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Satbayev University

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ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

NEWS

OF THE ACADEMY OF SCIENCES
OF THE REPUBLIC OF KAZAKHSTAN
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NAS RK is pleased to announce that News of NAS RK. Series of geology and technical sciences scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of geology and technical sciences in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of geology and engineering sciences to our community.

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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**DEVELOPING SCENARIOS OF SUSTAINABLE WATER-SUPPLY
FOR KAZAKHSTAN POPULATION AND ECONOMY UNDER
CLIMATIC AND ANTHROPOGENIC CHANGES AT THE REGIONAL,
NATIONAL, AND TRANSBOUNDARY LEVELS UNTIL 2030**

Abstract. Principle of method is in the analysis of external environment for key factors and their combining for creating alternative development scenarios. Alternatives formed in the scenario approach allow identifying an aggregate of possible directions of environment development and thus create a basis for making strategic decisions. This paper considers theoretical and methodological basis of scenario planning, including various approaches and methods of scenario formation. Experience of this method application in Kazakhstan and abroad was studied.

The paper identifies natural factors affecting water-supply conditions. Advisability of forming external environment development scenarios was justified for further development of alternative strategies for hydrogeological survey improvement. Based on the algorithm of forming and transboundary levels until 2030 of the proposed principles, scenarios were developed for creating plans of sustainable water-supply under conditions of climatic and anthropogenic changes at the regional, national and transboundary levels.

In order to develop strategies and scenarios, as well as to identify vulnerabilities and negative impacts of climate change, it is necessary to have complete information and data on the entire basin. Therefore, it is necessary to collect and share the necessary information, data and models related to the basin as a whole, as well as all components of the water cycle. Managing the process of adaptation to climate change, it is necessary to monitor the situation and regularly update assessments, climate change scenarios and forecasts of the state of the water balance.

Climate change should be considered as one of the main causes of changes in the environment of water basins, and as one of the many factors that put pressure on water resources. Therefore, adaptation scenarios for specific basins should take into account not only climate change, but also changes in the demographic situation, economic growth dynamics, dietary preferences, and so on. These scenarios should be developed with the greatest possible cooperation with neighboring countries, and most importantly, using data and models that are consistent with them.

Key words: Scenarios method, external environment factors, strategy, alternative scenario.

Introduction. One of main tools actively used for the development of strategy in the past three decades by the majority of western companies is the scenarios method. For today, there is no a concurrent view on identification of the term “scenario planning”. Different researchers give their own interpretations of the notion. From quoted identifications of many authors one can conclude that a scenario is deferent from a forecast (description of comparatively predictable progression of events in the present) and is not a projection – desirable future that a company endeavors to achieve. Forecasts and projections conceal risks, scenarios on the contrary, make risk management possible. Scenarios are a qualitative description of a situation containing individual quantitative estimates. This is their difference from forecasts where emphasis is made on quantitative indicators as a rule. Scenario planning represents not only the development of a company development scenarios, it is closely connected with strategic planning. Thus, a

scenario is a description of a vision of the future comprising interconnected factors, with different probability leading to predictable status of the conditions under study in the future.

Scenarios development. This stage includes: selecting of influencing factors; forecasting different results of scenarios; combining significant factors and scenarios forming. While selecting factors, it is recommended to rest upon the results of external environment analysis, to identify the most significant factors that will be the basis for the scenarios. As a method applied at this stage with the purpose of identifying the most significant factor. The stage must result in the selection of several most significant and independent factors.

Fundamentals of scenario planning. Under conditions of the area of water supply to population and the country economy, important is forecast of development of so-called scenario forecasting and development of practical recommendations taking into account existing environmental and anthropogenic conditions of the territories. Scenario planning helps managers get adapted to various versions of events in the area of wide groundwater use, have certain specific solutions and alternative options of developments.

Within the framework of scenarios, incoming general economic preconditions, economic factors of territories development level and government regulation, socioeconomic development, status of level of water supply hydrogeological conditions can be considered. Theoretical aspects of strategic management with considering of scenario planning toolbox, strategic and comparative analysis were taken as the methodological basis for scientific research.

Development of practical recommendations for drinking quality groundwater prospected resources sound management has special importance. Especially important this status should be taken into consideration under conditions of arid climate and water resources deficit. There are various approaches to identifying such notions as “scenario” or “scenario planning” among scientists in the area of strategic management. So Michael Porter is of opinion that the scenario planning (SP) should be represented as “inner consistent view of what the future can face about” [1]. Peter Schwartz gave the following definition to SP: “A tool for ordination of existing representations about possible conditions of activities in the future, where a decision made turns out to be a correct one” [2]. Jill Ringland believed that SP is “an element of strategic planning founded on methods and technologies of managing the uncertainties of the future” [3]. Paul Schoemaker identified SP as “a rational method to present possible options of the future where decisions made by the organizations may be executed” [4]. Scenario planning includes not only scenarios forming but also a set of managerial decisions, actions and activities within the framework of strategic planning [5].

A scenario is a vision of prospects that look like a population of events coordinated and logically mutually associated with a specific algorithm of actions which describes and gives details of the forecasted status of a system – object of the strategic planning in the future. Most often, scenarios represent a projection of qualitative nature, and here, some most important quantitative estimates are acceptable and necessary. Thus, SP is different from forecasting where emphasis is made on a multitude of justified indicators of quantitative nature.

SP is used in branches of economy, at enterprises and their strategic business units while evaluating environment macroeconomic factors and raw materials markets. Scenario method is useful in definition of the organization objectives, identification of development strategy, and also in long-term forecasting, when current achievements lose their importance and significance of new possibilities application grows. Theoretical aspects of strategic planning with consideration of scenario planning toolbox, strategic and comparative analysis were taken as a methodological basis of the scientific research.

In SP, H. Kahn rests upon dynamics of qualitative indicators using retrospective approach of macro-historic functioning and the system development. Thus, scenarios go from a hypothesis to facts. And as a result, scenarios, according to H. Kahn, are a hypothetic sequence of events used for studying cause-effect relations and leading to making strategic decisions [6].

Fresh groundwater as a part of mineral resources sector may be presented as a dynamically developing socioeconomic system comprising a number of sub-industries. Each option of mineral resources sector (MRS) development scenarios records certain dynamics of production development and change in processing volumes formed on the basis of combination of possible development conditions. Scenario approach allows consideration of all diversity of macroeconomic and technological conditions. Aggregative country or region groundwater resources efficient use development options alternatives in the

majority of cases is enough to describe on the basis of three scenarios – inertial, evolutionary and innovative.

In the part of ensuring favorable ecological situation, it is advisable to provide for in:

- the area of water sound management: construction and improvement of waterworks and treatment facilities, reduction of surface and underground water bodies pollution with waste water and hazardous substances arriving from urbanized and agricultural areas; providing population with clean drinking water;

- the area of land resources protection and use: ensuring complex approach to land (soil) use and protection for its sustainable management;

- the area of forest resources protection and use: ensuring stable functioning of forest ecosystems, preservation of forest biological and genetic diversity, increasing of ecologic-economic strength of the economy forest sector;

- the area of waste management: prevention or minimization of wastes generation at account of introduction of low- and waste-free technologies;

- the conservation of biological diversity, specially protected natural areas network optimization [7];

Water consumption growth which in the long term will become the main threat will occur under influence of both climatic peculiarities including temperature increase, as well as a consequence population pressure. To meet the need in foodstuffs and municipal needs, the humanity will need additional water resources, which according to data of Food and Agriculture Organization of the United Nations (FAO) by the mid-century will amount 70% of the current consumption level. Today, more than 1 bln people do not have access to clean drinking water, 2 bln – to wastewater disposal systems, 920 mln starve. To satisfy their needs and needs of another 2-2.5 bln new inhabitants of the planet, it will be necessary to add to current 4,200 km³ of water extracted from water sources, by almost 3,000 km³ more. This means that the humanity will encroach on those 9,000 km³ that still retain ecological natural value of water. Accordingly, irrespective of the increase or decrease in surface water, areas with poor water supply destined for increasing water deficit due to implacable water use growth [8].

Thus, it is necessary to search for additional sources of water and increase the productivity of available water resources. Right now it is difficult to forecast the extent of consumption increase in connection with temperature increase, change in air humidity, demographic transitions. But it is apparent that with the current unpredictability of all these changes, it is necessary to align water use mechanisms and tools with economic use of resources available to people.

Water survival mechanisms. Transition to water resources integrated management allows curtail water resources deficit drastically at account of public participation, integration of science and production, combining interests of various industries (horizontal integration), linking levels of water hierarchy and elimination of organizational losses on their junctions (vertical integration), and also engaging other water sources. This method has been applied and is still applied for centuries in Spain, Italy, France.

Water resources integrated management is based on several fundamental principles:

- basin hydrographic management, which means building of organizations responsible for supply of water, along its stream “top-down” with minimizing losses on junctions of water hierarchy and non-admission of administrative interference;

- public participation of all water-users, which mean active involvement of non-governmental organizations of water-users and water-consumers into top-down management on principles of parity with the right of decisive vote and participation in financing;

- recording and inclusion of all types of water;

- combining interests of all industries and enterprises of water use;

- water saving;

- priority consideration of nature requirements;

- financial stability.

Creation of a clear and well-controlled system of water resources management. Water economy of Israel (for arid area), water economy of the Netherlands (for coastal areas and areas of excessive humidity in general) and water economy of Switzerland (for moderate landscapes with intensive level of urbanization development) can be prototypes of future water management systems. For all above-listed countries, characteristic is reverence to water as the basis of natural complex that has a tremendous ethical, cultural and moral potential [9].

Natural and anthropogenic systems in these countries are closely interlaced. Here is a centralized public water management top-down identifying the order of distribution, limiting, monitoring of water resources and their use with direct management top-down with wide involvement of all stakeholders. The procedure set by the state for financing, interest of water-users and water organizations in water-saving, guarantees sufficient funds for maintaining, improvement and development of facilities with participatory interest of the state, but with a wide application of principles “user pays” and “polluter pays” (payment is higher as higher the use and pollution). All hydroeconomic and reclamation systems comply with the high technical level, are automated, equipped with on-line control, emergency forecasting and warning system. By level of productivity they are getting close to potential water productivity [10].

Water economy by the end of XXI. It is possible to suggest that by the end of XXI century, high technical level of future water economy systems will be ensured at account of the following components.

1. One hundred percent keeping record of all types of water (from basin main sources to the last discharge outlet to a user, including all groundwater - their intake from wells, attenuation) and their regular balancing on-line with SCADA systems. Such record-keeping will be accompanied by a dense network of climate stations recording and transmitting to end-users and water organizations the data allowing them with the use of programs available to them to adjust water consumption, mode of use and water distribution plan. SCADA systems that have been used for almost ten years (for instance in the Basin hydroeconomic association Syrdarya in Central Asia), ensure precision of water measurements and water supply $\pm 2\%$ with comparatively low cost. Climatic maintenance systems are very well tuned up in Canada, Israel, and a number of water districts of western U.S.

2. Well set up service of hydrological, climatic and reclamative forecasts with emphasis to forecast of emergencies based of computerized program of satellite and ground tracking, information and warning. Such services are operating successfully today in Korea and the Netherlands. In the Netherlands, the service controls emergency mode of flood control works of the highest technical level – closing riverbeds from the possibility of incoming of upsurge waves from the sea, operation of pump out houses, as we'll as complex networks of excess water entrapping and diversion [11].

Water supply and consumption in cities and rural areas will be ensured based on established regional norms both for quality and quantity as a mandatory prerequisite for residential zones functioning. Other needs will be satisfied (as in Israel) at account of service water use systems from unpolished, but permitted effluents or brakish water. All municipal effluents will be collected, treated and sent via water ducts, depending on treatment extent, to satisfy production needs, for watering of municipal and township plants, sanitary service of built-up centers. Similarly rain and meltwater from storm sewage system will be collected and used. “Green roofs” will gain ground – planting of vegetation on buildings’ roofs [12].

Irrigated farming as a major water consumer will change in a big way. Open channels supplying and distributing water will disappear in the world. Irrigation water will be transported (on the model of the majority of countries of Middle East) by closed pressure and free-flow conduits allowing avoidance of losses for evaporation and infiltration. Irrigated fields will become automated controlled, depending on climatic parameters, space. For soils with well-developed wicking properties in relatively plain valleys and individual plateaus, controlled subirrigation will be widely used. This is the system of moistening where all the water, save for precipitations, comes to a plant from groundwater. Groundwater level, depending on development stage of a plant and depth of its root zone, will be regulated by a system of underground pipelines spaced 1.5–3.0 m that will function both as deep drainage as well as water disposal during cessation of watering. Such pilot systems with automatic regulation of water conditions organized in Quebec (Canada) by McGill University, has been functioning for many years now [13-14].

Improved water-use systems will demand also improvement of drainage systems including collectors that will be closed. Dense observation network with sensors reflecting groundwater depth readable from the space, and also inspection manholes on collectors and drain lines with the same sensors will be under constant control of automated hydrogeological-reclamative parties. This will allow evaluation of drainage function, extent of salinity hazard, trace violations of forecasted water-salt balance and development of recommendations for using mineralized water and preventive maintenance of the drainage network for water-users [15].

Keeping of today’s trends in water resources use and management is disastrous and inadmissible. It is a path of conflicts, crisis, hunger and thirst.

Recommendations and scenarios for prevention and mitigation of adverse effects of groundwater status change at regional and national levels in Kazakhstan.

Climate change should be considered as one of the main reasons for change in water basins environment, as well as one of many factors exerting pressure upon water resources. Therefore, scenarios of adaptation measures for specific basins, it is necessary to take into account not only climate changes, but also changes in demographic situation, economic growth dynamics, nutritional preferences etc. These scenarios must be developed with the maximum possible cooperation with neighbor countries, and what is especially important – with the use of models and data agreed with them [16-17].

– One of effective approaches to fulfilling the task of water resources management adaptation to climate change is the development of a plan (national or transboundary) of adaptation measures in the scales of a specific water basin (river, lake or groundwater), which subsequently could be integrated into (existing) plan of respective basin management.

– To develop strategy and scenarios, and also to identify vulnerabilities and adverse effects of climate change, it is necessary to have full information and data about the whole basin. Therefore, it is necessary to ensure collection and sharing of required information, data and models related to the basin as a whole, as well as to all water cycle components. To be able to flexibly manage the process to adaptation to climate change, required is a system of situation monitoring and regular correction of estimates, scenarios of climate change and forecasts of water balance status.

Potential of adaptation to changes and water safety. Strengthening of water safety often requires combining of technical, economic, production, legal and institutional measures. Water safety concept may help identify which measures are priority. Selection of measures depends on conditions and goals. Each specific situation has its problems and context that affect what can and must be done [18].

Committee for water resources of re-created in 2019 Ministry of Ecology, Geology and Natural Resources (EG&NE RK) is the national body responsible for the use and protection of water resources. It issues permits and consents for the use of surface water and underground water resources. It is also responsible for water supply system management. With the help of eight basin organizations responsible for the use of water resources in river basins and having advisory powers, its activity covers water resources management at the level of river basins. Committee for Geology and Subsoil Use of environmental protection issues permits and monitors status of groundwater. The National hydrometeorological institute, Kazgidromet monitors water quality and quantity. Territorial administrations of environmental protection supervise at oblast level, perform environment impact assessment and ensure monitoring of wastewater discharges. Through the Committee for Geology and Subsoil Use, the Ministry of EG&NE RK is responsible for groundwater status monitoring, including water quality. The Ministry of Health monitors situation with access to drinking water and its quality. Ministry of Emergencies carries out relevant activities in case of floods, droughts and ensures protection of water bodies from pollution resulting from emergencies. It also deals with the issues of safeguarding and security of waterworks.

Groundwater. Groundwater is the largest source of fresh water for the humanity. Isotopic methods are based on the use of stable and radioactive isotopes, naturally present in groundwater to identify origin of such water and rate of its replenishment.

Groundwater makes about 30 percent of water stock of fresh water. another 69 percent are concentrated in polar ice, and only one percent of fresh water is rivers and lakes. Groundwater often occurs in deep aquifers, permeable rock and sediments and is extracted via wells equipped with pumps. Aquifers in many cases are renewable sources that are slowly recharged by infiltration of precipitations within hundreds or even many thousands years.

Growth of the plant population along with farming intensification and increasing commercial consumption results in constant increase in demand for groundwater. In many regions water management bodies have to face excessive use of available aquifers, which often results in the necessity to use water from deep ancient beds to ensure reliable fresh water supply. Besides, there are hazards related to groundwater penetration of pollutants and toxins used for instance in agriculture, industry or activities of municipal services.

Scientific assessment of aquifers origin and rate of replenishment has a decisive importance, so that they could carry out their function of a reliable long-term source of water supply. Stable and radioactive isotopes naturally present in groundwater can be used for obtaining detailed information about

groundwater origin and replenishment rate. Water isotopes (hydrogen, oxygen) and radioisotopes (tritium), dissolved carbon (carbon-14) and inert gases (helium-3, helium-4 and krypton-81) are used to assess groundwater age.

Struggle with groundwater pollution is not an easy task since pollution of aquifers is quite difficult to eliminate. Stable and radioisotopic indicators (nitrogen-15, carbon-13 and tritium) are used for recording pollution sources and quantitative estimation of pollutants transformation and biodegradation in aquifer systems.

How can climate change affect status of global water stock in hundred years? To answer such questions, scientists resort to help of scientific models. One of them is water balance isotopic model developed by IAEA, by virtue of which specialists may quite precisely and reliably forecast the impact of climate change upon water resources in the far future. Information collected by them can be useful for decision-making authorities while developing strategies of sustainable water-use for future generations.

Such models are based on available data and are used for studying and apprehension of hypotheses, objects and processes, direct observations of which can be difficult. This relates also to preliminary calculations such as forecast of weather conditions for the next week or evaluation of unemployment rates within next five years. Although this model is in substance a more general and simplified picture of real world, each of its components is thoroughly calibrated to ensure faithful representation of processes going on in the reality.

Water balance models describe hydrological cycle from the view of precipitations falling processes, cumulative evaporation, river flow and change in volumes of water stock. As opposed to many traditional models of water balance, calibration and verification of IAEA model are performed based on data about isotopes, as isotopes are characterized with well-defined features and constancy in behavior. Resting upon thoroughly calibrated and verified water balance model, scientists may obtain a precise assessment of the processes that will be going on in the future, for instance, impact of climate change upon water resources in one hundred and more years. [19-20].

Study of climate in Kazakhstan. Starting from early 60-s', Kazakhstan experiences constant increase of temperature. Seasons become warmer on average. Temperature constantly rises, and increase rate is about 0.028 degree a year, or 0.28 degrees every 10 years. The system of calculation and evaluation of damage needs reforming. "It is necessary to take into account not only losses that have happened here and now, but also consider future economic losses from damage to health, infrastructure destruction or impairment" - experts say.

According to data of studies of RK Ministry of Energy and UNDP, maximum number of extremes in the nature of Kazakhstan occurred in 1999 - 268 cases with frequent repetition of heavy precipitations, snowstorms with windstorms and hail. Minimum number is 72 in 1995. Experts note that climate is still changing and will change in the future, and every year manifestations will be more noticeable. The study says that Kazakhstan to significant extent is exposed to natural disasters due to climatic and weather conditions: country occupies vast territory with different climatic zones – from very hot and dry desert belts in the south to very cold in winter steppe and forest belts in the north. "Climate will be drier and harder. Due to high air temperature, evaporation will grow as well as water consumption.

In XXI century, in Kazakhstan further significant climate warming in all scenarios under consideration should be expected. The forecasted change of average annual air temperature by 2030 will be within 1.5-1.7 degrees, and by 2085 temperature rise may make 2.7-4.7 degrees", - the experts say. East of Kazakhstan and Almaty oblast will suffer from changes in nature. Eastern and south-eastern territories of Kazakhstan may suffer to greater extent due to changes in nature. In mountainous area, all types of natural disasters are possible: landslides, mud flows, avalanches, floods, hurricane winds, hails, storm precipitations, frosts and droughts. Experts believe that Almaty oblast is under the highest exposure of extremes. Almost every second case happens in this region: heavy rains, wind, snow and snowstorm. Here, in the period of 2003-2015, as compared to previous period of 1990-2002, average annual number of cases with heavy rains increased by 3.9 times, with heavy snow – by 3.3 times, with strong wind – by 1.6 times. "Increase of number of mudflow events almost by two times, strengthening of output of extreme weather events – damage to environment, infrastructure and health of population, and this represents pressure not only to the state providing services of transportation, healthcare, prevention of emergencies, but to business operating in climate-oriented industries – tourism, agriculture, water resources. Companies operating in these areas will also experience and spend due to climatic events, and

this also needs evaluation and expertise”, a specialist noted. Climate changes impacted and will impact all the population of the country, for instance, agricultural branch will be harmed. According to experts, intense atmospheric and soil draught is possible, which will destructively impact productivity of crops. Watering zones for crop farming will be shifted to zones where will be more ample precipitations and those zones will be losing their area.

Conclusion. This paper combines contemporary views about water safety and suggests methods of actualization of the concept in practice. It rests upon scientific literature and experience of partners along the chain of knowledge of the Global Water Partnership (GWP) about concept application in practice. The paper considers three components. The first – explains the concept of water safety and describes various frameworks where the concept is used. Comparison was made of approaches to water safety between development approach and the approach based on risk assessment. Second part describes relations between the concept of water safety and Water Resources Integrated Management (WRIM) and states that they are interconnected and that water safety should be considered as a WRIM goal. Third part suggests frameworks for quantitative estimation of water safety giving notes and recommendations, how to apply them at the national level, level of a riverbasin or city, and in a project scale. There is no “one-size-fits-all” solution. Decisions of water safety increase must be adapted to local conditions of each country, river basin, city, project and other management areas.

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**2030 ЖЫЛҒА ДЕЙІН ӨНІРЛІК, ҰЛТТЫҚ ЖӘНЕ ТРАНСШЕКАРАЛЫҚ
ДЕҢГЕЙЛЕРДЕ КЛИМАТТЫҚ ЖӘНЕ АНТРОПОГЕНДІК ӨЗГЕРІСТЕР
ЖАҒДАЙЫНДА ҚАЗАҚСТАН ХАЛҚЫ МЕН ЭКОНОМИКАСЫН ТҰРАҚТЫ
СУМЕН ҚАМТАМАСЫЗ ЕТУ СЦЕНАРИЙЛЕРІН ӨЗІРЛЕУ**

Аннотация. Әдістің мәні негізгі факторлардың болуы үшін сыртқы ортаны талдау және баламалы даму сценарийлерін құру үшін біріктірумен байланысты. Сценариялық көзқараста қалыптасқан баламалар қоршаған ортаны дамытудың мүмкін бағыттарының жиынтығын анықтауға және сол арқылы стратегиялық шешімдер қабылдауға негіз жасауға мүмкіндік береді. Бұл мақалада әртүрлі тәсілдер мен сценарийлерді қоса, сценарийді жоспарлаудың теориялық және әдіснамалық негіздері қарастырылады. Бұл әдісті Қазақстанда және шетелде қолдану тәжірибесі зерттелді.

Мақалада сумен жабдықтау жағдайына әсер ететін табиғи факторлар анықталған. Гидрогеологиялық жұмыстарды жетілдірудің балама стратегияларын одан әрі дамыту үшін сыртқы ортаны дамыту сценарийлерін құрудың орындылығы дәлелденді. Ұсынылған қағидалардың 2030 жылға дейінгі құрылыс алгоритміне және трансшекаралық деңгейге сүйене отырып, аймақтық, ұлттық және трансшекаралық деңгейлердегі климаттық және антропогендік өзгерістер жағдайында тұрақты сумен жабдықтау жоспарларын әзірлеу сценарийлері жасалды.

Сценарийлер шеңберінде кіретін жалпы экономикалық алғышарттар, аумақтарды дамытудың экономикалық факторлары және мемлекеттік реттеу анықталды. Әлеуметтік-экономикалық даму, сумен қамтамасыз етудің гидрогеологиялық жағдайларының жай-күйі қаралды. Ғылыми зерттеудің әдістемелік негізіне сценарийлік жоспарлау, стратегиялық және салыстырмалы талдау құралдарын қарастырумен стратегиялық басқарудың теориялық аспектілері алынған.

Стратегия мен сценарийлерді әзірлеу үшін, сондай-ақ климаттың өзгеруінің осалдықтары мен теріс салдарларын анықтау үшін барлық бассейн туралы толық ақпарат пен деректерге ие болу қажет. Сондықтан жалпы бассейнге қатысты қажетті ақпаратты, деректер мен үлгілерді, сондай-ақ су циклының барлық компоненттерін жинауды және бірлесіп пайдалануды қамтамасыз ету қажет. Климаттың өзгеруіне бейімделу процесін икемді басқару мүмкіндігі болу үшін, жағдайды мониторингілеу және бағалауды, климаттың өзгеру сценарийлерін және су теңгерімі жай-күйінің болжамдарын тұрақты нақтылау жүйесі қажет. Климаттың өзгеруін су бассейндері ортасының өзгеруін тудыратын басты себептердің бірі ретінде және су ресурстарына қысым көрсететін көптеген факторлардың бірі ретінде қарастырған жөн. Сондықтан нақты бассейндер үшін

бейімделу шараларының сценарийлерінде климаттың өзгеруін ғана емес, сондай-ақ демографиялық жағдайдың өзгеруін, экономикалық өсу серпінін, тамақтанудағы артықшылық және т.б. ескеру қажет.

Ауыз су сапасындағы жер асты суларының барланған қорларын ұтымды пайдалану жөнінде практикалық ұсынымдар әзірлеудің аса маңызды мәні бар. Бұл жағдайды аридті климат және су ресурстарының тапшылығы жағдайында ерекше ескеру қажет.

