в построении базового уровня добычи, как отмечают специалисты, приведут к неадекватному подбору и планированию оптимальных ГТМ [7]. На практике фактическую эффективность ГТМ принято оценивать методами характеристик вытеснения нефти водой, т.е., по кривым обводнения – зависимостям типа $V_n = f(V_{ж})$ и по кривым изменения добычи нефти – зависимостям типа $V_n = f(t)$: здесь V_n и $V_{ж}$ – накопленные отборы соответственно нефти и жидкости; t – время. Согласно [7] общий эффект можно подразделять на эффект, обусловленный изменением характера вытеснения нефти и эффект, связанный с интенсификацией отбора жидкости. Рассчитывается дополнительное количество попутно добываемой воды. По кривым падения дебита нефти – зависимостям типа $V_n = f(t)$ определяется общий эффект ГТМ.

В настоящее время насчитываются десятки различных типов характеристик вытеснения [8, 9] и одной из проблем является выбор такой характеристики вытеснения, которая наилучшим образом согласовывалась с историей разработки объекта и обеспечивала наиболее точную экстраполяцию при прогнозе [10]. Так, в работе [11] рассматриваются некоторые вопросы, касающиеся

выбора наиболее точных методов оценки ГТМ, а также приводятся зависимости, отражающие возможные случаи дифференциации технологического эффекта метода повышения нефтеотдачи. По мнению автора, прогнозирование эффекта (т.е. расчет ожидаемого эффекта) ГТМ, основанное на экстраполяции кривых фактической и базовой добычи нефти, с использованием методов характеристик может быть не всегда надежным. Данное обстоятельство автор связывает со следующими причинами. По его мнению, при том, как продолжительность эффекта от применения некоторых видов ГТМ (например, ГРП) колеблется в интервале 5-7 лет использование кривых обводнения для сравнительно долгосрочных прогнозов может быть надежным только при высокой обводненности, как правило, превышающей 50-70%. При более низкой обводненности (на ранних стадиях) продолжительность прогноза не должна превышать 3-6 месяцев. Однако многие виды ГТМ проводятся в безводных или малообводненных скважинах.

Также в работе отмечается, что при наличии представительной информации по падающей добыче нефти после проведения ГТМ (не менее 4-6 точек) является возможным надежная экстраполяция характеристик вытеснения. В этих условиях целесообразным может быть применение методов прогнозирования, основанных на использовании коэффициентов падения дебита нефти. Если информация по отборам нефти после проведения ГТМ не представительна, то можно применять коэффициенты падения отборов по другим скважинам с более продолжительным периодом эксплуатации после ГТМ. Исходя из вышеизложенного совершенствование методов характеристик вытеснения и на сегодняшний день стоит на повестке дня и является вполне актуальным [12]. В работе [13] объектом прогноза являются скважины, кусты, участки, (группы скважин), цех, пласт, нефтегазодобывающее предприятие, и др., интервалы прогноза – месяц, квартал, год. В зависимости от характера и очередности планируемых мероприятий возникает необходимость проведения многовариантных расчетов, что в свою очередь требует соответствующего программного обеспечения с применением современного математического аппарата. В связи с этим в [13] рассмотрена технология расчетов прогнозных показателей, реализованная в интегральном программном комплексе (ИПК) «Баспро-аналитик» (разработка ЗАО «Аналитический центр СибИНКор») и применяемая в практике анализа показателей разработки месторождений Нижневартовского района. Решение задач предполагает использование двух программных модулей: «Баспро-характеристики» – обеспечивает расчет базовой добычи при сложившейся системе разработки и оценку эффекта от проведенных ГТМ; «Баспро-прогноз» – рассчитывает прогнозную добычу нефти с учетом предполагаемого эффекта от планируемых ГТМ.

В работе приводятся схемы, иллюстрирующие процесс расчета базового варианта добычи нефти, а также его прогнозного варианта. Показана классификация показателей технологической эффективности проведения ГТМ. Применительно к геологическому строению Ершового месторождения установлена эффективность различных ГТМ. Как отмечают авторы, данный принцип был в полной мере использован для составления программы ГТМ и прогнозирования технологических показателей разработки Ершового нефтяного месторождения, осуществляемой ОАО «Тюменская нефтяная компания». Расчетные показатели оценки эффекта ГТМ определяются в соответствии с «Методическим руководством по оценке технологической эффективности применения методов увеличения нефтеотдачи пластов». Используемая в программе методика основана на определении характеристик вытеснения, аппроксимирующих наилучшим образом фактические данные истории добычи нефти. Аппроксимация осуществляется на интервале настройки, задаваемом пользователем и принадлежащем интервалу истории. Погрешность аппроксимации оценивается «в смысле наименьших квадратов». Эффект в «Баспро-характеристики» автоматически разделяется на две составляющие: эффект по нефтеотдаче и эффект по интенсификации. Параллельно с двумя основными эффектами рассчитывается эффект от снижения объемов попутно добываемой воды. Если характеристика базовой добычи была уже рассчитана и хранится в базе «прогнозной добычи», «Баспро-характеристики» позволяет рассчитывать эффект, сопоставляя эти данные и фактическую добычу [14].

Развитие математических методов моделирования и современных средств вычислительной техники дает возможность определения технологической эффективности ГТМ для рассматриваемого нефтегазового объекта двумя возможными путями, считает автор унифицированной методики расчета эффективности ГТМ [9]: постоянно действующей многомерной детерминиро-

ванной моделью фильтрации; малопараметрической вероятностно-статистической моделью на основе данных истории разработки.

В первом случае требуется создание геологической и фильтрационной моделей объекта и наличие соответствующего программного обеспечения, описывающего процессы в пласте. Данный подход требует относительно больших затрат времени и средств.

Во втором случае оценка технологической эффективности выполняется без привлечения фильтрационной модели объекта. Второй подход не требует больших затрат времени и средств и может использоваться при определении эффективности ГТМ.

Методика предусматривает оценку достоверности исходных данных, теоретические предпосылки, тестирование предлагаемой методики, а также инструкцию к программному комплексу. Это позволяет повысить качество и достоверность принимаемых решений. Другие авторы [10] проводят анализ используемых в настоящее время методических положений по оценке технологической эффективности ГТМ, а также представляют результаты численных экспериментов по оценке эффективности ГТМ с использованием программного комплекса “БАСПРО-Характеристики” (методика СибНИИ НП) на реальных данных (ряде участков Самотлорского месторождения) и на модельных характеристиках, рассчитанных на идеализированной трехмерной гидродинамической модели.

На основе трехмерных гидродинамических расчетов модельных и реальных участков нефтяных пластов ими были проведены экспериментальные расчеты с использованием программных комплексов «Tempest MORE (Rohar) и Eclipse (Schlumberger)», результаты которых сопоставлялись с инженерными расчетами по следующим методикам оценки технологической эффективности ГТМ: методика ВНИИнефти [8, 15], СибНИИ НП [16], Казакова А.А. [7, 8, 17] и Шахвердиева А.Х. [18]. Такой подход к применению гидродинамических моделей дает возможность тестировать методики оценки технологической эффективности на «синтетических» показателях разработки, полученных в процессе моделирования по отдельным скважинам. В связи с анализом данных и поддержкой принятия решения о ГТМ тюменскими специалистами [19] предложена концепция корпоративной базы знаний ТНК, предназначенной для хранения, развития, использования опыта и эмпирических знаний специалистов компании, занимающихся геолого-технологическими мероприятиями (ГТМ) [11]. Организация работы с базой знаний основана на использовании Интернет. Содержание базы знаний структурируется в виде пар “ГТМ – ситуация, при которой выполнялось мероприятие”. Для формализации представления ситуаций, разработки алгоритмов ситуационного анализа (методы общего ситуационного подхода) и поиска использован математический аппарат гиперграфов.

Ситуационный метод (ситуационные модели в корпоративных базах знаний) основан на поиске и использовании аналогий, известных из реального опыта профессиональной деятельности. Реальность опыта для инженера может быть более важной, чем результаты математического моделирования. Интерес может представлять соединение обоих подходов, при котором ситуации-аналоги будут использованы для выбора предполагаемых параметров ГТМ.

Формированию базы данных ГТМ по скважинам, рекомендуемым под добычу, а также соответствующим критериям для выбора ГТМ посвящена работа [5]. Согласно данной работе для формирования базы данных ГТМ по скважинам по каждому пласту выбираются следующие критерии: текущая нефтенасыщенная толщина более 2 м; пласт не перфорирован, либо по текущему фонду скважина недобывающая; пласт не имеет слияния с перфорированным пластом, либо скважина недобывающая (данный критерий может не учитываться); в радиусе менее 500 м нет добывающих по текущему фонду скважин, работающих на данный пласт; глинистость пласта менее 6% (данный критерий может не учитываться, если предполагается применение МУН (разглинизация); проницаемость пласта более 0,07 мкм². По всем рассматриваемым пластам подсчитываются прогнозные дебиты. Размещение выбранных скважин проверяется по картам текущих нефтенасыщенных толщин. Выбранные скважины включаются в базу ГТМ как рекомендуемые для перевода под добычу нефти. По мнению авторов, предложенные критерии позволяют проводить выбор скважин для формирования базы данных с помощью ЭВМ с последующей проверкой по построенным картам, что при большом объеме информации гораздо эффективнее, чем выбор скважин вручную. Этот порядок формирования базы данных для разработки ГТМ был применен

при выработке рекомендаций по Абдрахмановской, Чишминской и Восточно-Сулеевской площадям Ромашкинского месторождения [20].

В статье [21] рассматривается решение задачи формирования базы данных ГТМ по скважинам, рекомендуемым под добычу, с использованием метода нечетких множеств на примере пласта «а» горизонта D_1 Восточно-Сулеевской площади Ромашкинского месторождения. Под нечетким множеством здесь понимается объект, о принадлежности к которому можно судить только с некоторой долей уверенности. Решение задачи выбора скважин для рекомендации под добычу для каждого пласта сводится к определению для всех скважин функций принадлежности к множеству «скважина, рекомендованная для перевода под добычу». Наличие множества критериев, зачастую противоречивых, создает затруднения в выборе наилучшего решения [22]. В связи с этим авторы сводят решение многокритериальной задачи к однокритериальной с помощью теории нечетких множеств, считая этот критерий как меру целесообразности проведения предусмотренного ГТМ, что, по их мнению, позволяет осуществить быструю ранжировку возможных вариантов решения по степени целесообразности и сформировать наиболее предпочтительный график работ.

Автор [23] при оценке эффективности мероприятий по увеличению добычи нефти и конечной нефтеотдачи предлагает следующую концепцию.

Для определения эффективности какого-либо дополнительного технического мероприятия по увеличению текущей добычи и конечной нефтеотдачи следует рассчитать два варианта разработки нефтяной залежи (эксплуатационного объекта): без дополнительного мероприятия (базовый вариант); с дополнительным мероприятием. Для достоверного определения действительно введенных в разработку начальных извлекаемых запасов нефти и жидкости, их изменений – необходима регулярная и удовлетворительная по точности информация о работе добывающих и нагнетательных скважин (их дебитах нефти и жидкости, закачке воды и забойных давлениях) по рассматриваемым эксплуатационным объектам [23, 24].

Анализ выполненных работ свидетельствует о том, что большинство авторов считает, что для уточнения геологических условий распределения текущих запасов нефти, оценки эффективности применения методов увеличения нефтеотдачи (МУН) и осуществления прогноза для новых участков залежи необходимо построение геолого-фильтрационных моделей. В этой связи рассмотрен методический подход к разработке и внедрению корпоративных программных продуктов, ориентированных на массового пользователя и предназначенных для эксплуатации геолого-фильтрационных моделей, применительно к задачам повышения нефтеотдачи пластов.

Для оперативного решения производственных задач авторами была использована программная продукция – трехмерная информационно-аналитическая система (ТРИАС), разработанная сотрудниками НИИ математики и механики им. Н.Г.Чеботарева и ООО «Венсис» при активном участии специалистов производственных организаций [25].

В рамках этой системы используется понятие постоянно действующей модели (ПДМ). Под ПДМ понимается единая компьютерная технология, представляющая собой совокупность цифровой интегрированной геологической, геофизической, гидродинамической информации (база данных), 3D геологической и фильтрационной моделей и программных средств построения и просмотра моделей, выдачи отчетного графического и табличного материала. В работе дано описание основных функций программных модулей. В расчетную группу входят три модуля, предназначенных для построения геологической, фильтрационной моделей и модели ГТМ. Модуль построения геологической модели работает при наличии базы данных по первичным показателям, модуль построения фильтрационной модели (Fluid) действует при условии построенной геологической модели (Geo), модуль оценки и прогноза эффективности ГТМ (GTM) использует для работы результаты построения геологической и фильтрационной моделей.

Таким образом, охватывается практически вся геолого-промысловая информация. Выделены классы нефтепромысловых задач. В связи с ГТМ в расчетной группе программных модулей имеется модуль GTM, который выполняет две функции: оценку эффективности применения ГТМ; анализ эффективности ГТМ в различных геолого-промысловых условиях.

Приведенный выше обзор свидетельствует о большом интересе исследователей к вопросу оценки эффективности ГТМ, разработке научно-обоснованных методических подходов, анализу и

выбору наилучших вариантов решений, и тем самым еще раз подтверждает важность и актуальность поиска решений по повышению эффективности ГТМ.

Как видно из вышеприведенного краткого обзора, выполнено большое количество исследований, посвященных оценке технологической эффективности как отдельного вида ГТМ, так и в целом, а также разработаны соответствующие руководящие документы.

Эти исследования, а также результаты проведенных в ряде районов ГТМ при их обобщении позволяют решить ряд задач, ответив на некоторые вопросы, в частности, прогнозной оценки относительной эффективности различных видов ГТМ на рассматриваемом конкретном объекте, а также установления объекта наиболее подходящего для конкретного вида ГТМ.

Решение этих вопросов затрудняется отсутствием подхода, заключающегося в тщательном статистическом анализе комплексной геолого-геофизической и технологической информации, моделей, выражающих связь показателей эффективности того или иного вида ГТМ с параметрами, характеризующими рассматриваемый объект (пласт). Кроме того, в ряде случаев принятие решений по выбору ГТМ существенно затрудняется отсутствием или недостаточностью информации.

Современный уровень развития математических методов и информационных технологий, а также результаты их успешного применения на различных этапах исследовательских работ позволяют решить поставленные задачи также в условиях ограниченного объема информации.

Как видно из обзора, это обстоятельство было учтено в ряде работ, посвященных оценке эффективности отдельных видов ГТМ.

Все известные методики определения технолого-экономической эффективности применения ГТМ основаны на сравнении определенных зависимостей, полученных в результате его внедрения, с базовой. Например, при оценке эффективности заводнения используются фактические зависимости вытеснения при применении данного метода и без него. При этом, очевидно, что основная задача заключается в правильной аппроксимации естественного базового хода процесса без применения ГТМ [8, 18, 26, 27].

В свете изложенного наряду с разработкой эффективных методик оценки технолого-экономической эффективности ГТМ особое значение приобретает разработка новых подходов, позволяющих дать технолого-экономическую оценку не только отдельно взятому ГТМ в конкретных условиях, но и сравнительной эффективности того или иного ГТМ в различных физико-геологических и технико-технологических условиях.

Это позволит осуществить рациональный подбор под те или иные ГТМ как скважин, залежей, так и их технологий.

В связи с этим в работе [26] предлагается система расчетов показателей эффективности ГТМ на основе данных о технологических, физико-геологических и промысловых признаках, комплексно характеризующих условия проведения того или иного ГТМ. С учетом этого нами выполнены исследования согласно несколько упрощенному и усовершенствованному варианту системы [26]. Согласно приведенной схеме состояние скважин, оборудования, историю освоения, технологию проведения ГТМ характеризуют технологические признаки; физико-геологические признаки – это состояние и свойства нефтяной залежи, а именно: пористость, проницаемость, нефтенасыщенность, продуктивность отложений и др.; промысловые – система разработки залежи, текущая и накопленная добыча нефти до и после проведения ГТМ, особенности взаимодействия скважин и др.

Таким образом, выбранные технологические, физико-геологические и промысловые признаки формируют информационный массив, позволяющий охарактеризовать рассматриваемый объект, технологию проведения ГТМ и их влияние на результаты проводимых мероприятий.

Анализ и оценка влияния геолого-технологических характеристик объекта на показатели эффективности ГТМ. Как показал анализ накопленных к настоящему времени исследований, для повышения эффективности разработки нефтяных месторождений и интенсификации добычи нефти применяется большое количество различных ГТМ. Эффективность их применения зависит от рационального сочетания большого числа физико-геологических, технологических и промысловых признаков, комплексно характеризующих условия проведения того или иного ГТМ. На практике, как правило, для конкретных месторождений выбор ГТМ, их параметров, так же, как и их технологическое и экономическое обоснование, осуществляется в геологических службах НГДУ на основе приобретенного опыта. При этом очень часто, несмотря на опыт и знания геоло-

гических служб НГДУ, выбор участков, ГТМ и их технологии проводится не всегда адекватно конкретным геологическим и технологическим условиям разработки. Практически отсутствует единый подход, с использованием которого можно было бы дать правильную технолого-экономическую оценку не только отдельно взятому ГТМ в конкретных условиях, но и прогнозную оценку сравнительной эффективности его в различных физико-геологических и технико-технологических условиях.

Благодаря развитию в последние годы методов, учитывающих отмеченные обстоятельства, появляется возможность решить поставленные задачи на более высоком уровне. Здесь имеется в виду возможность создания различных моделей, а также соответствующих программ, основывающихся на комплексной геолого-геофизической и технико-технологической информации и позволяющих принимать наиболее обоснованные технологические решения.

С целью построения таких моделей, использованы данные о геолого-технических мероприятиях, проводимых на объектах различных месторождений Казахстана [26, 28, 37]. В качестве признаков, от которых зависит эффективность геолого-технического мероприятия, служат: общая толщина пласта, м (x_1), нефтенасыщенная толщина, м (x_2), вскрытая нефтенасыщенная толщина, м (x_3), коэффициент песчаности (x_4), пористость д.ед. (x_5), проницаемость, $K_{пр} \cdot 10^{-3}$ мкм² (x_6), вязкость нефти, мПа·с (пластовое условие) (x_7), плотность нефти т/м³ (x_8), газосодержание, м³/т (x_9), начальная нефтенасыщенность, д.ед. (x_{10}), пластовая температура, Т⁰С (x_{11}), содержание в нефти парафина, % (x_{12}), содержание в нефти серы, % (x_{13}), дебит нефти до геолого-технического мероприятия, т/сут (x_{14}), дебит жидкости до геолого-технического мероприятия, т/сут (x_{15}), обводненность до геолого-технического мероприятия, % (x_{16}). В качестве показателей геолого-технического мероприятия служат: продолжительность эффекта, сут. (Y_1), дополнительная добыча нефти, т. (Y_2), прирост дебита нефти, т. (Y_3), дебит нефти после геолого-технического мероприятия, т/сут (Y_4), обводненность после геолого-технического мероприятия, % (Y_5).

Таким образом, исходные данные включают по каждому виду ГТМ 16 признаков и 5 показателей эффективности. Далее согласно работам [30, 32, 41], проводится преобразование исходных данных с целью сокращения числа входных переменных.

Далее с помощью корреляционного анализа устанавливались зависимости показателей ГТМ от отмеченных факторов и перед тем, как перейти к корреляционному анализу, необходимо убедиться в подчинённости данных нормальному закону распределения, что является одним из требований. Существует много различных критериев для проверки данного условия. Проверка на нормальность является обязательной процедурой в ходе проведения измерений, контроля, испытаний, обработки согласно Российскому ГОСТ. Существуют различные критерии, нами использован критерий Шапиро-Уилка [29, 37].

Критерий Шапиро-Уилка основан на отношении оптимальной линейной несмещенной оценки дисперсии к ее обычной оценке методом максимального правдоподобия. Статистика критерия имеет вид:

$$W = \frac{1}{s^2} \left[\sum_{i=1}^n a_{n-i+1} \cdot (x_{n-i+1} - x_i) \right]^2, \quad (1)$$

$$\text{где } s^2 = \sum_{i=1}^n (x_i - \bar{x})^2, \bar{x} = \frac{1}{n} \sum_{i=1}^n x_i$$

Числитель является квадратом оценки среднеквадратического отклонения Ллойда [30]. Определялись критические значения статистики $W(\alpha)$ согласно данным литературы, например, [29]. Если $W < W(\alpha)$, то нулевая гипотеза нормальности распределения отклоняется на уровне значимости α .

Проведенные расчеты дают возможность обосновать применение данных при корреляционном анализе.

С целью построения зависимостей выбранных критериев от влияющих факторов, данные об условиях и результатах ГТМ были подвергнуты корреляционному анализу. При этом данные подвергались статистической обработке двумя путями с применением программы линейной регрессии.

1. Строились зависимости показателей эффективности от геолого-технологических факторов по их натуральным значениям:

$$Y = a_0 + \sum_{i=1}^9 a_i x_i \quad (2)$$

2. Все данные предварительно логарифмировались, строилась такая линейная зависимость, которая путём потенцирования превращалась в мультипликативную, с дальнейшим уточнением путём последовательного приближения:

$$Y = a_0 x_1^{b_1} \cdot x_2^{b_2} \cdot \dots \cdot x_9^{b_9} \quad (3)$$

Каждое уравнение представляло собой зависимость того или иного показателя эффективности от выбранных факторов. Такие уравнения строились для каждого вида ГТМ.

После получения уравнений регрессии была установлена степень соответствия расчетных значений показателей эффективности для различных ГТМ по уравнениям фактическим. Количественная оценка степени соответствия определяется мерой идентичности согласно формуле, приведенной в работе [31], значения которой должны изменяться в пределах $0 \leq I \leq 1$:

$$I = \frac{1}{1 + \frac{\sum_{i=1}^N (Y_{расч\ i} - \bar{Y})^2}{\sum_{i=1}^N (Y_{факт\ i} - \bar{Y})^2}} \quad (4)$$

При использовании комплексной геолого-геофизической и технико-технологической информации для принятия наиболее обоснованного технологического решения в зависимости от типа ГТМ выбирается тот вид уравнения регрессии, который имеет большую меру идентичности.

Принятие решений при выборе ГТМ. Результаты расчетов по полученным моделям используются при принятии решений по выбору наилучшего ГТМ для рассматриваемых условий. Это осуществлялось с помощью показателей эффективности ГТМ, принятых в качестве критериев, таким образом, чтобы искомое решение должно было бы удовлетворять условиям 5 критериев. Как показывает обзор, разными авторами использовались различные критерии выбора ГТМ. Весь процесс можно представить в виде системы, упрощенная схема которой приведена на рисунке. При решении многокритериальных задач возникают трудности, связанные с одновременным удовлетворением всех критериев, т.е. приходится принимать решения в условиях неопределённости.

В последнее время для решения таких задач, успешно используются различные методы, такие, как метод объединения критериев в один, обобщённый, метод «наименьших уступок», положения теории нечетких множеств, разработанной Л. Заде. Приведённая в работах [2, 17] классификация неопределённостей позволяет оценить ситуацию и выбрать для принятия решений наиболее подходящий метод. Далее для принятия решений был использован метод, называемый методом «наименьших уступок» [32, 37].

При применении данного метода решение многокритериальной задачи сводится к поочередной максимизации (минимизации) частных критериев и выбору величин уступок. Причем вначале производится качественный анализ относительной важности частных критериев, и они нумеруются в порядке убывания важности. Затем назначают величину допустимого снижения значения первого по важности критерия и максимизируют второй по важности критерий при условии, что значение первого критерия не должно отличаться от максимального более чем на величину установленного снижения. Снова назначают величину уступки, но уже по второму критерию и находят максимум третьего по важности критерия при условии, чтобы значения первых двух критериев не отличались от ранее найденных максимальных значений больше чем на величины соответствующих уступок. Далее таким же образом используются все остальные частные критерии. Получаемые в итоге стратегии считаются оптимальными.

В последнее время проблемы управления и принятия решений все больше стали привлекать внимание исследователей-нефтяников. Для выбора геолого-технических мероприятий в работе А. А. Колтуна [39] используются данные об истории разработки (метод базовой кривой), что не позволяет в полной мере учесть гидродинамические процессы и взаимовлияния скважин, тем самым, снижая достоверность получаемых решений. Но широкое развитие гидродинамического



Упрощенная схема системы выбора ГТМ

моделирования, как средства для выбора геолого-технических мероприятий создало предпосылки для автоматизации их выбора [33].

В работе А. Cottini-Loureiro и М. Araujo [33, 34] было предложено использование карт эффективности для выбора схемы размещения скважин, но временные затраты на построение карт эффективности сильно зависят от размерности гидродинамической модели и являются процессом требовательным к вычислительным ресурсам. При введении в эксплуатацию новых скважин происходит изменение динамики работы существующих, что не позволяет анализируемому методу учесть взаимовлияния скважин во времени и обладает высокими требованиями к вычислительным ресурсам.

Благодаря близкому расположению скважин выбор схемы размещения их, как показано в работе G. Santellani и B. Hansen [35], приводит к затруднению учета их взаимовлияния, здесь также следует отметить, что применение метода, изложенного в данной работе, вынуждает отказаться от использования зарекомендовавших себя существующих схем размещения скважин.

В ряде исследований рассматриваются вопросы построения информационной системы поддержки принятия решений при выборе вида геолого-технического мероприятия на нефтедобывающей скважине для повышения ее производительности. В некоторых из них выбор вариантов на проведение определенного вида мероприятия ведется в соответствии с этапами системного анализа проблемных ситуаций [36]. В данной работе описание работы информационной системы дается на примере одного из основных программных модулей, позволяющего рассчитать экономическую эффективность геолого-технического мероприятия, такого, как гидроразрыв пласта [36]. Описаны основные этапы процесса принятия решений при выборе вида ГТМ. При этом процесс выбора скважин для проведения определенного вида ГТМ проходит следующие этапы: анализ ситуации (выявление потребности на проведение ГТМ для конкретной скважины); установление целей (определение параметров, на изменение значений которых должно быть направлено ГТМ); выработка решений и анализ альтернатив (формирование перечня возможных видов ГТМ для достижения поставленных целей, оценка их эффективности); реализация решения (проведение ГТМ); оценка результатов (мониторинг состояния скважины после проведения ГТМ, анализ результатов).

Предлагаемая информационная система включает в себя несколько программных модулей по числу видов ГТМ [36]. Как отмечают авторы, такой показатель, как достижение запланированного прироста дебита нефти, нельзя рассматривать как единственный критерий оценки эффективности проведения геолого-технических мероприятий. Очевидно, что для более полного анализа необходимым является дополнительный анализ таких показателей, как количество нефти, дополнительно добытое вследствие проведения ГТМ, а также продолжительность эффекта от мероприятия. В статье приведены результаты анализа эффективности ГТМ за 2011-2014 гг. с применением указанного подхода.

С учетом значительного количества месторождений, разрабатываемых ООО «ЛУКОЙЛ-ПЕРМЬ», все они условно разделены на группы по географическому признаку [38]. В отмеченной работе приведены сведения о проведенных в 2011-2014 гг. геолого-технических мероприятиях на скважинах по группам месторождений, направленных на увеличение продуктивности скважин, таких, как гидроразрыв пласта, кислотные обработки, радиальное бурение, повторная и дополнительная перфорации.

Как следует из представленных данных, чаще других на скважинах месторождений всех групп, за исключением северной, проводится повторная и (или) дополнительная перфорация. На скважинах северной группы месторождений наиболее распространенным видом воздействия, как отмечают авторы, является гидроразрыв пласта.

Таким образом, исследованиями в этом направлении показана возможность оценки сравнительной эффективности и принятия решений при выборе ГТМ в различных условиях.

Заключение. Практика применения ГТМ показывает, что нередко их внедрение оказывается малоэффективным. Поэтому представляет интерес проведение сравнительного анализа с целью оценки эффективности их применения не только в условиях их проведения, но и условиях, где они не проводились. Такая оценка должна основываться на соответствующих моделях, выражающих зависимость показателей эффективности от признаков, характеризующих геолого-физические условия применения того или иного мероприятия в рассматриваемых или аналогичных условиях другого месторождения.

Полученные для этой цели модели позволяют прогнозировать показатели эффективности того или иного вида ГТМ в новых геолого-физических условиях. В связи с этим предложены системы и расчетные схемы, с помощью которых можно прогнозировать показатели для условий, отличных от тех, где применялось ГТМ. Результаты расчетов были использованы при принятии решений по выбору наилучшего ГТМ для рассматриваемых условий. Это осуществлялось с помощью показателей эффективности ГТМ, принятых в качестве критериев, таким образом, чтобы принятое решение удовлетворяло бы всем принятым критериям.

Таким образом, в последние годы наблюдается развитие и совершенствование методов анализа, прогнозирования показателей и принятия решений, реализация которых позволила повысить эффективность проводимых геолого-технических мероприятий. В результате проведенных работ исследователями решена задача создания комплексной методики и ее математического, программного и информационного обеспечения для оценки эффективности и оптимального планирования геолого-технических мероприятий на нефтяных месторождениях; разработана структура автоматизированной системы поддержки принятия решения и алгоритм ее функционирования; путем преобразования признаков, характеризующих пласт, в соответствующие факторы, построены уравнения (линейное и мультипликативное), выражающие зависимость показателей эффективности ГТМ от сформированных факторов; путем вариантных расчетов и анализа сравнительной эффективности того или иного ГТМ в различных условиях показаны пути и получены результаты принятия решений по выбору наилучшего ГТМ.

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ҚАЗІРГІ ЗАМАНҒЫ ЖАҒДАЙЫ ЖӘНЕ ЖЕТІСТІКТЕРІ: ГЕОЛОГО-ТЕХНИКАЛЫҚ ШАРАЛАРДЫ ТАҢДАУ БОЙЫНША ШЕШІМНІҢ ҚАБЫЛДАНУЫ

Аннотация. Мұнай кенорындарын игеру кезінде ГТШ және әртүрлі жаңа технологияларды қолдану есебінен тиімділікті арттыруға көп көңіл бөлінеді. Нақты жағдайда қажетті технолого-экономикалық тиімділікті қамтамасыз етуде, ең жақсы әдісті дұрыс таңдауда, олардың технологияларын дамуы және МАӘ, сонымен қатар ГТШ кеңінен қолдануда көптеген сұрақтар қойылады. Мұндай сұрақтарға зерттеушілердің үлкен қызығушылықтарымен қатар, қазіргі таңда нақты жағдайда әртүрлі ГТШ түрлерін салыстырмалы бағалау кезінде маңызды қиыншылықтар туындайды. Қазіргі таңда кешенді геолого-физикалық және технологиялық ақпараттар негізінде ГТШ тиімділіктерін арттыру мәселелері актуалды және сәйкесінше шешім қабылдануға ие болады. Кенорынды игерудің тиімділігін арттыру мақсатында алдымен бар мүмкіндікті дұрыс реттеу сәйкесінше дұрыс бағыттауға мүмкіндігі бар бағдарламаларды және қазіргі таңдағы әдістерді қолданумен әртүрлі ГТШ қолдану жағдайы мұқият талдау жасауға мүмкіндік береді. Көп жылдар бойы зерттеулер әртүрлі ғылыми және өндірістік ұйымдарда, кенорында игерудің тиімділігін арттыруға бағытталып жүргізілді. Әртүрлі кенорында ГТШ енгізу және таңдау тәжірибелерін талдау қызығушылықты тудырады. Мақалада ГТШ таңдаудың қазіргі таңдағы жағдайын талдау және жинақтар келтіріледі. Әртүрлі кенорындарда ГТШ тиімділіктерін бағалау және қолдану мысалдары көрсетілген. Соңғы жылдары өткізілген геолого-техникалық шаралардың тиімділігін арттыру реализациясы, шешімдер қабылдану және көрсеткіштер болжамдары, талдау әдістерін жетілдіру және дамуы байқалады. Мұнай кенорындарында геолого-техникалық шараларын тиімді жоспарлау және тиімділікті бағалау үшін кешенді әдістерді құру және олардың математикалық, бағдарламалық және ақпараттық қамтамасыз ету тапсырмалары зерттеушілердің жүргізілген жұмыстары нәтижелерінде шешілген; шешімді қабылдауды қолдаудың және оның алгоритмінің жұмыс істеуінің автоматтандырылған жүйелер құрылымы игерілген; қалыптасқан факторлардан ГТШ тиімділігінің көрсеткіштерін көрсететін, сәйкесінше факторларға қабатты сипаттайтын, қайта құру белгілері жолымен (сызықты және мультипликативтік) теңдеулер құрастырылды; ең жақсы таңдау бойынша шешім қабылдау нәтижелері алынды және нұсқалық есептеулер жолымен және салыстырмалы тиімділікті талдау әртүрлі жағдайдағы сол немесе өзге ГТШ жолдары көрсетілген.

Түйін сөздер: геолого-техникалық шаралар (ГТШ), кенорынды игеру, шешім қабылдануы, мұнайды өндіру, мұнайбергіштік.

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SOIL COVER OF THE "ZAOVRAZHNY" MICRO-DISTRICT, CHEBOKSARY, AND ITS ECOLOGICAL STATE

Abstract. In July-August 2017, soil and agrochemical investigations of the territory of the Zaovrazhny micro-district in Cheboksary city were carried out.

The territory of the new Zaovrazhny micro-district in Cheboksary is located to the west of the north-western residential area of Cheboksary; it is bounded from the north by the coastal fortifications of the Cheboksary storage reservoir, and on the southern side by the M-7 highway (Cheboksary-Moscow).

Light gray forest heavy loam soils are widespread in the micro-district, in the middle and lower parts of the slope altered by water erosion. The undistorted soils are characterized by the following morphological features: a sod horizon A_d of 5-10 cm in thickness, a humus-eluvial horizon A₁ up to 15-20 cm. Below it, a transitional horizon A₁A₂ with a thickness of 5-15 cm is located. Gradually, A₁A₂ passes into the eluvial-illuvial horizon A₂B up to 20 cm thick. Illuvial horizon B consists of several subhorizons: B₁ – dark brownish-brown color with spots of humic substances and pseudopodzolic siliceous powder; it gradually shades into a more clarified B₂, followed by the transitional horizon BC and the soil-forming rock C (loess-like loam).

The content of heavy metals in the humus horizon and soil-forming rock, oil products, radio nuclides and benzapyrene corresponds to the background values and does not exceed the MPC.

The soil cover of the Zaovrazhny micro-district and its ecological state were studied for the first time.

Keywords: agrochemical properties, water erosion, humus horizon, soil-forming rocks, gray forest soils, heavy metals.

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ПОЧВЕННЫЙ ПОКРОВ МИКРОРАЙОНА «ЗАОВРАЖНЫЙ» Г. ЧЕБОКСАРЫ И ИХ ЭКОЛОГИЧЕСКОЕ СОСТОЯНИЕ

Аннотация. В июле-августе 2017 г. проводились почвенно-агрохимические исследования территории микрорайона «Заовражный» г. Чебоксары.

Территория нового микрорайона «Заовражный» г. Чебоксары расположена к западу от северо-западного жилого района г. Чебоксары; она с севера ограничена береговыми укреплениями Чебоксарского водохранилища, а с южной стороны автотрассой «М-7» (Чебоксары-Москва).

На территории микрорайона распространены светло-серые лесные тяжелосуглинистые почвы, в средней и нижней части склона измененные водной эрозией. Несмытые почвы характеризуются следующими морфологическими признаками: дерновый горизонт A_d мощностью 5-10 см, гумусово-элювиальный горизонт A_1 до 15-20 см. Под ним расположен переходный горизонт A_1A_2 мощностью 5-15 см. Постепенно A_1A_2 переходит в элювиально-иллювиальный горизонт A_2B мощностью до 20 см. Иллювиальный горизонт B состоит из нескольких подгоризонтов: B_1 – темно-буровато-коричневой окраски с пятнами гумусовых веществ и лессивированной кремнеземистой присыпки; он постепенно переходит в более осветленный B_2 , сменяющиеся переходным горизонтом BC и почвообразующей породой C (лессовидный суглинок).

Содержание тяжелых металлов в гумусовом горизонте и почвообразующей породе, нефтепродуктов, радионуклидов и бензапирена соответствует фоновым значениям и не превышают ПДК.

Почвенный покров микрорайона «Заовражный» и его экологическое состояние изучались впервые.

Ключевые слова: агрохимические свойства, водная эрозия, гумусовый горизонт, почвообразующие породы, серые лесные почвы, тяжелые металлы.

Введение. Территория нового микрорайона «Заовражный» г. Чебоксары расположена к западу от северо-западного жилого района г. Чебоксары; она с севера ограничена береговыми укреплениями Чебоксарского водохранилища, а с южной стороны автотрассой «М-7» (Чебоксары-Москва). Почвенный покров микрорайона «Заовражный» не изучен, и его исследование и определение экологического состояния изучалось впервые.

Материалы и методы. Почвенные исследования проводились в соответствии с ГОСТ 17.4.2.03-86. При диагностике почвенного покрова микрорайона «Заовражный» использовалась «Классификация и диагностика почв СССР» (1977 г.). Содержание подвижного фосфора и обменного калия определялось методом Кирсанова, рНобм. – ионометрически. Химический, бактериологический, гельминтологический анализы почвенных проб производились в ФГБУЗ ЦГиЭ № 29ФМБА России № 2637, а также в ФГУ ГЦАС «Чувашский».

Результаты исследований и их обсуждение. Территория микрорайона «Заовражный» расположена в Северо-Западной части г. Чебоксары и занимает площадь 41 га. До 2002 г. территория микрорайона использовалась в качестве пашни.

В 2017 г. она представляла собой залежь, поросшую осотом, пижмой и вейником с группировками молодого леса 10-15-летнего возраста, местами застроенную коттеджами, с проведенными инженерно-техническими сетями (электричество, водопровод) вдоль улиц.

Площадка настоящих изысканий в геоморфологическом отношении приурочена к правобережному плато долины р. Волга с генетическим типом поверхности – денудационным, в 300-350 м юго-восточнее площадки протекает р. Шупашкарка, правый приток реки Волги, с северо-востока и частью с юго-востока территория граничит с дачными участками, с северо-запада – с лесным массивом государственного лесного фонда.

Рельеф территории застройки полого наклонный, с понижением к северо-востоку, в сторону р. Волги.

Геологический разрез до изученной бурением глубины 10 м представлен в основном коренными верхнепермскими и среднеюрскими породами, которые сверху прикрыты четвертичными отложениями – лессовидными суглинками. Покровные тяжелые лессовидные суглинки – тяжелые, твердые, полутвердые, тугопластичные коричневого и светло-коричневого цвета, макропористые, с точками гумуса и прожилками известковистости, ожелезненные, с тонкими прослойками песка [6].

Подземные воды постоянного водоносного горизонта вскрыты в южной части площадки в скважинах на глубинах 2,6-7,2 м в верхней трещиноватой зоне верхнепермских отложений.

По химическому составу грунтовая вода пресная ($M = 0.3-0.5$ г/л), гидрокарбонатная, магниевое-кальциевая, от слабокислой до слабощелочной, жесткая, умеренно-жесткая, с pH 6,3-6,4.

В результате настоящих почвенных исследований выявлено, что на территории микрорайона «Заовражный» г. Чебоксары почвенный покров представлен смытыми разновидностями (слабо-смытыми, средне- и сильно-смытыми) светло-серой лесной почвы.

Несмытые почвы характеризуются следующими морфологическими признаками: дерновый горизонт A_d мощностью 5-10 см, гумусово-элювиальный горизонт A_1 светло-серого или серого цвета, небольшой мощности (до 15-20 см).

Переходный горизонт A_1A_2 светло-серой окраски, мелко-ореховато-комковатой структуры, мощностью 5-15 см. Постепенно A_1A_2 переходит в элювиально-иллювиальный горизонт A_2B мощностью до 20 см, для которого характерна мелкоореховатая структура, присыпка кремнезема на гранях структурных отдельностей в сочетании с пятнами вымывания гумуса и других веществ.

Иллювиальный горизонт В состоит из нескольких подгоризонтов: B_1 – темно-буровато-коричневой окраски с пятнами гумусовых веществ и лессивированной кремнеземистой присыпки; он постепенно переходит в более осветленный B_2 , сменяющиеся переходным горизонтом ВС и почвообразующей породой С (лессовидный суглинок).

При почвенных исследованиях к слабосмытым разновидностям относили почвы, в которых вспашкой затронута верхняя часть горизонта A_2B ; к среднесмытым – при вовлечении в пахотный слой большей части или всего горизонта A_2B , и его отсутствии; и к сильносмытым – почвы, в профиле которых отсутствовали горизонты A_2B и B_1 .

Особенности морфологических признаков почв залежи состоит в том, что бывший однородный пахотный слой A_p разделился на два генетических горизонта – A_1 и A_1A_2 , которые присутствуют в целинных почвах.

Описание профиля слабосмытой светло-серой лесной тяжелосуглинистой среднемощной почвы на лессовидном суглинке (разрез 1), заложенного на залежи, поросшей березами и осинами с изреженным травянистым покровом (костер, цикорий, тысячелистник, одуванчик) показано в таблице 1.

Таблица 1 – Описание профиля слабосмытой светло-серой лесной почвы

A_1	0-20 см	Влажный, серый, тяжелосуглинистый, комковатый, рыхлый, Встречаются корни, ходы червей, дождевые черви, личинки майского жука, переход ясный.
A_1A_2	20-25 см	Влажный, белесо-серый, тяжелосуглинистый, комковатый, плотный, встречаются корни, блестки кремнезема, ходы червей, переход ясный.
A_2B	25-38 см	Увлажненный, коричневато-серый, тяжелосуглинистый, комковато-мелкоореховатый, не вскипает от 10% соляной кислоты.
B_1	38-49 см	Увлажненный, коричневато-буроватый, тяжелосуглинистый, ореховатый, с блестками кремнезема и пятнами гумуса, не вскипает от 10% соляной кислоты.
B_2	49-91 см	Увлажненный, коричневый, тяжелосуглинистый, крупно-ореховатый, с пятнами гумуса, не вскипает от 10% соляной кислоты.
BC	91-130 см	Увлажненный, коричневый, с ходами корней, редкими пятнами гумуса, тяжелосуглинистый, бесструктурный, не вскипает от 10% соляной кислоты.
C	130-180 см	Увлажненный, светло-коричневый, тяжелосуглинистый, бесструктурный, в нижней части слабо вскипает от 10% соляной кислоты.