Бұл жұмыс су қауіпсіздігі туралы қазіргі заманғы түсініктерді біріктіреді және тұжырымдаманы іс жүзінде жүзеге асыру тәсілдерін ұсынады. Ол ғылыми әдебиеттерге және Жаһандық Су Серіктестік (GWP) білім тізбегі бойынша әріптестердің тұжырымдаманы тәжірибеде қолдану туралы тәжірибесіне сүйенеді. Жұмыста үш құрамдас бөлік қарастырылады. Біріншісі – су қауіпсіздігі тұжырымдамасын түсіндіреді және тұжырымдама қолданылатын түрлі шеңберлерді сипаттайды. Тәуекелдерді бағалау негізінде даму тәсілі мен тәсіл арасындағы су қауіпсіздігіне қатысты көзқарастарды салыстыру жасалды. Екінші бөлім су қауіпсіздігі тұжырымдамасы мен су ресурстарын интеграцияланған басқару (СРИБ) арасындағы қатынастарды сипаттайды және олардың өзара байланысты екенін және су қауіпсіздігін СРИБ мақсаты ретінде қарастыру керектігін бекітеді. Үшінші бөлім су қауіпсіздігін сандық бағалау үшін шектерді ұсынады, оларды ұлттық деңгейде, өзендік бассейн немесе қала деңгейінде және жоба ауқымында қалай қолдануға болады деген мысалдар мен ұсыныстарды келтіріледі. «Бір өлшемге сәйкес келетін» шешім жоқ. Су қауіпсіздігін арттыру жөніндегі шешімдер әрбір елдің, өзен бассейнінің, қаланың, жобаның және басқарудың басқа да салаларының жергілікті жағдайларына бейімделуі тиіс.

Түйін сөздер: сценарий әдісі, қоршаған орта факторлары, стратегия, балама сценарий.

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РАЗРАБОТКА СЦЕНАРИЕВ УСТОЙЧИВОГО ВОДОБЕСПЕЧЕНИЯ НАСЕЛЕНИЯ И ЭКОНОМИКИ КАЗАХСТАНА В УСЛОВИЯХ КЛИМАТИЧЕСКИХ И АНТРОПОГЕННЫХ ИЗМЕНЕНИЙ НА РЕГИОНАЛЬНОМ, НАЦИОНАЛЬНОМ И ТРАНСГРАНИЧНОМ УРОВНЯХ ДО 2030 ГОДА

Аннотация. Суть метода заключается в анализе внешней среды на наличие ключевых факторов и комбинировании их для создания альтернативных сценариев развития. Сформированные в сценарном подходе альтернативы позволяют выявить совокупность возможных направлений развития окружающей среды и тем самым создают основу для принятия стратегических решений. В данной статье рассмотрены теоретические и методические основы сценарного планирования, в том числе различные подходы и методы формирования сценариев. Изучен опыт применения данного метода в Казахстане и за рубежом.

В статье выявлены природные факторы, оказывающие влияние на условия водоснабжения. Обоснована целесообразность формирования сценариев развития внешней среды для дальнейшей разработки альтернативных стратегий для совершенствования гидрогеологических работ. На основе алгоритма построения и трансграничном уровнях до 2030 года предложенных принципов разработаны сценарии развития планов устойчивого водоснабжения в условиях климатических и антропогенных изменений на региональном, национальном и трансграничном уровнях.

В рамках сценариев рассмотрены входящие общеэкономические предпосылки, экономические факторы развития территорий и государственное регулирование, социально-экономическое развитие, состояние гидрогеологических условий водоснабженности. В методическую основу научного исследования положены теоретические аспекты стратегического управления с рассмотрением инструментария сценарного планирования, стратегического и сравнительного анализов.

Для разработки стратегии и сценариев, а также для выявления уязвимостей и негативных последствий изменения климата необходимо располагать полной информацией и данными обо всем бассейне, поэтому необходимо обеспечить сбор и совместное использование необходимой информации, данных и моделей, касающихся бассейна в целом, а также всех компонентов водного цикла. чтобы иметь возможность гибко управлять процессом адаптации к изменению климата, необходима система мониторинга ситуации и регулярного уточнения оценок, сценариев изменения климата и прогнозов состояния водного баланса.

Изменение климата следует рассматривать как одну из главных причин, вызывающих изменение среды водных бассейнов и как один из многочисленных факторов, оказывающих давление на водные ресурсы. Поэтому в сценариях мер адаптации для конкретных бассейнов необходимо учитывать не только изменение климата, но также и изменения демографической ситуации, динамики экономического роста, предпочтений в питании и т.д. Эти сценарии должны разрабатываться при максимально возможном сотрудничестве с соседними странами, и что особенно важно – с использованием согласованных с ними данных и моделей.

Особо важное значение имеет разработка практических рекомендаций по рациональному использованию разведанных запасов подземных вод питьевого качества. Особенно важно учитывать данное положение в условиях аридного климата и дефицита водных ресурсов.

Данная работа объединяет современные представления о водной безопасности и предлагает способы реализации концепции на практике. Она опирается на научную литературу и опыт партнеров по цепочке знаний Глобального Водного Партнерства (GWP) о применении концепции на практике. В работе рассматриваются три составляющие. Первая – объясняет концепцию водной безопасности и описывает различные рамки, в которых используется концепция. Сделано сравнение подходов к водной безопасности между подходом развития и подходом на основе оценке рисков. Вторая часть описывает отношения между концепцией водной безопасности и Интегрированным управлением водными ресурсами (ИУВР) и утверждает, что они взаимоувязаны, и что водную безопасность следует рассматривать в качестве цели ИУВР. Третья часть предлагает рамки для количественной оценки водной безопасности, приводя примеры и рекомендации, как их применять на национальном уровне, уровне речного бассейна или города и в масштабе проекта. Не существует решения «один-размер-подходит-всем». Решения по повышению водной безопасности должны быть адаптированы к местным условиям каждой страны, речного бассейна, города, проекта и другим областям управления.

Ключевые слова: метод сценариев, факторы внешней среды, стратегия, альтернативный сценарий.

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**SIMULATION OF SUBTERRANEAN HEATING OF COAL
BY PASSING ELECTRICAL CURRENT THROUGH
ELECTROTHERMAL BREAKDOWN CHANNEL**

Abstract. The paper describes a mathematical model that simulates the heating of an underground coal bed by passing electrical current through electrothermal breakdown channel. The breakdown channel, which is a heat source, is formed between two electrodes located in the wells inside the subterranean formation. The electrodes are connected by cables to the aboveground electrical equipment. The diameter of electrothermal breakdown channel at the time of formation is small, and it expands as the coal is heated and carbonized in the vicinity of the channel. The distance between the electrodes is set to 0.5 meters. The values of dielectric and thermal properties are taken on the basis of experimental and literature data for the coals of the Republic of Kazakhstan. The time dependences of the temperature in the center of the heated part of the reservoir at different heating powers are obtained. The images of the thermal field in the heated region and its immediate vicinity are shown. The results of calculations of electrical parameters of required for heating electrical equipment, and changes in these parameters over time as heating, is given.

Key words: Coal, breakdown, heating, carbonization, gas.

Introduction. Researchers offer a number of ways for heating the coal directly underground. The most common is the underground gasification due to incomplete combustion of coal [1-3]. According to this technology, an oxidant, which is mainly air or a vapor-air mixture, is injected into the underground reactor. A set of oxidative and reducing reactions produce a gas with a calorific value of 4–8 MJ/m³, which contains the hydrogen and carbon monoxide as main combustible components [1].

The limitations of this method include the high content of non-combustible components in the gas, mainly nitrogen and carbon dioxide. As a result, the gas produced has a low calorific value, and thus a narrow field of application. The main product of this technology is gas. Coal tar is formed in small quantities and is not used as a product.

Another approach is the heating using the outside heat, for example, from an electric heater. If we place the heaters directly in the wells, it will be possible to heat only that part of the coal that is removed from the well by no more than 2-3 meters. Heating of a more remote zone requires more time (more than six months) due to the low thermal conductivity of coal.

To eliminate this drawback, the heating element should be extended along the length of the bed. One of the known solutions is as follows. A fracture channel should be created between two wells and filled with granules of an electrically conductive substance, for example, graphite. Further, the formed current path is used as an electric heater [4,5].

Research methodology. We propose a method that is similar to the one described above, however, it eliminates a large number of expensive and complex preparatory operations. To pass a current through a section of the reservoir, the method requires two wells with electrodes (figure 1).

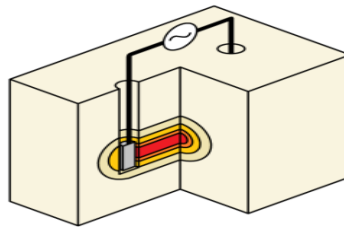


Figure 1 – Plan of subterranean heating method

An electric current causes the release of Joule heat in the coal:

$$Q(t) = \int_0^t U(t)I(t)dt = \int_0^t \frac{U^2(t)}{R(t)} dt, \quad (1)$$

where Q - is the thermal energy, I - is the current, U - is the voltage on the electrodes, R - is the resistivity of interelectrode space, t - is exposure time.

The specific electrical resistance of coal is 10^{10} - 10^{12} Ohm·cm that is relatively large [6-10]. Thus, a very high voltage will be required to provide the power release enough for heating. However, a decrease in the interelectrode resistance can be achieved by creating a breakdown channel. The breakdown channel is formed from the substance of coal modified by plasma of electrical discharges. As a result of pyrolysis under the action of high plasma temperature, the resistance of the coal decreases. It is known that in the temperature range of 350-500°C without air access, the coal substance carbonizes, as a result, its electrical resistance decreases to 10 - 10^2 Ohm·cm [6-9]. Due to this, the channel has a low resistance that is sufficient to pass current at a technically feasible voltage value.

To assess the effectiveness of the method, it is necessary to calculate the required voltage and power of the aboveground electrical equipment, as well as the achievable heating rate. The article describes mathematical simulation in order to determine the temperature dynamic in the vicinity of the channel, and to calculate the required technical characteristics of the aboveground power supply.

Thermochemical conversion of coal without access of external reagents

When coal is heated, the organic mass undergoes changes occurring under the action of temperature. In the range from the initial temperature to 120°C, the moisture is released, which is contained in the coal in both free and ion-bound form. Upon further heating from 120°C to 300°C, predominantly ion-bound and pyrogenic moisture is released. Further, in the range from 300°C to 550°C, solid organic compounds decompose with the formation of liquid and gaseous hydrocarbons. The residue from the decomposition reactions is coke or amorphous carbon. Due to the appearance of coke, the electrical resistance of coal is reduced. At temperatures above 550°C, secondary reactions of liquid and gaseous hydrocarbons with solid carbon occur. The products of these reactions are hydrogen and carbon monoxide.

Initial data for the heating calculation

Suppose that there are two wells drilled from the surface to the underground coal seam and located at a distance d from each other. The wells contain an electrodes placed at the bottom and connected by cables to an aboveground source of electrical energy. Electrodes are electrically connected to each other due to an electrothermal breakdown channel. The channel will operate as an electrical heating element, heating the subterranean formation. Let us consider the heating process.

The power of electric heating released in the reservoir will be spent on the heating of the surrounding space and thermochemical reactions. In addition, part of the thermal energy will be dispersed into the surrounding space. Thus, the heat balance of heating is as follows:

$$Q_r = Q_h + Q_{ch} + Q_s \quad (2)$$

where Q_r - is released heating energy, Q_h - is the energy spent on the heating of the rock, Q_{ch} - is the energy spent on thermochemical transformations, Q_s - is the energy dispersed into the surrounding space due to thermal conductivity.

Heat source

The heat source is an electrothermal breakdown channel. Heating starts from the moment when the electric discharge structures developing in the coal close the interelectrode gap [11]. At the time of the

formation of the through conductive channel, its diameter is very small compared with the interelectrode distance. Usually, it is not more than 0.1 mm [12,13]. The channel can be simply represented as a straight line connecting the electrodes. In this case, the heating source is a cylinder having electrical resistance:

$$R = \frac{1}{\sigma} \frac{d}{S} = \frac{4d}{\sigma \pi D^2}, \quad (3)$$

where R - is channel electrical resistance, d - is the channel length, σ - is electrical conductivity of carbonized coal, D - is the channel diameter. The channel consists of a coal substance after pyrolysis. The resistivity of this substance is about 100 $\Omega \cdot \text{cm}$ for the considered coal. As the area around the channel heats up, the coal in it also undergoes pyrolysis. Its resistance also decreases, thus conductive channel expands (figure 1).

The power released during heating can be mathematically written with the expression:

$$W_r = \sigma E^2, \quad (4)$$

$$E^2 = E_x^2 + E_y^2 + E_z^2, \quad (5)$$

where E - is modulus of the electric field vector, E_x, E_y, E_z - are its projections in three dimensions.

Heat absorption

As we can see from the heat balance equation (1), heat is used to heat the coal substance, as well as to thermochemical transformations. The component responsible for the heat of thermochemical transformations can be either positive or negative, depending on the balance of exothermic and endothermic reactions. In different temperature ranges, the pyrolysis heat flux can be positive or negative. On average, however, endothermic reactions dominate, so part of the heat is absorbed. The physical heat capacity of coal, without taking into account thermochemical reactions, also depends on temperature. It is not possible to determine the temperature dependence of the heat capacity of coal without taking into account the energy of thermochemical transformations. Therefore, the researchers more often use the effective heat capacity, i.e. heat capacity taking into account energy absorption at thermochemical transformations. Our calculations used the temperature dependence of the effective heat capacity, the analytical form of which is approximated in the temperature range according to a polynomial function.

Heat dispersion

Initially, the subterranean formation has some initial temperature. If we heat a part of the reservoir, some of the heat will be distributed to less heated surrounding areas due to heat conduction and mass transfer. Since coal is not transparent in the infrared, there is no heat transfer due to radiation. Presumably, the main heat sink will occur due to thermal conductivity, therefore mass transfer in the model is not taken into account.

The evolution of the temperature field is taken from the solution of the three-dimensional heat conduction task, which includes the heat conduction equation:

$$c\rho \frac{\partial T}{\partial t} = \frac{\partial}{\partial x} \left(\lambda \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left(\lambda \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left(\lambda \frac{\partial T}{\partial z} \right) + W(E) \quad (6)$$

where T - is temperature, t - is time, x, y, z - are spatial coordinates; c - is the heat capacity, ρ - is the density, λ - is the heat conductivity, $W(E)$ - is a source of heat.

We used a coefficient η as a measure of the change in the electrophysical and thermal characteristics of coal that occur as it heats. It is called the degree of conversion, and changing from 0 to 1 as the coal heats up. A value of 1 means that the coal in this area is fully pyrolyzed and has the highest electrical conductivity.

Heating conditions

The initial heating conditions are defined as follows:

$$t = 0: T_0 = 0, \eta = 0.$$

Taking into account the experimental and literature data for the coals of Kazakhstan, the following averaged parameter values were adopted:

$\rho = 1900 \text{ kg/m}^3$, the values of thermal conductivity and heat capacity are defined analytically in the form of a polynomial approximation with the temperature:

$$\lambda = k_0 + k_1T + k_2T^2 + k_3T^3 + k_4T^4 + k_5T^5 \tag{7}$$

$$c = k_0 + k_1T + k_2T^2 + k_3T^3 \tag{8}$$

The values of the coefficients are given in the following table:

The value of the coefficients for heat capacity and thermal conductivity

	k_0	k_1	k_2	k_3	k_4	k_5
c	$1,379 \cdot 10^3$	-11,763	0,145	$-3,964 \cdot 10^{-4}$	–	–
λ	1,566	-0,064	$1,215 \cdot 10^{-3}$	$-1,062 \cdot 10^{-5}$	$4,39 \cdot 10^{-8}$	$-6,927 \cdot 10^{-11}$

The dependence of resistivity on temperature is approximated by the function:

$$\rho = k_0 \exp(k_1T) \tag{9}$$

where $k_0 = 1,73968 \cdot 10^{11}$, $k_1 = -0,04647$.

The calculation was carried out using an implicit splitting scheme and coordinate-wise marching.

Results and its discussion. The calculations were carried out for an interelectrode distance of 0.5 m. Figure 2 shows the dependence of the temperature at the center of the interelectrode gap on the heating time. In this case, the constant heating power mode was used.

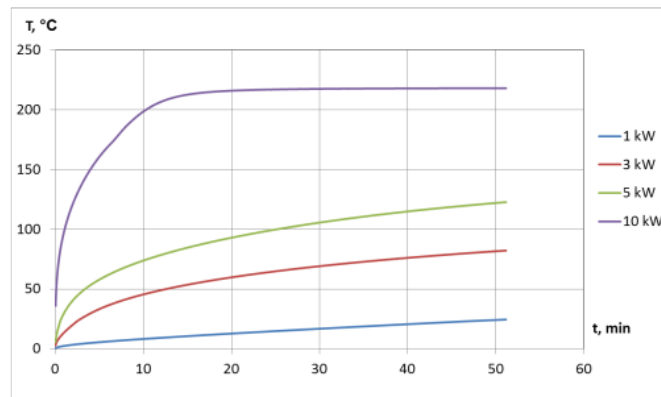


Figure 2 – Temperature in the center of the interelectrode gap at different values of the released power

Initially, the heating is intense, then, when the temperature near the electrodes becomes high, the heating slows down due to the outflow of heat into the surrounding space.

In addition to temperature in the interelectrode space, the efficiency of the technology is also affected by the distribution of thermal energy in the vicinity of the electrodes. Figure 3 shows images of the thermal field in the computational domain at different times with a heating power of 3 kW.

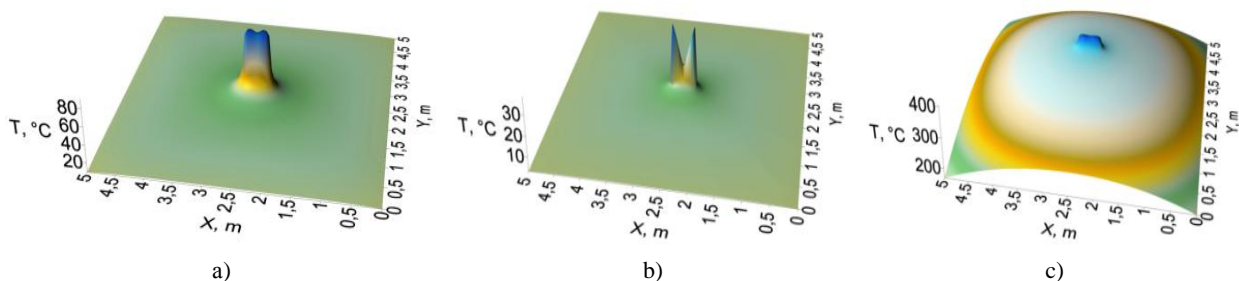


Figure 3 – Thermal field in the calculation plane at time points: (a) 5 minutes, (b) 30 minutes, (c) 10 hours.

The most notable are the following features. At the beginning of heating, the temperature increases sharply in close proximity to the electrodes. Next, the interelectrode space is heated, while the surrounding areas are weakly heated. After a longer time, the thermal energy begins to be distributed in the direction away from the electrodes, heating the area within a radius of several meters.

Preparation of technology field tests requires the values of the technical parameters of aboveground electrical equipment. Using the values of the initial and final (before and after pyrolysis) resistances of coal and calculation of the conversion degree, we can determine the change in interelectrode resistance as it heats up. Results for the interelectrode distance of 0.5 m are shown in figure 4a. Using the known resistance value, we can determine the required values of voltage and current. The calculation results for the fixed power mode of 3 kW are shown in figure 4b and c.

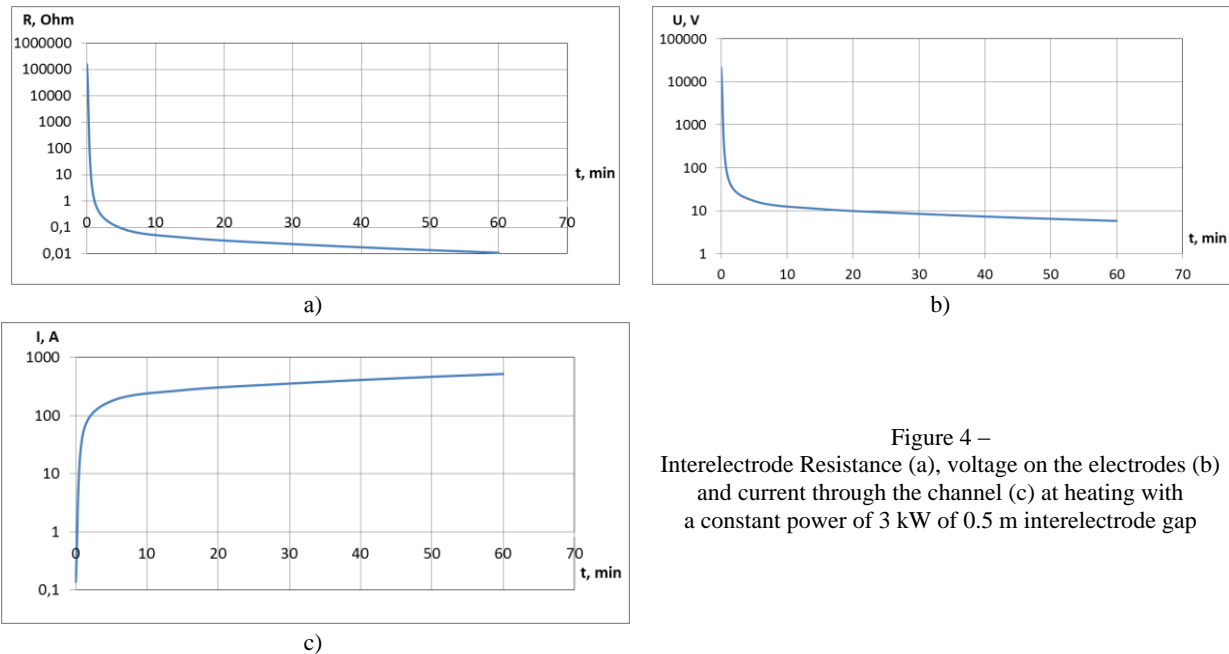


Figure 4 – Interelectrode Resistance (a), voltage on the electrodes (b) and current through the channel (c) at heating with a constant power of 3 kW of 0.5 m interelectrode gap

Thus, the results obtained can be used as a guide for the field equipment development. According to calculations, a voltage of about 22 kV will be required to initiate heating. As interelectrode gap is heated, the resistance will decrease. In accordance with the decrease in resistance, the voltage should be reduced and the current should be increased in order to maintain the power at a constant level [14,15]. Within an hour, the resistance decreases to less than 1 Ohm, so the given heating mode requires the current of about 500 A.

The considered model has a number of limitations. The model does not take into account the following factors that occur when a real underground formation is heated:

- the change in thermal conductivity due to cracking;
- the mass transfer;
- the dielectric and thermal properties of coal are assumed to be isotropic, although due to the layered structure, the thermal conductivity and electrical conductivity are likely anisotropic.

However, since the purpose of modeling is to estimate the first approximation of heating parameters, we suppose that these assumptions are justified.

Conclusion. The results of the calculations show the possibility of reaching of the pyrolysis temperature in the vicinity of the electrodes over a period of one hour, with heating power in few kilowatt and an interelectrode distance of 0.5 m. At the initial stage of heating, the temperature increases only in the immediate vicinity of the electrodes. In the next few hours, the area that is several meters away from the electrodes is heated. The initial resistance of the interelectrode area is large; it requires the voltage of tens of kilovolts to release the power enough for heating. During the first hour of heating, the resistance of the channel is significantly reduced, and maintaining heating requires passing a current of hundreds of amperes.

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ЭЛЕКТРОЖЫЛУУЛЫҚ ТЕСУ АРНАСЫНДА КӨМІРДІ ТОКПЕН ЖЕР АСТЫНДА ҚЫЗДЫРУДЫ МОДЕЛЬДЕУ

Аннотация. Көмірдің жер асты қабатының электр жылуын тесу арнасы арқылы өтетін электр тогымен қыздыруды сипаттайтын математикалық үлгі жасалған. Жылу көзі болатын тесу арнасы жер асты қабатының ішінде ұңғымаларда орналасқан екі электродтың арасында қалыптасады. Электродтар жер бетіндегі электр жабдығына кабельдермен қосылған. Электржылулық тесу каналы қалыптасу кезінде диаметрі аз болады және канал маңайындағы көмірдің қызуы мен карбонизациясы кезінде кеңейтіледі. Электродтар арасындағы қашықтықтың шамасы 0,5 метрге тең. Диэлектрлік және жылуфизикалық қасиеттерінің мәндері Қазақстан Республикасының көміріне арналған эксперименталды және әдеби деректер негізінде алынған. Қабаттың қыздырылатын учаскесінің ортасындағы температураның әртүрлі қыздыру қуатында уақыттың тәуелділігі алынды. Жылыту аймағында және оның жақын маңайындағы жылу өрісінің бейнесі алынды. Электр жабдықтардың қыздыру үшін талап етілетін электрлік параметрлердің есептеу мәндері және осы параметрлердің қыздыру шамасына қарай уақыттың өзгеру нәтижелері келтірілген. Бастапқыда жерасты қабатының өзіндік температурасы болады. Егер біз пласт аймағын жылытатын болсақ, жылу энергиясының бір бөлігі жылу өткізгіштігі мен масса тасмалдау есебінен азырақ қыздырылған қоршаған аймақтарға тарайды. Көмір инфрақызыл диапазонында мөлдір емес болғандықтан, сәулелену есебінен жылу беру болмайды. Негізгі жылу беру жылу өткізгіштігі есебінен жүргізілетіндіктен, модельдегі масса тасмалдау ескерілмеген. Көмірді қыздыру кезінде органикалық масса температураның әсерінен болатын өзгерістерге ұшырайды. Бастапқы температурадан 120 °С-қа дейінгі диапазонда бос күйінде және ионды-байланысқан түрде көмірде болатын ылғалдың шығуы орын алады. Одан әрі 120 °С-тан 300 °С-қа дейін қыздырғанда, көбірек ионды-байланысқан және пирогенді болып шығады. Одан әрі 300 °С-тан 550 °С-қа дейінгі диапазонда сұйық және газ тәрізді көмірсутектердің пайда бола жүретін қатты органикалық қосылыстары ыдырайды. Ыдырау реакцияларының қалдығы – кокс-аморфты көміртек. Кокстың пайда болуы есебінен көмірдің электрлік кедергісі төмендейді. 550 °С-қа жоғары температураларда қатты көмірдің сұйық және газ тәрізді көмірсутектердегі екіншілік реакциялары жүреді. Бұл реакциялардың өнімдері – газ тәрізді сутек және көміртек монооксиді. Жылулық баланс теңдеуінен, жылу шығыны көмір затының қызуына, сондай-ақ термохимиялық айналуға жұмсалатындығын көре аламыз. Термохимиялық айналулар жылуына жауапты компонент экзотермиялық және эндотермиялық реакциялардың балансына байланысты оң да, теріс те болуы мүмкін. Бұл термогравиметриялық анализдің жылу ағынының қисығынан байқалады. Әртүрлі температура диапазонында пиролиздің жылу ағыны оң немесе теріс болуы мүмкін. Дегенмен, орта есеппен эндотермиялық реакциялар басымырақ, сондықтан жылу бөлігі жұтылады. Термохимиялық реакцияларды есепке алмағанда, көмірдің физикалық жылу сыйымдылығы да температураға байланысты. Термохимиялық айналулар энергиясын есепке алмай, көмірдің жылу сыйымдылығының температуралық тәуелділігін анықтау мүмкін емес. Сондықтан тиімді жылу сыйымдылығын, яғни термохимиялық айналуға сіңірілген энергия есепке алынған жылу сыйымдылығын жиі қолданады. Есептерде аналитикалық формасы полиномиалды функция бойынша температуралық диапазонда аппроксимацияланған тиімді жылу сыйымдылығы қолданылды. Электрод аралық кеңістік температурасынан басқа, технология тиімділігіне электродтардың маңайындағы жылу энергиясының таралуы әсер етеді. 3 кВт қыздыру қуатында әртүрлі уақыт мезетінде есептік аймақтағы жылу өрісінің бейнелері көрсетілген. Келесі ерекшеліктер ең жақсы сипаттаманы береді. Қыздыру басталғанда, электродтарға тікелей жақын аймақтарда температура күрт өседі. Одан әрі электрод аралық кеңістіктің қызуы орын алады, ал қоршаған аймақтар әлсіз қызады. Біраз уақыт өткеннен кейін жылу энергиясы электродтардың бағыты бойынша тарала бастайды. Осылайша, бірнеше метр радиустағы аймақ қызады.