В среднесмытых светло-серых лесных почвах на залежи с густым разнотравьем процессы водной эрозии резко ослаблены, на месте бывшего серовато-бурого цвета пахотного слоя образовался дерновый горизонт A_d и гумусово-элювиальный горизонт A_1 или переходный A_1A_2 . Они равномерно серого цвета с включениями коричнево-бурых глинистых комочков, иногда со светлой кремнеземистой присыпкой.

Под ними залегает переходный горизонт A_2B , по глубине верхней границы которого определялась степень смытости почвы (таблица 2).

В сильносмытых светло-серых лесных почвах, окаймляющих нижнюю часть склона, процессы водной эрозии под разнотравьем также ослабились, и на месте бывшего пахотного слоя также образовался дерновый горизонт A_d , который подстилается иллювиальным горизонтом В.

Вследствие ослабленности элювиально-элювиального почвообразовательного процесса из-за низкой водопрочности агрегатов, сильного бокового стока воды профиль сильносмытых светло-серых лесных почв укорочен (таблица 3).

В результате проведенных почвенных исследований составлена почвенная карта микрорайона «Заовражный» в масштабе М 1:500 (ГОСТ 17.4.2.03-86).

Таблица 2 – Описание профиля среднесмытой светло-серой лесной почвы

A _d	0-8 см	Влажный, серый, с отдельными комочками коричнево-буроватого цвета, тяжелосуглинистый, комковатый, рыхлый. Густо переплетены корни, встречаются ходы червей, дождевые черви, редко – личинки майского жука, переход ясный.
A ₁ A ₂	8-23 см	Влажный, белесо-серый, с отдельными комочками белесовато-бурого цвета, тяжелосуглинистый, мелкоореховато-комковатый, уплотненный, встречаются корни, блестки кремнезема, ходы червей, переход ясный.
A ₂ B	23-26 см	Увлажненный, коричневато-серый, тяжелосуглинистый, комковато-мелкоореховатый, плотный, не вскипает от 10% соляной кислоты.
B ₁	26-36 см	Увлажненный, коричневато-буроватый, тяжелосуглинистый, ореховатый, с блестками кремнезема и пятнами гумуса.
B ₂	36-85 см	Увлажненный, коричневый, тяжелосуглинистый, крупно-ореховатый, с пятнами гумуса.
BC	85-110 см	Увлажненный, светло-коричневый, тяжелосуглинистый, бесструктурный, не вскипает от 10% соляной кислоты.

Таблица 3 – Описание профиля сильносмытой светло-серой лесной почвы

A _d	0-7 см	Влажный, серовато-бурый, тяжелосуглинистый, комковатый, рыхлый. Густо переплетены корни, встречаются ходы червей, дождевые черви, личинки майского жука, переход ясный.
AB	7-16 см	Влажный, серовато-красновато-бурый, тяжелосуглинистый, уплотненный,
B ₂	16-59 см	Увлажненный, коричневый, тяжелосуглинистый, крупно-ореховатый, с пятнами гумуса.
BC	59-82 см	Увлажненный, светло-коричневый, тяжелосуглинистый, бесструктурный, не вскипает от 10% соляной кислоты.

Почвенные исследования выявили, что на территории микрорайона общая площадь эродированных почв составляет 86,7%, что соответствует выводам, полученным в результате мониторинга почв Чувашской Республики – эродированно более 80% пашни [2, 5].

На общей площади 41 га сформировались следующие почвенные разновидности светло-серых лесных почв (таблица 4).

Таблица 4 – Площади почвенных разновидностей на территории микрорайона «Заовражный» г. Чебоксары

№	Название почв	Индекс почвы	Площадь	
			га	%
1	Светло-серые лесные тяжелосуглинистые среднесмытые почвы на лессовидном суглинке	Л ₁ с/л	5,1	12,4
2	Светло-серые лесные тяжелосуглинистые среднесмытые слабосмытые почвы на лессовидном суглинке	Л ₁ с/л↓	20,7	50,6
3	Светло-серые лесные тяжелосуглинистые, среднесмытые, среднесмытые на лессовидном суглинке	Л ₁ т/л↓↓	11,1	27,0
4	Светло-серые лесные тяжелосуглинистые, среднесмытые, сильносмытые на лессовидном суглинке	Л ₁ т/л↓↓↓	4,1	10,0
	Всего		41	100,0

Результаты агрохимических анализов образцов почв характеризуют почвы как типичные для светло-серой лесной почвы северной природно-сельскохозяйственной зоны Чувашии [3, 4, 7].

Содержание гумуса в почвах площадки низкое – от 1 до 3% (очень низкое и низкое). Сумма обменных оснований (S) в верхнем горизонте почв составляет 16,7-21,3 мг-э/100 г, гидролитическая кислотность (Нг) – 1,03-4,43 мг-э/100 г почвы. Содержание подвижного фосфора и обменного калия характерное для светло-серых лесных почв: в основном среднее и повышенное. Степень насыщенности основаниями почвы составляет 82-94%. Реакция почв колеблется от среднекислой до нейтральной.

Изучение содержания радионуклеидов (цезий-137 и стронций-90) в верхнем горизонте почвы (B_1) показало низкое их содержание – 8,6 – 12,20 и 3,3 – 4,4 Бк/кг соответственно.

Согласно показателям ГОСТ 17.5.3.06-85 и расчетам мощность плодородного слоя почв на общей площади строительной площадки общей площадью 41 га в среднем составляет 20 см. Общая масса плодородного слоя почвы при средней плотности сложения 1,14 г/см³ составляет при этом 2280 тонн.

Общая масса потенциально плодородного слоя мощностью 25 см и средней плотностью сложения 1,25 г/см³, расположенного под плодородным слоем, составляет в среднем 3125 тонн/га.

Выводы. В результате проведенных исследований выявлен почвенный покров микрорайона «Заовражный». Современное состояние качества почв территории микрорайона соответствуют санитарно-эпидемиологическим требованиям. Результаты исследований однозначно свидетельствуют об экологическом благополучии территории города Чебоксары Чувашской Республики [1], учитывая расположенные рядом с овражной системой новостройки.

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ЧЕБОКСАРЫ ҚАЛАСЫНЫҢ «ЗАОВРАЖНЫЙ» МӨЛТЕК АУДАНЫНДАҒЫ ТОПЫРАҚ ҚҰРАМЫ МЕН ЭКОЛОГИЯЛЫҚ ЖАҒДАЙЫ

Аннотация. 2017 жылдың шілде-тамыз айларында Чебоксары қаласындағы «Заовражный» мөлтек ауданындағы топырақтың агрохимиялық құрамы зерттелді.

Чебоксары қаласындағы жаңа «Заовражный» мөлтек ауданы территориясы Чебоксары қаласының солтүстік-батысында орналасқан; ол солтүстігінен Чебоксары су қоймасының жағалаулық су бекіністерімен, ал оңтүстік жағынан «М-7» көлік жолымен шектелген (Чебоксары-Москва).

Мөлтек ауданы территориясында ашық-сұр түсті орманның ауыр батпақты топырағы таралған, ал орта және төменгі тұстарында ол су эрозиясына ұшырап өзгерген. Сумен шайылған топырақтар келесідей морфологиялық белгілерімен сипатталады: A_d дерналық қабатының қалыңдығы 5-10 см, қарашірікті-элювиальды A_1 қабаты 15-20 см дейін. Олардың астында қалыңдығы 5-15 см құрайтын A_1A_2 өтпелі қабаты орналасқан. Біртіндеп A_1A_2 қалыңдығы 20 см дейін жететін A_2B элювиальды-иллювиальды қабатына өтеді. В – иллювиальды қабаты бірнеше қабат қатпарларынан тұрады: B_1 – қара-қоңыр түсті қарашірікті заттардық тең-

білдері бар және лессивировты кремни ренді себінделерден құралады; ол біртіндеп ақшыл тартқан В₂ қабатына, содан кейін өтпелі ВС және топырақ құраушы С (лессогоұқсас суглинок) қабаттарына айналады.

Топырақ құраушы қарашірікті қабаты құрамындағы ауыр металдардың, мұнай өнімдерінің, радионуклеидтер мен бензапирендер мөлшерлері фондық мәндеріне сәйкес келеді және ШРК аспайды.

«Заовражный» мөлтек ауданындағы топырақ қабаты мен оның экологиялық жағдайы алғаш рет зерттелінді.

Түйін сөздер: агрохимиялық қасиеті, су эрозиясы, қарашірікті қабат, топырақ құраушы породадар, сұр түсті орман топырағы, ауыр металдар.

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**COMPLEX MINERALOGICAL AND LITHOLOGICAL STUDY
OF SEDIMENTARY OIL AND GAS BEARING ROCKS
OF THE PRECASPIAN REGION BY EPR, IR-SPECTROSCOPY,
X-RAY DIFFRACTOMETRY AND THERMAL ANALYSIS**

Abstract. This article presents the results of the determination of clay minerals of the kaolinite group (kaolinite, montmorillonite) by electron paramagnetic resonance (EPR), IR spectroscopy, X-ray diffractometry and thermal analysis in the mineralogical analysis of sedimentary rocks of the Caspian depression.

Comparison of data on the content of kaolinite in the studied rocks, which were obtained by X-ray diffractometry and thermal analysis, with intensities of the anisotropic EPR signal from kaolinite shows a good correlation. In this connection, we propose an express method for determining kaolinites in petroleum rocks, based on a linear relationship between the intensity of an anisotropic ($g_{\parallel} = 2,046$ and $g_{\perp} = 2,0028$) EPR signal and the content of kaolinites in sedimentary rocks.

The developed method of processing the spectral characteristics of EPR and IR spectra, diffractometric and thermal characteristics of clay kaolinite minerals of sedimentary strata can also be used as reference and information data for identification of montmorillonite and kaolinite clays during the isolation of horizons with high screening properties.

Key words: kaolinite, montmorillonite, sedimentary rocks, clay cap rocks, smectite, mixed-layer mineral (MLM).

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**КОМПЛЕКСНОЕ МИНЕРАЛОГИЧЕСКОЕ И
ЛИТОЛОГИЧЕСКОЕ ИССЛЕДОВАНИЕ ОСАДОЧНЫХ
НЕФТЕГАЗОНОСНЫХ ПОРОД ПРИКАСПИЙСКОГО РЕГИОНА
МЕТОДОМ ЭПР, ИК-СПЕКТРОСКОПИИ, РЕНТГЕНОВСКОЙ
ДИФРАКТОМЕТРИИ И ТЕРМИЧЕСКОГО АНАЛИЗА**

Аннотация. В статье приводятся результаты определения глинистых минералов группы каолинита (каолинит, монтмориллонит) методами электронного парамагнитного резонанса (ЭПР), ИК-спектроскопии, рентгеновской дифрактометрии и термического анализа при минералогическом анализе осадочных пород Прикаспийской впадины.

Сравнение данных о содержании каолинита в исследуемых породах, полученных методом рентгеновской дифрактометрии и термического анализа с интенсивностями анизотропного сигнала ЭПР от каолинита показывает неплохую корреляцию. В этой связи предлагается экспресс-метод определения каолинитов в нефтяных породах, основанный на линейной зависимости между интенсивностью анизотропного сигнала ($g_{||} = 2,046$ и $g_{\perp} = 2,0028$) ЭПР и содержанием каолинитов в осадочных породах.

Разработанная методика обработки спектральных характеристик ЭПР, ИК-спектров и дифрактометрических и термических характеристик глинистых каолиновых минералов осадочных толщ, может использоваться также, в качестве справочно-информационных данных для идентификации прежде всего монтмориллонитовых и каолиновых глин при выделении горизонтов с высокими экранирующими свойствами.

Ключевые слова: каолинит, монтмориллонит, осадочные породы, глинистые покрывки, смектит, ССМ.

Исследование физико-химических особенностей пород, перекрывающих и имеющих скопления УВ, позволяет выделять породы с выраженной тенденцией к экранированию, к проницаемости, к пористости и прогнозировать глинисто-карбонатные породы, как вероятные места скопления углеводородов.

Известно, что глины и глинистые породы характеризуются большим разнообразием минералогического и гранулометрического составов, а следовательно, огромным набором физико-химических свойств. Так, например, присутствие в породах минералов из групп каолинита и монтмориллонита в значительной мере ухудшает диффузионную и фильтрационную их проницаемость, что отводит этим образованиям качества хороших покрывок [1, 2].

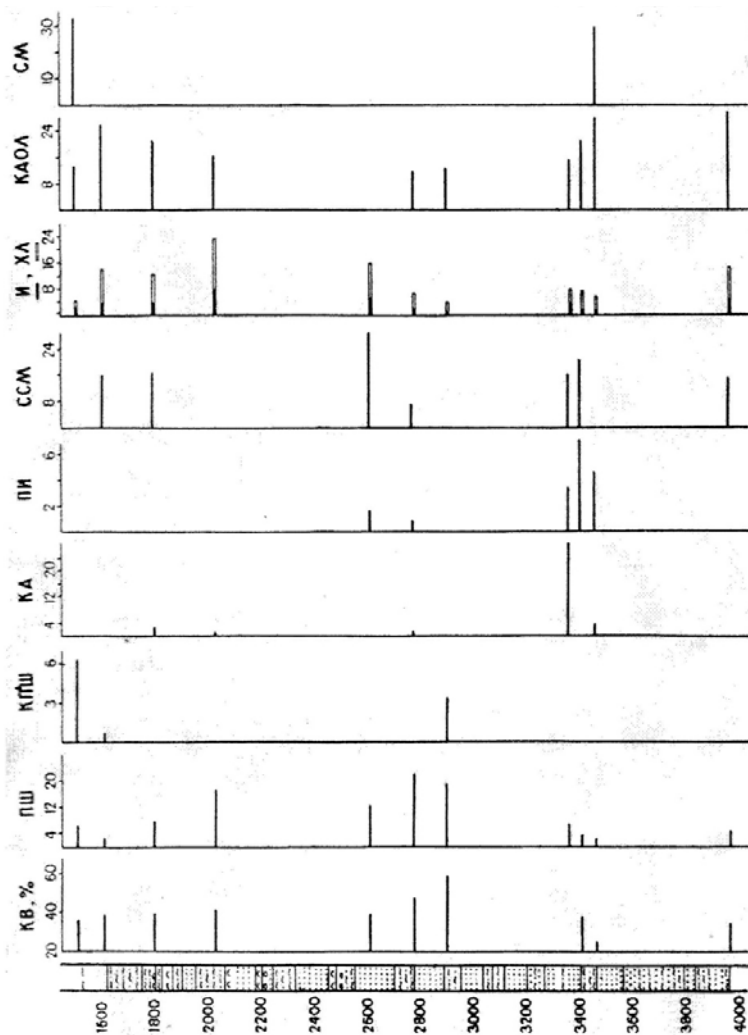


Рисунок 1 – Минеральный состав отложений терригенной пачки уч. Терескен

Figure 1 – Mineral composition of sediments terrigene block Teresken

Рентгенофазовым полуколичественным анализом изучен валовый минеральный состав образцов кернового материала, отобранного по скважинам 11 участков: Тортколь, Синельниковская, Урихтау, Жанатал, Кожасай, Жанажол, Тобускен, Арансай, Терескен, Кенкияк, Тортай (128 образцов и их гранулометрические фракции от 2 мм до 0,001 мм). В качестве примера, на рисунке 1 и 2 показан минеральный состав отложений терригенной пачки уч. Терескен, Тортколь, Жанатал, пл. Синельниковская.

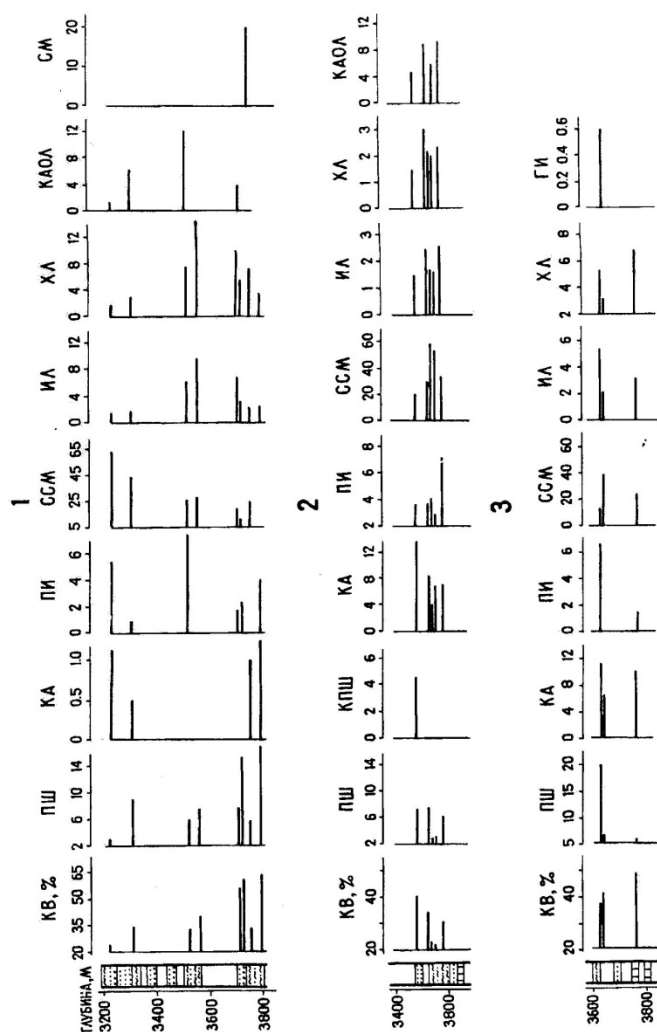
Изучаемые осадочные породы характеризуются полиминеральным составом, включающим до 10-12 минералов. Для определения методами рентгеновской дифрактометрии кристалло-химических особенностей глинистых минералов: смектитов, хлоритов, иллитов, каолинитов, степени иллитизации смектитов, размеров кристаллитов, соотношения ширины дифракционных пиков и т.д. использовались глинистые фракции крупностью 0,001-0,005 мм и менее 0,001 мм.

Дифрактометрическое изучение кристаллохимических особенностей глинистых минералов позволяет определять ряд количественных рентгенометрических характеристик: интегральная ширина рефлекса, отношение интенсивностей базальных рефлексов разных порядков отражения, коэффициент вариации межплоскостных расстояний базальных рефлексов, состав и упорядоченность ССМ (тип, содержание и упорядоченность слоев в смешанослойной структуре, тип чередования, гетерогенность), размер блоков (кристаллитов).

Форма профиля дифракционного отражения зависит от степени трехмерной упорядоченности структуры минерала, степени дефектности и величины области когерентного рассеяния. Присутствие гетерогенных минеральных образований повышает диффузность рефлексов, связанную с переменным объемным составом кристаллов.

Рисунок 2 –
Минеральный состав пород:
1 – Тортколь,
2 – Жанатал,
3 – пл. Синельниковская

Figure 2 –
Mineral composition of rocks:
1 – Tortkol,
2 – Zhanatan,
3 – pl. Sinelnikovskaya



В данном сообщении наряду с рентгенофазовым анализом приводятся результаты определения глинистых минералов методами электронного парамагнитного резонанса (ЭПР), ИК-спектроскопии и термического анализа (ТА).

На рисунке 3 приведен спектр ЭПР глинистой породы месторождения Таган, взятой с глубины 515-520 м из скважины 1. Такой спектр характерен для глинистых пород многих месторождений Прикаспийского региона. Параметры анизотропного спектра близкого к параметрам так называемых «А-центров» каолинита [3]. Анизотропный сигнал полностью совпадает с сигналом от стандартного минерала каолинита Ново-Алексеевского месторождения [4]. Сигнал, названный «А-центром» был описан как результат дырочного захвата мостикового кислорода, стабилизированного двухвалентным катионом, как Mg^{2+} [5, 6].

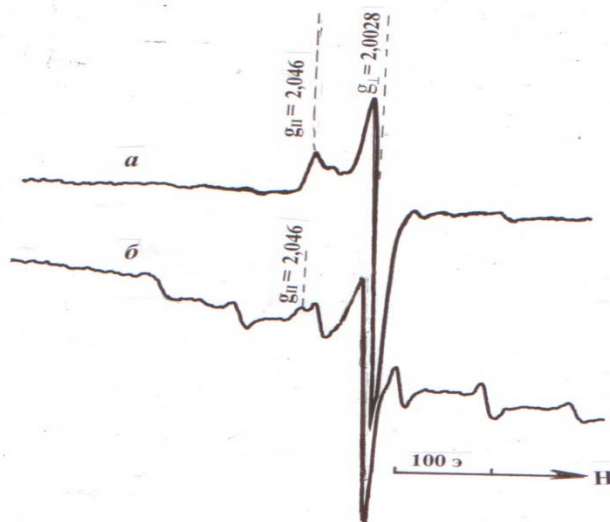


Рисунок 3 – Спектры ЭПР каолинит содержащих пород:
а - месторождение Таган, скв. 1 (глубина 515-520 м); б - месторождение Кемерколь, скв. 4 (глубина 1105-1110 м)

Figure 3 – EPR spectra of kaolinite rocks:
a - Tagan field, borehole. 1 (depth 515-520 m);
b - field Kemerkol, well. 4 (depth 1105-1110 m)

Химический состав каолинита $[Al_2Si_2O_5(OH)_4]$. Этот минерал содержит высокую концентрацию алюминия, который, как известно не сменяется ионами двухвалентного марганца. Это свойство каолинита очень важно при изучении его парамагнитных свойств методом электронного парамагнитного резонанса.

Обобщаются результаты измерений ЭПР кернов, полученных из разных нефтегазовых скважин Прикаспия с различной глубины. Как показывает анализ спектров, методом ЭПР из большого числа элементов, определенных методом рентгенофлуоресцентного анализа (РФА) регистрируются ионы Fe^{3+} и Mn^{2+} .

Исходя из свойств и структуры минерала каолинита спектры ЭПР Fe^{3+} и Mn^{2+} исследуемой породы для обнаружения каолинита являются непригодными, так как они связаны с включениями Fe^{3+} и Mn^{2+} в другие минералы, поскольку алюминий в каолинитах менее сменяем этими ионами.

Недавние исследования авторов работы [7,8] месторождений Журавлиный Лог (Южный Урал) и Чаймат (Южный Вьетнам) методом ЭПР каолинитов также подтверждают, что наблюдаемый в ЭПР электронно-дырочный центр, локализующийся на кислороде, представляет собой комплекс $O^- - Mg^{2+}$, замещающий в структуре каолинита комплекс $O^{2-} - Al^{3+}$.

Необходимо отметить, что часто на сигнал с $g_{\parallel}$ -фактором 2,046 «А-центр» накладываются линии двухвалентного иона марганца в осадочных породах и в этом случае определение каолинита по интенсивности данного сигнала невозможно. В этом случае его содержание определяется лишь по интенсивности сигнала с $g_{\perp}$ -фактором 2,0028 «А-центр», который наблюдается между 3 и 4 компонентами сверхтонкой структуры от иона Mn^{2+} . Этот случай демонстрируется на рисунке 3б. Наличие каолинита в исследуемых породах также подтверждается данными рентгеновского анализа (рисунок 4) и таблица 1.

Так, например на Молдабекском месторождении, скв. 16 залежь (218-232) экранируется покрывшей 213-216 м (ССМ 37% + каолинит 27%, а залежь месторождения Кемерколь, скв. 9 (1362-1367 м) перекрывается покрывшей из смектита (1355-1360 м). На остальных месторождениях наблюдается такая же закономерность.

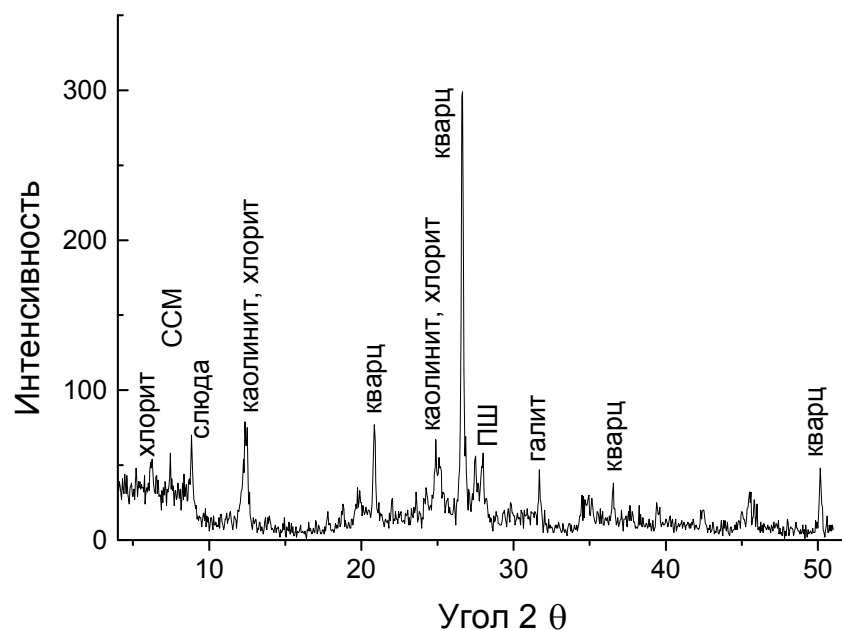


Рисунок 4 – Дифрактограмма обр. пл. Молдабек, 16 , гл. 213-216м каолинит содержащей породы:
C = 27 % масс. каолинита

Figure 4 – Diffraction pattern of sample from Moldabek area, 16, depth: 213-216 m of kaolinite containing rocks:
C = 27% by weight of kaolinite

Исследованные методом ЭПР-спектроскопии каолинитовые породы были также изучены методом ИК-спектроскопии.

Таблица 1 – Результаты рентгенофазового анализа пород Прикаспия
Table 1 – Results of X-ray phase analysis of the PreCaspian rocks

Месторождение, номер скважины	Интервал отбора керна, м	Глубина залегания нефти, м	Содержание минералов, %		
			Смектит	ССМ	Каолинит
Молдабек, скв. 16	207-210		отс.	20	10
скв. 16	213-216	218-232	отс.	37	27
Сазанкурак, скв. 2	476-481, низ		отс.	отс.	10
скв. 2	481-485, верх	485-490	отс.	3	8
Сазанкурак, скв. 7	449-460, верх	460-475	отс.	9	44
скв. 7	480-490, низ		отс.	3	5
Кемерколь, скв. 9	1050-1055		отс.	23	13
скв. 9	1085-1090	1092-1100	37,4	отс.	отс.
скв. 9	1350-1355		отс.	отс.	14
скв. 9	1355-1360	1362-1367	отс.	отс.	28
Кемерколь, скв. 20	1240-1245	1246-1250	отс.	отс.	29
Котыртас, скв. 22	1203-1206	1226-1229	отс.	отс.	33
Таган, скв. 1	515-520	597-601	отс.	отс.	32
Ю.Камышитовый, скв. 3	256-261		отс.	27	16
скв. 3	363-369	389-400	отс.	13	22
скв. 3	396-402		отс.	22	6
Онгар, скв. 6	655-660	600-604	отс.	отс.	6,5

Примечание. Смектит – собирательное название глинистых минералов монтмориллонита. ССМ – смешанно-слоистый минерал с чередующимся слоем гидрослюда и монтмориллонита.

Инфракрасная спектроскопия – один из наиболее универсальных, информативных и чувствительных методов анализа минерального состава осадочных пород. На рисунке 5 приведен полный ИК-спектр осадочной породы месторождения Онгар, скважина 6 (интервал 655-660 м). В минеральном составе образца преобладает каолинит - $\text{Al}_4[(\text{OH})_8\text{Si}_4\text{O}_{10}]$ – 3696, 3651, 3620, 1109, 1033, 1011, 939, 913, 799, 538, 473, 433 cm^{-1} [9, 10], зафиксировано присутствие альбита $\text{Na}[\text{AlSi}_3\text{O}_8]$ – 1164, 645, 588, 473, 433 cm^{-1} [9] и кварца $\alpha\text{-SiO}_2$ – 799, 780, 696 cm^{-1} [9, 10].

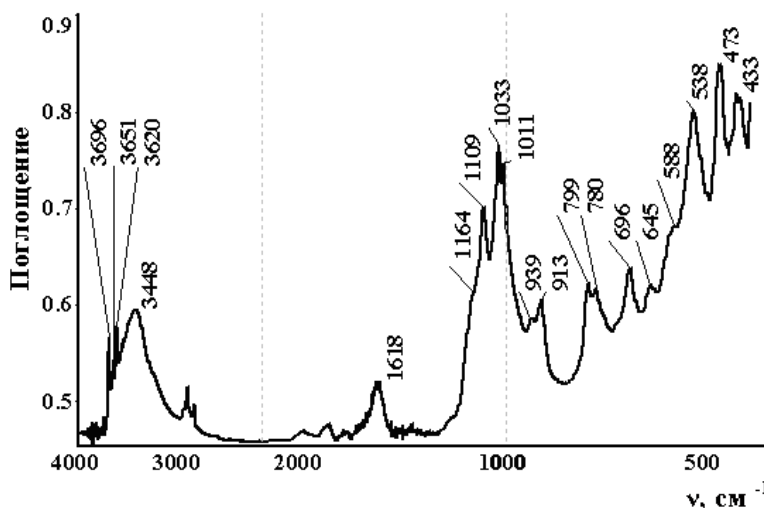


Рисунок 5 – ИК- спектр породы месторождения Онгар, скв. 6 (655-660 м)

Figure 5 – IR spectrum of the Ongar field, well #6 (655-660 m)

На рисунке 6 приведен ИК-спектр мономинерального образца каолинита Ново-Алексеевского месторождения. В высокочастотной области спектра наблюдаются четыре полосы поглощения валентных колебаний гидроксильных групп каолинита с максимумами при волновых числах 3695, 3670, 3651, 3620 cm^{-1} . В спектрах пород месторождений Южное Камышитовое и Онгар зафиксированы только три высокочастотных полосы 3697 (3696), 3651, 3620 cm^{-1} . Полоса поглощения при 3620 cm^{-1} , характеризующая гидроксильные группы каолинита, направленные к октаэдрическим вакансиям [11] имеет наибольшую интенсивность в обоих образцах.

Прослеживается зависимость от содержания каолинита в образце интенсивности полосы гидроксильных групп, расположенных перпендикулярно плоскости силикатного слоя между слоями в каолините, проявляющейся при 3697 (3696) cm^{-1} [11]. При сопоставлении ИК-спектров

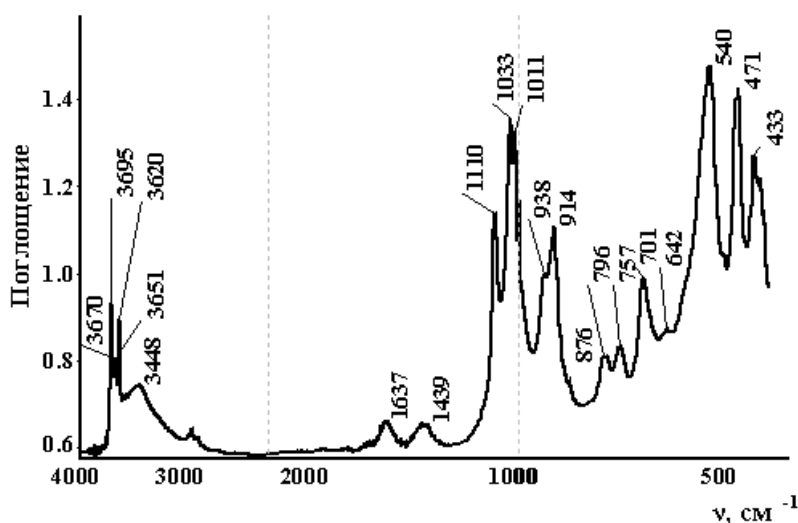


Рисунок 6 – ИК-спектр каолинит Ново-Алексеевское месторождение

Figure 6 – IR spectrum of kaolinite from Novo-Alekseevskoye field

исследуемых образцов (рисунки 5, 6) осадочных пород месторождений Южное Камышитовое и Онгар с эталонным образцом мономинеральной фракции каолинита месторождения Ново-Алексеевское в диапазоне волновых чисел $2000-450\text{ см}^{-1}$ наблюдается уменьшение числа полос поглощения каолинита и снижение их интенсивностей в пробе месторождения Южное Камышитовое в сравнении с образцом месторождения Онгар, что также свидетельствует о более низком содержании каолинита.

ИК-спектры некоторых осадочных пород, которые были исследованы с помощью метода ЭПР, приведены на рисунке 7. Здесь на полосу поглощения каолинита накладываются полосы другого минерала (рисунок 7а) [12]. В подобных случаях методом ИК-спектроскопии не представляется возможным охарактеризовать все полосы поглощения, которые наблюдаются от основных минералов, входящих в состав изучаемой породы. Подобные задачи решаются при комплексном применении методов ЭПР, ИК-спектроскопии и рентгеновской дифрактометрии.

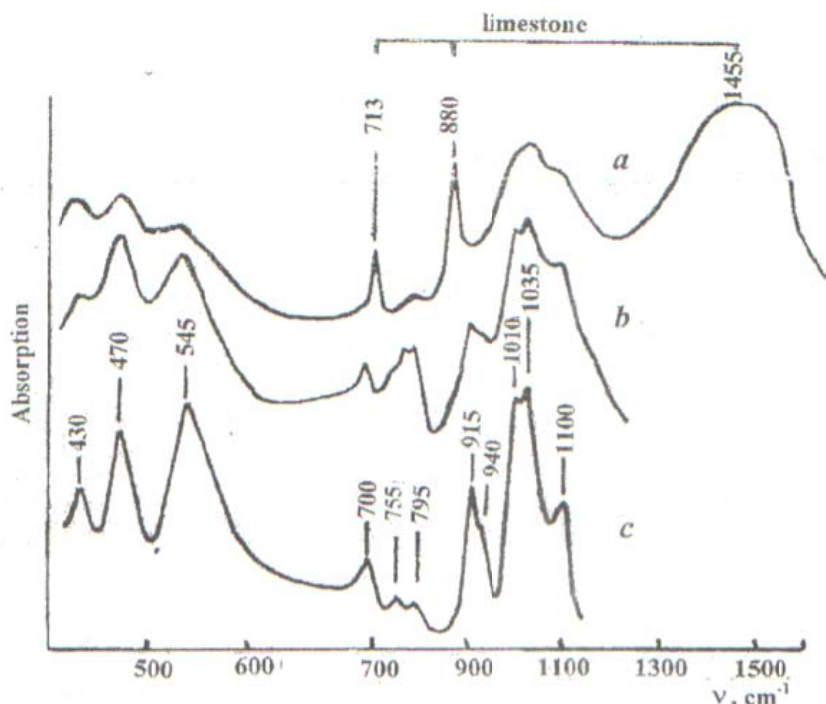


Рисунок 7 – ИК-спектры некоторых осадочных пород: а – Южное Камышитовое, скважина 3 (219-224 м); б – Сазанкурар, скважина 2 (476-481 м); в – каолинит месторождения Ново – Алексеевское

Figure 7 – IR spectra of some sedimentary rocks: a - South Kamyshitovoye, well #3 (219-224 m); b - Sazankurak, well #2 (476-481 m); c - kaolinite from Novo-Alekseevskoe field

В данной работе также приводятся результаты термического анализа по определению в составах осадочных пород Прикаспийского региона глинистого минерала – каолинита.

Термическая диагностика минерального состава пород производилась по результатам градиентного прокаливании образца в диапазоне температур $20-1000^{\circ}\text{C}$ на дериватографе Q-1500D системы F.Paulik, J.Paulik, L.Erdey. Термохимическое состояние пробы описывались кривыми: Т (температурной), DTA (дифференциальной термоаналитической), TG (термогравиметрической) и DTG (дифференциальной термогравиметрической),

Съемка осуществлялась в воздушной среде, в диапазоне температур $20-1000^{\circ}\text{C}$. Режим нагревания – динамический ($dT/dt = 10$ град/мин), эталонное вещество – прокаленный Al_2O_3 , навеска образца – 500 мг., чувствительность весов – 100 мг на шкалу в 200 мм.

Изучение термического поведения порошковой пробы проводилось по морфологиям термических кривых и численных значений интенсивностей эндо- и экзотермических эффектов с использованием сопряженных с ними термогравиметрических показаний TG-линий.

Количество указанного минерала в составе исследуемых проб (по результатам неизотермической термогравиметрии и показаний ДТА-кривых) представлено в таблице 2.

Результаты анализа сравнивались с данными атласов термических кривых минералов и горных пород и сопоставлялись с описаниями термического поведения веществ, изложенных в других справочных источниках и накопленных в банке данных лаборатории, проводившей эти исследования.

Из серии полученных термических проявлений (эффектов) на ДТА-кривой была проведена дифференциация пиков, вызванных деструкцией каолинита.

В качестве главных термических критериев, по которым производилась диагностика указанного минерала, и определялось его содержание в породе, являлись эндотермическая реакция ($360\sim 700^\circ\text{C}$), обусловленная выбросом из октаэдрического слоя кристаллической решетки гидроксильной воды и экзотермический эффект ($\sim 950^\circ\text{C}$), связанный с образованием в системе новой фазы (рисунки 9 и 10). С помощью дифференциальной термоаналитической (ДТА) кривой и термогравиметрических показаний пробы, были определены процентные содержания каолинита в породах и определены параметры, отвечающие за степень совершенства его кристаллической структуры.

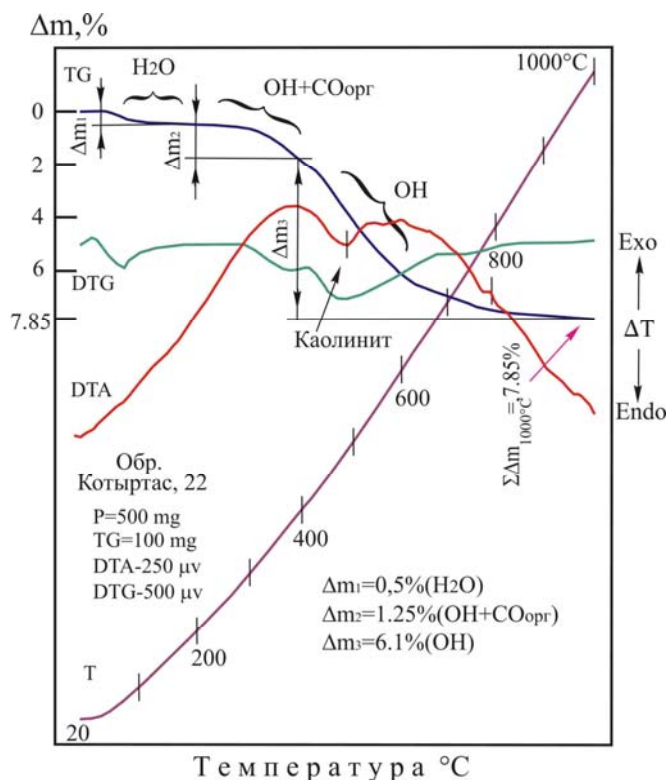


Рисунок 9 – Дериватограмма образца из площади Котырасс.

По данным термогравиметрии содержание каолинита в составе образца соответствует 23%

Figure 9 – Derivatogram of the sample from the Kotytrass area.

According to thermogravimetric data, the kaolinite content in the sample corresponds to 23%

Количества указанного минерала в составах исследуемых проб (по результатам неизотермической термогравиметрии и морфологии ДТА-кривой) представлены в таблице 2.

Данные термического анализа о процентном содержании каолинита оказались здесь несколько ниже показаний, полученных по результатам рентгеновской дифрактометрии и ЭПР определениям, что обусловлено особенностями диагностики и расчета состава образца выполненными этими методами. Так, рентгенофазовые и ЭПР-определения выявляли количество каолинита относительно окристаллизованной части минерального состава образца, тогда как термический анализ определил это содержание с учетом наличия в системе еще и аморфной ее составляющей.

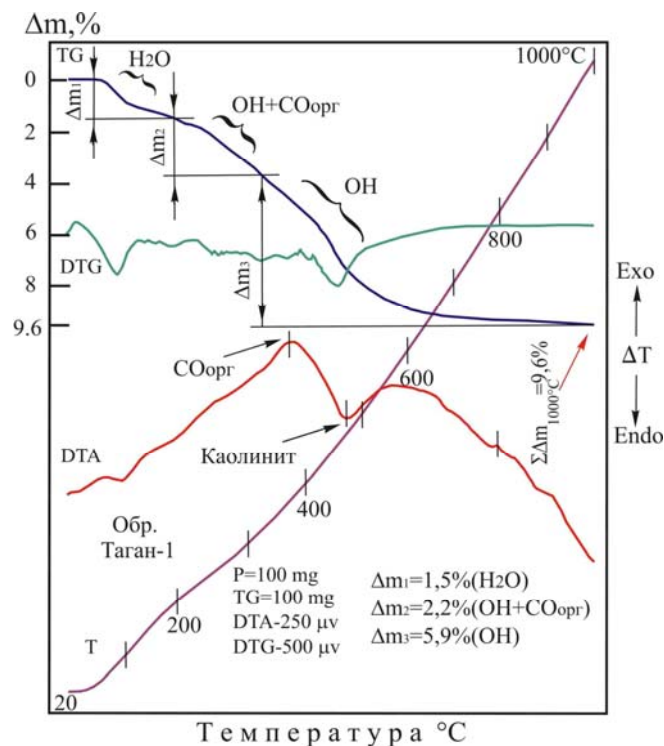


Рисунок 10 – Дериватограмма образца из площади Таган-1.
По данным термогравиметрии содержание каолинита в составе образца соответствует 22.8%

Figure 10 – Derivatogram of the sample from the Tagan-1 area.
According to the thermogravimetric data, the kaolinite content in the sample corresponds to 22.8%

Таблица 2 – Результаты определения каолинита в породах Прикаспийского региона

Table 2 – Results of the determination of kaolinite in the rocks of the Caspian region

Месторождение, номер скважины	Интервал отбора, м	Содержание каолинита, в % масс.		
		по рентгеновской дифрактометрии	по термическому анализу	по ЭПР
Эталонный каолинит (Ново-Алексеевское)		100	100	100
Онгар, 6	655-660	6,5	4.0	7,5
Кемерколь, 8	915-920	28,7	18.0	28,1
Кемерколь, 9	1350-1355	14	10,0	13,2
Кемерколь, 9	1355-1360	28	19,0	27,4
Кемерколь, 20	1240-1245	29	20.0	28,3
Молдабек, 16	213-216	27	18.0	25,5
Котыртас, 22	1203-1206	33	23.0	33,0
Таган, 1	515-520	32	22.8	32,1

Таким образом, процентный состав исследуемого слоистого силиката, по данным РФА и ЭПР определениям, с одной стороны и термическим анализом – с другой, представлены относительными числами. В связи с этим, результаты количественных определений каолинита, полученные указанными методами, при переводе их в одну измерительную систему, вполне сопоставимы между собой, и отражают реальное содержание их в пробах.