Технологияны табиғи сынақтарға дайындау қыздыруға қажетті жабдықтардың талап етілетін техникалық параметрлерін білуді міндеттейді. Көмірдің бастапқы және соңғы (пиролизге дейін және одан кейін) кедергілерінің белгілі шамалары бойынша, сондай-ақ айналу дәрежесін есептей отырып, электрод аралық кедергінің қыздыруға қарай өзгеруін анықтай аламыз. Электрод аралық қашықтық 0,5 м болғандағы нәтижелер суретте көрсетілген.

Түйін сөздер: көмір, тесу, қыздыру, карбонизация, газ.

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МОДЕЛИРОВАНИЕ ПОДЗЕМНОГО НАГРЕВА УГЛЕЙ ТОКОМ В КАНАЛЕ ЭЛЕКТРОТЕПЛООВОГО ПРОБОЯ

Аннотация. Построена математическая модель, описывающая нагрев подземного пласта угля электрическим током, протекающим через канал электротеплового пробоя. Канал пробоя, являющийся источником тепла, формируется между двумя электродами, расположенными в скважинах внутри подземного пласта. Электроды подключены кабелями к наземному электрооборудованию. Канал электротеплового пробоя в момент формирования имеет малый диаметр и расширяется по мере нагрева и карбонизации угля в окрестности канала. Величина расстояния между электродами задана равной 0,5 метра. Значения диэлектрических и теплофизических свойств взяты на основании экспериментальных и литературных данных для углей Казахстана. Получены зависимости температуры в центре нагреваемого участка пласта от времени при разной мощности нагрева. Получены изображения теплового поля в нагреваемой области и ее ближайшей окрестности. Приведены результаты расчетов электрических параметров электрооборудования, требуемого для нагрева, и изменения этих параметров во времени по мере нагрева. Изначально подземный пласт имеет некоторую исходную температуру. Если мы нагреваем участок пласта, часть тепловой энергии будет распространяться в менее нагретые окружающие области за счет теплопроводности и массопереноса. Поскольку уголь не прозрачен в инфракрасном диапазоне, теплопередача за счет излучения отсутствует. Предположительно, основной теплоотвод будет происходить за счет теплопроводности, поэтому массоперенос в модели не учтен. При нагреве угля органическая масса претерпевает изменения, происходящие под действием температуры. В диапазоне от исходной температуры до 120°C происходит выход влаги, которая содержится в угле как в свободном, так и в ионно-связанном виде. При дальнейшем нагреве от 120°C до 300°C выходит преимущественно ионно-связанная и пирогенетическая влага. Далее в диапазоне от 300°C до 550°C происходит разложение твердых органических соединений с образованием жидких и газообразных углеводородов. Остатком от реакций распада является кокс – аморфный углерод. За счет появления кокса снижается электрическое сопротивление угля. При температурах выше 550°C происходят вторичные реакции жидких и газообразных углеводородов с твердым углеродом. Продуктами этих реакций являются газообразный водород и монооксид углерода. Как видно из уравнения теплового баланса, расходование тепла происходит на нагрев угольного вещества, а также на термохимические превращения. Компонент, отвечающий за теплоту термохимических превращений, может быть как положительным, так и отрицательным в зависимости от баланса экзотермических и эндотермических реакций. Это видно по кривой теплового потока термогравиметрического анализа. В разных диапазонах температур тепловой поток пиролиза может быть положительным или отрицательным. В среднем, однако же, доминируют эндотермические реакции, таким образом, часть тепла поглощается. Физическая теплоемкость угля без учета термохимических реакций также зависит от температуры. Определить температурную зависимость теплоемкости угля без учета энергии термохимических превращений не представляется возможным. Поэтому чаще используют эффективную теплоемкость, т.е. теплоемкость с учетом поглощения энергии на термохимические превращения. В расчетах использована эффективная теплоемкость, аналитическая форма которой аппроксимирована в температурном диапазоне по полиномиальной функции. Кроме температуры в межэлектродном пространстве, на эффективность технологии влияет также распределение тепловой энергии в окрестности электродов. Показаны изображения теплового поля в расчетной области в разные моменты времени при мощности нагрева 3кВт.

Наиболее характерными являются следующие особенности. В начале нагрева температура резко возрастает в непосредственной близости с электродами. Далее происходит прогрев межэлектродного пространства, при этом окружающие области нагреваются слабо. Спустя более продолжительное время тепловая энергия начинает распределяться по направлению от электродов, прогревая таким образом область в радиусе нескольких метров. Подготовка натуральных испытаний технологии требует знания требуемых технических параметров оборудования для нагрева. По известным величинам начального и конечного (до и после пиролиза) сопротивлений угля, а также рассчитав степень превращения, можем определить изменение межэлектродного сопротивления по мере нагрева. Результаты для межэлектродного расстояния 0,5 м приведены на рисунках.

Ключевые слова: уголь, пробой, нагрев, карбонизация, газ.

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RATIONAL DIAGRAM OF DRILLING AND VALUES OF WORKING ANGLES OF A DRILLING TOOL CUTTING BIT

Abstract. The process of the rotary drilling process and proposes rational drilling pattern applicable for drilling operations is considered in this article. The analysis of the kinematics of the drilling tool in the process and the direction of drilling speed is determined. The values of the working angles of the cutting tooth of the drilling tool are assigned, which strengthen and prevent the sinking of the walls of the wells, and also prevent the occurrence of vibrations in the drilling tool. The dynamic loads associated with speed change in the process are transmitted to the cutting tool. If the speed of movement is uniform, then inertial forces arise at the time of sudden braking. If the motion is accelerated or slowed down, then inertial forces arise in the process of motion itself. In contrast to existing designs, when for most drilling tools, a pair of acting forces is directed along the direction of rotation of the drilling tool, that is, horizontally, in our case, a pair of forces is directed along the axis of the drilling tool - vertically. The vertical direction of the pair of forces along the axis of the drilling tool reduces the resistance to drilling, as well as the appearance of a retracting force down the axis of the well. The optimal geometry of cutting teeth with rational values is proposed. The studies were conducted to determine the durability of the drilling tool, depending on the emerging drilling forces. According to the research results, a drilling tool with cutting teeth from a carbide plate was designed and manufactured.

Key words: rotary drilling, hole, rock cutting tool, drill string, drilling pattern, shearing forces, wear, soil, cutting speed, drilling speed, vibration, rock, drill fluid.

Introduction. One of the most widely used methods for creating production and exploration wells is rotary drilling. It is provided by the transmission of rotational movements from the surface rotor to the drill string [1].

Rotary drilling has been used for over one hundred and forty years [1,2]. The technology of this method of wells punching was first used in the United States of America in the early eighties of the nineteenth century. Since then, it has not changed much, with the exception of minor innovations that have led to the efficiency of the process. The changes affected rock-cutting tools - they were improved, new liquid media were created for washing the wells, and the strength of the parts of the mechanism was strengthened [1,2].

In rotary drilling, the static axial loads are greatest and are created by the deadweight of the drill string. Other loads leading to tensile stresses include pipe friction against the rock when lifting the column, pressure drop in the turbodrill and drill bit, force caused by sticking and tightening of the column. During the drilling tool round trip operations, dynamic loads are transferred to the drill string connected with a change in speed. If the speed of movement is uniform, then inertial forces arise at the moment of sudden braking. If the movement is accelerated or slowed down, then inertial forces appear in the process of movement itself. In the vertical sections during rotation, variable loads appear due to the curvature of the column as a result of stability loss [3].

The relevance of research. Basically, in rotary drilling, the roller drill bit is the most loaded and critical element of the drilling rig, for the life cycle of which (almost more than 10 years), the costs of used bits are usually several times higher than the cost of the machine itself [4,5].

In connection with the crisis rise in the cost of drilling operations, research by scientists is aimed at solving the following main directions [4,5].

- a) Improvement the design of drilling rigs in order to increase their reliability;
- b) Improvement and creation of new high-speed and wear-resistant structures of drilling tools for a number of typified mining, geological and technological conditions of quarries;
- c) Improvement the organization of drilling operations management and forms of service maintenance;
- d) Optimization of the technological process of drilling wells directly in the industrial conditions of existing quarries.

It should be noted that the first two directions are carried out outside the quarries, differ in evolutionary development and are the subject of mainly design developments [4÷7].

It is known that when drilling deep wells, 11 factors were identified that affect the wear of a drilling tool, the geometry of the drilling tool itself being prevailing [6].

On these topical issues, a group of scientists on the project “AP0513118 Creation of drilling tools for drilling wells in the extraction of solid, liquid and gaseous minerals (contract No. 164 of 03/15/2018)” explore a new drilling scheme [7÷11].

Purpose of work: Study of rational drilling patterns and the values of the working angles of the drilling tool of the rake angle γ , relief angle α , wedge angle β , and also the angle of inclination of the cutting tooth ω .

Materials and research results. In existing drilling tools during drilling, the nature of the developed compressive and shearing forces, the size of particles separated from the massif depends on many factors [12÷18].

Upon reaching stresses in the rock being destroyed at a critical level, a chipping will occur in front of the leading edge of the cutting edge of the drilling tool. Further, the drilling tool rotating around its axis will stretch against a recently formed chip ledge and the process will be repeated. When a drilling tool slips during drilling process crushing, shredding and chipping of rock is occur.

As the hardness of rocks increases from soft to medium, the angle of the cutting edge α of the tapered teeth increases from $30\div 40^\circ$ to $80\div 90^\circ$, and the size of the rock-cutting teeth and inserts decreases [12÷15].

With such values of the rear angle α , the cutting taper of the drilling tool becomes dull, and obviously the drilling forces will increase significantly.

For carbide rock cutting tools, the working front, rear, and taper angles are not interconnected, since the reinforcing plates can be of various shapes, and for drilling tools with diamond-carbide plates most often can be round cylinders. The point angle δ of such plates is 90° , and the front β and rear α are interconnected. The cutting force F_{cut} and the formation of cleaved rocks depend on the value of the rake angle β .

The greater the negativity of the rake angle, the higher the resistance of the rock to cutting. The magnitude of the rear angle depends on the kinematic, technical, mining and technological conditions of cutting [19].

It is proved that the resistance of the rock to crushing R_c and chipping R_{ch} are proportional to the contact strength P_c [20]: $R_c = 0.24P_c$; $R_{ch} = 0.06P_c$ - for incisors with a positive rake angle β ; $R_{ch} = 0.07c$ - for incisors with zero rake angle β ; $R_{ch} = 0.08P_c$ - for incisors with a negative rake angle β .

Usually, to prevent the cutting element from landing on the rear face when passing through the top on a descent from each wave, the value of the back angle should not exceed 14.5° , and since the rock-cutting drill reinforced with diamond-hard-alloy drill plates, the front β and rear α angles are structurally interconnected (at an angle of sharpening $\delta = 90^\circ$), then the maximum negativity with a minimum increase in cutting force for new generation crowns is the rake angle β equal to 15° [19].

Some scientists believe that the working rear angle α_p in mining tools is usually $5 \div 20^\circ$. It is not recommended to increase it too much at the front positive angle, as this leads to a decrease in the strength of the cutting part. With the front, negative angle, it can be increased to 30° without much damage to the strength. Wear sites in this case grow less intensively [21].

In practice, depending on the strength of the rocks, rational values of the angle of sharpening δ and the working rake angle characterizing the strength of the cutting part are established: soft - $\delta = 60\div 65^\circ$; $\beta_p = 0\div 10^\circ$; medium strength - $\delta = 65\div 70^\circ$, $\beta_p = -5\div 0^\circ$; above the average strength - $\delta = 70\div 90^\circ$, $\beta_p = -25\div -10^\circ$ [22÷24].

The proposed drilling patterns are significantly different from existing methods. The difference lies in the fact that the cutting disk located at a certain angle ω relative to the axis of the drilling tool 1, vertically from bottom to top, planes the rock (figure 1).

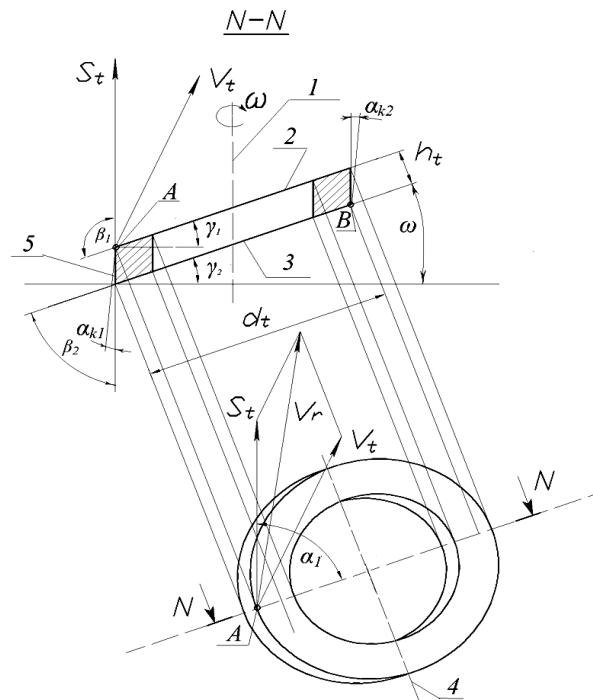


Figure 1 – Scheme for determining the working angles of a cutting tooth of a drilling tool

In the half-turn of the drilling tool, the left part of the tooth along axis 4 with surface 2 cuts off the soil from the walls of the well, where the right part of the tooth with surface 3 along axis 4 smooths the treated surface of the well. To study the drilling pattern and determine the optimal working angles of the cutting wedge, experiments on a drilling tool were carried out on teeth 2,3,4,5, which are made of high-speed steel (figure 2). For cutting into the soil in the design of the drilling tool provided tip 1 mounted on the housing 6 and equipped on three rows with round carbide inserts.

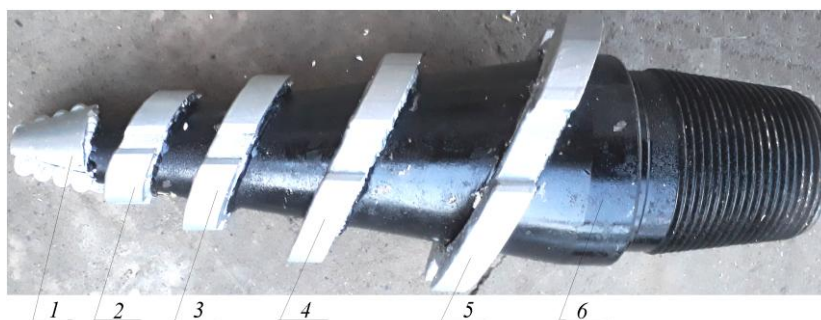


Figure 2 – Drilling tools with cutting teeth made of high-speed steel grade P6M5

The difference between the emerging pair of forces from the drilling tools used in the direction. If the majority of drilling tools have a pair of forces directed on the direction of the drilling tool rotation [4,6,12,16,18], that is, horizontally, then in our case, a pair of forces is directed along the axis of the drilling tool in the vertical direction (figure 1). This confirms the forecasts for a decrease in drilling forces, as well as the appearance of a retracting force down the hole. For this, it is necessary to conduct additional research to optimize the angle of inclination ω and to refine the technological process with respect to the ratios of the values of penetration and rotation of the drilling tool.

It should be noted that according to the geometry of the drilling tools in existing drilling methods, the back face touches and rubs against untreated soil, the cutting element lands on the back side [20÷23]. In this connection, the drilling process as a whole is deteriorating.

In the studied design of the drilling tool, the back relief angles α_1 and α_2 along surface 5 have zero values in statics, and in kinematics it will reach negative values (figure 1), which will smooth and tamper the cut surface of the well. It turns out that by treating the surface of the rear surfaces of the cutting teeth of the walls of the borehole, we strengthen it, preventing shedding and fragments of parts of the walls after drilling. In addition, the full contact of the surface 5 during the drilling process does not allow vibrations in the drilling tool (figure 1).

Preliminary calculations of the geometric parameters of the cutting tooth were made taking into account the volume of the element capturing the rock was calculated based on the volume of the trapezoidal slot in the disk knife (figure 3). There are special slots for the removal of cut soil to the top with drilling mud on the cutting tooth.

According to the deformation of solids [25,26], to obtain a clean shear, taking into account the tooth thickness h , and the volume of rock extracted per one revolution, the lifting angle of the cutting tooth was set as $\omega = 18 \div 22^\circ$ (figure 1). At such values of the tooth elevation angle, it becomes possible to obtain a shear angle of the rock close to $\beta = 45^\circ$. It is known that with such kinematics of the cutting tooth, minimal efforts are spent to destroy a solid [25–27].

The experiments were carried out on drilling of mixed soils with a drilling tool with cutting teeth made of high-speed steel grade P6M5 (figure 3).

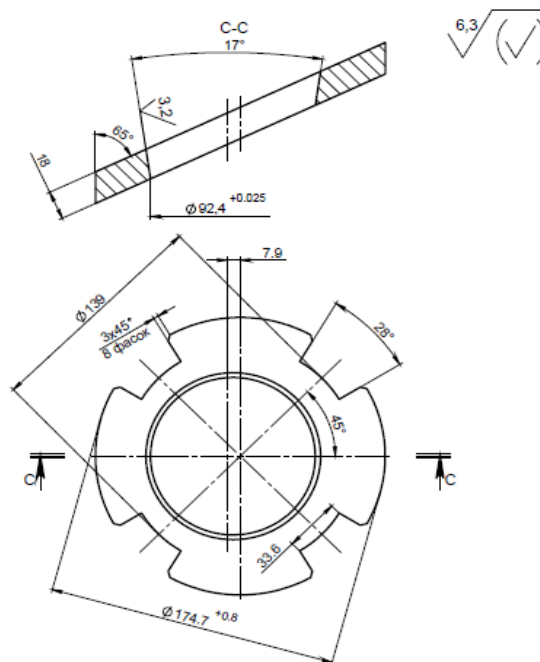


Figure 3 – The design of the fifth cutting tooth (figure 2)

The drill tool contains a sleeve 6 (figure 2), four parallel-mounted teeth 2,3,4,5 mounted in it in the form of disks having cutting edges *A* and *B* (Figure 1). The cutting edges have the same relief angles equal to $\alpha_1 = \alpha_2 = - (0 \div 1.5^\circ)$ and the rake angles with the values $\gamma_1 = 20 \div 25^\circ$, $\gamma_2 = - (20 \div 25^\circ)$.

Based on the obtained research data, a boring tool with cutting bit was made from a carbide blade of the BK6 brand (figure 4). The boring tool is designed for drilling of hard rock, it has: 1 - a cone-shaped tip equipped with solid plates in two grooves; 2,3,4,5 - cutting bit in the form of a disk made of structural steel grade 45 steel. The disks are mounted on the drilling tool sleeve (6) and are equipped with hard plates on the front surfaces; 7,8,9,10 - hole for the delivery of drilling fluid into the drill zone, under a certain pressure. It should be noted that the drilling fluid is supplied separately to the drill zone for each bit which facilitates the removal of cut soil. In the sleeve 1, the design of the drilling tool provides a shank with a tapered thread, which is installed with a sleeve adapters on standard drill pipes.

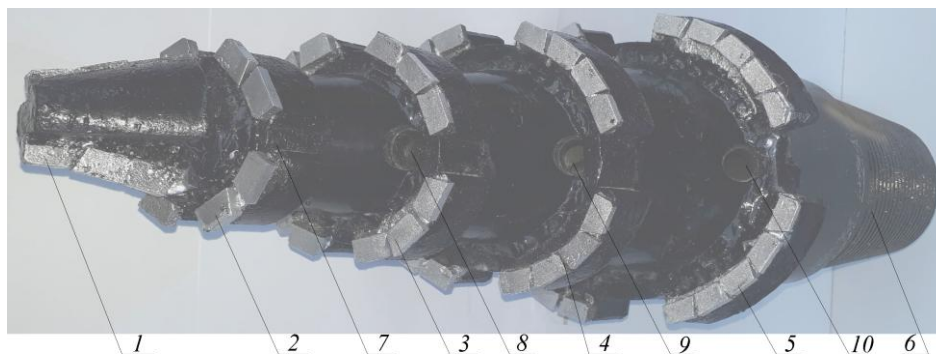


Figure 4 – A boring tool with cutting bit from a BK6 carbide plate

Conclusions. According to the research, the following results are formed:

1. The studied drilling pattern is rational, applicable for drilling operations. The drilling speed V_r at point A will be directed upward at an angle depending on the values of revolution and feed of the drilling tool. The resulting pair of forces is directed along the axis of the drilling tool vertically making it possible to reduce the drilling forces, as well as the appearance of a retracting force down the borehole (figure 1).

2. Negative values of the rear angles α_1 and α_2 along the surface 5 of the cutting bit will smooth, tamp the cut surface of the well, preventing crumbling of the walls of the well (figure 1). The presence of contact between the rear surfaces of the bits strengthens the walls of the borehole, prevents shedding and occurrence of vibrations in the drilling tool (figure 1).

3. An optimal geometry of cutting bit with rational values has been developed (figure 3).

4. Based on the calculations and experiments, the working angles of the cutting bit are assigned (figure 1): - the angle of the cutting bit rise is $\omega = 18 \div 22^\circ$, where minimal effort is spent to destroy the solid; trailing angles equal to $\alpha_1 = \alpha_2 = - (0 \div 1,5^\circ)$ and rake angles with values $\gamma_1 = 20 \div 25^\circ$, $\gamma_2 = - (20 \div 25^\circ)$.

5. Based on the results obtained, a drilling tool with cutting bits was designed and manufactured from a carbide blade of the BK6 brand to determine the resistance and study the emerging drilling forces (figure 4).

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РАЦИОНАЛДЫ БҰРҒЫЛАУ СҰЛБАСЫ ЖӘНЕ БҰРҒЫЛАУ ҚОНДЫРҒЫСЫНЫҢ КЕСУ ТІСТЕРІНІҢ ЖҰМЫС БҰРЫШЫНЫҢ МАҢЫЗДЫЛЫҒЫ

Аннотация. Жұмыста бұрғылаудың айналмалы процесі қарастырылып, бұрғылау жұмыстары үшін қабылданатын ұтымды бұрғылау сызбасы ұсынылған. Бұрғылау құралының кинематикасын талдау барысында бұрғылау жылдамдығының бағыты анықталған. Роторлы айналмалы бұрғылау кезіндегі шарлы қашау – бұрғылау станогының ең жоғары жүктемесі және ең жауапты элементі, демек, оның өмірлік циклы үшін (іс жүзінде 10 жылдан астам) жұмсалған қашаудың шығындары машинаның өз құнынан бірнеше есе асып түседі. Бұл бұрғылау станоктарының сенімділігін арттыру және бұрғылау құралдарының жаңа, жылдамырақ және төзімді конструкцияларын жасау мақсатында бұрғылау станогының конструкцияларын жетілдіруге бағытталған ғалымдардың эксперименттік зерттеулерінің қайта жаңғыруына себеп болды.

Бұрғылау жұмыстарының дағдарыстық қымбаттауына байланысты, ғалымдардың зерттеулері келесідей негізгі мақсаттарға бағытталған: бұрғылау станоктарының сенімділігін арттыру мақсатында олардың конструкцияларын жетілдіру; карьерлердің бірқатар типтелген тау-кен-геологиялық және технологиялық жағдайлары үшін бұрғылау құралдарының жаңа, жылдам және төзімді құрылымдарын жетілдіру және құру; бұрғылау жұмыстарын басқаруды және сервистік техникалық қызмет көрсетуді ұйымдастыруды жетілдіру; жұмыс істеп тұрған карьерлердің өнеркәсіптік жағдайында ұңғымаларды бұрғылаудың технологиялық процесін оңтайландыруға бағытталған. Бірінші екі бағыт карьерлерден тыс жүзеге асырылады, даму эволюциялық сипатымен ерекшеленеді және негізінен конструкторлық әзірлемелердің мәні болып саналады.

Бұрғылау құралының зерттелетін конструкциясында артқы бұрыштардың статикада нөлдік мәні бар және кинематикада олар ұңғыманың кесілген бетін тегістейтін және үтіктейтін теріс мәндерге жетеді. Яғни ұңғыма қабырғаларының кесетін тістерінің артқы бетін өңдеп, бұрғылаудан кейін қабырғалардың бөліктерінің төгілуі мен сынуын болдырмай, оны нығайтты. Бұдан басқа, бұрғылау процесінде үстіңгі қабаттың толық байланысы бұрғылау құралында дірілдің пайда болуына жол бермейді.

Жұмыс істеп тұрған құрылымдарға қарағанда, бұрғылау құралдарының көпшілігінде жұмыс істейтін күштер жұбы бұрғылау құралының айналу бағыты бойынша бағытталған, яғни көлденең, біздің жағдайда күштер жұбы бұрғылау құралының осі бойынша – тігінен бағытталған. Бұрғылау құралының осі бойынша күштер жұбының тігінен бағытталуы бұрғылауға кедергі күштерінің төмендеуіне, сондай-ақ ұңғыманың осі бойынша төмен қарай тартушы күштің пайда болуына әкеп соғады. Тік орналасқан учаскелерде айналу процесінде орнықтылықты жоғалту нәтижесінде бағананың қисаюы салдарынан ауыспалы жүктемелер пайда болады.