Сравнение данных о содержании каолинита в исследуемых породах, полученных методом рентгеновской дифрактометрии и термического анализа с интенсивностями анизотропного сигнала ЭПР от каолинита показывает неплохую корреляцию (таблица 2). В этой связи предлагается

экспресс-метод определения каолинитов в нефтяных породах, основанный на линейной зависимости между интенсивностью анизотропного сигнала ($g_{\parallel}$ и $g_{\perp}$) ЭПР и содержанием каолинитов в осадочных породах.

Главной особенностью спектра ЭПР глинистых пород (рисунок 11) триасовых отложений междуречья Урал-Эмба является наличие очень широкого сигнала, на фоне которого видны линии от Mn^{2+} , и более узкого в слабом поле, соответствующего $g = 4,3$, который принадлежит иону Fe^{3+} . Такой спектр соответствует монтмориллонитовым минералам, которые были обнаружены методом ЭПР при исследовании глинистых монтмориллонитовых минералов Американского нефтяного института [3]. Принадлежность сигнала ЭПР (рисунок 11) к минералам группы монтмориллонита подтверждается данными рентгеноструктурного анализа исследуемой породы (содержание смектита составляет 37,4%, таблица 1).

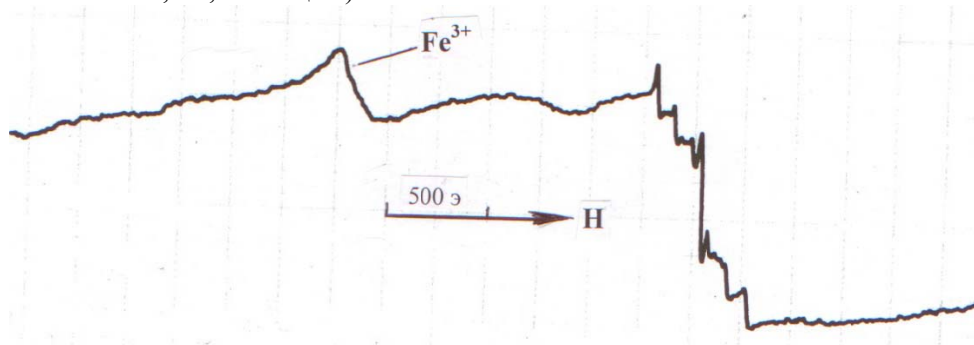


Рисунок 11 – Спектр ЭПР монтмориллонит содержащей породы Молдабекского месторождения, скв. 16 (глубина 213-216 м)

Figure 11 – EPR spectrum of a montmorillonite bearing rock of the Moldabek field, well #16 (depth 21 -216 m)

На рисунке 12а приведен ИК-спектр монтмориллонитсодержащей породы Имашевского месторождения, изученный методом ЭПР. Для более точного отнесения полос спектра к минералу монтмориллонита, содержащемуся в этой породе, на рисунке 12б приведен ИК-спектр эталонного монтмориллонита. При сопоставлении расположения полос этого образца и исследуемой породы, были установлены полосы монтмориллонита и доломита. Как показывают результаты анализа этого спектра, основными порообразующими минералами являются: монтмориллонит – $(Al_{1,67}Mg_{0,33})[(OH)_2Si_4O_{10}]^{0,33} \cdot Na_{0,33}(H_2O)_4$ – 3630, 1096, 1026, 916, 852, 647, 524, 472 cm^{-1} ; мусковит $KAl_2[(OH,F)_2AlSi_3O_{10}]$ – 3620, 1026, 472, 422 cm^{-1} ; кварц $\alpha-SiO_2$ – 1171, 799, 780, 695 cm^{-1} ; доломит $CaMg[CO_3]_2$ – 1812, 1459, 883, 852, 728 cm^{-1} .

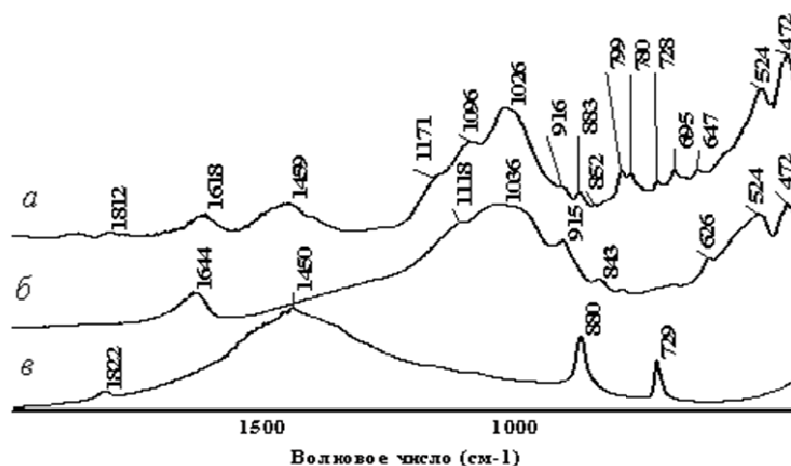


Рисунок 12 – Инфракрасный спектр: а - проба Имашевского месторождения, скв. 1 (3416-3421м.); б - монтмориллонит Na-форма; в - доломит

Figure 12 – Infrared spectrum: а - sample of Imashevsky field, well #1 (3416-3421 m); б - montmorillonite Na-form; в - the dolomite

Разработанная методика обработки спектральных характеристик ЭПР, ИК-спектров и дифрактометрических и термических характеристик глинистых каолинистых минералов осадочных толщ, может использоваться также, в качестве справочно-информационных данных для идентификации прежде всего монтмориллонитовых и каолинистых глин при выделении горизонтов с высокими экранирующими свойствами.

Выводы.

1. Дифрактометрические оценки кристаллохимических характеристик минералов по профилю разреза осадочных толщ позволили уточнить направление процессов их преобразования, выявить влияние глин на формирование пород с определенными коллекторскими, фильтрационными и экранирующими свойствами, прогнозировать нефтегенерирующий потенциал изучаемых толщ.

2. Проведенные исследования позволили изучить состав и структурные особенности глинистых минералов выделенных литогенетических типов пород и фаций зон, наиболее перспективных для процессов нефтеобразования и нефтенакпления.

3. Результаты детального рентгенодифрактометрического изучения образцов пород и глинистых фракций, отобранных по разрезам изучаемых участков, стали объективной основой для развития представлений об условиях формирования и преобразования отложений, палеогеографических реконструкций, оценки их перспективности на поиски месторождений нефти и газа.

4. Сравнение данных о содержании каолинита в исследуемых породах, полученных методом рентгеновской дифрактометрии и термического анализа с интенсивностями анизотропного сигнала ЭПР от каолинита показывает неплохую корреляцию. В этой связи предлагается экспресс-метод определения каолинитов в нефтяных породах, основанный на линейной зависимости между интенсивностью анизотропного сигнала ($g_{||} = 2,046$ и $g_{\perp} = 2,0028$) ЭПР и содержанием каолинитов в осадочных породах.

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**КАСПИЙ МАҢЫ АЙМАҒЫНДАҒЫ МҰНАЙ ОРНАЛАСҚАН ШӨГІНДІ ТАУ ЖЫНЫСТАРЫН
ЭПР, ИҚ-СПЕКТРОСКОПИЯЛЫҚ, РЕНТГЕНДІК ДИФРАКТОМЕТРИЯ ЖӘНЕ ТЕРМИЯЛЫҚ
ТАЛДАУ ӘДІСТЕРІМЕН КЕШЕНДІ МИНЕРАЛДЫҚ ЖӘНЕ ЛИТОЛОГИЯЛЫҚ ЗЕРТТЕУ**

Аннотация. Жұмыста Каспий маңы аймағындағы тау жыныстарының минералдарынан электрондық парамагниттік резонанс (ЭПР), ИҚ-спектроскопия, рентгендік дифрактометрия және термиялық талдау әдістерімен сазды минералдарды (каолинит, монтмориллонит) анықтау ісі қарастырылған.

Рентгендік дифрактометрия және термиялық талдау әдістері көмегімен зерттелген тау жыныстары ішінен каолинитті анықтап, оны ЭПР-дің анизотропты сигналының қарқындылықтарымен салыстырып, олардың арасында жақсы корреляция бары тағайындалды. Бұл жағдай ЭПР әдісін мұнай жатқан қабаттардағы каолинитті анықтау ісіне қолдануға мүмкіндік берді ($g_{||} = 2,046$ және $g_{\perp} = 2,0028$).

Ұсынылған әдіс каолинит минералдарының ЭПР, ИҚ-спектрлерінің және рентгендік дифрактометрия, термиялық талдау әдістерімен спектралды сипаттамаларын алуға, екінші жағынан монтмориллонитті және каолинитті минералдардың геологиялық қабаттардағы экрандаушы қасиеттерінен ақпаратты-анықтамалық мәліметтер алу үшін өте қажет.

Түйін сөздер: каолинит, монтмориллонит, шөгінді тау жыныстары, сазды қабат, смектит, қабатты араласқан минерал.

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**SCIENTIFIC-TECHNICAL BASICS OF VISCOSITY REDUCTION
OF THE KAZAKHSTANI OILS, WHICH PROVIDE
A SIGNIFICANT INCREASE OF OIL RESERVOIRS**

Abstract.

The aim of the work: Scientific-technical basics of viscosity reduction of the Kazakhstani oils, which provide an essential increase of oil reservoirs.

In modern economic conditions, the oil and gas industry of Kazakhstan continues to remain in the area of active growth, along with maintaining its high investment attractiveness.

The contrast of experimental results on the study of spectral responses to external pulse effects and theoretical developments on the types of equilibrium for interplanetary cycles allows us to draw the following conclusions:

1. Obtaining information on changes in the state of the interface between phases by measuring spectral responses provides the necessary potential for searching for cause-effect relationships in all ranges of external influences.

2. The change in the quantitative relationships in the "impact-response" system is suggested to be estimated by the formula of Smirnov A.P., which makes it possible to reflect three-stage processes in the whole variety of their manifestations.

3. It is shown that the state of water (supplier of hydrogen and oxygen) at the interface between phases affects the processes of synthesis and decomposition of hydrocarbons. The observed effect is of practical importance in the development of geotechnology to reduce viscosity under natural underground conditions.

Keywords: oil recovery, impact-response, spectral composition, interface, property management, natural occurrences.

One of the favorable factors for this is the development of the positive dynamics of the global oil and gas industry, which determines the expanded opportunities for sales of products in foreign markets and the liquidity availability, which is available for investment in exploration and extraction. Export volumes of hydrocarbons are growing. At the same time, Kazakhstan has great prospects with the expansion of production capacity of a number of existing fields; and the oil refining sector and the sale of petroleum products in order to increase the added value of products and more complete provision of the domestic market with petroleum products [1-3].

Nowadays the scale of oil and gas production has increased significantly and is being introduced into the development of a field with complex geological-physical conditions, the most important problem of increasing the completeness of oil extraction from the subsoil is being solved, since the average value of the oil recovery coefficient is 0.3-0.4 [4-9].

Thus, the formulation of the objectives of the extraction completeness from oil reservoirs, that have reached the economic limit of operation, becomes particularly relevant in the modern oil and gas industry. However, it becomes economically unprofitable to solve such problems with the help of modern methods of increasing oil recovery, since the scientific-technical basics of hydrocarbon synthesis (UW) in the conditions of natural occurrence are insufficiently worked out. Therefore, in order to create a new geotechnology it is necessary to change the scientific paradigm, which considers the oilfield as an unchanged

statically natural formation conditioned by previous transformations, called the oilfield. This definition (place of birth) much more fully reflects the essence of the dynamic approach to solving the problem of increasing oil recovery, because it allows us to consider the conditions of occurrence as a functioning long-term reactor operating at a certain speed of hydrocarbon synthesis (UW). By pumping lighter components, certain conditions are created for the viscosity increase, which can be reduced by natural reactor hydrogenation with hydrogen, which is present in excess in formation water. Therefore, the main attention in our work is paid to the methods of water decomposition in reservoir conditions. If the conditions of hydrogenation in a natural reactor are provided, it will work at a set speed and chemical composition [10]. Since any process begins and is initiated by the state of the phase separation boundary, in this work the results of the experiments on the spectral composition studies of the responses to the external influence on the phase separation boundary for Kazakhstan UW are shown.

Methods of work conduction. The well-known postulate "all processes start and proceed at the interface of phases" was used in the physical modeling of the synthesis and decomposition of hydrocarbons. For this purpose an experimental module, consisting of an acting device (pulse signal generator) and a receiver in the form of a USB spectrometer in the kilohertz range, was created. In the natural reactor of the formulated module there is water with an oil slick, information about the state of which is brought to tungsten electrodes, which are located on the border of the "oil-water" phase. The electrodes are at a distance of 1/4 and 3/4 of the length of the measuring unit. Impact on the interface is carried out at the frequency of water decomposition (42.8 kHz).

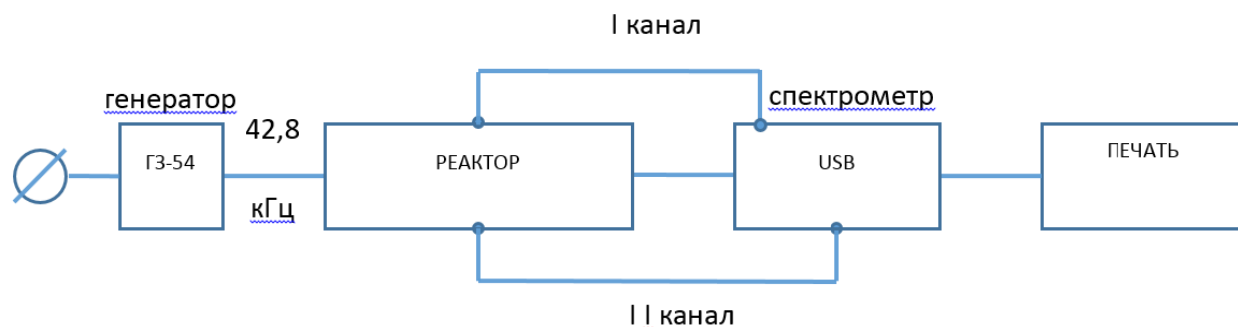
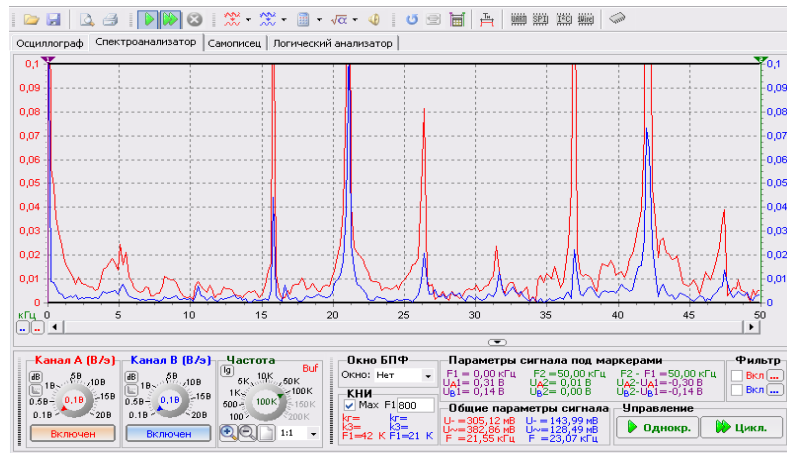


Figure 1 – Functional pattern of the experimental module. Experimental results

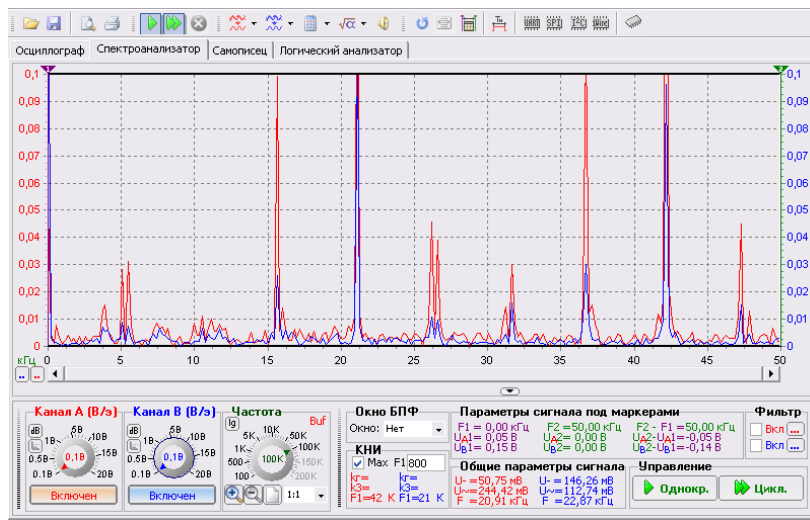
Akzhar. When applying impulses at a frequency of 42.8 kHz onto the oil slick of the Ak-zhar oilfield it can be noted that the amplitude values of the first channel are 2-3 times larger than the values of the second channel. At the same time, the spectral composition of the responses does not correspond to the positions of the harmonic series of the acting frequency (see figure 2a). So the response of the supplied frequency shifted to 1.3-1.5 kHz to the low frequencies for both channels. Proportional to the response rate (41.6 kHz) there is a response with a maximum of 21 kHz - which is the first harmonic of the response's fundamental frequency. After it there should theoretically be present the responses on the 2nd and 3rd harmonics of this frequency. They're not on the spectrogram. However, there are responses with large amplitudes at frequencies 36.5 and 16 kHz. In the high-frequency region there are responses (at) near 47 kHz. This is the spectral composition of the responses at the interface of the oil-water phases in the initial state.

At the same time, the harmonic series of the action supplied to the slick is easy to identify, since it corresponds to frequent decomposition of water, i.e. for water the characteristic frequencies are 42.8; 21.4; 10.7; 5.3; 2.6 kHz. The other responses (36.5; 16, etc.) correspondingly reflect the structural components of the oil slick.

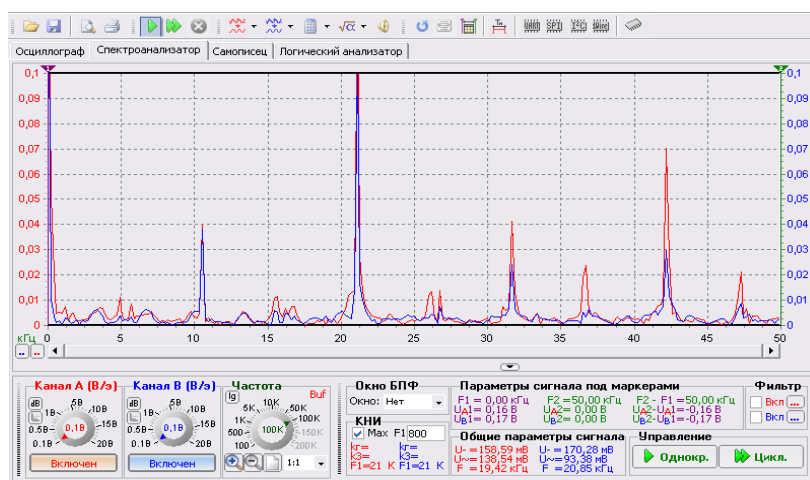
After 8 hours of exposure the appearance of the spectrogram has changed significantly (see figure 2b), indicating a change in the chemical composition of the interface. Firstly, the response at the fundamental frequency $\Delta f = 42,8 - 41,8 = 1 \text{ kHz}$ shifted towards lower frequencies by 1 kHz, i.e. less than in the original state, and secondly-there were new responses at frequencies 26; 26,5 and 5; 5,5, which have a doublet structure. The appearance of doublets is a sign of uneven reactions progression along the length of the experimental reactor.



a – Theinitialslick

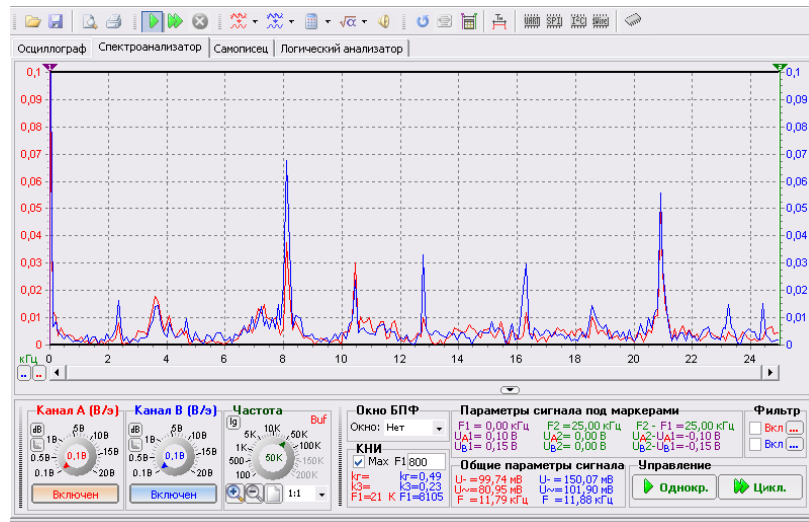


b – After exposure during 8 hours

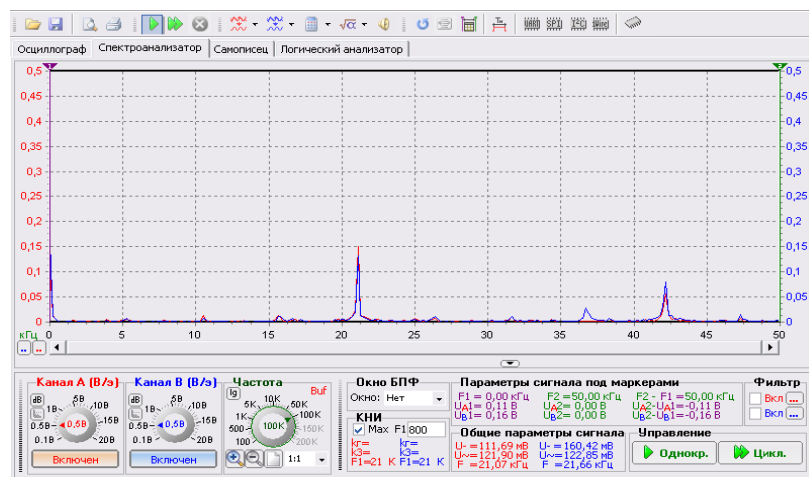


c – After 3 days of aging

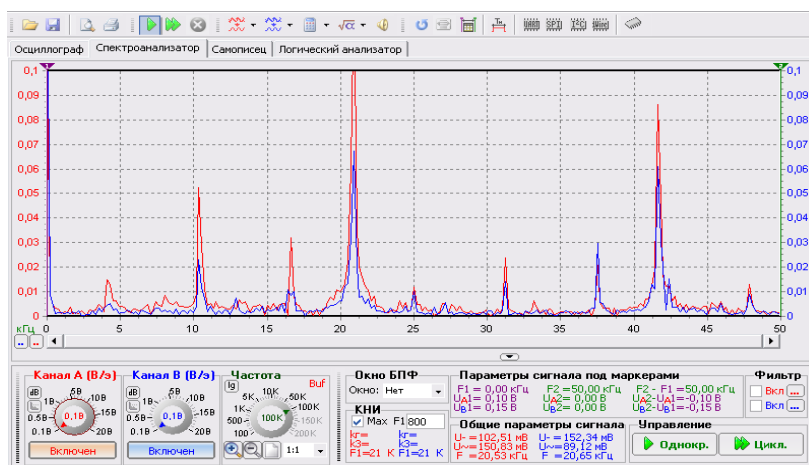
Figure 2 – The spectral composition of the boundary responses (Akzhar)



a – The initial state



b – After exposure during 24 hours



c – After 2 days of aging

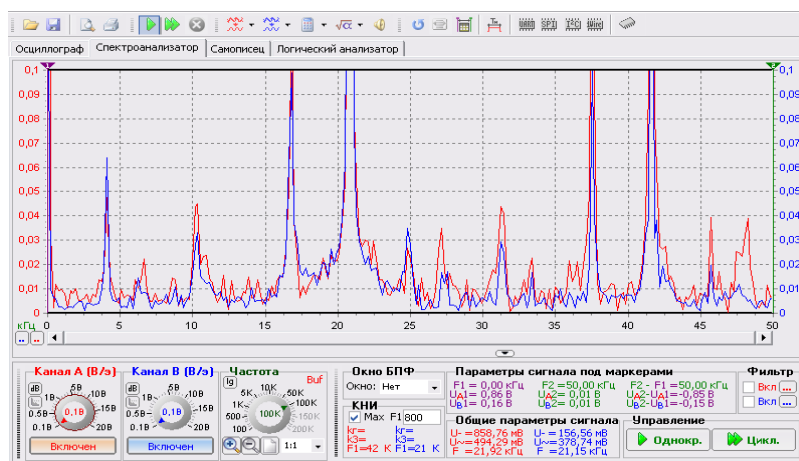
Figure 3 – The spectral composition of the “oil Karabulak – water” interface response

The spectrogram of the responses, taken after 3 days of aging, gives an idea about the stability of new structural components (see figure 2c). Here, the spectrogram has almost no displacement of the main frequency of the action, but the amplitude response value is half less of the first harmonic (21.2 kHz), which means that the response is dominated by larger elements of the structure that are no subject to any changes (to aging). On the 2nd and 3rd harmonics their numbers are less, but they correspond to a number of the fundamental frequency.

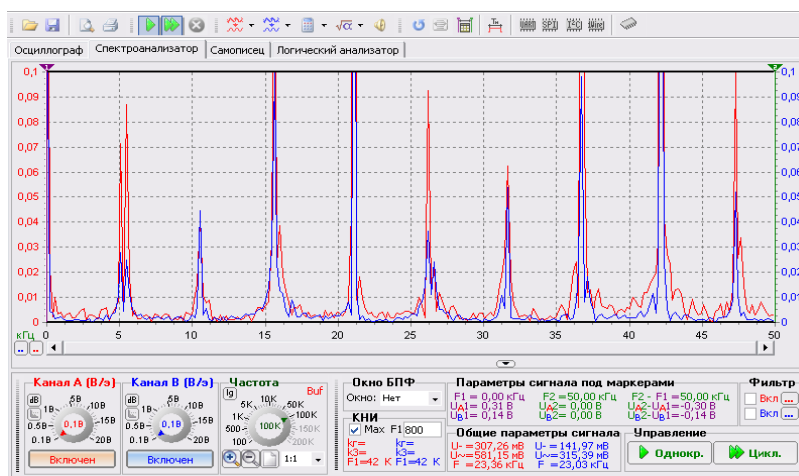
Thus, based on the obtained results, it can be concluded that under the influence of the water decomposition frequency on the interface new structural elements appear both from the synthesis of larger structures, on the basis of water, and also from the decomposition of hydrocarbon, which acquire a high-frequency response.

A similar study was given for a composition consisting of an oil slick from the Karabulak oilfield on the surface of tap water mineralization. In the initial state (figure 3a.) the spectrogram is similar to the response shown in figure 2. The main difference is the appearance of low-frequency responses near 22, 17, 14, 6 kHz, which can be considered as signs of the appearance of the structures of the main chemical composition of the researched oil.

After processing the composition during the day (figure 3b) the type of response spectrogram has changed significantly-the responses at low frequencies have disappeared. The response to 21 kHz has amplitude twice the amplitude of the original signal, which is the main sign of changes in the chemical



a – The initial state (reactor orientation: East-West)



b – After exposure during 24 hours (reactor orientation: North-South)

Figure 4 – The spectrogram of the response of the composition "oil Zhanatan - water"

composition of the phase boundary components in the direction of larger regular structures. In the course of aging (figure 3c.) these structures do not change their acquired peculiarities, i.e. the responses are stored at frequencies 37, 32, 21, 10.5 kHz. The main feature of this spectrogram is the absence of displacement at the frequency of exposure, which means full coverage of the acting signal of the entire volume of the reactor.

To understand the reaction from the diurnal rotation, spectrograms of responses were taken at different positions of the experimental modulus relative to the cardinal directions (see figure 4). In the initial state, when the reactor is located along the East-West direction, the response spectrogram has the same regularities that are inherent in the initial "oil-water" compositions for other oil fields, i.e. there are responses of the harmonic series of the acting frequency (42,8; 21; 10; 5). These responses characterize specific features of the formation of water structures, as they reflect the process of water decomposition (42,8 Puharich frequency [11]). To assess the impact of the change in the state of the oil surface from the Zhanatan field, one may consider frequencies of 37.5, 32, 16.5 kHz, the amplitudes of which are commensurable with the magnitude of the acting signal. These are signs of a resonant response. The basis for this assumption is the almost identical speed of propagation of mechanical (acoustic) waves in the water and oil environments [12, 13].

After an impact on the Puharich frequency during 24 hours (figure 4), with the orthogonally (N-S) changed orientation of the ditch, a unique spectrogram of the response was obtained in which the entire harmonic series for water and oil has doublet responses shifted 1- 2 kHz relative to the main signal. It should be noted that almost all responses have amplitude values commensurate with the response of the impact frequency. This experimental fact means that in the entire volume of the reactor, the processes of formation of both small (47 kHz) and larger structures occur in the most boundary composition. At the same time, a regular structured film becomes the master of specific formations, the state of which it can control. The observed effect of the occurrence of regularity of responses makes it possible to predict the results of external action on the change in the rate of HC synthesis under natural conditions.

Scope of application of results. For a comparative analysis of the qualitative features of the change in the state of the phase boundary during the course of the action, a table of the spectral composition of the responses for three oil fields was compiled: Akzhar, Zhanatan, Karabulak.

Spectral composition of responses for water and oil harmonics of the interface (Akzhar, Zhanatan, Karabulak)

Conditions of the experiment (oil field)	Amplitude of spectral response, B								
	Frequencies of the harmonic series of water, KHz				Frequencies of the harmonic series of oil, KHz				
	41,6	20,5	10,5	5	37	32	25	16	8
Ak-Zhar, initial condition of oil	0,22	0,15	–	0,02	0,1	0,02	0,08	0,1	–
Ak-Zhar, 8 hours of treatment	0,25	0,15	–	0,025	0,1	0,01	0,05	0,1	–
Ak-Zhar, aging 72 hours	0,02	0,15	0,04	0,01	0,02	0,04	–	0,1	–
Karabulak, initial condition of oil	–	0,05	0,03	–	–	–	–	0,03	0,07
Karabulak, 24 hours of treatment	0,1	0,15	–	–	<0,05	–	–	–	–
Karabulak, aging 48 hours	0,09	0,15	0,03	–	0,03	–	0,03	0,03	–
Zhanatan, initial condition of oil East-West	0,2	0,03	0,045	0,055	0,15	0,045	0,04	0,15	–
Zhanatan, 24 hours of treatment North-South	0,22	0,15	0,12	0,05	0,18	0,15	0,09	0,17	–

Tabular data indicate that during the treatment the amplitude of the responses varies, both for the components of the harmonics of the water series, and for the special frequencies of the oil film. In this case, the response of each oil field has specific features. Therefore, when developing software for properties management, it is necessary to take into account the individual characteristics of the oil field [14, 15].

In dynamical systems, whose potential for external influences exceeds the possibilities for the material to return to the previous type of equilibrium - the processes of melting, dissolution, chemical reactions, plastic deformation, etc., the transition to a new state takes place in stages, accompanied first by the destruction of weaker bonds, then by intermediate and most energy-intensive bonds.

The quantitative relations in the multistage process of the phase transition fit well in the equation of Smirnov A. P. [17]:

$$\ln \eta / (1 - \eta) - \ln \eta_i / (1 - \eta_i) = \varepsilon_i ((D - D_i) / D_i)^n.$$

This relationship establishes the link of the energy necessary for the transition to another state of the multiparticle system in the condition of a change in the fraction of particles in the excited state from η_i to η (the left side of the equation). The right-hand side of the equation of equilibrium characterizes the energy of the change in the measure of action on the system from D_i to D (D can be temperature, magnetic field, pressure, frequency, density, velocity and other parameters changing under the action of external forces).

Analysis of the systemic bonds [17] in a solid, carried out for four levels of consideration, showed that the value of ε_i can be equal to 1, 10, 100, 1000 depending on the type of energy conversion during the interaction process. For example, in the process of decomposition of water by energy storage substances, three types of resonance interactions were identified, in which ε_i has values of 10, 100, 1000.

Thus, this equation can characterize several types of equilibrium in which the quantitative relations between the excited and unexcited elements of the structure are balanced by changing the physical properties of the substance. If this relationship has the force of law, then in already existing types of equilibrium, inter phase and intra-phase - these relationships must be satisfied. The left side of the equation gives a quantitative representation of the changes in the reacting system, and the right reflects all the varieties of responses to the external action mathematically described by the value of the power-law dependence of n . The physical meaning of this indicator reflects the change in properties in the 1D, 2D, 3D dimensions.

Experimentally observed values of the degree n :

$$n = 1; \quad n = 1/2; \quad n = 3/2.$$

An exponent $n = 1$ is characterized by changes in properties, which are described by linear relationships, for example, frequency, refractive index, diffusion, and others. We used this relation with $n = 1$ to determine the interaction frequency for environments moving with different velocities. The well-known formula of Krasilnikov V.A. [12] is a particular case of this law. In the matrices of systemic relationships that we have developed, the exponent equal to one is used for processes and states of level 1 of consideration.

The exponent $n = 1/2$ (square root) can be used for the second level of consideration (2D processes), where changes in states associated with the transformation of electromagnetic energy into mechanical one and vice versa prevail. In our case, these are processes and states of the second level of consideration (exponent relations).

Responses for 3D levels of consideration include processes associated with the impact of the dynamic effect of daily rotation of the planet, where the space-time parameters are determined by Kepler's third law [18-21].

Comparison of experimental results on the study of spectral responses to external impulse actions and theoretical developments based on the types of equilibrium for intraplanetary cycles allows us to draw the following conclusions:

1. Obtaining information on changes in the state of the interface between phases by measuring spectral responses provides the necessary potential for searching for cause-effect relationships in all ranges of external influences.

2. The change in the quantitative relationships in the "impact-response" system is suggested to be estimated by the formula of Smirnov A.P., which makes it possible to reflect three-stage processes in the whole variety of their manifestations.

3. It is shown that the state of water (supplier of hydrogen and oxygen) at the interface between phases affects the processes of synthesis and decomposition of hydrocarbons. The observed effect is of practical importance in the development of technology to reduce viscosity under natural underground conditions.

The results of the work were obtained during the implementation of the topic AP05130483 "Scientific and technical basis for reducing the viscosity of Kazakhstani oils, which provide a significant increase in oil recovery from oil fields" (2018-2020).

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**ҚАБАТТЫҢ МҰНАЙ БЕРГІШТІГІН АЙТАРЛЫҚТАЙ АРТТЫРУ МАҚСАТЫНДА
ҚАЗАҚСТАНДЫҚ МҰНАЙ ТҮТҚЫРЛЫҒЫН ТӨМЕНДЕТУДІҢ
ҒЫЛЫМИ-ТЕХНИКАЛЫҚ НЕГІЗДЕРІ**

Аннотация.

Жұмыстың мақсаты: Мұнай қабаттарының мұнай беругіштігін айтарлықтай арттыру мақсатында қазақстандық мұнайдың тұтқырлығын азайту үшін ғылыми-техникалық негізінде құру.

Қазіргі экономикалық жағдай барысында Қазақстанның мұнайгаз саласы оның жоғары инвестициялық тартымдылығын сақтай отырып, белсенді өсу аймағында болуды жалғастыруда.

Сыртқы импульстік әсер етуіне спектрлік жауап (жаңғырық) және теориялық әзірлемелер түрлері бойынша эксперименттік нәтижелерін салыстыру барысында тепе-теңдік үшін планета ішілік зерделеу бойынша цикл мынадай қорытындылар жасауға мүмкіндік береді:

1. Қазақстандық мұнайдың тұтқырлығын азайту процесін программалық камтамасыз ету міндеті барысында, әр кенорнында әртүрлі болғандықтан, анықталған әсер етудің жауабының (жаңғырықтың) спектрлік құрамын зерттеу үшін физикалық үлгілеу жүргізу керек болды.

2. Спектрлік жауапты өлшеу жолымен фазаның бөліну шекарасының өзгеруі жайлы ақпарат алу – барлық сыртқы әсер ету диапазоңдарының себеп-салдарлық өзара байланысының қажетті қуатын іздеу болып табылады.

3. «Әсер ету-жауап алу» жүйесінде сандық қатынастардың өзгеруін үш стадиялық процестің көптірлік пайда болуын көрсетуге мүмкіндік беретін А.П.Смирновтың формуласымен бағалау ұсынылды.

Түйін сөздер: мұнай бергіштік, әсерге жауап беру, спектрлік құрам, бөліну шекарасы, қасиеттерді басқару, тау жыныстарының табиғи орны.

Г. Ж. Молдабаева, Г. П. Метакса, Ж. Н. Алишева

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НАУЧНО-ТЕХНИЧЕСКИЕ ОСНОВЫ СНИЖЕНИЯ ВЯЗКОСТИ КАЗАХСТАНСКИХ НЕФТЕЙ, ОБЕСПЕЧИВАЮЩИХ СУЩЕСТВЕННОЕ ПОВЫШЕНИЕ НЕФТЕОТДАЧИ ПЛАСТОВ

Аннотация.

Цель работы: Разработка научно-технических основ снижения вязкости казахстанских нефтей, обеспечивающих существенное повышение нефтеотдачи пластов.

В современных экономических условиях нефтегазовая отрасль Казахстана продолжает находиться в зоне активного роста, наряду с сохранением ее высокой инвестиционной привлекательности.

Сопоставление экспериментальных результатов по изучению спектральных откликов на внешние импульсные воздействия и теоретических разработок по видам равновесия для внутрипланетных циклов позволяет сделать следующие выводы:

1. Получение информации об изменениях химического состава границы раздела фаз путем измерения спектральных откликов обеспечивает необходимый потенциал поиска причинно-следственных взаимосвязей во всех диапазонах внешних воздействий.

2. Изменение количественных соотношений в системе «воздействие-отклик» предложено оценивать по формуле Смирнова А.П., дающей возможность отражать трехстадийные процессы во всем многообразии их проявлений.

3. Показано, что состояние воды (поставщика водорода и кислорода) на границе раздела фаз влияет на процессы синтеза и разложения углеводородов. Обнаруженный эффект имеет практическое значение при разработке технологии снижения вязкости в условиях природного залегания.

Ключевые слова: нефтеотдача, воздействие-отклик, спектральный состав, граница раздела, управление свойствами, природные залегания.

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**CONTROL OF TRACE QUANTITIES OF METALS
IN THE ENVIRONMENTAL SAMPLES,
USING MERCURY-FILM INDICATIVE MICROELECTRODES**

Abstract. Theoretical bases for the determination of trace quantities in the environmental samples by the method of stripping voltammetry, whose accuracy and reproducibility is associated with the use of the proposed mercury-film tungsten electrode, have been developed. The methods for the formation of a stable mercury film on a substrate of this material have been developed; the factors effecting the sensitivity and resolution of the film electrode have been studied.

Perspectiveness of using the electrochemical methods of analysis, in particular, stripping voltammetry, for exercising a control over toxic and heavy metals in technology-related and mineral raw materials of Kazakhstan has been demonstrated.

Key words: indicative electrode, mercury-film electrode, tungsten, stripping voltammetry, amalgamation.

Nowadays, the transformation of any technology process into a recycling waste-free production is one of the most important tasks. In this connection special attention should be paid to monitoring and regulation of the technology process itself and the determination of the content of toxic substances in industrial waste dumps and industrial wastewaters.

In connection with the accumulation of a large amount of secondary raw materials, containing harmful impurities, including heavy metals, the task of their detection and quantitative determination remains topical up till now. Only the data of analytical control may provide the people with a thread for managing the environmental purity and indicate the moment of necessary intervention for its protection from the accumulation of toxic substances and ecological poisons, whereto heavy metals are directly related. Passing into the human organism through air and water, including the chain: soil → water → animal, they cause various diseases.

The developed indicative microelectrodes on a substrate of the iron family metals and alloys on the basis of such metals, as well as a carbon-containing material, carbon-fiber reinforced plastic, which can be safely related to new means of controlling toxic substances have been earlier proposed as the means for exercising control over toxic and heavy metals [1].

Physical and chemical characteristics of these electrodes and the mechanism of the processes, proceeding at the electrode-solution interface have been studied at the stages of preparation of their surface and subsequent amalgamation. Optimal parameters of their functioning have been determined. A design of a rotating electrode has been developed, which has allowed the metrological characteristics to be improved and analytical signals of toxic elements, such as mercury, zinc, cadmium, lead and copper, to be detected when they are jointly present in the analyzed samples.

While carrying out an electrochemical analysis of the toxic metal compounds a large effect upon the cathode-anode processes is produced by the nature of the indicative electrode matrix, background composition and the presence of other components. The impurities, possessing the same or close values of

potentials, as well as the impurities, forming intermetallic compounds with the analyzed metals, especially hinder the registration of analytical signals. The indicated circumstances determine a necessity to solve a complex problem of development of electrodes, using inexpensive and available materials with the valuable physicochemical and electrochemical properties.