Эксперименттер Р6М5 маркалы жылдам кесетін болаттан жасалған кескіш тістері бар бұрғылау құралымен аралас топырақты бұрғылау бойынша жүргізілді.

Жүргізілген зерттеулердің алынған мәліметтері негізінде ВК 6 маркалы қатты балқитын пластинадан кескіш тістері бар бұрғылау құралы әзірленді. Бұрғылау құралы қатты жыныстарды бұрғылауға арналған, екі пазада қатты пластиналармен жабдықталған конус түріндегі ұштығы бар 45 маркалы конструкциялық болаттан жасалған диск түріндегі кесетін тістері бар. Дискілер бұрғылау құралының корпусына бекітілген және алдыңғы беттеріне қатты пластиналармен жабдықталған; бұрғылау ерітіндісін бұрғылау аймағына белгілі арынмен жеткізуге арналған тесік орын алған. Бұрғылау аймағына әрбір тіске арналған бұрғылау ерітіндісі бөлек беріледі, бұл ажыраған топырақтың ағуын жеңілдетеді. Бұрғылау құралы конструкциясының корпусында стандартты бұрғылау құбырларына арналған өткізгіштердің тығынымен орнатылатын конустық бұрандасы бар өзекше қарастырылған.

Жүргізілген зерттеулер нәтижесінде бұрғылаудың ұтымды сұлбасы ұсынылған, оған сәйкес, туындайтын күштер буы бұрғылау құралының осі бойынша тігінен бағытталған, бұл бұрғылау күшін төмендетуге, сондай-ақ бұрғылау ұңғымасы бойынша төмен қарай тартқыш күшке ие болуға мүмкіндік береді.

Кескіш тістің беті бойынша α_1 және α_2 артқы бұрыштарының теріс мәндері үтіктеледі, ұңғыма қабырғаларының бітелуін болдырмай, ұңғыманың кесілген бетін тегістейді. Тістердің артқы беттерінің жанасуының болуы бұрғылау құралында дірілдің пайда болуына жол бермей, ұңғыманың қабырғаларын нығайтады.

Бұрғылау күштеріне төзімділікті анықтау және зерттеу үшін ВК6 маркалы қатты балқитын пластинадан кескіш тістері бар бұрғылау құралы құрастырылды. Пайда болған бұрғылау күштеріне байланысты бұрғылау құралының беріктігін анықтау бағытындағы зерттеулер жүргізілген. Зерттеу нәтижесінде, қаттықұймалы тақтайшадан тұратын тістері бар кесетін бұрғылау құралы дайындалып, жасалған.

Түйін сөздер: айналмалы бұрғылау, ұңғыма, тау-кен кесуге арналған құрал, бұрғылау бұрышы, бұрғылау үлгісі, жылжу күштері, тозу, топырақ, кесу жылдамдығы, бұрғылау жылдамдығы, діріл, тау жынысы, бұрғылау ерітіндісі.

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РАЦИОНАЛЬНАЯ СХЕМА БУРЕНИЯ И ЗНАЧЕНИЯ РАБОЧИХ УГЛОВ РЕЖУЩЕГО ЗУБА БУРИЛЬНОГО ИНСТРУМЕНТА

Аннотация. В работе рассмотрен процесс вращательного способа бурения и предложена рациональная схема бурения, применимая для бурильных работ. Проведен анализ кинематики бурильного инструмента в процессе работы, определены направления скорости бурения. При роторном вращательном бурении шарошечное долото является самым высоконагруженным и ответственным элементом бурового станка, за жизненный цикл которого (практически более 10 лет) затраты на израсходованные долота в несколько раз превышают стоимость самой машины. Это и явилось причиной возобновления экспериментальных исследований ученых, направленных на совершенствование конструкций буровых станков с целью повышения их надежности и создание новых скоростных и износостойких конструкций буровых инструментов.

В связи с кризисным удорожанием буровых работ исследования ученых направлены для решения следующих основных направлений: совершенствование конструкций буровых станков с целью повышения

их надежности; совершенствование и создание новых скоростных и износостойких конструкций буровых инструментов для ряда типизированных горно-геологических и технологических условий карьеров; совершенствование организации управления буровыми работами и форм сервисного технического обслуживания; на оптимизацию технологического процесса бурения скважин непосредственно в промышленных условиях действующих карьеров. Необходимо отметить, что два первых направления осуществляются вне карьеров, отличаются эволюционностью развития и являются предметом в основном конструкторских разработок.

В исследуемой конструкции бурильного инструмента задние углы имеют нулевые значения в статике, и в кинематике они будут достигать отрицательных значений (рисунок 1), которые будут выглаживать и трамбовать срезанные поверхности скважины. Получается, что обрабатывая поверхность задними поверхностями режущих зубьев стен скважины, мы укрепляем его, предотвращая осыпания и отломки частей стен после бурения. Кроме этого, полный контакт поверхности в процессе бурения не допускает появления вибраций в бурильном инструменте.

В отличие от существующих конструкций, когда у большинства бурильных инструментов пара действующих сил направлена по направления вращения бурильного инструмента, то есть по горизонтали, в нашем случае пара сил направлена по оси бурильного инструмента – по вертикали. Направление пары сил по оси бурильного инструмента по вертикали приводит к снижению сил сопротивления бурению, а также появлению втягивающей силы вниз по оси скважины. На вертикальных участках в процессе вращения появляются переменные нагрузки вследствие искривления колонны в результате потери устойчивости.

По результатам исследований сконструирован и изготовлен бурильный инструмент с режущими зубьями из твердосплавной пластины.

Эксперименты проводились по бурению смешанных грунтов бурильным инструментом с режущими зубьями из быстрорежущей стали марки Р6М5.

На основе полученных данных проведенных исследований изготовлен бурильный инструмент с режущими зубьями из твердосплавной пластины марки ВК6. Бурильный инструмент предназначен для бурения твердых пород, имеет наконечник в виде конуса оснащенной твердыми пластинами в двух пазах; режущие зубья, в виде диска изготовленные из конструкционной стали марки 45. Диски закреплены на корпусе бурильного инструмента и на передних поверхностях оснащены твердыми пластинами; отверстие для доставки бурового раствора в буримую зону, под определенным напором. В буримую зону для каждого зуба бурильный раствор подается по отдельности, что облегчает увод срезанного грунта. В корпусе, конструкции бурильного инструмента предусмотрено хвостовик с конусной резьбой, которые устанавливается с втулкой переходниками на стандартные бурильные трубы.

В результате проведенных исследований предложена рациональная схема бурения, в соответствии с которой, возникающая пара сил направлена вертикально по оси бурильного инструмента, что дает возможность снизить силы бурения, а также проявиться втягивающей силе вниз по буримой скважине.

Отрицательные значения задних углов α_1 и α_2 по поверхности режущего зуба будут выглаживать, трамбовать срезанную поверхность скважины, предотвращая крошения стен скважины. Наличие контакта задних поверхностей зубьев укрепляет стены скважины, предотвращая осыпания и не допуская появления вибраций в бурильном инструменте.

Для определения стойкости и исследования возникающих сил бурения сконструирован бурильный инструмент с режущими зубьями из твердосплавной пластины марки ВК6. Проведены исследования по определению стойкости бурильного инструмента в зависимости от возникающих сил бурения. По результатам исследований сконструирован и изготовлен бурильный инструмент с режущими зубьями из твердосплавной пластины.

Ключевые слова: вращательное бурение, скважина, инструмент для горной резки, бурильная колонна, схема бурения, силы сдвига, износ, грунт, скорость резания, скорость бурения, вибрация, порода, буровая жидкость.

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**USE OF EXTREME PROPERTIES OF DEFORMATION
FOR ESTIMATION OF STRENGTH OF CONSTRUCTIVE
CONCRETE AND REINFORCED CONCRETE**

Abstract. To estimate the resistance of structural concrete and reinforced concrete to destruction, as a criterion for reaching the ultimate state, extreme properties of the energy (power) of compressed concrete deformation are used.

Normal and inclined to the longitudinal axis of the bending elements cross sections are considered in the most stressed zones. The limitation of the “stress-strain” diagram used in calculations for concrete is justified by the level of the beginning of macro-destructurization, which makes it possible to exclude a re-evaluation of strength. The value of the ultimate strain is determined on the descending branch of the diagram at the point corresponding to the maximum deformation energy. Super limiting strain is accompanied by a sharp decrease of stresses and structural rupture of the material. The dependence of the ultimate strain value on the parameter of the elastic-plastic characteristics of concrete is given.

The values of the ultimate strains for concrete of different classes are obtained. The strength problem of a compressed inclined element near the supports as a component of the truss analogy is solved. The result is obtained on the basis of a variational method in the theory of plasticity. The functional of virtual velocities principle is used. Concrete is considered as a rigid-plastic body. The shear failure occurs within the boundaries of the inclined element. Intense deformation is considered localized in a thin layer on the failure surface. To determine the value of the ultimate load the upper estimate is applied. The minimum power of plastic deformation is used as a criterion. The area of implementation of the truss analogy method is specified.

Key words: concrete, reinforced concrete, extreme deformation properties, ultimate deformation, shear, truss analogy.

Introduction. To estimate the strength of concrete and reinforced concrete structures, a non-linear deformation model has recently been widely used, which forms the basis of a number of author and normative techniques [1-6]. It examines the distribution of the strain in the sections normal to the longitudinal axis of the elements and allows use the stress diagrams in a compressed zone concrete corresponding to it and experimentally confirmed. This shows the actual work in the ultimate state. The most proven relationship between stresses σ_c and strains ε_c of concrete is the fractionally rational function [5,6]. Meanwhile, it should be noted that the value of the ultimate strain of concrete, which bounds the “ $\sigma_c - \varepsilon_c$ ” diagram on the descending branch, is not uniquely determined. At the moment, the experimentally determined values of the ultimate strain of concrete vary over a fairly wide range [2,3,7] and require a clarification.

The tasks of estimating the strength of elements in inclined sections are solved on the basis of the method of truss analogy with the introduction of empirical coefficients [8-10]. At the same time, the shear form of failure is experimentally confirmed, both within the boundaries of the compressed strut (strip) and

under the dangerous inclined crack [9-12]. At the same time, the empirical approach does not allow the establishment of clear boundaries for its implementation.

In [13], the cyclic strength of asphalt concrete was determined depending on the level of deformation. In [14], the safety margins of the truss structure were established using the criterion of the minimum perceived mobile load.

In accordance with the abovementioned, the solution of the problems under consideration on a general theoretical basis is relevant. The application of the extreme principles of mechanics of a solid deformed body seems promising.

The purpose of this study is to improve the methods for estimating the strength of structural concrete and reinforced concrete based on extreme deformation properties and the theory of plasticity.

Research methods. To achieve this purpose, the methods of mechanics of a solid deformed body are used. As criteria for solving problems of strength, the extreme properties of the energy (power) of concrete deformation are considered. The concept of rigid plastic body is implemented. The variational method is used in the theory of plasticity, the principle of virtual velocities, the upper estimate of the ultimate load, discontinuous solutions. The functional principle of the virtual velocities is investigated on a stationary state. As a condition of plasticity at a certain range of stresses, strength condition [15] is used, which generalize classical theories of Mohr and Mises – Henki for fragile materials. The values of the ultimate deformation of the concrete, beyond which comes the macrofailure of its structure, meets the criterion of the maximum potential deformation energy. To estimate the strength of the elements under the shear, kinematically possible schemes of its failure are considered, and that one is taken at which the plastic deformation power is minimal.

Results. The task of evaluating strength in normal sections of reinforced concrete elements under bending in [3,4] is proposed to be solved by determining the values of the moments corresponding to the maximum in the “moment – curvature” or “moment – deformation” diagrams. In this case, the condition of not exceeding the ultimate value ε_{cR} by the strain rate of the extreme fiber of the compressed zone should be observed.

The stress-strain relationship for concrete (figure 1) is fairly accurately described by a rational function or a polynomial of the 5th degree, which is harmonized according to research data [3,16]. Meanwhile, to clarify the parameters of these functions and check the condition $\varepsilon_c \leq \varepsilon_{cR}$, it is necessary to establish the value ε_{cR} for different classes of concrete. ε_{cR} limits the part of the descending branch of the “ $\sigma_c - \varepsilon_c$ ” diagram used in the calculations, where the potential deformation energy increases. With an increase in the level of deformation above the beyond, destructurization and destruction of concrete occur.

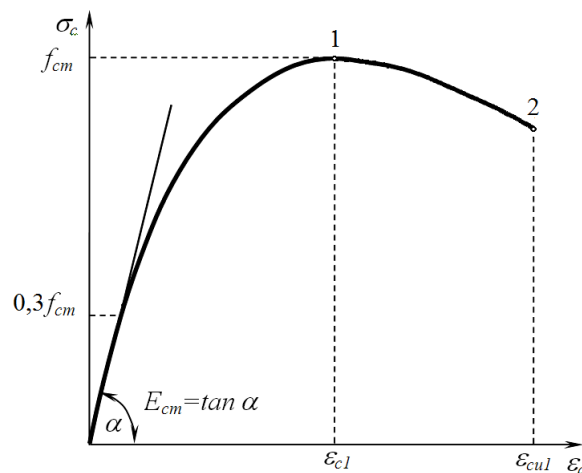


Figure 1 – "Stress – strain" diagram of compressed concrete:

f_{cm} and E_{cm} – average values, respectively, of the compressive strength of the concrete and the initial modulus of elasticity

The relations for fractional rational function and the 5th degree polynomial are written respectively in the form

$$\sigma_c / f_{cd} = (k\eta - \eta^2) / [1 + (k-2)/\eta], \quad (1)$$

$$\sigma_c / f_{cd} = a_1\eta + a_2\eta^2 + a_3\eta^3 + a_4\eta^4 + a_5\eta^5, \quad (2)$$

where f_{cd} – design value of concrete compressive strength; $k = 1,05 E_{cd} / E_{c1,cd}$ – characteristic of the elastic-plastic properties of concrete; E_{cd} – design modulus of concrete elasticity; $E_{c1,cd}$ – secant module at the top of the diagram (fig. 1); $\eta = \varepsilon_c / \varepsilon_{c1,cd}$ – level of strain; $\varepsilon_{c1,cd}$ – strain at maximum stress; a_1, a_2, a_3, a_4, a_5 – polynomial coefficients.

It is proposed to determine the calculated value of the ultimate strain ε_{cdR} using the extreme property of deformation – the achievement of the maximum deformation energy of concrete, from the equation

$$\sigma_c \varepsilon_{cdR} = \max(\sigma_c \varepsilon_c). \quad (3)$$

To obtain the polynomial coefficients, the characteristic points 1 and 2 are considered, as well as the area of the diagram bounded by the deformation ε_{cdR} (figure 1). The results are given in table 1.

Table 1 – 5th degree polynomial coefficients

Coef- ficient	Concrete compression class									
	C12/15	C16/20	C20/25	C25/30	C30/35	C32/40	C35/45	C40/50	C45/55	C50/60
a_1	2.9777	2.8383	2.7013	2.5758	2.4873	2,3852	2.302	2.2463	2.1595	2.0663
a_2	-3.4783	-3.1001	-2.7361	-2.3919	-2.1608	-1,8925	-1.6834	-1.5473	-1.3431	-1.1369
a_3	2.1287	1.7705	1.4358	1.1021	0.8943	0,6499	0.4727	0.3632	0.2103	0.0752
a_4	-0.7334	-0.5939	-0.4685	-0.3317	-0.2554	-0,1629	-0.1032	-0.0696	-0.0292	-0.0049
a_5	0.1053	0.0852	0.0675	0.0457	0.0346	0,0203	0.0119	0.0074	0.0025	0.0003

Functions (1) and (2), the initial modulus of elasticity E_{cd} and the secant modules at the specified points $E_{c1,cd}, E_{cR,cd}$ determine the stress diagram in the compressed zone of the reinforced concrete element under the condition that the strain achieves in the most compressed fiber the value $\varepsilon_{cR,cd}$.

The ultimate value of a bending moment that a reinforced concrete element can perceive

$$M_u = f_{yd} A_s d (1 - \chi \bar{\xi} \omega) = f_{cd} b d^2 \bar{\xi} \omega (1 - \chi \bar{\xi} \omega) \quad (4)$$

in [4] it is recommended to determine from the condition

$$M_u = \max(\varepsilon_c), \quad (5)$$

where d – working section height; $\bar{\xi} = x/d$ – relative height of the compressed zone of concrete; ω – ratio of stress diagram completeness; χ – characteristic that determines the distance from the point of application of the resultant force in concrete to the compressed face of the element (figure 2).

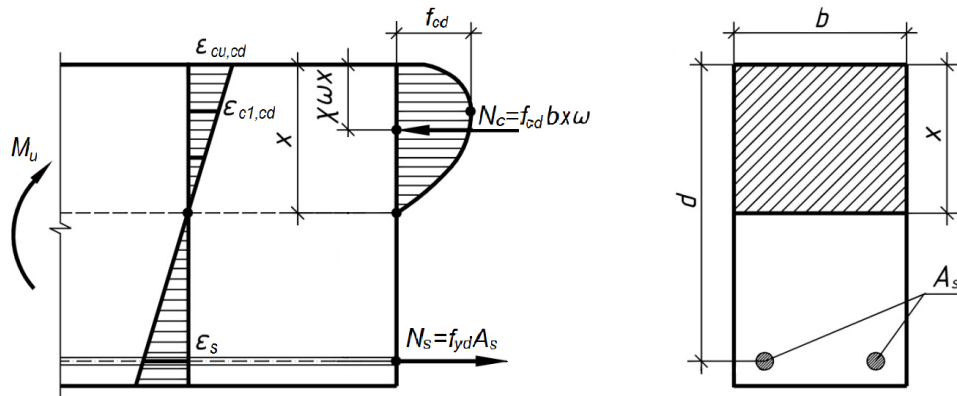


Figure 2 – The design scheme of the reinforced concrete element in the normal section: distribution of forces, stresses and strains

The authors proposed formulas for engineering calculation, defining the above characteristics by parameter k

$$\eta_u = \eta_R \sqrt{1.8/k}, \tag{6}$$

$$\omega = 0.5 + 0.24\sqrt[4]{k-1}, \tag{7}$$

$$\chi = 2/3 - 0.12\sqrt[4]{k-1}, \tag{8}$$

$$\text{at } k \neq 2 \quad \eta_R = \frac{1}{2k-4} \left[\sqrt{\left(\frac{k^2-2k-3}{2}\right)^2 + 4k^2 - 8k} + \frac{k^2-2k-3}{2} \right], \text{ at } k = 2 \quad \eta_R = 4/3, \tag{9}$$

where $\eta_u = \varepsilon_{cu,cd} / \varepsilon_{c1,cd}$ – strain level at $M_u = \max$; $\eta_R = \varepsilon_{cR,cd} / \varepsilon_{c1,cd}$ – ultimate strain level (table 2).

Table 2 – Ultimate strain level of concrete η_R

Concrete compression class									
C12/15	C16/20	C20/25	C25/30	C30/35	C32/40	C35/45	C40/50	C45/55	C50/60
1.8093	1.7144	1.6269	1.5705	1.5264	1.4841	1.4495	1.4272	1.3934	1.358

The condition that the value of the current concrete strain ε_c does not exceed the value $\varepsilon_{cR,cd}$ indicates that the concrete is working up to the boundary of its macro-destructuring and can be written as

$$\eta_u \leq \eta_R. \tag{10}$$

Estimation of the strength of reinforced concrete elements on the support areas by the inclined section using the method of truss analogy considers the shear form of failure of the compressed element (strut). In this case, the calculated dependencies include a number of empirical coefficients.

For the theoretical justification of the implementation of the truss analogy, the problem of the strength of an inclined prism loaded at the ends of the compressive and tangential components of the transverse force is solved. The scheme of a rigid-plastic body is used. The prerequisites for applying the theory of plasticity are represented in [17-20]. The solution is based on the principle of virtual velocities, whose functional in the absence of inertial and mass forces is

$$I = \int_{S_l} W_{cl} dS - \int f_i^* V_i dS, \tag{11}$$

where f_i^* – forces in the direction of velocities V_i , given on the surface of the body S ; W_{cl} – power density of plastic deformation of concrete.

The functional is investigated on a stationary state $\delta I = 0$.

The simplest one is a solution in discontinuous functions of velocities.

The plastic deformation is considered localized in a thin layer on the failure surface S_l , which divides the element into two absolutely rigid disks. The jumps of the tangential ΔV_t and normal ΔV_n to the surface S_l components of the movement velocity V of one disk relative to another are expressed through of the angle of inclination of the failure surface γ and the ratio of the velocities $m = V_1 / V_2$ in the direction of the action of forces T_u and N_u . The angle of the direction of velocity V to the surface S_l is $\psi = \text{arctg } m - \gamma$.

The variational method is used in the theory of plasticity. Parameters m and γ vary. The power W_{cl} on the area S_l is considered as a function of deformation velocities, which takes into account the dilatancy of concrete.

The kinematic scheme of the failure of the strut is shown in figure 3.

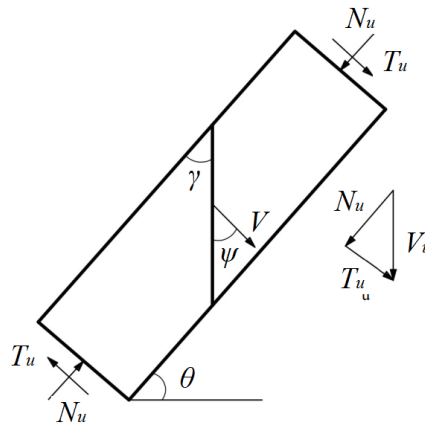


Figure 3 – The kinematic scheme of the compressed element failure

The formula for estimating the strength of a reinforced concrete inclined element has the form

$$\frac{V_u}{f_{cd} b l_c} = \frac{\sqrt{4(1 - \chi + \chi^2) / 3} \sqrt{(m - \tan \gamma)^2 + (1 + m \tan \gamma)^2} - (1 - \chi)(m - \tan \gamma)}{(\tan \theta + m) \tan \gamma} \sqrt{1 + \tan^2 \theta}, \quad (12)$$

where b and l_c – cross section dimensions; $l_c = z / \sqrt{2}$, $z = 0.9d$.

The results of the calculation with respect to the resistance of concrete to tension and compression $\chi = f_{ctd} / f_{cd} = 0.07$ are given in table 3.

Table 3 – Ultimate relative forces perceived by an inclined element

$\theta, ^\circ$	$\tan \theta$	m	$\tan \gamma$	$\gamma, ^\circ$	$N_u / f_{cd} b l_c$	$T_u / f_{cd} b l_c$	$V_u / f_{cd} b l_c$
45	1	10.51	1.21	50.4	0.305	0.305	0.432
30	0.577	176	1.32	52.9	0.179	0.309	0.357
21.8	0.4	4054	1.33	53	0.124	0.309	0.333

Both characteristics of concrete strength are taken into account, in contrast to the dependence of the method [5,6]. The need to take into account the tensile strength of concrete f_{ctd} is due to the shear form of failure. It is well known that shear strength depends both on f_{ctd} and f_{cd} .

Comparative analysis of the results of evaluating the strength of reinforced concrete elements in inclined sections near the supports on the basis of a refined method of a truss analogy with experimental data indicates the convergence of theoretical and experimental values. The design scheme (figure 3) is confirmed by the failure pattern observed in experiments. Plastic strains are localized on the cut surface in thin layers, which is confirmed by systematic experimental studies [21].

If condition $1 \leq \cot \theta \leq 1.5$ is met failure occurs within the boundaries of the inclined compressed brace. In the case $\cot \theta > 1.5$ there is a shear of the concrete of the compressed zone of the bending element over a dangerous inclined crack, which is described by the well-known disk model [9,22,23].

Conclusion. The stress-strain diagram “ $\sigma_c - \varepsilon_c$ ” used in the calculations on the descending branch must be limited to the starting point of the macro-destructuring of concrete. The value of the ultimate strain ε_{cdR} corresponds to the maximum potential deformation energy $\sigma_c \varepsilon_{cdR} = \max(\sigma_c \varepsilon_c)$.

When evaluating the strength of reinforced concrete elements in normal sections, the condition of not exceeding by the level of strain the most compressed fiber of concrete at the stage of failure of the level of ultimate strain $\eta_u \leq \eta_R$ should be checked. When strain exceeds the ultimate value ($\eta_u > \eta_R$), a fragile avalanche-like failure occurs along the concrete of the compressed zone.

The strength problem of a compressed inclined element (strut) in the support sections as a component of the truss analogy is solved by a variational method in the plasticity theory of concrete. As a criterion for determining the ultimate force value perceived by the concrete strut under shear, the minimum of the plastic strain capacity is used that is localized in a thin layer on the failure surface. When designing reinforced concrete elements, it is recommended to take the inclination angle of the inclined element corresponding to the most efficient use of the resistances of concrete and shear reinforcement.

For a more accurate mapping in the calculations of the behavior of constructive concrete and reinforced concrete at the failure stage and improvement of the method of estimating their strength, the future development of the deformation model, the use of different methods with the specification of the areas of their implementation and the application of extreme principles of mechanics of deformable solid body are perspective.

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КОНСТРУКЦИЯЛЫҚ ЖӘНЕ ТЕМІР БЕТОННЫҢ БЕРІКТІГІН БАҒАЛАУДА ДЕФОРМАЦИЯНЫҢ ЭКСТРЕМАЛДЫ ҚАСИЕТТЕРІН ПАЙДАЛАНУ

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ИСПОЛЬЗОВАНИЕ ЭКСТРЕМАЛЬНЫХ СВОЙСТВ ДЕФОРМАЦИИ ДЛЯ ОЦЕНИВАНИЯ ПРОЧНОСТИ КОНСТРУКТИВНОГО БЕТОНА И ЖЕЛЕЗОБЕТОНА

Аннотация. Для оценивания сопротивления конструктивного бетона и железобетона разрушению в качестве критерия достижения предельного состояния используются экстремальные свойств энергии (мощности) деформирования сжатого бетона.

Рассматриваются нормальные и наклонные к продольной оси изгибаемых элементов сечения в наиболее напряженных зонах.