The creation of a mercury-film electrode (MFE) is one of the greatest achievements in the inversion methods of electroanalysis. MFE combines the advantages of a solid and mercury electrodes: it has a wide operating interval of potentials, sufficiently reproducible surface; it does not display, as a rule, any intermetallic interactions of the deposited metals. MFE is obtained by applying mercury to an inert electroconductive substrate [2, 3].

Upon the creation of new indicative electrodes special requirements are set forth for increasing their corrosion resistance, sensitivity, selectivity, expansion of the range of operating potentials, etc. The most promising in this respect are the mercury-film electrodes with an inert substrate, which make it possible to work within a very wide range of potentials, thereby expanding the analytical capabilities.

Graphite and glass carbon are usually used as a substrate. However, the use of such substrates does not ensure the formation of a uniform film due to the presence of microdefects (microscratches, chips, cracks) on the surface. Such material requires an additional treatment, involving certain physical and material costs. This may be excluded by using metal substrates.

It is known that mercury is isolated in the form of a uniform film only on amalgam-forming metals [4,5]. The drawbacks of mercury-film electrodes (MFE) on metal substrates are an instability of the thickness and composition of a mercury film as a result of the deep penetration of mercury into the metal and the formation of amalgams of different concentrations, as well as possible interactions of the analyzed metals, isolated on the electrode, with the substrate metal. These circumstances indicate an important role of a substrate in the electrode functioning.

Precious metals are usually used as metal substrates for mercury, which are inert to mercury and adhere well thereto [6, 7].

Method of procedure. Measurements by the method of stripping voltammetry were carried out with the help of PI-50-1.1 potentiostat and CBA-1 system, using molybdenum and tungsten as an electrochemical sensor, MB-50 alloy with the visible surface area of 0.2 cm^2 . Electrochemical regeneration of the electrode surface was carried out after each measurement, holding an electrode at the positive potential of 0.7 V and mechanical regeneration was carried out by grinding the working surface with a special paste (or Al_2O_3 powder), then by filter paper. A silver chloride (Ag^+/AgCl) electrode (s.c.e.), whose potential in relation to a normal hydrogen electrode of 0.1 M KCl is equal to +0.222 V at 20°C , was used as a reference; a platinum wire was used as an auxiliary electrode. Voltammograms were registered on GTDA-1 two-dimensional recording potentiometer in the mode of anode stripping voltammetry with a potential sweep rate of 0.1 V/s.

Experimental. A mercury-film electrode (MFE) combines the advantages of a solid and mercury electrodes: it has a wide operating interval of potentials, sufficiently reproducible surface; it does not display, as a rule, any intermetallic interactions of the deposited metals. MFE is obtained by applying mercury to an inert electroconductive substrate [1-4].

It is known that mercury is isolated in the form of a uniform film only on amalgam-forming metals [4, 5]. The drawbacks of mercury-film electrodes (MFE) on metal substrates are an instability of the thickness and composition of a mercury film as a result of the deep penetration of mercury into the metal and the formation of amalgams of different concentrations, as well as possible interactions of the analyzed metals, isolated on the electrode, with the substrate metal. These circumstances indicate an important role of a substrate in the electrode functioning, which should ensure good adhesion with mercury and be inert thereto. With this purpose mainly precious metals are used [2-5]. Mercury-film electrodes on an iridium substrate allow one to determine the presence of Cd and Pb within the range of contents of 0.1–5 mg/l [3]. A mercury-film electrode of platinum with electrochemical regeneration of a mercury film has been studied in detail *in situ* in the presence of cadmium ions ($C < 2 \cdot 10^{-6} \text{ mol/l}$), providing good adhesion of mercury to a platinum substrate [6].

It has been shown that the electrochemical properties of the obtained MFE remain constant with the thickness of a mercury film of $\sim 10 \text{ } \mu\text{m}$ ($d = 0.14 \text{ mm}$) and $\sim 25 \text{ } \mu\text{m}$ ($d = 0.45 \text{ mm}$). It is assumed, that with an increase of the diameter d of Pt-film an edge effect becomes more pronounced. This requires an increase

of the film thickness. When using an immobile MFE at the background of 0.1 M HC10_4 strong signals of cadmium and indium (III) reduction have been recorded in the presence of complexonates, causing their ligand-induced adsorption.

Precious metals are mainly used as metal substrates for mercury, which have good adhesion to mercury and are inert in relation thereto [3-6, 9].

The material, proposed by us as a substrate, tungsten, possesses such physical properties as strength, hardness and elasticity, and has an obvious advantage over the precious metals by its cost (much more inexpensive as compared with them), being, therefore, an available constructional material. Besides, it is practically insoluble in mercury ($L = 6.8 \cdot 10^{-20}$ at.%) [10], which affords us ground to assume that MFE on its basis should correspond by its properties more to the mercury electrodes and mercury.

The mercury potential depends, to a large extent, on the nature of anions, which is connected with the tendency of ions of mercury (I) and (II) to form salts of low solubility and complex ions (table).

Standard mercury potentials in the solutions under study [9]

Electrode reaction	$E_0, \text{V (n.h.e.)}$	$E_0, \text{V (s.c.e.)}$
$\text{Hg} + 2\text{OH}^- = \text{HgO} + \text{H}_2\text{O}$	0.929	0.689
$2\text{Hg} + \text{SO}_4^{2-} = \text{Hg}_2\text{SO}_4 + 2\text{e}$	0.615	0.378
$2\text{Hg} + 2\text{Cl}^- = \text{Hg}_2\text{Cl}_2 + 2\text{e}$	0.268	0.031
$2\text{Hg} + 4\text{Cl}^- = \text{HgCl}_4^{2-} + 2\text{e}$	0.48	0.243
$2\text{Hg} + 2\text{SCN}^- = \text{Hg}_2(\text{SCN})_2 + 2\text{e}$	0.22	-0.017
$2\text{Hg} + 2\text{OH}^- = \text{Hg}_2\text{O} + \text{H}_2\text{O} + 2\text{e}$	0.123	-0.114

In the non-complex-forming medium the standard mercury potential is shifted to the positive values up to $\sim +0.4 \div +0.7$ V. If any substance, forming an insoluble compound or complex with mercury ions, is present in the solution, the potential shifts to the less positive and even negative values the stronger the less soluble the precipitate is, the more stable the complex is, and the higher the concentration of the substance, forming the precipitate or complex, is. It is known that the precipitates with mercury are formed in the presence of ions of Cl^- , Br^- , I^- , N_3^- , OH^- , SH^- , S^{2-} etc., the complexes are formed with SCN^- , CN^- , SO_3^{2-} , $\text{S}_2\text{O}_3^{2-}$, EDTA, etc. [3].

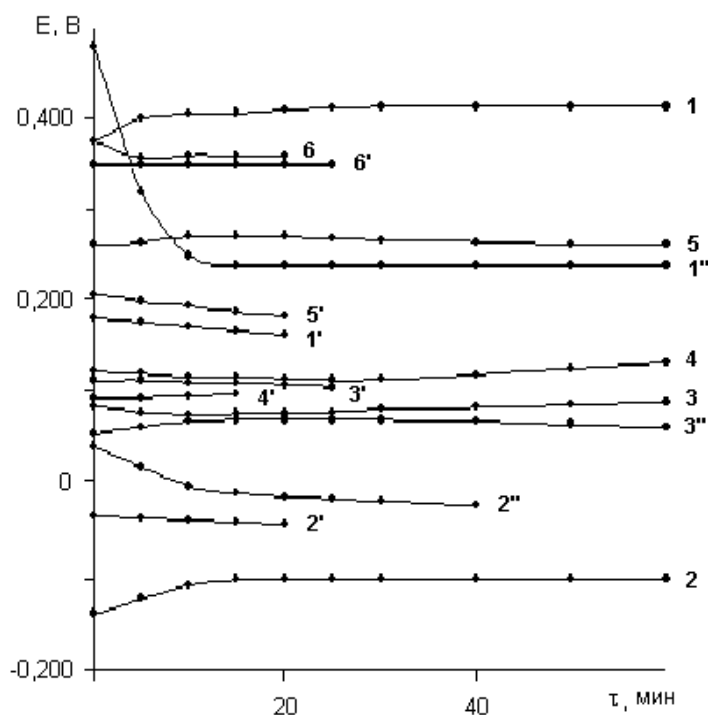


Figure 1 –
Potential-time dependences of RPWE (1-6),
RE (1'-6'), RPSUE (1''-3'')
in 0.1N solutions of electrolytes
1-1'' – H_2SO_4 ;
2-2'' – KSCN ;
3-3'' – KCl ;
4, 4' – HCl ;
5, 5' – H_3PO_4 ;
6, 6' – $\text{H}_2\text{SO}_4 + 1.68 \cdot 10^{-2} \text{ N HgSO}_4$

In this connection, for the identification of the peculiarities of the mercury-film electrodes on the basis of tungsten (RPWE), the stationary potentials (E_c) of the mercury-film samples based on W have been compared with the mercury pool and RPSUE in 0.1 N solutions of various electrolytes (figure 1).

As it follows from the obtained results, E_c of the mercury-film samples on the basis of tungsten is close to E_c of the above mercury electrodes. A certain difference in the values of the steady-state potentials seems to be explained by an interaction between mercury and the substrate metal. We guess that in the surface layer of a metal substrate, upon mercury deposition, the formation of tungsten bronzes (Hg_xWO_3) is possible, whereupon a mercury coating is formed.

Upon adding of Hg^{2+} ions to 0.1 NH_4SO_4 solution the recorded potential E_c for all electrodes has the same values. This is due to the fact, that since Hg on all electrodes is present as metal, in the elemental state, its activity is equal to 1 and mercury ions are potential-defining in the indifferent H_2SO_4 solution, containing $1.68 \cdot 10^{-2} NHg^{2+}$.

The study of the steady-state potentials of the mercury-film samples in different media shows not only the defining role of mercury on their surface, but also an effect of the substrate metal upon the electrochemical characteristics of the electrode. It has been established, that the behavior of the electrode with a tungsten substrate somehow differs from that of the pure mercury electrodes [2, 11, 12].

Alongside with the potentiometric measurements, which have made it possible to study the electrodes without the imposition of external polarization, the cathode-anode processes proceeding on the electrode have been studied and the range of the operating potentials has been established for the evaluation of the effect of the substrate metal upon the functional characteristics of the electrode by way of recording cyclic voltammetric curves.

Voltammograms of pure mercury, represented by the mercury pool (RE) and mercury-film samples of tungsten and platinum in the sulfuric medium, have been taken for comparison (figure 2).

The comparison of the polarization curves shows that in case of RPWE a current horizontal area is narrower than that of a mercury electrode, since the field of potentials of the curve kinetic site is wider.

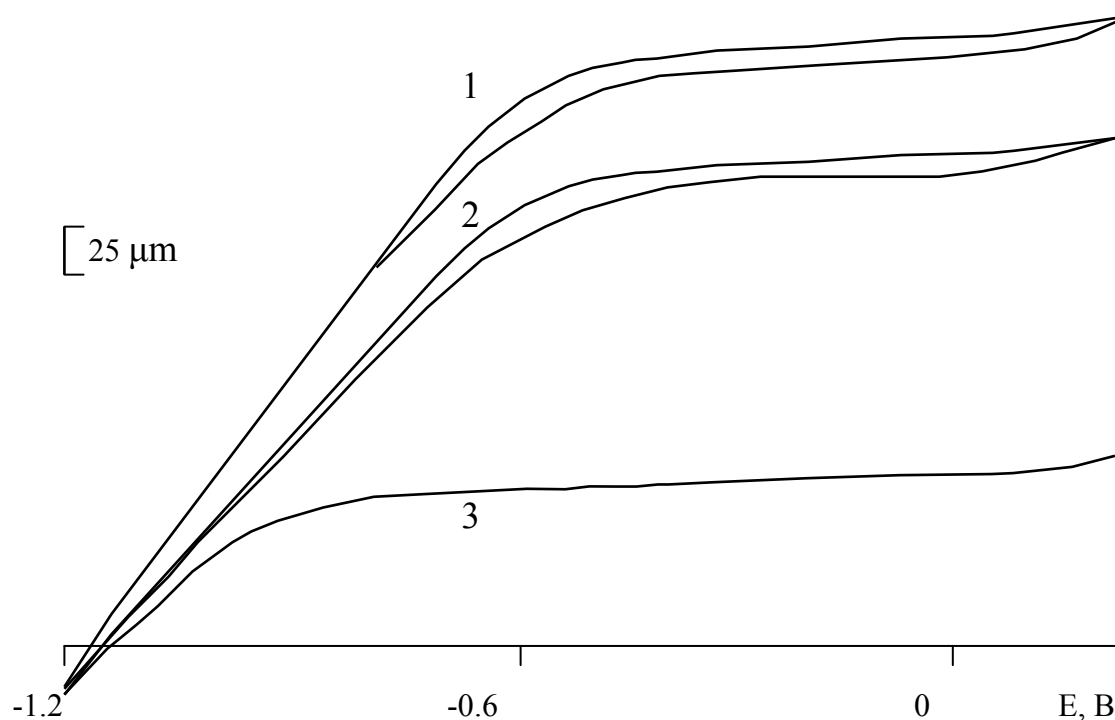


Figure 2 – Comparison of the working region of the potentials of RPWE (1), RPPRtE (2) and RE (3) in 1M H_2SO_4

This seems to be explained by an interaction between mercury and tungsten, and results in decreasing of hydrogen overpotential (down to the value of -0.8 V), in comparison with the mercury electrode ($\geq 1B$) [1].

Probably, the shift of the reduction potential of H^+ -ions to the positive side occurs due to the change of the nature of the surface substrate layer. The horizontal curve area and ranges of operating potentials (figure 2) show an identity of polarization curves for RPWE and RPRtE (curves 1, 2) and similarity of the characteristics of these electrodes to RE (curve 3).

Thus, the established similarity of the electrochemical properties of the mercury-film electrodes on a metal substrate (RPWE and RPRtE) affords us ground to conclude that the functional characteristics of the electrodes are mainly determined by the nature of the substrate metal.

A possibility of evaluating the quality of coating has been shown by the method of cyclic voltammetry, and the correctness of such an estimate has been established when using new materials as indicative electrodes in the method of stripping voltammetry. The conditions ensuring selectivity of their determination have been revealed using the example of Pb and Tl.

The regularities of the electrochemical behavior of Pb, Hg, Tl, Cu and Au have been studied in indifferent and complex-forming electrolytes on the new microelectrodes. The new electrodes have been approved for the first time in the analysis of waters and gold-containing products. Persepectiveness of their using as indicative electrodes for electroanalysis has been demonstrated.

A conclusion has been drawn that one of the criteria for choosing electrode materials is their solubility in mercury and corrosion resistance in the working electrolytes, which, in its turn, is determined by the composition and structure of their crystalline lattice, physical and chemical properties of the oxide films, formed on the sample surface and solid reaction products.

Conclusions. Thus, the established similarity of the electrochemical properties of the mercury-film electrodes on a metal substrate (RPWE and RPRtE) affords us ground to make a conclusion of a possibility to use a mercury-film tungsten indicative microelectrode for exercising control over the trace quantities of metals in the environmental samples.

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КОНТРОЛЬ СЛЕДОВЫХ КОЛИЧЕСТВ МЕТАЛЛОВ В ОБЪЕКТАХ ОКРУЖАЮЩЕЙ СРЕДЫ С ИСПОЛЬЗОВАНИЕМ РТУТНО-ПЛЕНОЧНЫХ ИНДИКАТОРНЫХ МИКРОЭЛЕКТРОДОВ

Аннотация. Разработаны теоретические основы определения следовых количеств металлов в объектах окружающей среды методом инверсионной вольтамперометрии, точность и воспроизводимость которых связана с использованием предлагаемого ртутно-пленочного вольфрамового электрода. Разработаны методы формирования устойчивой ртутной пленки на подложке из этого материала; исследованы факторы, влияющие на чувствительность и разрешающую способность пленочного электрода.

Показана перспективность использования электрохимических методов анализа, в частности, метода инверсионной вольтамперометрии, для осуществления контроля токсичных и тяжелых металлов в техногенном и минеральном сырье Казахстана.

Ключевые слова: индикаторный электрод, ртутно-пленочный электрод, вольфрам, инверсионная вольтамперометрия, амальгамирование.

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ҚОРШАҒАН ОРТА ОБЪЕКТІЛЕРІНДЕ СЫНАП-ПЛЕНКАЛЫ ИНДИКАТОРЛАР МИКРОЭЛЕКТРОДТАРДЫ ПАЙДАЛАНА ОТЫРЫП МЕТАЛДАРДЫҢ ӨТЕ АЗМӨЛШЕРІН БАҚЫЛАУ

Аннотация. Инверсті вольтамперометрия тәсілін қолданып қоршаған орта объектілерінде металдардың өте аз мөлшерінің теориялық негіздерін анықтау, жаңадан өндірілуі және дәлдігі ұсынылатын сынап-пленкалы вольфрамды электродты пайдаланумен байланысты. Осы материалдан тұрақты сынап пленкасын қалыптастыру әдістері әзірленді; пленкалы электродтың әсер етуші факторларға сезімталдығы мен рұқсат беретін қабілеті зерттелді.

Электрохимиялық талдау әдістерін пайдалану болашағы көрсетілген, атап айтқанда, вольтамперометрия инверсті әдісін жүзеге асыру үшін ҚР техногенді және минералды шикізаттарда уытты және ауыр металдардың мөлшерін бақылау.

Түйін сөздер: индикаторлық электрод, сынап-пленкалы электрод, вольфрам, инверсті вольтамперометрия, амальгамирлену.

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THE EFFICIENCY OF DISTRICT HEATING SYSTEMS IN CONDITIONS OF JOINT USE OF HEAT PUMPS

Abstract. The article describes the main problems of traditional heat supply in the Republic of Kazakhstan, discusses possible solutions to this problem. Development of practical examples of the implementation of heat pump technology at specific sites of a heat supply leads to the improvement of technical and economic parameters of the heating system. The development is aimed at the concept of using nontraditional sources of heat for the transition of heating systems to a new level of heat.

By analyzing existing examples of implementation in the work of heating systems with alternative heat sources and the results of the study determined the effectiveness of the installation of heat pumps in the Central heating station that uses the independent scheme of connection of consumers of heat. The use of a heat pump reverse system water to the evaporator as a source of low potential energy leads to a reduction in consumption of direct network of water from combined heat and power CHP heating unit quarterly network and consequently will decrease the flow rate of fuel combusted at the CHP.

Keywords: central heating; heat pump; mains water; teploelektrocentral; heating network; energy efficiency; low-grade heat.

In Kazakhstan, centralized heat supply based on combined heat and power generation at central heating plants (CHP) has been most widely developed and is currently the dominant system.

In the period from 1990-2005 the commissioning of new capacities at the CHP was carried out on a limited scale in connection with the economic downturn in the years of perestroika. The key problem in all operating links of the district heating system is the moral and physical wear and tear of fixed assets. Low demand for thermal energy has led to deterioration in the technical and economic performance of heat supply systems. This led to an increase in the cost of production of heat and electricity.

Increasing the energy efficiency of district heating should be carried out in accordance with the program "Energy Saving-2020", adopted by the Decree of the Government of the Republic of Kazakhstan dated August 29, 2013, No. 904 [1]. The program pays much attention to the selection of the main heat sources, as this is the most important task in the design of energy-efficient heat supply systems for housing and communal services.

The program "Energy Saving 2020" determines not only the creation of technical, technological, legal, economic and organizational bases and measures to stimulate the efficiency of heat supply systems, but also their mutual coordination aimed at reducing the amount of resources used, in particular fuel resources for heat supply, while maintaining the appropriate useful effect from their use.

For effective resource and energy saving in the centralized heat supply systems of the Republic of Kazakhstan, the following main problems must be solved.

When talking about resource saving or reducing energy losses, they do not mean a quantitative expression, since it is automatically controlled by the first law of thermodynamics, but implies a qualitative characteristic of the energy itself. In the general case, the conservation of energy of heat is, in essence, the preservation of its quality.

The task of energy efficient heat supply depends on a number of problems that depend on the geographic location of the heat supply facility, the duration of the heating period, taking into account the average ambient temperature.

The cost of heat supply depends on the climatic conditions of Kazakhstan. According to the official source of information [2], the average January temperature in the Republic of Kazakhstan (2015) $-11,0^{\circ}\text{C}$ (table 1).

Table 1 – Average temperature of January in different regions of the Republic of Kazakhstan

Region	Temperature, $^{\circ}\text{C}$
Akmola	- 16,8
Aktobe	- 14,9
Almaty	- 6,5
Atyrau	- 9,6
East_Kazakhstan	- 16,5
Zhambyl	- 5,0
West Kazakhstan	-13,5
Karaganda	-14,5
Kyzylorda	-9,1
Kostanay	-17,0
Mangystau	-2,9
Pavlodar	-17,6
North-Kazakhstan	-18,1
South Kazakhstan	-2,0

Before the design of the heating system of buildings and the selection of the source of heat, the heat balance is calculated, which takes into account:

- the number of emissions from heat sources that operate on natural fuels;
- rational use of traditional natural resources, the influence of the "greenhouse effect" due to the release of harmful substances into the atmosphere;
- thermal density of the built-up area;
- deficiency of generation of thermal energy; kind of available local fuel;
- washing of existing engineering systems and heat networks;
- it is impossible to lay new heating mains.