Обосновано ограничение применяемой в расчетах диаграммы «напряжения – деформация» бетона уровнем начала макроструктуризации, что позволяет исключить переоценку прочности. Диаграмма описывается дробно-рациональной функцией и гармонизированным полиномом 5-ой степени. Для уточнения

коэффициентов полинома рассматриваются характерные параметры диаграммы: точка в ее вершине, соответствующая максимуму напряжений, точка предельного уровня деформации, до которой бетон как материал еще способен воспринимает возрастающую нагрузку, а также площадь диаграммы, ограниченной предельной деформацией. Используются начальный модуль деформации бетона и секущие модули в вершине диаграммы и в точке, которая ее ограничивает на нисходящем участке. Приведены коэффициенты полинома для бетонов разной прочности.

Решена задача прочности балочного железобетонного элемента в нормальном сечении. Предельное значение изгибающего момента определяется из условий максимальной величины нагрузки и не превышения деформацией уровня, с достижением которого начинается макроструктуризация. Значение предельной деформации на нисходящей ветви диаграммы установлено в точке, соответствующей максимуму энергии деформирования.

Запредельная деформация сопровождается резким снижением напряжений и нарушением структуры материала. Приведена зависимость величины предельной деформации и параметров расчетного нормального сечения от упруго-пластической характеристики бетона. Получены значения уровня предельной деформации для бетонов разных классов.

Определена прочность сжатого наклонного элемента возле опор как составляющего ферменной аналогии. Рассмотрено разрушение путем среза моделирующей сжатый элемент бетонной призмы, нагруженной по торцам нормальной сжимающей и касательной силами.

Результат получен на основе вариационного метода в теории пластичности. В качестве пластического потенциала принято условие прочности. Используется математический аппарат теории пластичности с учетом дилатансии бетона, определяющий зависимости напряжений от скоростей деформаций и функционал принципа виртуальных скоростей.

Бетон рассматривается как жестко-пластическое тело. Интенсивная деформация считается локализованной в тонком слое на поверхности разрушения. Примыкающие к поверхности разрушения области принимаются абсолютно жесткими. Для определения величины предельной нагрузки применяется верхняя оценка.

Функционал метода виртуальных скоростей исследуется на стационарное состояние. Варьируются угол наклона поверхности разрушения и соотношение скоростей в ортогональных направлениях, через которые выражены нормальные и касательные к поверхности среза скачки скоростей. В качестве критерия использован минимум мощности пластической деформации.

Предложена подтвержденная экспериментальными исследованиями кинематическая схема разрушения сжатого бетонного элемента и зависимость для оценки его прочности. Приведены результаты решения при разных углах наклона призмы к продольной оси элемента. Уточнена область реализации метода ферменной аналогии.

При проектировании железобетонных элементов рекомендуется принимать угол наклона наклонной полосы, соответствующий наиболее эффективному использованию сопротивлений бетона и поперечной арматуры.

Указано на необходимость и перспективность дальнейшего развития деформационной модели, использования и совершенствования методов оценивания прочности с уточнением областей их реализации и применение экстремальных принципов механики твердого деформированного тела для более точного и обоснованного отображения в расчетах поведения конструктивного бетона и железобетона на стадии разрушения.

Ключевые слов: бетон, железобетон, экстремальные свойства деформации, предельная деформация, срез, ферменная аналогия.

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INTENSIFICATION OF COMBUSTION FUEL MIXTURE IN PETROLAIR THERMAL TOOLS WITH EJECTOR NOZZLE

Abstract. The article considers the problem of increasing the power of the air-petrol thermal tools for destruction of rocks in the extraction and processing (stabilizing) block of stone, due to the intensification of combustion of the fuel mixture in a supersonic high-temperature jet torch burner. The model of shock wave excitation process in ejector nozzle, described by the equations of preservation of mechanics of continuous environments is given. As a result, the solution to this equation found the main operating and design parameters of the ejector nozzle, the parameters of the supersonic gas stream flowing from the Laval's nozzle of the burner into the cavity of the ejection nozzle, and the speed and temperature of the gas stream in the mixing chamber (combustion), the area of the output section and the diameter of the ejection of the mixing chamber, diameter and length of the free jet.

Key words: petrol-air thermal tool, supersonic high-temperature jet, heat flow, fuel components (gasoline, kerosene, air), detonation waves.

The intensification of combustion fuel mixture at the air-petrol thermal tools with ejector nozzle, made with perforations in the region of the initial section of the jet considered in the assumption of the creation on this site of powerful shock waves. Shock waves are formed when meeting with obstacle in a cylindrical nozzle (surface roughness ejected cold air) at the end of the supersonic gas jet from the nozzle of the main burner [1,2].

The supersonic jet carries particles of unburned fuel when the excess air ratio is equal to $\alpha_T = 0.5...0.7$, which, passing through the shock wave front, are burnt with high speed, forming a new high speed jet, thus greatly increasing the total energy capacity of the burner [3,4,5].

The conversion of chemical energy into heat and, simultaneously, to kinetic takes place in a cylindrical nozzle, which in this case is the combustion chamber. In the combustion chamber is heterogeneous combustion (part of the components is in the liquid phase and the other in the gas phase), that is there are chemical and aero-thermodynamic processes in a moving reactive gas environment. In this case, the object of study of combustion may serve as the gas flow behind a strong shock wave. A peculiar form of burning in this case is detonation, which is characterized by extremely high velocities of combustion and a large local increase in pressure and temperature.

Model of the process of development of the detonation wave (shock wave) is described in domestic and foreign literature [6-12].

Let us consider the properties of planar shock fronts, which is widely used in one-dimensional models of the detonation wave. Common to all one-dimensional models are the representation of the detonation wave in the form of a complex consisting of the shock front and the adjacent reaction zone. Therefore, before proceeding to analyze the situation that occurs when supply chemical energy to the flow behind the shock front, we consider the laws that determine the properties of stationary shock waves in nonreactive environment.

Let us consider a planar shock front propagating at a steady velocity W_s . Pressure, density and velocity of the gas are denoted by ρ , p and u respectively. It is possible to simplify the analysis by transforming to a coordinate system with an origin fixed at the shock front to replace a laboratory frame of reference. The resulting flows are shown in figure 1.

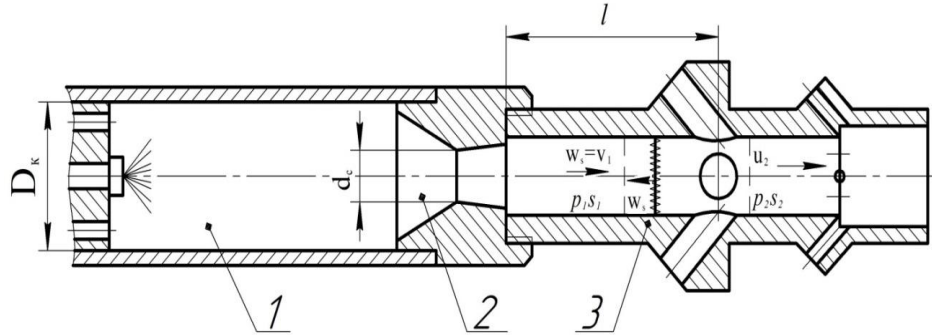


Figure 1 – Model of shock wave excitation process in the ejector nozzle
 1 – combustion chamber; 2 – Laval's nozzle; 3 – ejector nozzle

Here the gas flows into the stationary shock front with a velocity W_s and emerges from the front with a velocity $u_2 = W_s - u'_2$, where u'_2 is the velocity of the gas relative to a stationary observer. Although the processes which occur in the vicinity of the shock front are irreversible, the three mechanical conservation conditions apply rigorously to the flows through the control surfaces.

In integral form they may be expressed as [6,11]

$$\rho_1 W_s = \rho_2 u_2 \text{ (conservation of mass);} \tag{1}$$

$$p_1 + \rho_1 W_s^2 = p_2 + \rho_2 u_2^2 \text{ (conservation of momentum);} \tag{2}$$

$$\rho W_s (h_1 + W_s^2/2) = \rho u_2 (h_2 + u_2^2/2) \text{ (conservation of energy),} \tag{3}$$

where $h = e + pV$ – is the specific enthalpy, e – is the internal energy and $V = 1/\rho$ – is the specific volume. Furthermore, for the strengths of shocks typical of detonation, the ideal equation of state for a gas can generally be assumed to hold [8]:

$$p = \rho RT, \tag{4}$$

where R - is the gas constant, T – temperature.

Equations (1) - (4) have five unknown quantities, W_s , u_2 , ρ_2 , p_2 , T_2 , so that all the properties of the post-shock flow in region 2 can be expressed in terms of the velocity of the front and the initial conditions of the gas.

Equations (1) and (2) give an expression for the mass flow through the shock, p , thus:

$$(W_s \rho_1)^2 = (u_2 \rho_2)^2 = (p_2 - p_1) / (V_1 - V_2). \tag{5}$$

Equation (5) demonstrates that the mass flow into the shock is given by the square root of the negative slope of the straight line in the p - v plane which joins initial (1) and final (2) states. This line is termed the Rayleigh line. Equations (1) – (3) can be combined to produce [9]

$$h_2 - h_1 = (1/2)(p_2 - p_1)(V_1 + V_2)$$

or

$$e_2 - e_1 = (1/2)(p_2 + p_1)(V_1 - V_2). \tag{6}$$

Equation (6) is denoted the Rankine-Hugoniot.

It characterizes the initial and final states resulting from a given change in energy or enthalpy across the shock front. In other words, it is the counterpart of the relationship for isentropic and adiabatic processes [9]:

$$de = -pdV \text{ or } pV = \text{const.} \tag{7}$$

Equations (1) – (4) can be combined to yield pressure, density and temperature ratios across the front in terms of its Mach number, $M_s = W_s/a_1$, where a_1 is the speed of sound in the medium ahead of the shock:

$$p_2/p_1 = p_{21} = [2kM_s^2 - (k-1)] / (k+1); \quad (8)$$

$$\rho_2/\rho_1 = \rho_{21} = (k+1) M_s^2 / [(k-1) M_s^2 + 2]; \quad (9)$$

$$T_2/T_1 = T_{21} = - \frac{[kM_s^2 - (k-1)/2][1 + (k-1)M_s^2/2]}{[(k+1)M_s^2/2]}, \quad (10)$$

where $k = \frac{c_p}{c_v}$ – is adiabatic index.

If the equation of species conservation (1) – (10) to write given the fact that in sections 1 and 2 thermodynamic parameters, structure and molecular weight of the mixture, the equation of the detonation adiabatic instead of 10 will look [10]

$$\frac{k_2 + 1}{k_2 - 1} p_2 V_2 - \frac{k_1 + 1}{k_1 - 1} p_1 V_1 - p_2 V_1 + p_1 V_2 = 2Q, \quad (11)$$

Finally, from the equation of state for section 2 will receive

$$T_2 = \frac{p_2 V_2}{c_{v2}(k-1)}. \quad (12)$$

To increase the power of the jet gas stream carrying unburned fuel, it is necessary to introduce a jet of oxidizer is oxygen, so the ejector nozzle performed ejection bores.

The nozzle, formed by drilling ejection to ejection of the outer atmospheric air inside the nozzle promotes additional combustion of fuel components in the stream of oxygen ejection air. Nozzle and diffuser of the ejector are no different from ordinary nozzles and diffusers, the calculation of which is set out [8].

In determining the parameters of the ejector only significant coefficients of maintaining total gas pressure in these devices, the initial pressure of mixed gas, find the total pressure on the cut nozzles p_1^* and p_2^* and the full pressure of the mixture of p_3^* - total pressure at the exit of the diffuser p_4 . These coefficients are chosen according to the experimental data.

The main objective in the calculation of the ejector is to determine the parameters of the gas mixture at the outlet of the mixing chamber in the parameters of the gases before mixing.

Parameters ejection gas in the inlet section will be noted by index 1, the parameters ejection gas index 2, the parameters of the mixture in the outlet section - index 3. We assume given all the parameters of the flow in the inlet section of the chamber and build the solution so that from the equations of conservation of mass, energy and momentum flux to determine the temperature of braking, the velocity and total pressure of gas mixture in the outlet section of the chamber [8].

From the solution of the equations by the method [7,14] we obtain

$$\sqrt{(n+1)(1+n\theta+\nu)}z(\lambda_3) = z(\lambda_1) + n\sqrt{\theta}z(\lambda_2). \quad (13)$$

This equation is called the *main equation of the ejection*. According to the initial parameters of gases and ejection coefficient, it is possible to determine the gas-dynamic function $z(\lambda_3) = \lambda_3 + \frac{1}{\lambda_3}$, and given the speed of the mixture λ_3 .

Knowing the parameters of the ejected and the ejected gases before mixing, we find a dimensionless value of n - ejection coefficient. This value can be expressed through the parameters of the flow in the inlet section of the chamber and is thus independent. Substituting into the expression for the coefficient of ejection of the magnitude of costs miscible gases, recorded with the help of relations (13), we obtain

$$n = \frac{G_2}{G_1} = \frac{p_2^* F_2 q(\lambda_2) \sqrt{T_1^*}}{p_1^* F_1 q(\lambda_1) \sqrt{T_2^*}}, \quad (14)$$

or

$$n = \frac{1}{\Pi_0 \alpha \sqrt{\theta}} \frac{q(\lambda_2)}{q(\lambda_1)}. \quad (15)$$

Equation (15) relates the coefficient of ejection n geometric parameter of the ejector α and parameters of the gases at the entrance to the chamber.

Further, it is necessary to experimentally find the temperature of the heat flow inside the nozzle, or the temperature of the inner wall of the ejector nozzle. To determine the temperature of the heat flow inside the nozzle must perform the inverse problem of heat conduction through a cylindrical wall that is slightly different for the determination of temperature at one and the same wall thickness of the cylindrical or flat [13].

To improve the energy parameters of gas-jet thermal tool proposes a new design of the working body with ejector nozzle and diffuser – a special nozzle for injecting atmospheric air).

Figure 1 presents a thermodynamic working body with ejector nozzle.

Relationships for calculation of achievable parameters and the optimum relationship of the cross sections of the gas-jet injectors (nozzles) can be derived based on the equations of the characteristics of these devices [14].

The result of the calculations obtained the main parameters of the ejection nozzle, when the ejection ratio $u = 4$, $P_p = 0,5$ МПа = 506625 h/m², $w = 1285$ m/s, $T = 2020$ K (table).

Estimated data regime and design parameters of thermal tools with a nozzle at the cost of fuel components 17, 25, 35 l/hour

Regime and design parameters	17 l/hour, air 6 M ³ /min	25 l/hour, air 9 M ³ /min	35 l/hour, air 12 M ³ /min
The estimated performance of the injector G_c , kg/sec	0,4368	0,684	0,9428
Expense of a working stream G_p , kg/sec	0,1092	0,171	0,2357
Expense of the injected stream G_{th} , kg/sec	0,3276	0,513	0,7071
The critical section of the working nozzle d_{p^*} , mm	20	22	26
The exit section of the ejector nozzle of the Laval's nozzle d_j , mm	24	30	36
Length of the free jet l_{cl} , mm	262,5	328,24	393,8
Diameter of the free jet d_2 , mm	148,8	186	223,2

Figure 2 shows the schedule of change of a stream range of the thermal tool with ejector nozzle depending on consumption characteristics of fuel components.

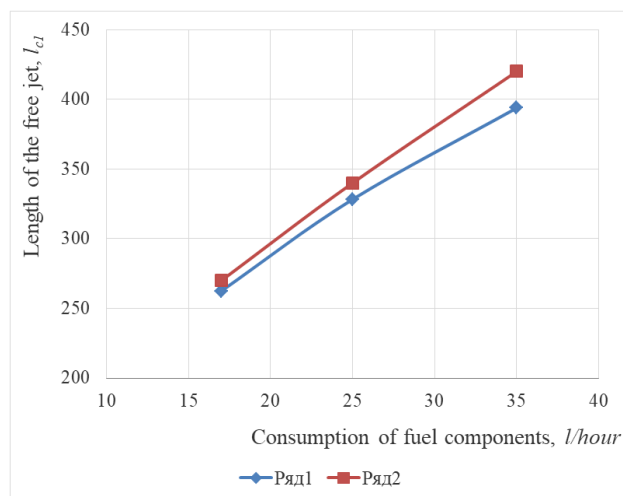


Figure 2 – The schedule of change of a stream range of the thermal tool with ejector nozzle depending on consumption characteristics of fuel components: 1 – theoretical, 2 – experimental data

Thus, the main parameters achievable compression pressure and the pressure in the inlet section of the mixing chamber and the main geometric dimensions of the gas-jet injector with diffuser – special nozzle for air injection.

We consider the case when the transfer of heat through a homogeneous and isotropic wall to one surface of the specified boundary conditions of the second kind in the form $q_c = const$ (at $x = 0$); on another surface is set to the heat-transfer coefficient α_2 , and the ambient temperature $t_{\text{жс2}}$, i.e. boundary conditions of the third kind (figure 3). Internal sources in the wall are missing ($q_c = 0$).

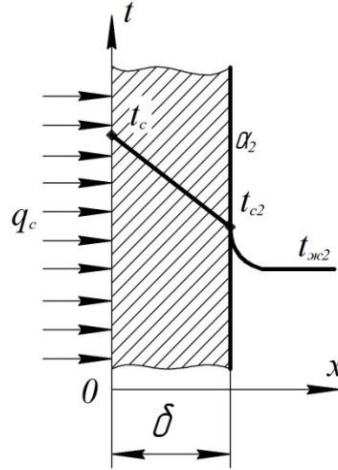


Figure 3 – The transfer of heat through a flat wall (mixed boundary conditions)

This problem is reduced to finding the temperature distribution in the wall and the temperatures on its surface. Because of the stationarity of the thermal regime we can write the following equation:

$$q_c = (t_{c1} - t_{c2}) \frac{\lambda}{\delta}; \quad q_c = \alpha_2 (t_{c2} - t_{\text{жс2}}). \quad (16)$$

From equations (16) it follows that for a given value of q_c

$$t_{c2} = t_{\text{жс2}} + q_c \frac{1}{\alpha_2}; \quad t_{c1} = t_{\text{жс2}} + q_c \left(\frac{1}{\alpha_2} + \frac{\delta}{\lambda} \right). \quad (17)$$

We find from the formula (17) the temperature inside the ejection nozzle:

$$q_c = (t_{c1} - t_{c2}) \frac{\lambda}{\delta}; \quad q_c = \frac{\lambda t_{c1} - \lambda t_{c2}}{\delta}; \quad \lambda t_{c1} - \lambda t_{c2} = q_c \delta; \quad \lambda t_{c1} = q_c \delta + \lambda t_{c2};$$

$$t_{c1} = \frac{q_c \delta + \lambda t_{c2}}{\lambda}$$

where is λ – the heat transfer coefficient for metal, $\lambda = 35$ W/mK; δ – the thickness of the nozzle, $\delta = 5$ mm = 0,005 m; q_c – the heat flow; t_{c2} – temperature, $t_{c2} = 1473$ K.

In accordance with figure 4 estimates the temperature of the metal by its colour temperature of the nozzle $T_n = 1100...1200^{\circ}\text{C}$ (1373...1473⁰K) and given the increase in temperature of the working gas flow due to heat of combustion of unburned fuel, but with high temperature (2000⁰C) and loss on heating of the metal nozzle, take the temperature of the mixed gas stream $T_n = 2000^{\circ}\text{C}$.



Figure 4 – The comparative analysis of heating temperature of a surface a thermal tool nozzle according to metal temperature on its color [15]:
 a – process of the surface treatment of thermal tool with gasdynamic nozzle;
 b – estimation of metal temperature nozzle on its color

Determine the temperature in the nozzle t_{c1} when various consumable fuel component (17 L/h, 25 L/h, 35 L/h). Get the temperature in the zone of intense combustion in the nozzle $t_{c1} = 1854\text{K}$.

Conclusions:

1. The model of shock wave excitation process in gas-dynamic nozzle is developed;
2. The gas flow flowing in the gas-dynamic nozzle is strictly subject to the three equations of solid media mechanics conservation: the equations of mass conservation, motion quantity and energy conservation;
3. The main ejection equation has been found, which allows to determine the main kinematic and structural parameters of the ejection nozzles, which allows to significantly increase the energy parameters of the thermal flow of a gasoline-air thermal tool;
4. To find the thermal parameters of gas treacle inside the nozzle - gas mixing chamber, an experimental method of determining the temperature of the outer surface of the nozzle from the table of metal beads colors was used;
5. To find the parameters of the thermal flow of gas in the nozzle, the inverse problem of heat conductivity for calculating the temperature of the inner surface of the nozzle for a flat wall has been solved;
6. As a result of calculation of a new design of a thermal tool with gas-dynamic, ejection nozzles, its main kinematic and structural parameters were obtained.

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ЭЖЕКЦИОНДЫ САПТАМАСЫ БАР БЕНЗИН-АУАЛЫ ТЕРМОҚҰРАЛДАРЫНДА ОТЫН ҚОСПАСЫНЫҢ ЖАНУЫН ИНТЕНСИФИКАЦИЯЛАУ

Аннотация. Мақалада термоқұрал жалынының дыбысты жоғары температуралы ағынында отын қоспасының жануын қарқындату арқылы блокты тасты өндіру және өңдеу (пассировкалау) кезінде тау жыныстарын бұзу үшін бензин-ауалы термоқұралдардың қуатын арттыру мәселесі қарастырылған. Тұтас орта механикасының сақталу теңдеулерімен сипатталған эжекциялы саптамада соққы толқынының өршу процесінің моделі келтірілген. Бұл теңдеуді шешу нәтижесінде эжекционды қондырманың негізгі режимдік және конструктивтік параметрлері табылды. Термоқұралдың Лаваль шүмегінен эжекционды қондырманың саңылауынан өтетін дыбысты газ ағынының параметрлері де табылды. Атап айтқанда, жану камерасындағы газ ағынының жылдамдығы мен температурасы, шығу қимасының ауданы және эжекционды қондырманың

камерасындағы диаметрі, бос ағыстың диаметрі мен ұзындығы табылды. Саптаманың ішіндегі жылу ағынының температурасы және саптаманың ішкі қабырғасының температурасы эксперименталды табылды. Қондырма ішіндегі жылу ағынының температурасын анықтау үшін цилиндрлік қабырға арқылы жылу өткізгіштіктің кері есебі орындалған, бұл цилиндрлік немесе жазық қондырма қабырғасының бір қалыңдығы кезінде температураны анықтау бойынша ерекшеленеді. Металдың температурасы оның түсі бойынша бағалау негізінде термоқұралдың қондырмасы бетінің қыздыру температурасының салыстырмалы талдауы келтірілген. Газ ағынының температурасын анықтау үшін, металдың қызуын оның түсі бойынша температуралық бағалау бойынша саптаманың сыртқы қабырғасының температурасын анықтаймыз және содан кейін жылу өткізгіштік теңдеуді шешеміз, саптаманың ішкі қабырғасының температурасын немесе саптаманың газ ағынының температурасын табамыз. 17, 25, 35 л/сағ жанармай шығындары кезінде газдинамикалық саптамасы бар термоқұралдардың режимдік және конструктивтік параметрлерінің есептік деректері және отын компоненттерінің шығыс сипаттамаларына тәуелді жанарғы ағысының алыс төзімділігінің өзгеру кестесі ұсынылған. Сонымен қатар бұл мақалада энергетикалық параметрлерді арттыру үшін инжекторы және диффузоры бар газ ағынды термоқұралының жаңа конструкциясы – атмосфералық ауаны инжектендіруге арналған арнайы қондырмасы ұсынылған. Араластыру камерасының кіріс қимасындағы қысу мен қысымның қолжетімді қысымының негізгі параметрлері, сондай-ақ диффузоры бар газ ағынды инжектордың негізгі геометриялық өлшемдері (ауаны инжектендіруге арналған арнайы саптама) анықталды.

Түйін сөздер: бензин-ауалы термоқұралдар, дыбысты жоғары температуралы ағыс, жылу ағыны, отын компоненттері (бензин, керосин, ауа), детонациялық толқындар.

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ИНТЕНСИФИКАЦИЯ ГОРЕНИЯ ТОПЛИВНОЙ СМЕСИ В БЕНЗОВОЗДУШНЫХ ТЕРМОИНСТРУМЕНТАХ С ЭЖЕКЦИОННЫМ НАСАДКОМ

Аннотация. В статье рассмотрена проблема повышения мощности бензовоздушных термоинструментов для разрушения горных пород при добыче и обработке блочного камня за счет интенсификация горения топливной смеси в сверхзвуковой высокотемпературной струе факела горелки. Приведена модель процесса возбуждения ударной волны в эжекционной насадке, описанная уравнениями сохранения механики сплошных сред. В результате решения этих уравнений найдены основные режимные и конструктивные параметры эжекционной насадки. Найдены параметры сверхзвукового газового потока, истекающего из сопла Лаваля горелки в полость эжекционной насадки. А именно: скорость и температура газового потока в камере смешения (сгорания); площадь выходного сечения; диаметр эжекционной камеры смешения; диаметр и длину свободной струи факела горелки. Экспериментально найдены температура теплового потока внутри насадки и температура внутренней стенки насадки. Для определения температуры теплового потока внутри насадки выполнена обратная задача теплопроводности через цилиндрическую стенку, что незначительно отличается по определению температуры при одной и той же толщине стенки цилиндрической или плоской насадки. Приведен сравнительный анализ температуры нагрева поверхности насадки термоинструмента по оценке температуры металла по его цвету. Для определения температуры газового потока внутри насадки по температурной оценке нагрева металла по его цвету определяем температуру наружной стенки насадки и затем, решая уравнение теплопроводности, находим температуру внутренней стенки насадка или температур газового потока в насадке. Представлены расчетные данные режимных и конструктивных параметров термоинструментов с газодинамической насадкой при расходах горючего 17, 25, 35 л/час и график изменения дальности струи горелки в зависимости от расходных характеристик топливных компонентов. Также в данной статье для повышения энергетических параметров представлена новая конструкция газоструйного термоинструмента с инжектором и диффузором – специальной насадкой для инжектирования атмосферного воздуха). Определены основные параметры достижимого давления сжатия и давления во входном сечении камеры смешения, а также основные геометрические размеры газоструйного инжектора с диффузором – специальной насадки для инжектирования воздуха.

Ключевые слова: бензовоздушные термоинструменты, сверхзвуковая высокотемпературная струя, тепловой поток, топливные компоненты (бензин, керосин, воздух), детонационные волны.