The drawbacks of traditional heat sources are their low energy, economic and environmental efficiency (in the case of small boiler houses), since the burning of organic fuel pollutes the environment. Plus, the constantly rising tariffs for released thermal energy, aggravated by transportation costs in the production and distribution of energy. Hence, a low exergetic ECE, characterizing the maximum work that occurs when the thermodynamic system with a specified parameter is reversed into equilibrium with the surrounding medium.

In addition, there is an unreasonably high cost of building and maintaining heat networks, which are the most unreliable element of central heating systems.

At present, the heat networks of the Republic of Kazakhstan are characterized by a high degree of wear, about 70-80%, high accidents, and losses in heating networks are much higher than world indices.

The most effective and obvious option for solving energy saving problems in heat networks is the use of rational process flow sheets with heat pumps. The prospects for the use of heat pumps TN in the Republic of Kazakhstan are determined by the technological demand and the tendency to increase prices for fuel, heat and electricity.

Overcoming with the help of factors TN that reduce the efficiency of heat supply from the CHP is fully possible only in newly constructed district heating systems (DHS) and in new construction of residential and industrial buildings.

The new projects provide for increased requirements for thermal and sound insulation. For windows, double-glazed windows of increased tightness are used. Inside the premises, there is a mandatory installation of heat metering and air temperature control devices, heating devices with more intensive heat transfer from the network water (finned-surface finned radiators, "warm floors", etc.), which help to reduce both the temperature of direct supply water and reduce the temperature of the return network water due to intensive heat extraction.

So for "warm floors" the temperature of direct and reverse network water can lie in the range of $45 \div 30^\circ\text{C}$. Under these conditions, a radical change in the temperature graph of direct and reverse water is possible—a reduction in these temperatures to a level sufficient for heating the premises and favorable for work TN with a high conversion factor. Under these conditions, a complete transition of the district heating systems DHS to the TN (CHP + TN system) is possible.

Currently, the network water is returned to the CHP plant at a temperature of $45 \div 70^\circ\text{C}$. To achieve higher values of the TN conversion factor, this temperature should be reduced to $25\text{--}30^\circ\text{C}$. This is possible not only by improving the design of buildings and their heating system, which was mentioned above. In addition to these solutions, it is possible (and appropriate) to lower the temperature of the return network water by installing heat pumps at central heating points (CHP). For TN, the source of low-potential heat will be the reverse network water.

In work [2] the system of heat supply of an apartment house with heat sources heat pump - thermal networks where the heat pump provides from 50 to 70% of heat demand is developed. The total duration of the operation of heat pumps depends on the value of the outside air temperature at the bivalent point on the heat load graph, determined by means of climatic data (Table 1).

In [3, 4], the idea of using low-potential heat concentrated on GRES-CHP by means of heat pump plants, which can be placed in centralized and individual heat points (CHS, IHP), which are part of the DHS, was proposed for the first time.

It is known that in DHS heat supply from CHP, as well as from the district boiler house, is carried out by a dependent and independent scheme for connecting external heat consumers. This circumstance, in turn, predetermines the appearance of a variety of schemes and methods for connecting heat pumps to the heat supply system, with the placement of TN both at the central heating point CHS and in close proximity to consumers.

All the listed shortcomings of traditional heat supply in conditions of energy saving and minimal harm to the environment, urgently require a different approach to solving the problem of heat supply for newly constructed housing. A possible solution to this problem is the beneficial use of low-temperature natural heat ($+4 \dots +40^\circ\text{C}$) or waste industrial heat for heat supply with the help of heat pumps.

Figure 1 is a schematic diagram of the connection of heat pump plants to the heating and hot water supply system at the central heating station (CHS). The flow of direct network water (DNW) from the CHP enters the traditional heat exchangers 1 of heating the return quarterly water of the heating circuit, in which part of the flow of return quarterly water (flow G_{1k}) is heated. Another part of G_{tn} of reverse quarterly water enters the condenser of the heat pump system and heats up at $\Delta t = 15^\circ\text{C}$. In the evaporators of the HPP, part of the flow of the reverse network water $G_{2k} = G_1 - \Delta G$ is sloughed, after which it is discharged into the main collector of the reverse network water and then returned to the CHP.

After the mixer 3, the heating water from the district heating circuit through the internal distribution heating networks is supplied to the heating of the objects of the quarterly network, after which it returns to heating in the TN and TO-1 according to the scheme described above.

By slackening the return flow network of the SS, the direct water supply from the TPS is reduced in proportion to the amount of heat collected from the SS in the evaporator TN. It is the amount of low-potential heat (LPH) from the SS that lowers LPH in the cold source at the CHP, which ultimately leads to a reduction in fuel consumption directly to the CHP and, at the same time, to a reduction in heat consumption from the CHP to CHS at the central heating network of the quarterly network. This ensures a reduction in the price paid by consumers of this quarter of the city for heat supply.

To discuss the results of the calculation, as an example, the costs and temperatures of the network water are taken in the conditions of the CHS: $\Sigma G_{2k} = 70 \text{ m}^3 / \text{h}$. $\Sigma G_{TH} = 25 \text{ m}^3 / \text{h}$. $T_1 \text{ rep} = 50^\circ\text{C}$; $T_2 \text{ right} = 65^\circ\text{C}$.

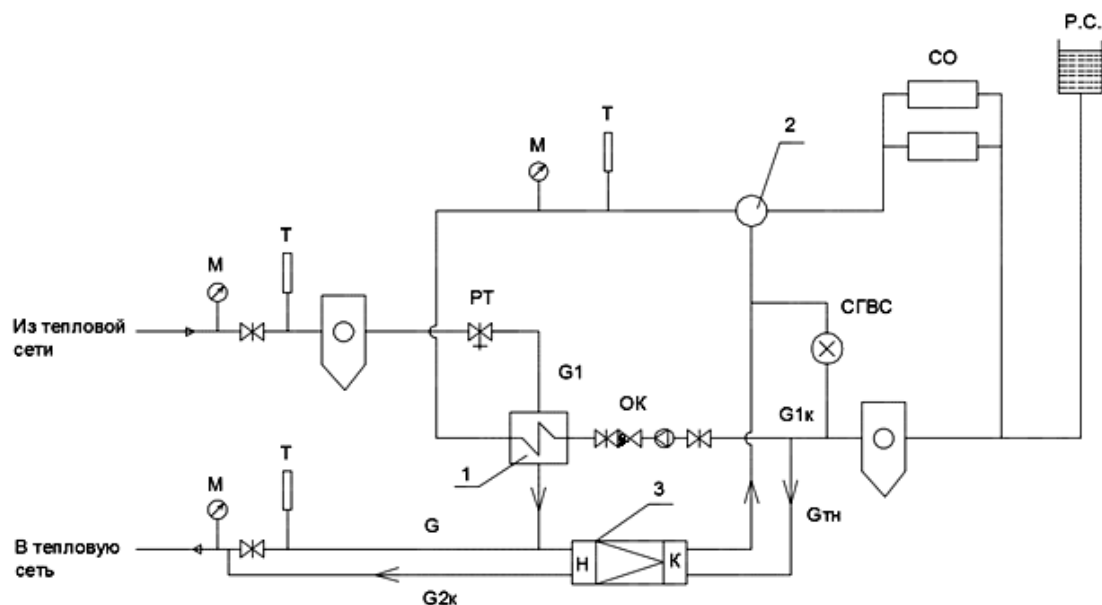


Figure 1 – Thermal diagram of the CHS with a TN with an independent heating circuit:

1 - water-water heat exchanger for the heating circuit (plate), 2-mixer, 2 - heat pump (TN), SS, HWS - external heat consumers of the heating and hot water supply system; G1 - direct grid flow to the CHS from the CHP; G_{2k} - the return flow of return water returned to the CHP after TN; G_{TH} - the return water flow rate of the quarterly heating circuit, supplied for heating in TN; G_{1k} - return water flow rate of the quarterly heating circuit, supplied for heating to the water-to-water heat exchanger (WWHE) of the traditional heat supply scheme; ΔG is the unused amount of return network water after the heat exchanger, returned to the CHP plant or for other purposes.

Heat output of the heat pump is determined by the formula (1)

$$Q = G_{TH} C_B \rho_B (T_{2прям} - T_{1обр}), \quad (1)$$

for the condition of the example in question, $Q = 436 \text{ kW} = 0.375 \text{ Gcal / h}$. Taking into account this heat load, one HT-300 water-to-water heat pump is chosen. The characteristics of the manufacturer for HT-300 are given in [5]. The HT-300 water-to-water heat pump operates on R-134 A refrigerant with a maximum condensation temperature of 60°C.

With the duration of the heating season in Almaty in 2015-16, equal to 4248 hours (177 days) and the operation of one TN-300, the expected annual heat production with HPP will be 1593 Gcal, the electric power consumption for the drive will be TN - 382.6 MW·h. With the adopted tariffs for thermal (3890.72 tenge per 1 Gcal.) And electric energy (7.5 tenge per 1 kWh for energy-producing enterprises) for residential objects: proceeds from the sale of heat supply will be 6.2 million KZT, electricity costs - 2.87 million KZT.

One of the important advantages of such a thermal scheme is the lowering of the temperature of the return water, which makes it possible to increase the combined generation of electric power by the CHP on thermal consumption. This is all the more topical because the temperature of the return network water returned to the CHP is constantly overestimated, which has many different causes, and not only technical ones. The practice of the operation of heat networks in different cities of the Republic of Kazakhstan shows that the water temperature in the return line of the heat supply systems in excess of the normative thermal schedule is exceeded by 5-8 °C in winter.

The capacity for hot water TN-300 is $G_{TH} = 25 \text{ m}^3/\text{h}$. At the same time, water is taken from the low-potential source (return water of heating systems) to the evaporator TH-300 - $G_{2k} = 50 \text{ m}^3/\text{h}$. Here it should be noted that with the same independent heating scheme without the installation of heat pumps, the flow of network water to the water-to-water heat exchangers of the heating circuit (plate) was $G_1 = 70 \text{ m}^3/\text{h}$. If one TH-300 is installed, this flow rate will be $G_{2k} = 50 \text{ m}^3/\text{h}$, i.e., $\Delta G = G_1 - G_{2k} = 20 \text{ m}^3/\text{h}$ will be less.

Thus, the installation of heat pumps makes it possible to reduce the flow of the heating water flow to the heat exchangers.

By stalling the flow of SS (return network water), the direct water supply from the CHP is reduced in proportion to the amount of heat taken away from the SS in the HPP evaporator. Cooling of return water for this mode of operation of the TN is from $t_{2R}=50^{\circ}\text{C}$ to $t_{1R}=40^{\circ}$, $\Delta t=10^{\circ}\text{C}$.

Figure 2 shows the p-H diagram of the thermodynamic cycle of a single-stage steam-compression heat pump HT-300.

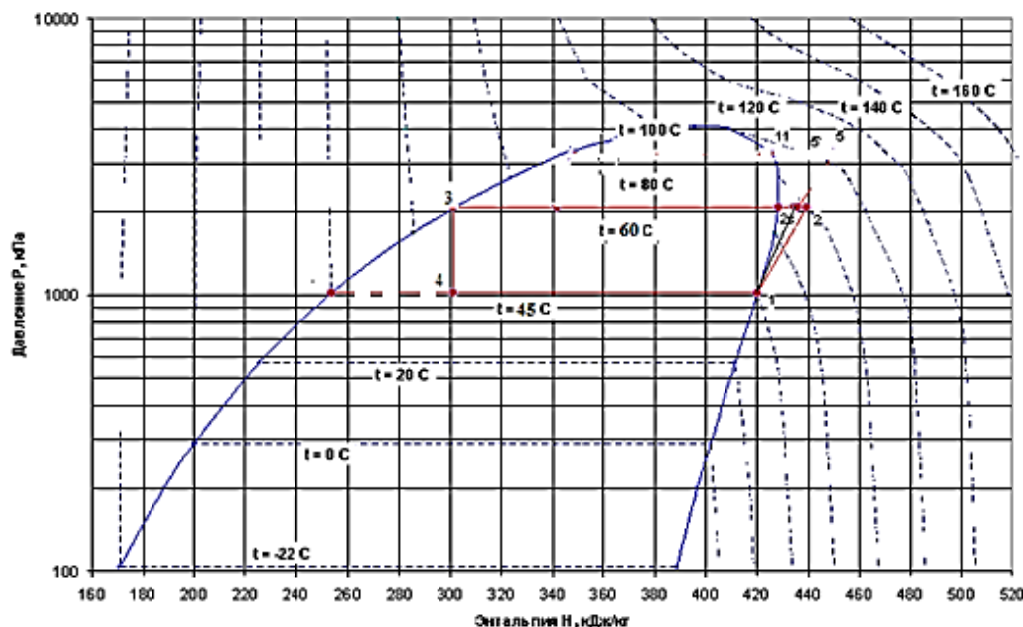


Figure 2 – Thermodynamic cycle of a single-stage steam-compression heat pump HT-300 with R-134A refrigerant in the p-H diagram

The temperature of the working agent R-134A in the heat pump condenser is $t_R = 60^{\circ}\text{C}$, in the evaporator $t_0 = 45^{\circ}\text{C}$. In the p-H diagram, the process of condensation corresponds to line 2-3, evaporation process 1-4. The coefficient of thermal energy conversion by the TH-300 heat pump was calculated using parameters of the constructed thermodynamic cycle (Figure 2).

The coefficient of conversion of thermal energy by a heat pump is determined by the formula

$$\mu = \frac{Q_{\kappa}}{N_e}, \quad (2)$$

where Q_{κ} – heat output of the heat pump; N_e - the electric power of the compressor drive and is $\mu = 4.84$, which is acceptable from the point of view of the efficiency of the heat pump application.

Conclusions.

1. The use of heat pumps in the conditions of operation of the central heating point of heating systems along with traditional heat sources can significantly reduce the cost of direct network water from the heat source - CHP.

2. Installation of heat pumps in the central heat station allows rationally provide heat to consumers who have an independent scheme for connecting heating systems.

3. The thermal scheme of the central heat point of the central heating station with a heat pump providing heat to consumers of the quarterly heating and hot water supply system has been developed.

4. Calculations of the heat output of the heat pump installed in the CHS show that as a result of slackening of the return water flow in the evaporator TN, the direct water supply from the CHP is reduced in proportion to the amount of heat extracted from it.

5. The value of the coefficient of conversion of thermal energy by the heat pump TH-300 confirms the efficiency of using a heat pump in the operation of the CHS of heating networks.

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ЖЫЛУ СОРҒЫЛАРЫН БІРЛЕСІП ҚОЛДАНУ ЖАҒДАЙЫНДАҒЫ ОРТАЛЫҚТАНДЫРЫЛҒАН ЖЫЛУМЕН ҚАМТУ ЖҮЙЕЛЕРІНІҢ ТИІМДІЛІГІ

Аннотация. Мақалада Қазақстан Республикасының жылумен қамдаудың дәстүрлі жүйесінің негізгі мәселелері сипатталып, мәселені шешудің мүмкін болатын жолдары қарастырылған. Нақты объектілерде жылу сорғыларға негізделген технологияларды енгізу жылумен қамтамасыз ету жүйелердің техникалық-экономикалық көрсеткіштерінің жақсаруына әкеледі. Өзірленген тұжырымдама дәстүрлі емес жылу көздерін пайдалану арқылы жылумен қамтамасыз ету жүйелері жұмысын жаңа деңгейге ауыстыруға бағытталған. Баламалы жылу көздерін жылу желінің жұмысына енгізудің қолданыстағы мысалдарын қарастыру және зерттеу нәтижелерін талдау арқылы жылуды тұтынушыларды желіге тәуелсіз қосу схемасын пайдаланатын

орталық жылу пунктінде жылу сорғыларын пайдалану тиімділігі анықталды. Жылу сорғысы орталық жылу пунктінде кері желілік суды буландырғышта төменгі қуатты жылу көзі ретінде пайдаланып, нәтижесінде жылуэлектр орталығынан берілетін жүйелік су шығынын қысқартады және оның салдарынан ЖЭО-да жағылатын отын шығыны төмендейді.

Түйін сөздер: орталықтандырылған жылумен қамдау, жылу сорғысы, жүйелік су, жылуэлектр орталығы, жылуды тұтыну, энергия тиімділігі, төменгі қайратты жылу.

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ЭФФЕКТИВНОСТЬ РАЙОННЫХ ОТОПИТЕЛЬНЫХ СИСТЕМ В УСЛОВИЯХ СОВМЕСТНОГО ИСПОЛЬЗОВАНИЯ ТЕПЛОВЫХ НАСОСОВ

Аннотация. В статье описываются основные проблемы традиционного теплоснабжения в Республике Казахстан, рассматриваются возможные пути решения этой проблемы. Разработка практических примеров внедрения технологии тепловых насосов на конкретных участках теплоснабжения приводит к улучшению технических и экономических параметров системы отопления. Разработка нацелена на концепцию использования нетрадиционных источников тепла для перехода отопительных систем на новый уровень тепла.

Проанализировав существующие примеры внедрения в работе отопительных систем с альтернативными источниками тепла, и результаты исследования определили эффективность установки тепловых насосов в Центральной тепловой станции, которая использует независимую схему подключения потребителей тепла. Использование системы обратной воды системы теплового насоса для испарителя в качестве источника с низкой потенциальной энергией приводит к снижению потребления прямой сети воды из комбинированной тепловой и тепловой электростанции ТЭЦ, ежеквартальной сети и, следовательно, будет уменьшать расход топлива, сжигаемого на ТЭЦ.

Ключевые слова: центральное отопление; Тепловой насос; вода в сети; teploelektrocentral; тепловая сеть; энергоэффективность; низкосортная теплота.

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МАЗМҰНЫ

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Требования для авторов журнала НАН РК Серия геологии и технических наук

Уважаемые авторы!

Прошло более семидесятипяти лет, как издается журнал «Известия НАН РК. Серия геологическая», а с 2011 г. «Серия геологии и технических наук». За период существования журнал завоевал широкий круг читателей и стал известен не только в Казахстане, но и в странах ближнего и дальнего зарубежья.

В журнале на русском, казахском, английском языках публикуются статьи о результатах исследований по актуальным проблемам обширной геологической науки (региональной геологии, минералогии, нефти и газа, геофизики, сейсмологии, гидрогеологии, экологии, географии), а так же статьи методического характера.

Все эти годы журнал служит источником оперативной информации о новейших достижениях геологической науки Казахстана и призван способствовать повышению эффективности научных исследований.

Авторы несут ответственность за достоверность и значимость научных результатов и актуальность научного содержания работ. Не допускается плагиат.

1. Представленные для опубликования материалы должны удовлетворять следующим требованиям.

Статья сопровождается разрешением на опубликование от учреждения, в котором выполнено исследование и представляется рецензия.

Статья представляется в одном экземпляре. Размер статьи не должен превышать 15 страниц включая аннотацию в начале статьи перед основным текстом, которая должна отражать цель работы, метод или методологию проведения работы, результаты работы, область применения результатов, выводы (**аннотация** не менее 15 предложений – 1/4 стр. (на английском языке) через 1 компьютерный интервал), таблицы, рисунки, список литературы (через 1 компьютерный интервал), напечатанных в редакторе Word, шрифтом Times New Roman, поля – верхнее и нижнее – 2 см, левое – 3 см, правое – 1,5 см. Количество рисунков не более 10. Название рисунков и подрисуночная подпись, а также название таблиц печатается на русском и английском языках.

СТАТЬЯ НАЧИНАЕТСЯ на английском языке. В начале, посередине страницы, идет название статьи прописными жирными буквами, далее на следующей строчке – инициалы и фамилии авторов обычным жирным шрифтом, затем на следующей строчке – название организации(ий), в которой выполнена работа, город, страна, затем на новой строчке – адреса E-mail авторов. С красной строки идут ключевые слова (**Key words**), и с новой строчке – сама аннотация (**Abstract – не менее 150 слов**).

Далее, после отбивки одной строки, начинается на **русском языке**.

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Отбиваем одну строку и начинается сама **статья**. Следом за статьей идет список **Литературы**. Ссылки на литературные источники даются цифрами в прямых скобках по мере упоминания (не менее 20). Список литературы оформляется следующим образом:

[1] Иванов А.А. Процессы протаивания грунта // Известия НАН РК. Серия геологии и технических наук. – 2007. – № 1. – С. 16-19.

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- 4) выделяем год полужирным шрифтом;
- 5) указываем язык статьи (in Russ.).

Пример:

[1] White S.R., Sottos N.R., Geubelle P.H., Moore J.S., Kessler M.R., Sriram S.R., Brown E.N., Viswanathan S. *Nature*, **2001**, 409, 794-797 (in Eng.).

[2] Soldatenkov N.M., Koljadina I.V., Shendrik A.T. Fundamentals of organic chemistry of medicinal substances. M.: Himija, **2001**. 192 p. (in Russ.).

В конце статьи дается резюме на казахском языке. Оформляется аналогично русскому варианту. Посередине страницы пишется: 1) название статьи; 2) авторы; 3) название организации; с красной строки – **Түйін сөздер**, после – **Аннотация**.

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