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**MODERN SITUATION AND DYNAMICS OF ANTHROPOGENIC
IMPACT ON ECOGEO MORPHOLOGICAL CONDITIONS
(CASE STUDY OF THE EASTERN KURA DEPRESSION)**

Abstract. The article analyzes in detail the anthropogenic factors affecting the ecogeomorphological conditions in the the Eastern Kura depression (Kura-Araz lowland and surrounding areas). According to the reviewed literature theoretical base of human effects on geomorphological environment and modern situation of human activity were analyzed in the studied area. On the base of supervised and unsupervised classification of the Landsat images (1976-2017) land use-land cover (LULC) map of the territory was compiled with application of GIS technologies. Six land cover types were distinguished with a geomorphological interpretation executing the classification for the year 1976 and 2017: water, green, bare land, salinity, parcel and urban (settle areas). It was estimated the area, decrease and increase of each land cover type. The dynamic and transformation of land covers were determined with the change detection function. For example, it was defined that the most increasing land cover in the area of transformation since 1976 to 2017 is the sown area. Due to the anthropogenic development of the studied territory, the largest reduction in the area of bare (33.85%) and salinization (25.43%) land covers occurred during this period.

Key words: Anthropogenic factor, Ecogeomorphological condition, GIS, land use, land cover.

Introduction. The Eastern Kura depression which is an important agricultural region and constitutes more than 30% of the territory of the Azerbaijan Republic, with a number of international and regional transport corridors (International Silk Road, North- Southern corridor, Baku-Tbilisi-Jeyhan oil pipeline, TANAP gas pipeline, etc.), communication lines, Kura-Baku drinking water pipeline require detailed ecogeomorphological research here. Various types of endogenous (mud volcanism, modern tectonic movements, seismicity) and exogenous (fluvial, arid-denudation, thalassogenic, swampy and salinity) relief formation processes, including anthropogenic factors (irrigation erosion, intensive grazing, exploitation of oil and gas deposits, construction materials, etc.) create more complicated ecogeomorphological conditions and increase the relevance of the research [1,2,3,4,5,6,7,8,9,10,11]. Thus, most studies conducted in the field of anthropogenic effects on ecogeomorphological conditions express their theoretical provisions and are focused on individual components. However, studies on the anthropogenic impacts on ecogeomorphological conditions on the base of land use-land cover classification have not been conducted. From this point of view, the presented research work is of significant scientific and practical importance.

The object of the study, methods and data. The study area lies in the northern hemisphere between latitudes 38°49'09" - 40°51'48,71" N and longitudes 46°40'53,61" - 49°35'23,41" E in the east of Greenwich (figure 1). Supervised (Maximum-likelihood algorithm) and unsupervised (ISODATA clustering) classification methods have been applied using corrected Landsat 2 MSS (1976) and Landsat 8 OLI & TIRS (2017) images with a band combination (RGB) of near-infrared (0.7-0.8 mkm), red (0.6-0.7 mkm) and green (0,5-0,6 mkm) wavelengths and multitemporal LULC maps were composed. Change detection of 1976 and 2017 LULC maps was conducted in SagaGIS and ArcGIS software (figure 3).

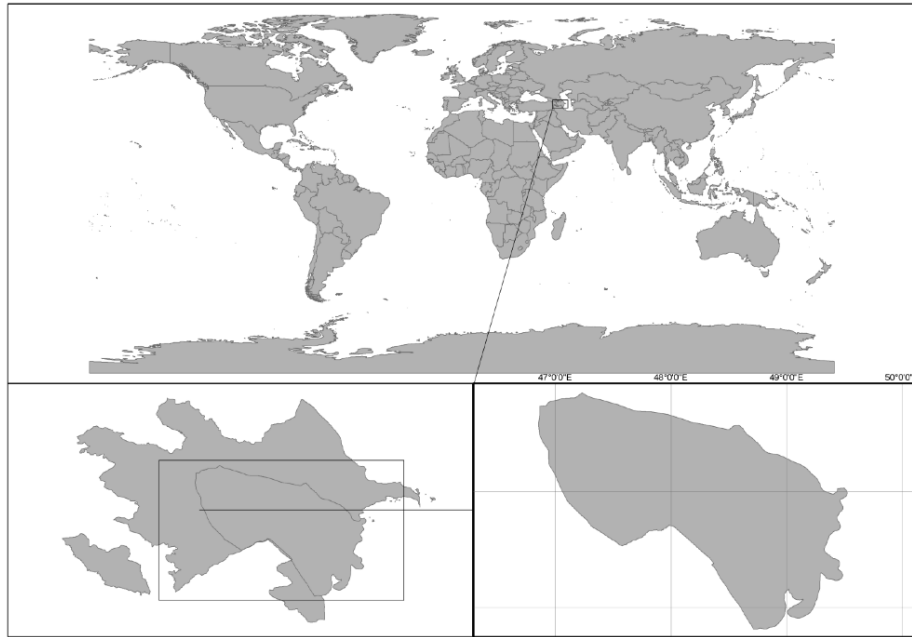


Figure 1 – The location map of the Eastern Kura depression

Results and discussion. Anthropogenic factors affecting the ecogeomorphological conditions of the Eastern Kura depression in the modern era include man-caused activities (oil and gas extraction, building materials production oil and gas extraction, building materials production, construction and exploitation of irrigation systems), artificial irrigation, pasture-cattle breeding, settlements and etc. (figure 2). The Eastern Kura depression is an important agricultural region but also an area of international importance, where the Silk Road, the North-South transport corridors pass. In addition to it, the highways of national importance in the depression, local and rural, urban and interurban roads, with asphalt and ground cover, and railways of international importance have some influence on the environmental conditions of the studied area [12].



Figure 2 – Anthropogenic impact map in the Eastern Kura depression

The hydrological regime and environmental conditions of the Eastern Kura depression have been significantly altered through irrigation systems such as Mingachevir Reservoir, Upper Shirvan (123 km) and Upper Karabakh (172.4 km) canals, Bahramtapa hydropower station (6-7 m height of dump) and the Rasularkh (51 km, irrigating 18.3 thousand ha), the main Mugan (34 km, irrigating 65 thousand ha), Azizbeyov (46 km, irrigating 37 thousand ha) canals, the Mil-Mugan hydropower station (40 m height of concrete dump, with length of 1026 m) and the main Mil canal (37.1 km), etc. Along the main canals there are large settlement and planting areas, orchards, intra-farm and inter-farm distribution channels, a dense network of drainage and collectors, and other anthropogenic complexes. Perennial irrigation and melioration measures caused generating of anthropogenic relief forms here [13].

As a result of direct impact of water reservoirs, canals and drainage collectors erected to increase soil fertility, thousands of hectares of land were withdrawn from economic turnover, and as a result of indirect impact exogenous processes such as irrigation erosion, salinization and swamping were accelerated. Although irrigation and land reclamation measures have been aimed at improving soil fertility, it has often led to increased irrigation erosion, development of salinization and waterlogging processes. Completion of operation of drainage-collector systems (Main Shirvan, 251.5 km; Mil-Karabakh, 168 km; Main Mil-Mugan, 143.7 km, etc.), designed to prevent the mentioned processes, and the spread of saltwater flowing from them to the surrounding areas further aggravated the ecogeomorphological conditions. The main cause of the mentioned harmful exogenous processes is the gradual deformation of the open irrigation canals and drainage-collector systems as a result of natural and anthropogenic effects and loss of water carrying capacity. Natural impacts include different natural processes (natural pollution, landslides, weeding, soil, wind, rain, etc.), and anthropogenic impacts include insufficiency on existing design and construction of canals and drainage collectors, grazing of cattle, effects of machinery and etc. According to the calculations, over 20 km³ of irrigation water has been leaked into the soil over the period of operation of the Upper Karabakh canal for more than 50 years. This figure, which is generally considerably larger than the Mingachevir reservoir (16 km³), provides a clear picture of the severe consequences of major defects in the construction of main irrigation canals [14].

On the base of LULC analyze it was determined that the sown areas were less transformed land cover (11,25%) during the years 1976-2017 and most transformed land covers were erosion-accumulation (bare land and salinity) areas (47,62%). The largest quantitative transformation was between the areas of erosion-accumulation and sown areas (figure 3). 1828,487 sq. km (33,85%) of erosion-accumulative areas have changed into sown areas (table).

Transformation of land cover in the Eastern Kura depression

Land cover, sq. km (%)	2017	Water 1657,29	Green- 847,84	Bare land - 3552,63	Salinity- 3475,2	Settled areas- 2520,19	Sown areas- 15287,09
1976							
Water-1854,95 (100)	1259,1 (68)		156,7 (8,4)	39,18 (2,1)	74,84 (4)	41,67 (2,2)	283,79 (15,3)
Green-891,45 (100)	99,8 (11,2)		549,42 (61,63)	36,38 (4)	100,02 (11,22)	3,06 (0,34)	102,76 (11,52)
Bare land -1976 - 5401,544 (100)	211,01 (3,9)		88,04 (1,6)	2829,16 (52,38)	377,73 (6,99)	67,1 (1,24)	1828,49 (33,85)
Salinity-1976- 4222,289 (100)	30,28 (0,72)		20,42 (0,48)	302,91 (7,17)	2766,13 (65,51)	32,43 (0,77)	1070,11 (25,34)
Settled areas- 2196,23 (100)	6,70 (0,3)		2,92 (0,13)	14,31 (0,65%)	11,22 (0,5 %)	1654,36 (75,33%)	506,72 (23,07%)
Sown areas - 12830,3712 (100)	75,77 (0,59%)		34,83 (0,27%)	330,70 (2,58%)	151,19 (1,18%)	722,65 (5,63%)	11515,22 (89,75%)

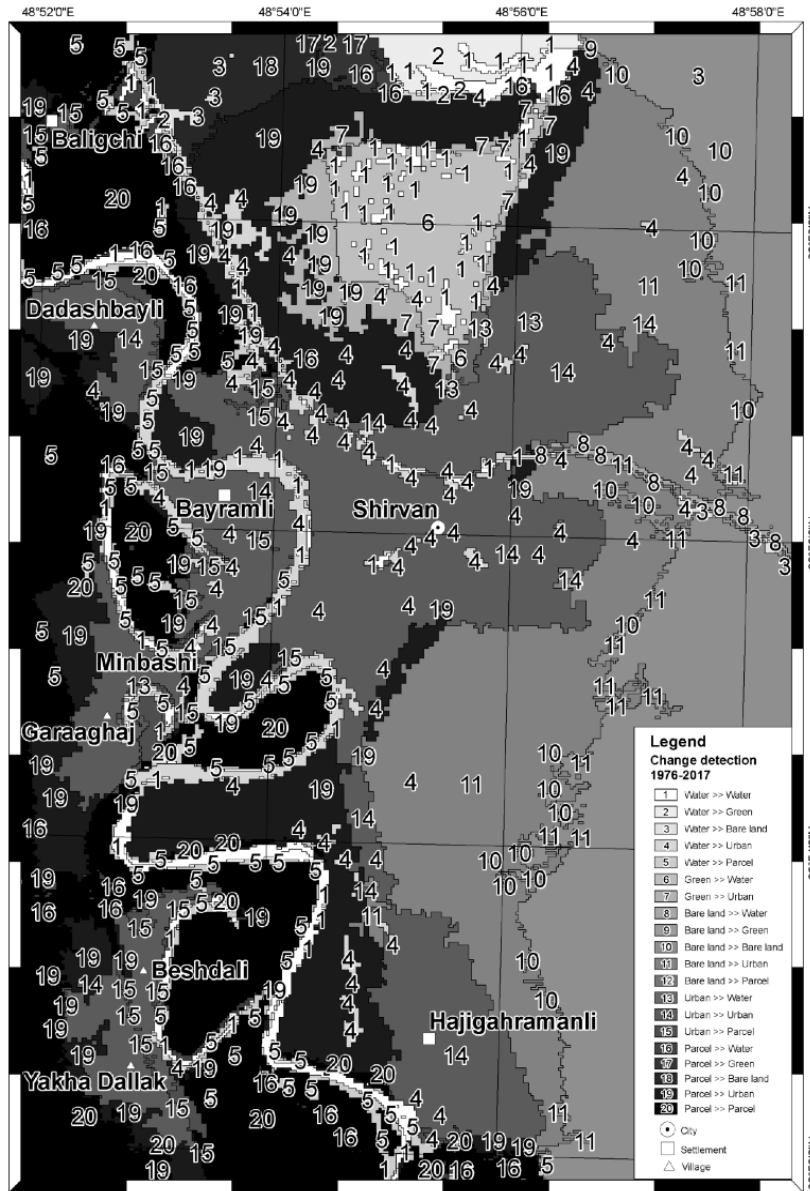


Figure 3 – Change detection map of LULC in Shirvan city and surrounding areas (1976-2017)

Conclusions and proposals. During the 41-year period (1976-2017) as a result of the anthropogenic transformation of the territory, sown areas with irrigation erosion and accumulation increased by 2456,72 sq. km (245672,28 ha) and settlement areas increased by 323,96 sq. km (32396,13 ha). The average annual increase in sown areas and settle areas during the mentioned period amounted to 59,92 sq. km (5992 ha) and 7,9 sq. km (790 ha) respectively. In general, 15,3% of the water bodies (283,786 sq. km), 11,52% of vegetation cover (102,76 sq. km), 33,85% (1828,487 sq. km) of erosion-accumulation areas, 25,34% (1070,115 sq. km) of salines, 23,07% (506,719 sq. km) of settlement areas have turned into sown (cultivated) area (table) and it is estimated as the most increasing land cover in the area of transformation since 1976 to 2017 (11515,216 sq. km).

In order to prevent the development of swamping, saline and erosion processes along the trunk and intra-farm canals in the Eastern Kura depression, first of all, it is important deepening the bottom of these canals, and cover with concrete, asphalt-concrete, bitumen, special clay, etc. on the surface. It is important improvement of the taking irrigation water from the canals and to adhere to the irrigation norm. Also, the maximum and minimum levels of water in the canals and collectors should be strictly controlled not to exceed the intended scope of the project, and repairs should be carried out in a timely manner. It is necessary to pass from the classic method of irrigation to the modern drip irrigation method.

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**ЭКОГЕОМОРФОЛОГИЯЛЫҚ ЖАҒДАЙЛАРҒА АНТРОПОГЕНДІК
ӘСЕР ЕТУДІҢ ҚАЗІРГІ ЖАҒДАЙЫ МЕН ДИНАМИКАСЫ
(КУРИН ДЕПРЕССИЯСЫНЫҢ ШЫҒЫС БӨЛІГІН МЫСАЛҒА АЛУ НЕГІЗІНДЕ)**

Аннотация. Мақалада курин депрессиясының шығыс бөлігіндегі экогеоморфологиялық жағдайларға әсер ететін антропогендік факторлар (Құра-Араз ойпаты және іргелес аумақтар) жан-жақты талданады. Зерттелетін ауданда адамның геоморфологиялық ортаға әсерін және адам қызметінің қазіргі жай-күйін талдау жүргізілді. Антропогендік факторлардың арасында (Мұнай және газ өндіру, құрылыс материалдарын өндіру, жайылымдық мал шаруашылығы, қоныстар және т.б.) олардың тікелей және жанама әсерлері, кең ауқымды және елеулі әсерлері (иригациялық жүйелерді салу және пайдалану, жасанды суару) егжей-тегжейлі сипатталған. Су қоймаларын, арналарды, коллекторлық-дренаждық жүйелерді салу кезінде шаруашылық айналымнан мың гектар жер шығарылды, ал оларды пайдалану кезінде иригациялық эрозия, тұздану және батпақтану сияқты зиянды экзогенді процестер дамыды. Көрсетілген процестерді болдырмау үшін салынған коллекторлық-дренаждық жүйелерді пайдалану мерзімінің аяқталуы, сондай-ақ тұздалған судың қоршаған ортаға ағып кетуі экогеоморфологиялық жағдайларды одан әрі нашарлатты. Табиғи (лайлану, сырғымалар, шаю және т.б.) және антропогендік (арналар мен дренаждық коллекторлардың қолданыстағы құрылымдары мен құрылыстарын жобалаудағы қателіктер, мал жаю және т.б.) факторлар, сондай-ақ ашық иригациялық және коллекторлық-дренаждық жүйелердің істен шығуына ықпал етті.

ГАЗ-технологияларды қолдана отырып орындалған Ландсат (1976-2017 ж.) көп арналы суреттерінің бақыланатын және бақыланбайтын дешифрлеу негізінде зерттелетін аумақтың жер пайдалану және жер жамылғысы (LULC) картасы жасалды. Жер жамылғысының алты түрі: су, өсімдік, жалаңаш жерлер, тұздану, егістік алқаптары және селителі аумақтар геоморфологиялық интерпретация кезінде дешифрлеу негізінде бөлінген. Жер бетінің әр түрінің азаюы мен ұлғаюы анықталды. Жер жамылғысының динамикасы мен трансформациясы өзгерістерді анықтау функциясының көмегімен анықталды. Мысалы, 1976 жылдан бастап 2017 жылға дейін трансформация аймағындағы ең ұлғайтылған жер жамылғысы – егіс алаңы екені анықталды. Зерттелетін аумақты антропогендік игеру есебінен, аталған кезең ішінде жалаңаштанған (33,85 %) және тұздалған (25,43 %) жер жамылғыларының ауданы барынша азайған.

Мақалада, сондай-ақ зерттеу аумағының экогеоморфологиялық жағдайына кері әсер ететін экзогенді процестердің (эрозия, тұздану, батпақтану) дамуын болдырмау үшін қорғау шаралары ұсынылды. Қолда бар суару каналдарының түбін тереңдету, бетін бетонмен, асфальтбетонмен, битуммен және т.б. жабу, суару және мелиоративтік жүйелерде жөндеу жұмыстарын жүргізу, дәстүрлі иригациялық жүйеден тамшылатып суару жүйесіне көшу – тұтастай алғанда аумақтың экологиялық жағдайын жақсарту жөніндегі маңызды шара.

Түйін сөздер: антропогендік фактор, экогеоморфологиялық жағдай, ГАЗ, жер жамылғысы, жер пайдалану.

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**СОВРЕМЕННОЕ СОСТОЯНИЕ И ДИНАМИКА АНТРОПОГЕННОГО ВОЗДЕЙСТВИЯ
НА ЭКОГЕОМОРФОЛОГИЧЕСКИЕ УСЛОВИЯ
(НА ПРИМЕРЕ ВОСТОЧНОЙ ЧАСТИ КУРИНСКОЙ ДЕПРЕССИИ)**

Аннотация. В статье подробно анализируются антропогенные факторы, влияющие на экогеоморфологические условия в восточной части Куринской депрессии (Кура-Аразская низменность и прилегающие территории). Был проведен анализ воздействия человека на геоморфологическую среду и современного состояния результатов человеческой деятельности в исследуемом районе. Среди антропогенных факторов (добыча нефти и газа, производство стройматериалов, пастбищное скотоводство, поселения и др.) описаны подробно те из них (строительство и эксплуатация ирригационных систем и искусственное орошение), которые имеют прямые и косвенные эффекты, более широкий диапазон и значительное влияние. При строительстве водохранилищ, каналов, коллекторно-дренажных систем было выведено из хозяйственного оборота тысячи гектаров земли, а во время их эксплуатации развивались такие вредные экзогенные процессы, как ирригационная эрозия, засоление и заболачивание. Окончание срока эксплуатации коллекторно-дренажных систем, построенных для предотвращения указанных процессов, а также утечка

засоленной воды в окружающую среду еще больше ухудшили экогеоморфологические условия. Природные (заиление, оползни, промывание и др.) и антропогенные (ошибки в проектировании существующих конструкций и сооружений каналов и дренажных коллекторов, выпас скота и др.) факторы также способствовали выходу из строя открытых ирригационных и коллекторно-дренажных систем.

На основе контролируемого и неконтролируемого дешифрирования многозональных снимков Ландсат (1976-2017 гг.), выполненных с применением ГИС-технологий была составлена карта землепользования и земельного покрова (LULC) исследуемой территории. Шесть типов земельного покрова: вода, растительность, обнаженные земли, засоленность, посевные площади и селитебные территории были выделены при геоморфологической интерпретации, на основе дешифрирования. Была вычислена площадь и выявлено уменьшение и увеличение каждого типа земного покрова. Динамика и трансформация земного покрова определялись при помощи функции обнаружения изменений. Например, было выявлено, что наиболее увеличенной земельным покровом в зоне трансформации с 1976 по 2017 год является посевная площадь. За счет антропогенного освоения исследуемой территории произошло наибольшее уменьшение площади обнаженных (33,85%) и засоленных (25,43%) земельных покровов в течение указанного периода.

В статье также были предложены защитные меры для предотвращения развития экзогенных процессов (эрозии, засоления, заболачивания), негативно влияющих на экогеоморфологические условия территории исследования. Углубление дна существующих оросительных каналов, покрытие поверхности бетоном, асфальтобетоном, битумом и т.д., проведение ремонтных работ в оросительных и мелиоративных системах, переход от традиционной ирригационной системы к капельной оросительной системе в целом являются важными мерами по улучшению экологического состояния территории.

Ключевые слова: антропогенный фактор, экогеоморфологическое состояние, ГИС, земельный покров, землепользование.

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**DEVELOPMENT OF AIR-PLASMA TECHNOLOGY
FOR HARDENING CUTTING TOOLS
BY APPLYING WEAR-RESISTANT COATINGS**

Abstract. This work describes an air-plasma installation and a method of hardening cutting tools by applying wear-resistant coatings. There are shown the results of commissioning of an air-plasma installation and the results of calculation and evaluation of the performance of the developed plasmatron. A plasmatron was made in order to reduce the heat load and improve the quality of the sprayed layer of the plasmatron operating life, as well as this plasmatron include a cooled anode, a swirl unit, an interelectrode insert, and a cathode. There was performed thermal analysis of the plasmatron design using the SolidWorks finite element method. The analysis results showed that the elements of water and gas communications of the plasmatron withstand pressure with a nominal value of 2.5-3 atm. at a power of 25 kW. The results of a study of the structure and properties of TiN and SiC coatings are shown. The results of tribological tests showed that TiN and SiC coatings can improve the tribological properties of P6M5 high-speed steel.

Key words: coating, air-plasma spraying, structure, titanium nitride, plasmatron, silicon carbide.

Introduction. One of the further development tasks of mechanical engineering is to increase the service life of metal-cutting tools (drills, taps, reamers, etc.) [1]. As it is known [2-6], modification by high-energy exposure is an effective means of increasing the service life and improving the physicomechanical and operational properties of the surface of cutting tools. Improving the operational properties of the cutting tool is largely determined by the hardening technology. Widely known ion-plasma hardening technologies by applying nitride, carbonitride coatings require the use of special expensive equipment and are economically feasible only for mass and large-scale production [7-10].

In practice, such restrictions do not occur when working surfaces hardening of the tool by the air-plasma method [11-13]. In addition, the use of air as an active plasma-forming medium greatly simplifies the installation for spraying and increases the safety of work and reduces the cost of coatings. However, the phase-structural transformations and the physical mechanisms of the formation of coatings are still insufficiently studied in spite of some successes achieved in the practical implementation of air-plasma processes. In addition, studies on the effect of air-plasma hardening on the structure and properties of high-speed steels have practically not been carried out [14-18]. Therefore, the method has not yet been implemented in tool production. In this regard, the task in this work was to develop a technology for hardening cutting tools by applying wear-resistant coatings on the working surface by the air-plasma method.

The authors of this work developed and manufactured an installation for air-plasma spraying of coatings, which consists of a plasmatron, an inert gas supply system for argon and air, an inverter type 500 A power source with an open circuit voltage of 60 V, and an autonomous cooling system for the plasmatron. Figure 1 shows a general view of an installation for air-plasma coating.

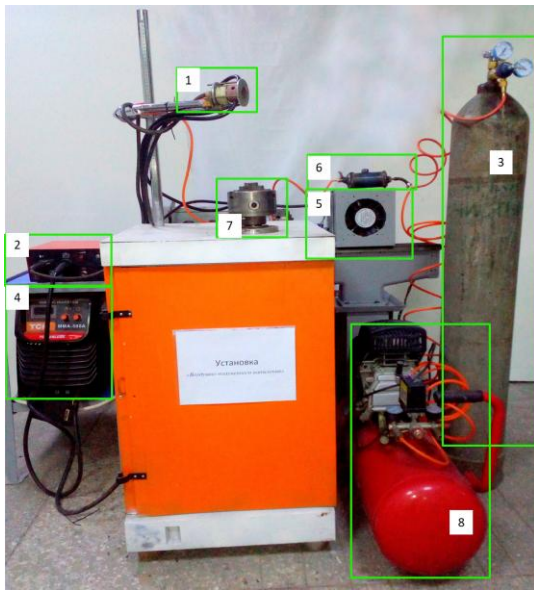


Figure 1 – Installation for air-plasma coating:
 1 - plasmatron, 2 - process control unit, 3 - gas supply cylinder,
 4 - power supply system, 5 - cooling system, 6 - bifurcated powder
 supply channel with expansion barrel, 7 - sample holder, 8 - compressor

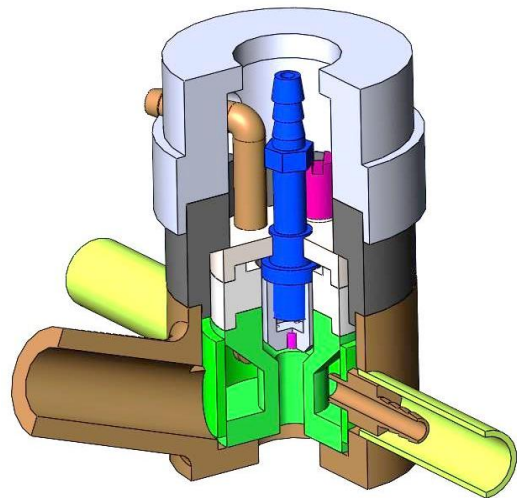


Figure 2 –
 3D model of a plasmatron

One of the problems in the field of air-plasma technology is the short life of the plasmatron. In this regard, we set the task of increasing the life of the plasmatron and carried out a number of works. We developed a plasmatron design on the bases of study of existing plasmatron models for APS, which consists of the following parts: anode, cathode, interelectrode ceramic insert, electricity, insulating ceramic nodes, powder, coolant, plasma forming gas, and carrier gas supply nodes. Argon and air are used as the working gas in the developed plasmatron design. The plasmatron body is cooled by water flow through a special cooling channel through the coolant supply fitting. Figure 2 presents a 3D model of the developed plasmatron. The developed plasmatron design differs from existing plasmatron for APS in that the outlet openings in the nozzle are made in the form of rectangular tapering-expanding channels. This gives an additional acceleration of the plasma flow at the exit of the nozzle.

A thermal analysis of this circuit was performed using the SolidWorks finite element method in order to evaluate the performance of the plasmatron [19]. Figure 3 presents the color differentiation a) the temperature of the solid; b) temperature of the fluid; c) flow rate. The analysis results showed that the elements of water and gas communications of the plasmatron withstand pressure with a nominal value of 2.5-3 atm. at a power of 25 kW. Thus, the developed design of the plasmatron fully satisfies the condition of air-plasma spraying.

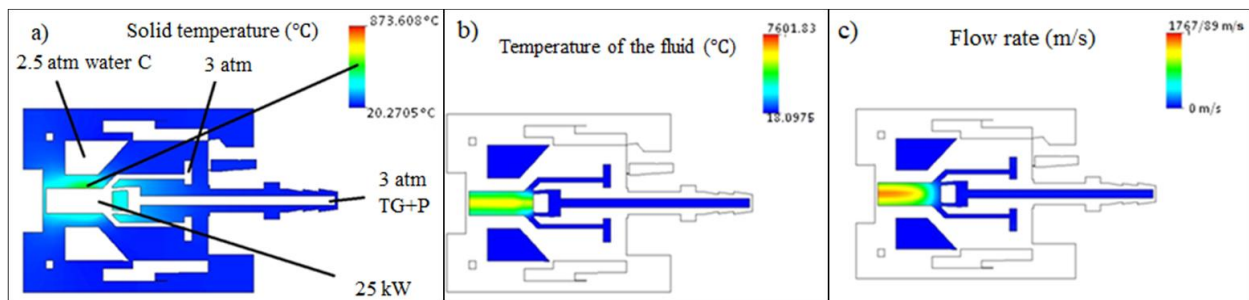


Figure 3 – Results of thermal analysis (TG - transporting gas, C - coolant, P - powder):
 a) solid temperature; b) temperature of the fluid; c) flow rate

We have made a prototype plasmatron on the bases of the developed plasmatron designs. Full-scale tests of the plasmatron were carried out at various capacities. The results showed that the 12X18H10T stainless steel anode material begins to break down at high powers (20 kW) and molten areas are observed on the surface, as well as areas sprayed with molten powders that were used for spraying. In addition, the fluoroplastic plasmatron case also became brittle after 3 hours of plasmatron operation. In this connection, we modernized the plasmatron, in particular, we developed a system for introducing powder into the plasma (swirl unit), which rotates the anode spot and prevents local burning of the anode, as well as replaced the anode material and the case material with copper (copper of M0 grade), which has high heat and electrical conductivity compared to steel. The construction design of the swirl assembly is developed on the basis of finite element modeling.

These changes allow to prevent the local burning of the anode, poor passability of the powder through the spray channels and heating of the plasmatron body, which increased the durability of the plasmatron nodes and resources of plasmatron work. Also, full-scale experiments of the plasmatron showed that the introduced changes made it possible to stably apply coatings without destroying the plasmatron nodes. Figure 4 shows a general view of the plasmatron before and after modernization.

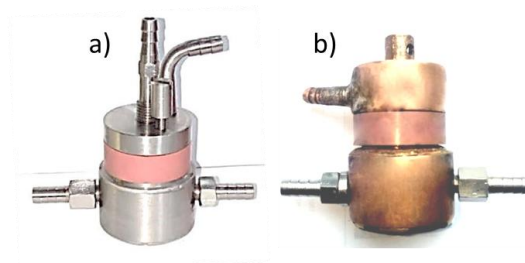


Figure 4 – General view of the plasmatron before (a) and after modernization (b)

The installation was equipped with a non-contact "arc excitation" system based on the high-frequency current oscillator OSSD 500 in order to ensure more stable arc excitation. Figure 5 shows a non-contact "arc excitation" system and a matching circuit between the power source and the oscillator. As a result, it became possible to automatically start the plasmatron with a gap between the anode and electrode of up to 5 mm.

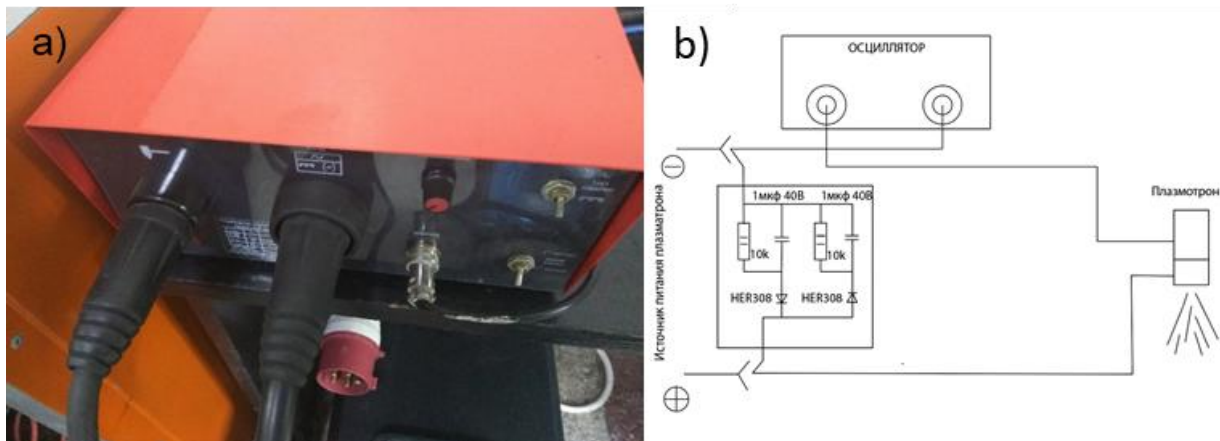


Figure 5 – The system of non-contact "arc excitation" (a) and the matching scheme of the power source and oscillator (b)

The developed technology and installation for air-plasma spraying can be carried out in the conditions of a small thermal section of single and small-scale production, pilot and repair enterprises with minimal costs for equipment, auxiliary materials and electricity, with ease of implementation and maximum processing efficiency. An experiment on the production of carbide and nitride coatings on the surface of high-speed steels was carried out on the developed air-plasma spraying (APS) installation, as well as laboratory experiments of the coatings were carried out.

Material and methods of research. P6M5 high-speed steel was chosen as the research material. The experiments on obtaining coatings based on SiC and TiN were carried out in the following mode: moving speed 2-30 mm/s, the distance between the plasmatron and the product 45-55 mm, the diameter of the spray spot 10-25 mm. The temperature of the parts during spraying does not exceed 150-200 °C. Preliminary sandblasting with dry corundum was carried out to improve adhesion (at an air pressure of 0.3-0.6 MPa, the distance from the nozzle exit of the jet-abrasive gun to the work surface is 80-100 mm).

The method of studying friction wear resistance by using a device that allows measuring the sliding friction force in alternating motion was applied in order to evaluate the tribological characteristics of carbide and nitride coatings obtained by the APS method [20]. A SiC ball with a diameter of 4 mm and a hardness of $H_V = 2800$ mm was tightly pressed (with F_n gain) to the surface of the sample. The system consists of two supporting bodies moving in the same direction. The system that moves the plate consists of two load-bearing bodies moving in the same direction, which allows the friction force to be divided. The drive was an electric drive consisting of a stepper motor and a helical gear. The power of movement was transmitted from a larger trolley to a smaller one using a strain gauge. The system allowed the installation of a fixed displacement of the steel plate relative to the ball with a certain speed V_s and displacement S , the force causing the FT motion was recorded with a frequency of 10 Hz. The path length was 12 m, speed 2 cm/s, load 5 N.

The experiments results of obtained coatings. Using these powders, coatings were obtained on the surface of P6M5 high-speed steel under various conditions. Coating modes are shown in table.

Modes of air-plasma coating from TiN and SiC

Powder	TiN			SiC		
№	1	2	3	4	5	6
Arc current, A	135	160	175	135	150	250
Coating Thickness, μm	28	23	14	21	89	20

There were carried out metallographic research of transverse sections of coated samples. Figure 6 presents a fragment of the microstructure of the transverse section of SiC and TiN coatings during air-plasma spraying.

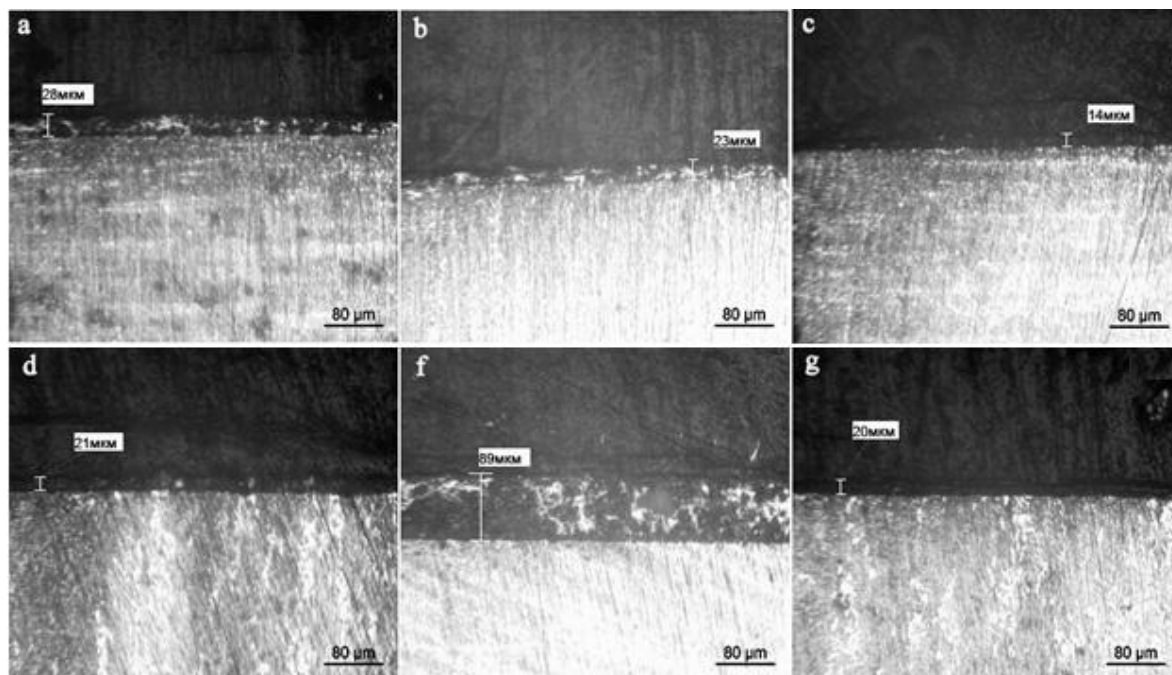


Figure 6 – Image of the cross section of the sample coatings with TiN and SiC powders:
a) TiN at 135 A, b) TiN at 150 A, c) TiN at 175 A, d) SiC at 135 A, f) SiC at 150 A, g) SiC at 175 A

Figure 7 shows the friction coefficient of the sample at a normal force of 5 N and a mutual displacement velocity of 0.94 cm/s, the value of the friction coefficient is in the range from 0.2 to 0.8 μ . TiN coatings are characterized by a more stable running-in period: a friction coefficient of $\sim 0.2 \mu$. The running-in period of 7 m is already 0.8 μ for the P6M5 high-speed grease substrate. The friction coefficient was 0.2 μ , and the substrates - 0.3 μ for SiC coatings.

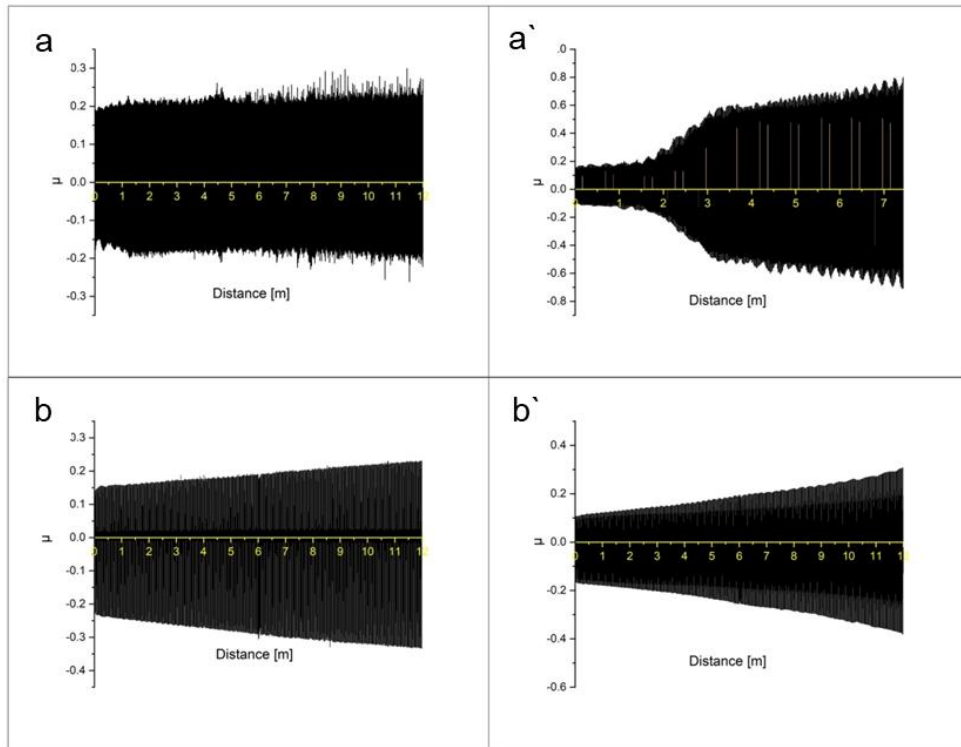


Figure 7 – The friction coefficient of the sample:
a) TiN (135 A), a') substrate, b) SiC (250 A), b') substrate

Figures 8, 9 present the diffraction patterns of the substrate, the initial powder, and the resulting TiN and SiC coatings. The phase composition of coatings on the surface of P6M5 steel corresponds to the composition of the initial powders. In this case, substrate reflections appear on the diffractograms of the coated samples. Thus, X-ray phase analysis showed that after deposition new phases are not formed both on the coating and in the substrate, which confirms the low temperature of the substrate heating during the deposition process. This, in turn, confirms the absence of softening of the substrate.

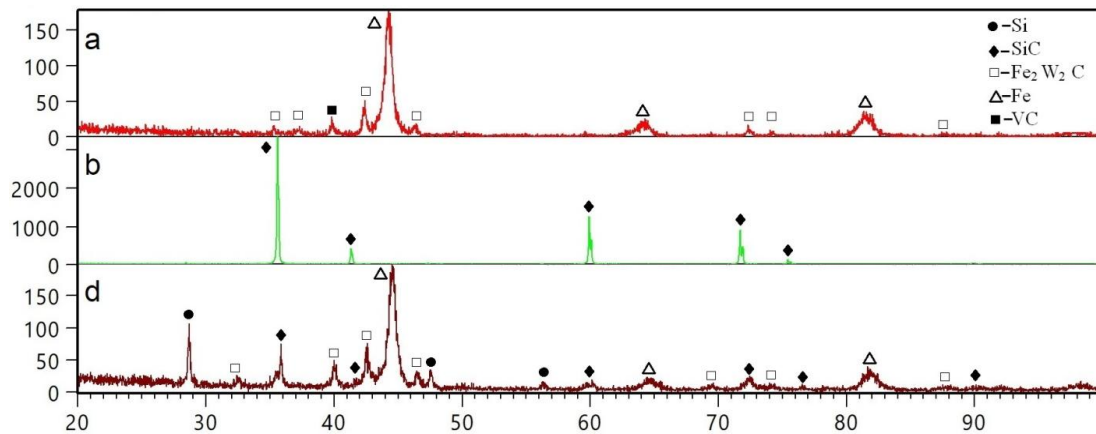


Figure 8 – Diffraction pattern of samples: a) P6M5, b) SiC powder, d) SiC coatings

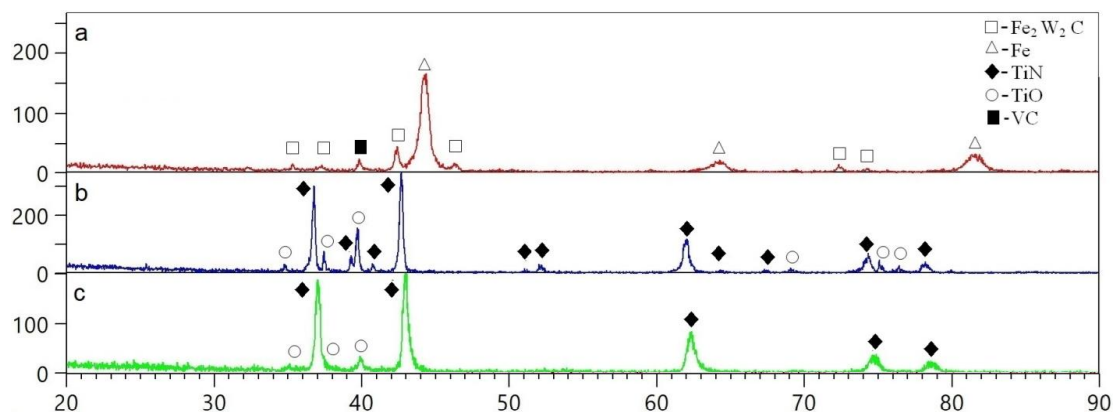


Figure 9 – Diffraction pattern of samples: a) P6M5, b) TiN powder, c) TiN coatings

Conclusion. Analyzing the results, we can draw the following conclusions:

- An installation has been developed for air-plasma spraying, which consists of: a plasmatron, an inert gas supply system for argon and air, an inverter type 500 A power source with an open circuit voltage of 40 V, and an autonomous cooling system for the plasmatron.

- A plasmatron has been developed, which consists of a cooled anode, a swirl unit, an interelectrode insert, and a cathode. The advantage of the developed plasmatron is that the outlet openings in the nozzle are made in the form of rectangular tapering-expanding channels, as well as the anode is made completely welded and its surface has a radiator profile that will allow disassembling and assembling the plasmatron during repair work without compromising its quality.

- It has been determined that TiN and SiC coatings can improve the tribological properties of high-speed steel, in particular, the friction coefficient decreases by a factor of 2–3, and the wear resistance increases by a factor of 1.5 times.

Thus, the conducted research have shown the promise and feasibility of using the developed technology for increasing the wear resistance of cutting tools.

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ТОЗУҒА ТӨЗІМДІ ЖАБЫНДАРДЫ ЖАҒУ ЖОЛЫМЕН КЕСКІШ ҚҰРАЛДАРДЫ БЕРІКТЕНДІРУДІҢ АУА-ПЛАЗМАЛЫҚ ТЕХНОЛОГИЯСЫН ӘЗІРЛЕУ

Аннотация. Машина жасауды одан әрі дамыту міндеттерінің бірі – металл кескіш құралдардың (бұрғы, метчик, қашау және т.б.) қызмет ету мерзімін арттыру. Жоғары қуатты модификация – бұл қызмет мерзімін ұлғайтудың және кесу құралдарының бетінің физикалық, механикалық және пайдалану қасиеттерін жақсартудың тиімді құралы. Кескіш құралдың жұмыс істеу қасиеттерін арттыру көбінесе өңдеу технологиясымен анықталады

Осыған байланысты бұл жұмыста тозуға төзімді жабындарды жағу жолымен кескіш құралдарды беріктендірудің ауа-плазмалық технологиясын әзірлеу міндеті қойылды. Осы мақсатта ауа-плазмалық тозаңдату қондырғысы (АПТ) жасап шығарылды. Қондырғының негізгі сипаттары плазмотрон, аргон мен ауаны инертті газбен қамтамасыз ету жүйесінен, кернеуі 60 В ашық инвертор түріндегі 500 В қуат көзінен, автономды плазмотронды салқындату жүйесінен тұрады. Плазмотронның әзірленген конструкциясында жұмыс

газы ретінде аргон мен ауа пайдаланылады. Плазмотронның жұмысқа қабілеттілігін бағалау мақсатында SolidWorks бағдарламалық ортасында осы схемаға термиялық талдау жүргізілді.

Доғаның тұрақты қозуын қамтамасыз ету үшін қондырғы ОССД 500 жоғары жиілікті ток осцилляторының негізінде байланыссыз «доғалық қозу» жүйесімен жабдықталған. Әзірленген ауа плазмалық тозаңдату қондырғысында карбидті және нитритті жабындарды алу бойынша эксперимент жүргізіліп, зерттеулер жасалды. Төсеніш зерттеу материалы ретінде Р6М5 жылдам кесетін болат таңдалды. SiC және TiN негізінде жабындарды алу бойынша эксперименттер мынадай режимде жүргізілді: ауыстыру үлгісінің қозғалу жылдамдығы – 2-30 мм/с, плазмотрон мен үлгі арасындағы қашықтық – 45-55 мм, тозаңдату дақтарының диаметрі – 10-25 мм. Тоzaңдату кезінде бөлшектерді қыздыру температурасы 150-200 °С-тан аспайды. Адгезияны жақсарту үшін құрғақ корундпен алдын ала құм бүріккіш арқылы өңдеу жүргізілді (ауа қысымы – 0,3-0,6 МПа, ағысты-абразивті соплдан бетке дейінгі қашықтық 80-100 мм құрайды).

АПТ әдісімен алынған карбид және нитридті жабындардың трибологиялық сипаттамаларын бағалау мақсатында ауыспалы қозғалыстағы үйкеліс күшін өлшеуге мүмкіндік беретін құрылғының көмегімен үйкеліс кезінде тозуға төзімділікті зерттеу әдісі қолданылды. Жүріс ұзындығы – 12 м, жылдамдығы – 2 см/с, жүктеме – 5 Н.

Жабыны бар үлгілердің көлденең қималарына металлографиялық зерттеу жүргізілді. Мақалада 5 Н қалыпты жүктемедегі үлгінің үйкеліс коэффициенті және 0,94 см/с өзара жылжу жылдамдығы көрсетілген, үйкеліс коэффициентінің мәні 0,2-ден 0,8 м дейінгі аралықта болады. TiN жабындарына тұрақты жұмыс істеу кезіндегі үйкеліс коэффициенті ~ 0,2 м. Ал тез кесетін болат Р6М5 үшін үйкеліс коэффициенті 0,8 м құрайды. SiC жабындары үшін үйкеліс коэффициенті 0,2 м құрайды.

Р6М5 Болат бетіндегі жабындардың фазалық құрамы бастапқы ұнтақтардың құрамына сәйкес келеді. Бұл ретте дифрактограммаларда жабыны бар үлгілерде төсеніш фазаларының рефлекстері пайда болады. Осылайша, рентгенофазалық талдау тозаңданудан кейін жабында жаңа фазалар түзілмейтінін көрсетті, бұл тозаңдату процесінде төсеудің төмен температурасын растайды. Бұл, өз кезегінде, төсеніштің термиялық өңдеуге ұшырамағанын растайды.

Түйін сөздер: жабын, ауа-плазмалық тозаңдану, құрылым, титан нитридi, плазмотрон, кремний карбидi.

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РАЗРАБОТКА ВОЗДУШНО-ПЛАЗМЕННОЙ ТЕХНОЛОГИИ УПРОЧНЕНИЯ РЕЖУЩИХ ИНСТРУМЕНТОВ ПУТЕМ НАНЕСЕНИЯ ИЗНОСОСТОЙКИХ ПОКРЫТИЙ

Аннотация. Одной из задач дальнейшего развития машиностроения является повышение срока службы металлорежущих инструментов (сверла, метчики, развёртки и др.). Как известно, модифицирование высокоэнергетическим воздействием является эффективным средством повышения срока службы и улучшения физико-механических и эксплуатационных свойств поверхности режущих инструментов.

Повышение эксплуатационных свойств режущего инструмента в значительной мере определяется технологией упрочнения. В связи с этим, в данной работе была поставлена задача разработки технологии упрочнения режущих инструментов путем нанесения износостойких покрытий на рабочей поверхности воздушно-плазменным методом. Авторами данной была разработана и изготовлена установка для воздушно-плазменного напыления (ВПН) покрытий, которая состоит из плазмотрона, системы подачи инертных газов аргона и воздуха, источника питания инверторного типа 500 А с напряжением холостого хода 60 В, системы автономного охлаждения плазмотрона. На основе изучения существующих моделей плазмотрона для ВПН нами была разработана конструкция плазмотрон, который состоит из следующих частей: анод, катод, межэлектродная керамическая вставка, изолирующие керамические узлы, узлы подачи порошка, охлаж-

дающей жидкости, плазмообразующего газа и транспортирующего газа. В разработанной конструкции плазматроне в качестве рабочего газа используется аргон и воздух, охлаждение корпуса плазматрона осуществляется водным потоком через специальный охлаждающий канал через штуцера подачи охлаждающей жидкости.

С целью оценки работоспособности плазматрона был произведён термический анализ данной схемы методом конечных элементов SolidWorks. С целью обеспечения более устойчивого возбуждения дуги установка была оснащена системой бесконтактного «возбуждения дуги» на основе осциллятора токов высокой частоты ОССД 500. На разработанной установке воздушно-плазменного напыления был поведён эксперимент по получению карбидных и нитридных покрытий на поверхности быстрорежущих сталей и проведены лабораторные испытания полученных покрытий.

В качестве материала исследования была выбрана быстрорежущая сталь Р6М5. Эксперименты по получению покрытий на основе SiC и TiN проводились в следующем режиме: скорость перемещения 2-30 мм/с, расстояние между плазматроном и изделием 45-55 мм, диаметр пятна напыления 10-25 мм. Температура нагрева деталей при напылении не превышает 150-200С°. Для улучшения адгезии была проведена предварительная пескоструйная обработка сухим корундом (при давлении воздуха 0,3-0,6 МПа, расстояние от среза сопла струйно-абразивного пистолета до обрабатываемой поверхности составляет 80-100 мм). С целью оценки трибологических характеристик карбидных и нитридных покрытий, полученных методом ВПН, был применен метод исследования износостойкости при трении с помощью устройства, позволяющего измерять силу трения скольжения в переменном движении. Длина пробега составляла 12 м, скорость 2 см/с, нагрузка 5 Н.

Было проведено металлографическое исследование поперечных шлифов образцов с покрытиями. В статье показан коэффициент трения образца при нормальной силе 5 Н и скорости взаимного перемещения 0,94 см/с, значение коэффициента трения находится в пределах от 0,2 до 0,8 μ . Для покрытий TiN характерен более стабильный период приработки: коэффициент трения \sim 0,2 μ . А для подложки из быстрорежущей стали Р6М5 период приработки 7 м составляет уже 0,8 μ . Для покрытий SiC коэффициент трения составил 0,2 μ , а подложки – соответственно 0,3 μ . Фазовый состав покрытий на поверхности стали Р6М5 соответствует составу исходных порошков. При этом на дифрактограммах образцов с покрытием появляется рефлекс подложки. Таким образом, рентгенофазовый анализ показал, что после напыления не образуются новые фазы как на покрытии и так в подложке, что подтверждает низкую температуру нагрева подложки в процессе напыления. Это, в свою очередь, подтверждает отсутствие разупрочнения подложки.

Ключевые слова: покрытие, воздушно-плазменное напыления, структура, нитрид титана, плазматрон, карбид кремния.

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**MOTOR WITH EXTERNAL HEAT SUPPLY BASED
ON THERMO-ACOUSTIC EFFECT FOR
AN AUTONOMOUS THERMAL POWER PLANT**

Abstract. The problem of efficient power supply has not been fully resolved yet. One way to solve this problem is to develop a micro thermal power plant that can operate on almost any fuel. Using your own energy source will reduce the cost of its production. Significantly increase the reliability indicators of power supply and ensure its uninterrupted supply to the consumer. Our proposed power plant is driven by a heat engine with an external supply of heat. The goal is to create an alternative cogeneration energy source for remote rural consumers, capable of operating on almost any type of fuel or waste that has been burned. This will allow the villager to produce locally without paying for transport losses of electricity, to produce electric and thermal energy in the complex. In our work, we take into account the positive results, experience and achievements of foreign ones, to create our own design.

The solution to the problem of efficient power supply to rural consumers can be the introduction of micro thermal power plants. The basis of a micro thermal power plant is an engine with an external supply of heat operating on the Stirling principle. The analysis of the level of modern achievements in the field of microelectric power plants. The direction of development of scientific research on the development of an engine with an external heat supply is established. The task is to ensure that it is able to function on local low-calorie fuel. It is necessary to completely exclude the use of diesel fuel, coal, fuel oil and other imported fuel, which does not allow to achieve low cost of energy produced.

There are a number of advantages of the design features of microthermal power plants. Firstly, it is his so-called omnivorousness, any source of thermal energy from wood to nuclear fuel. Laboratory models worked from the heat of heated water, the flame of a candle and a gas burner, and we also tested household wastes exposed to burning various organic fuel mixtures from dried plant residues mixed with animal waste. Secondly, it is possible to make a simpler design of the heat engine, since it does not have a valve system and gas distribution with a shaft, a high-voltage ignition system. If the engine is accurately and correctly manufactured, then it will not require adjustment and adjustment during the entire operation. Thirdly, the simplicity of the design will increase its service life with the right choice of seals and heat exchanger material will allow it to go through without repair for about 20 thousand hours, which will ensure its autonomy. Fourth, a few times fewer number of parts will provide a large motor resource and minimum oil consumption, making its operation inexpensive.

The advantages of using cogeneration micro thermal power plants in rural areas with external combustion engines using local fuel in the regions of the Republic of Kazakhstan can be identified:

- independence from the price of hydrocarbon fuel, as well as the rejection of the costs of its storage and transportation.

- multi-fuel and the use of available fuel for a given area, as well as the prospect of creating enterprises for its processing.

- refusal to lay electric lines and the costs associated with their maintenance.

- the cost of 1 kW / h of generated electricity using a cogeneration plant will be from 3 to 5 tenge, which is 2-3 times cheaper than existing tariffs.

- when burning fuel, the CO content in the exhaust gases is 3 times lower than that of ICE and the content of NO and CH is much lower, which corresponds to the most stringent world environmental standards.

- payback period of cogeneration plants of 2 - 3 years.

The article shows the dependence of the developed mechanical power on the number of revolutions of the crankshaft at various pressure values, as well as the dependence of torque on the pressure in the cylinders at various values of the crankshaft rotation speed. A conclusion is drawn based on the presented graphs.

Key words: Thermal power station, Stirling engine, cogeneration, electric energy, thermal energy, integrated production, power supply, heat supply, alternative energy, heat engine.

Our goal is to create an alternative cogeneration energy source for remote consumers in rural areas, able to work on virtually any kind of fuel or waste that has been burned. This will allow the villager to produce on site without paying transport losses of electricity, to produce electrical and thermal energy in the complex. The high cost of energy leads to significant costs in the production of agricultural products and makes it expensive, that is, it decreases its competitiveness. In all regions of Kazakhstan, an annual increase in tariffs is observed, not only for electricity, but also for heat. About 300 small rural settlements do not have a centralized energy supply at all. To build a system of its own autonomous power supply, modern industry can offer, besides gasoline and diesel electric power stations, the cogeneration sources of which are based on the Stirling cycle engine with external heat supply. There are foreign developments of micro thermal power plants (MTES) using engines with external heat supply, with economic indicators and technical characteristics superior to internal combustion engines (ICE) and gas-turbine installations (PG). A preliminary scientific analysis showed that in the last century, many modifications were developed with external heat supply engines operating according to the Stirling cycle with the participation of foreign firms Philips, STM Inc., Daimier Benz, Solo, United Stirling, and serial samples operated in transport, household and agriculture, but these MTES are not adapted to the fuel available in rural regions of Kazakhstan [1-3]. The engine with external heat supply DVPT was improved and patented by Pastor Stirling in 1817. There are examples of certain successes, the Philips company producing compact electric generators used DVPT, this type of engine was also used together with a solar concentrator, its efficiency was about 40%, which is not yet achievable for modern solar modules [4-5]. It is also necessary to take into account the experience of modern manufacturers: Ecopower, WhisperGen, Microgen, Lion-Powerblock, Honda, EcoGen using similar technologies. The samples developed by them allow the complex production of electric and thermal energy for an autonomous energy supply system, while 5 kW of thermal energy is produced for 1 kW of electric energy for a heating system [6]. Modern foreign samples have high efficiency and cost per 1 kW of power, while working mainly on natural gas. For example, WhisperGen with a power of 1 kW costs about 6 million tenge. We completely reject the copying of sample data and set ourselves the task of developing an engine of a high-temperature combustion engine of our own design and is able to work effectively on almost any kind of fuel available in rural areas or waste burned, and also to be easy to operate. The second point is to solve the problem of its further production at the lowest possible price using materials and technologies that have Kazakhstan content. The maximum exclusion of imported components and the designed DVPT greatly complicates the task at the initial stage, but future scientific and experimental design should serve as the basis for the successful implementation of the project and the relevance of our development. To do this, we will make a number of changes to the typical known structures of the high-temperature structural element, including the mechanical and electrical parts. It is necessary to work out its design of the heater, regenerator, cooler and seals, to achieve the highest possible efficiency. The cooling system will be a liquid cooler with a blown radiator [7-8].

As it was said earlier, the basis of our development is DVPT working according to the Stirling cycle, but on a completely different principle in contrast to classical structures and this difference is the use of the thermoacoustic effect [9]. This is a well-known method of exciting sound with the help of heat, described in 1877 by Relem in the book *Theory of Sound*. In the mid-20th century, scientists worked to study thermo-acoustic oscillations in combustion chambers of installations with large temperature differences, and in the 70s of the last century N. Rott discovered that a sound field can create a unidirectional heat flow. Using the above theoretical and practical achievements, we have developed various laboratory samples, on which we perform the testing of our future thermo-acoustic DVPT, for a cogeneration thermal power plant of super low power. The advantage of thermo-acoustic DVPT in relation to the classic variants of the Stirling engine "Alpha", "Beta" and "Gamma", as well as freely piston, is a higher efficiency and a resource of more than 100 000 hours [10-11].

An analysis of world experience showed that in various years of the past and the present century, scientists worked on the creation and improvement of a thermo-acoustic engine (TAE) with an external supply of heat. For example, PH Ceperley for the first time described the effect of a traveling sound wave, T Yazaki demonstrated his sample TAE, S Backhaus and GW Swift developed a thermoacoustic engine with a reversed Stirling cycle in the regenerator [12]. A more complex TAE design than Yazaki allowed to achieve higher thermal efficiency - 30%, which corresponds to 41% Carnot efficiency. Recently, for the same engine type, Tijani and Spoelstra set a new record at 49% Carnot efficiency. Using the accumulated world experience in this field of science, we conducted a number of studies to develop our own design of a thermo-acoustic engine with an external supply of heat. For this calculation, the DeltaEC computer program (Design Environment for Low-amplitude Thermo-Acoustic Energy Conversation - developed by Los Alamos National Laboratory, USA, free license) was used [13-15].

The scientific novelty of our work is to obtain new dependences of the parameters of the thermo-acoustic engine with structural differences from their analogues. The difference is the presence of an additional regenerator from the side of the hot heat exchanger, this allows you to increase the efficiency from 4 to 6%. A steam-air mixture is used as a working fluid, this allows to increase engine power without increasing its mass by 12-15%, which is the scientific and practical novelty of this work. From a practical point of view, foreign authors consider a thermo-acoustic engine only as an electric generator or cryogenic installation, but do not consider it as a cogeneration source capable of complex production of electric and thermal energy with a total efficiency of up to 80% of energy. The simplicity of the design ensures reliable operation and low cost of production, therefore, it is possible to use these sources for power supply of low-power remote autonomous consumers of thermal and electric energy [16-18].

Thermo-acoustic motor with a traveling wave, converts thermal energy into acoustic energy, due to the completion of the thermodynamic cycle closest to the Stirling cycle. Acoustic energy obtained by heating its heat exchanger is converted into electrical energy, which is produced using a linear permanent magnet alternator or a bi-directional turbine by a synchronous generator. Thermal energy is removed from the cooling circuit and can be directed to the heating system of an autonomous object. Structurally, a DVPT is obtained with a minimum number of moving parts and an electrical efficiency of 30–50% of the Carnot cycle efficiency, while it lacks a piston and a displacer, without which the Alpha, Beta and Gamma DVTT cannot work [19]. Accordingly, a number of difficult problems with seals and piston friction simply do not exist, there are simply no friction parts in the engine. After analyzing the materials of the study and the design of engines with an external heat supply, we developed a laboratory sample, which is shown in figure 1.

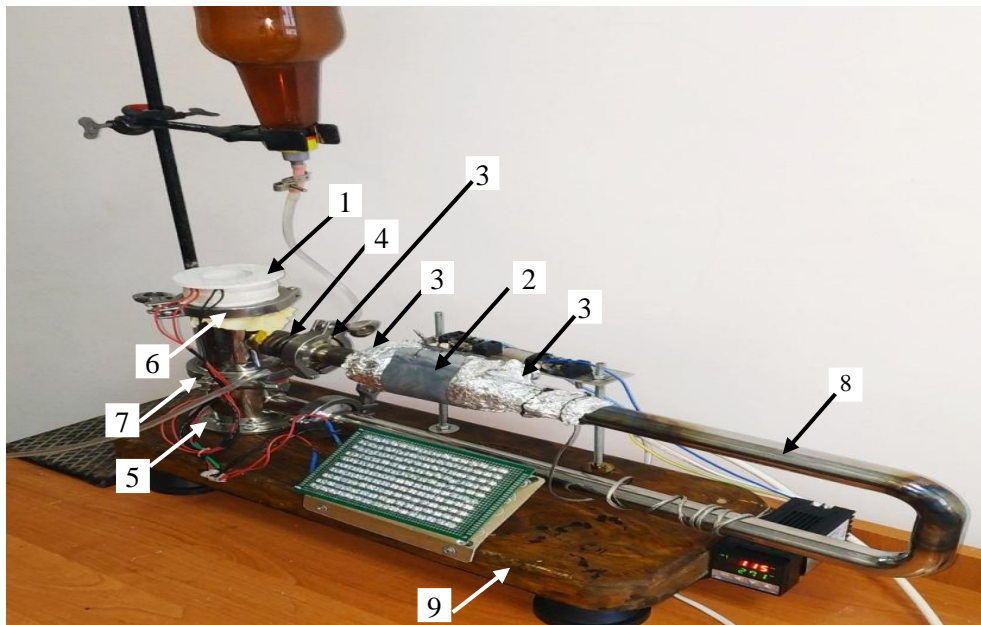


Figure 1 – The current model of thermo-acoustic engine with an external heat supply

As stated earlier, one of the advantages of this type of DVPT is the absence of pistons and propellant with seals, a massive flywheel and other rotating parts. Its metal consumption is orders of magnitude smaller than that of the Alpha, Beta and Gamma DVPTs, this allows competing in weight / size / power parameters to any even a turbocharged diesel engine. At the same time, the simplicity of the design makes it possible to make available materials and, in contrast to a free piston DVPT, high-precision fitting of parts and adjustment of elastic elements are not required. As the main parts, it is possible to single out a linear generator 1 that has a coil wound on a frame with a copper enameled double wire with a diameter of 0.4 mm and three 5 x 30 mm podomovy magnets. The coil is wound by hand in bulk, without strictly observing the sequence of a series of approximately 2500 turns. The material is stainless steel AISI310, which is not the best thermal conductivity of the heat exchanger wall. Heating is carried out using an open flame of a gas burner or a dry fuel in the heating zone 2. The wire regenerator is located in area 3, made of steel wire with a diameter of 1 mm, its length is about 7 cm. Cooling the working fluid (air) is carried out in area 4.

A cotton cloth moistened with water is used as a cooler. The design of the ring resonator is attached to a wooden board 9, 5 cm thick, with the help of 4 screws and a flange 5. Without rigid attachment of the flange to the baseboard 9, normal operation of the resonator 8 is not possible. The resonator is made of a steel tube 25 mm in diameter 10 to the outlet is 450 mm. In the experiments, we used resonators 250 and 350 mm long, but the best performance was shown by a 450 mm long resonator. The resonator is welded to two tubes with a diameter of 63 mm. The main working element is two membranes 6, made of gley balloons or you can use medical gloves. As a load, 160 LEDs with a power of 0.06 W are used. Linear generator consisting and two parallel coils produces a total electric power of alternating current of about 10 W, with this voltage reaches 12 volts, frequency up to 58 Hz, depending on the heating intensity of the working fluid in the heat exchanger in region 2. The engine has the ability to self-start (self-start) , unlike the classic Stirling engines.

The principle of action of our engine is based on the effect of acoustic waves that are generated when the regenerator is heated and transmitted through a resonator with two membranes that create a resonance. Three permanent magnets are fixed on the upper membrane, which vibrate with the frequency of the acoustic wave. The magnetic field intersects the winding of the inductor and alternating current is generated [20]. The second membrane 7 is necessary to prevent circular circulation of the working fluid (air) in the resonator 8. The important point is good sealing by the joint where the membranes and the resonator are installed, for this we use a clamp 10 with a screw clamp and seals. Most of the resonator does not heat up and remains cold (ambient temperature of the room), so it can also be performed with ABC plastic or polypropylene, which can significantly simplify the design and reduce the cost.

Main working areas resonators: cooling zone; heating zone; regenerator zone. The working fluid performs an alternate movement from the heater to the cooler and back passing through the regenerator, giving partial heat to the air flow (working fluid) and then taking it as it moves to the cooling zone. The plate heat exchanger must be installed in the region of 1–16 the length of the resonator tube from its beginning of the membrane 6, while the end of the resonator is awakened by the membrane 7.

Using the well-known effect, Rayleigh, which leads to the excitation of sound vibrations described as far back as 1877 when the wire regenerator is heated, and also opened in 1859 by P. L. Rijke, professor of physics at the University of Leiden in the Netherlands. Subsequently, this design was called the Rijke tube, we made a resonator operating on these effects. Figure 3 shows the movement of the working fluid inside the resonator. The working medium, the air circulates in a confined space, going through a heating and cooling cycle. Circulating air drives the membrane. There is a permanent magnet on the upper membrane, under the weight of which it bends and to be in the lower position when the resonator is inoperative. With heating and expansion of the working fluid, the membrane rises to the top. After cooling air in the cooling zone, the working fluid is compressed, and the membrane is drawn into the cavity tube. This DVPT works according to the Stirling principle.

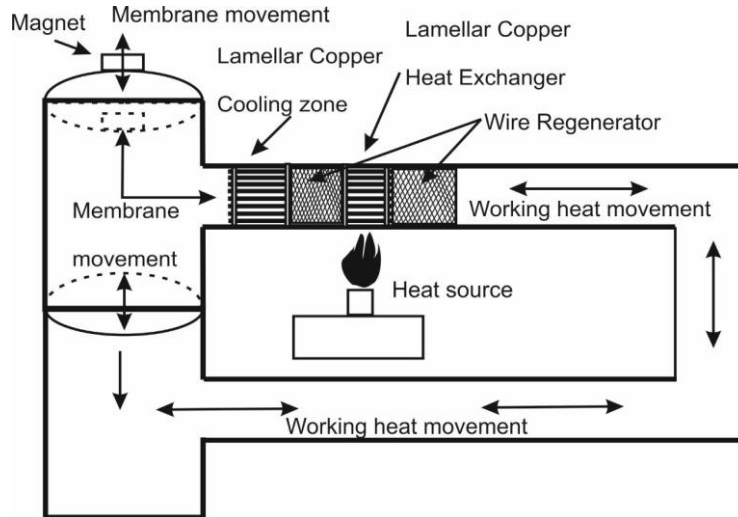


Figure 3 – The movement of the working fluid inside the resonator

Figure 4 shows a graph of pressure and speed of the traveling acoustic wave as a function of time. When heated inside the resonator, noise with a wide frequency spectrum is generated. The resonator amplifies exactly that sound frequency of sound vibrations, the wavelength of which is equal to the length of the tube and the engine starts to work. Minor initial sound vibrations are amplified to the maximum possible value. The maximum sound volume inside the engine occurs when the sound amplification power using heat exchangers is equal to the power loss, i.e. the sound attenuation power. The maximum value reaches a value of about 160 dB. This is more than the sound of a jet taking off, such sound pressure can cause injury to the human ear, but the sound is not able to go beyond the resonator, which is airtight. The warmed DVPT is practically not heard. Sound amplification occurs in the regenerator.

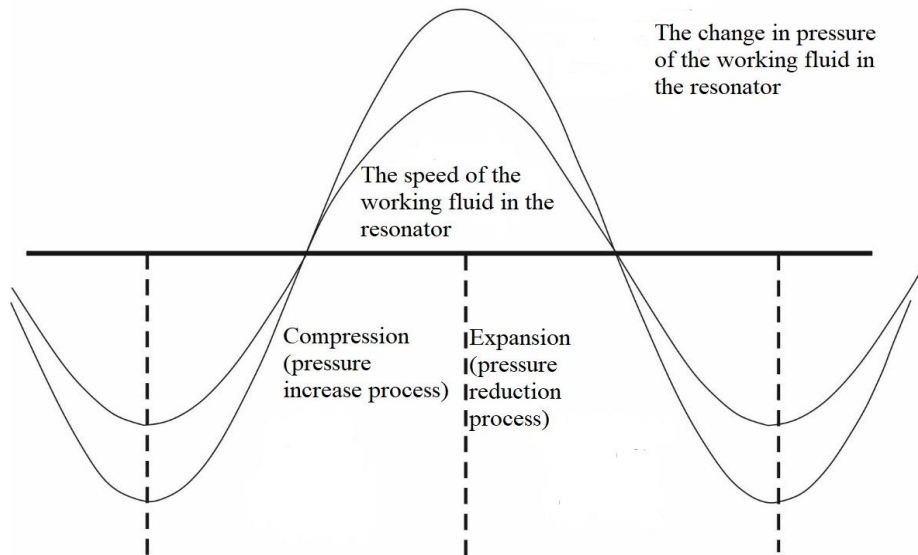


Figure 4 – Graph of changes in pressure and speed of a traveling acoustic wave as a function of time

Figure 5 shows some of the results of our experiments, the results were processed using a third-degree polynomial approximation with a certain regressive value of the reliability of the experimental results. Graph 1 was built in the experiment with the heating temperature of the working fluid up to 430°C, allowed to reach a sound pressure of 187 dB, graph 2 was built in the experiment with the heating temperature of the working fluid to 390°C, allowed to reach the sound pressure of 173 dB. Increasing the pressure and temperature allows you to increase the power of the thermo-acoustic engine with an external heat supply, also reduces the time of self-starting and the beginning of its work.

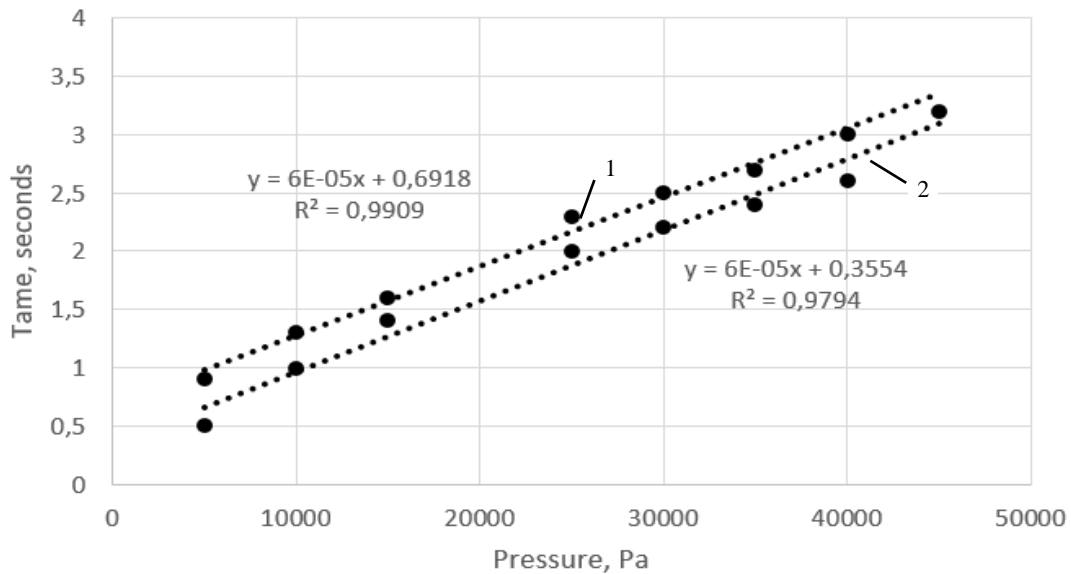


Figure 5 – Graph of growth of pressure and sound pressure at a temperature of the working fluid, 187 dB 430°C Graph 1 and 173 dB at 390°C Graph 2.

The conclusion is, the engine without moving parts and theoretically capable of achieving the efficiency of the Stirling cycle, and hence Carnot. In reality, the best performance is 40-50% of the efficiency of the Carnot cycle. The use of an engine with an external heat supply based on a thermoacoustic effect will make it possible to develop an autonomous thermal power plant of cogeneration type with high efficiency indicators (Efficiency) and environmental friendliness compared to ICE. MTES is capable of comprehensively generating electrical energy using a linear generator and thermal energy through a cooling circuit approximately in the ratio of 1 to 5. The constructive simplicity of the engine, and the absence of rubbing and rotating parts will ensure a high resource of more than 100 000 hours of continuous work, and can also compete in relation to the weight / size / power parameters for any turbocharged diesel engine. The only problem is the resource of the membranes, which in the process of testing were often out of order.

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ШАЛҒАЙДА ОРНАЛАСҚАН АУЫЛДАҒЫ ТҰТЫНУШЫЛАРДЫ ЭЛЕКТРМЕН ҚАМТАМАСЫЗ ЕТУГЕ АРНАЛҒАН КОГЕНЕРАЦИОНДЫ МИКРОЖЫЛУ ЭЛЕКТР СТАНЦИЯСЫ

Аннотация. Бүгінгі күнге дейін тиімді электрмен қоректендіру мәселесі әлі толық шешілген жоқ. Бұл мәселені шешудің бір әдісі – кез келген отынмен жұмыс істей алатын шағын жылу электр станциясын пайдалану. Жеке қуат көзін пайдалану оны өндірудің өзіндік құнын төмендетеді. Электрмен жабдықтаудың сенімділік көрсеткіштерін едәуір арттырып, оны тұтынушыға үздіксіз жеткізуді қамтамасыз ету өте маңызды. Біздің ұсынып отырған микро электр станциямыз сыртқы жылу көзі бар жылу қозғалтқышымен басқарылады. Мақсаты – шалғайдағы ауылдық тұтынушылар үшін кез келген дерлік жанармай түріндегі немесе жағылған қалдықтармен жұмыс істей алатын балама когенерация энергия көзін құру. Бұл ауыл тұрғынына электр энергиясының көлік шығындарын төлемей, жергілікті жерде өндіруге, кешенде электр және жылу энергиясын өндіруге мүмкіндік береді. Біз өз жұмысымызда шетелдік дизайнерлердің оң нәтижелерін, тәжірибелері мен жетістіктерін ескере отырып, өз дизайнымызды жасаймыз.

Ауыл тұтынушыларын тиімді электрмен жабдықтау мәселесінің шешімі микро жылу электр станцияларын енгізу болуы мүмкін. Микрожылулық электр станциясының негізі – бұл Стирлинг принципіне сәйкес сыртқы жылу берілісі бар қозғалтқыш. Микроэлектр станциялары саласындағы заманауи жетістіктер

деңгейіне талдау жасалды. Сыртқы жылумен қамтамасыз етілген қозғалтқышты дамыту бойынша ғылыми зерттеулердің даму бағыты анықталды. Жұмыстың міндеті – жергілікті төмен калориялы отынмен жұмыс істей алатын микро электр станциясының жеке жасау. Дизель отынын, көмірді, мазутты және басқа импортталатын отынды пайдалануды толығымен алып тастау қажет, бұл өндірілетін энергияның төмен бағасына қол жеткізуге мүмкіндік бермейді.

Микрожылулық электр станцияларының дизайн ерекшеліктерінің бірқатар артықшылықтары бар. Біріншіден, бұл оның бәріне танымал, ағаштан бастап ядролық отынға дейінгі кез келген отын көзін пайдалана алу мүмкіндігінде. Зертханалық модельдер жылытылған судан, шамнан және оттықтың жалынынан жұмыс істеді, сонымен қатар жануарлардың қалдықтарымен араластырылған кептірілген өсімдік қалдықтарынан әртүрлі органикалық отын қоспаларын жағуға арналған тұрмыстық қалдықтарды тексердік. Екіншіден, жылу қозғалтқышының қарапайым дизайнын жасауға болады, өйткені онда клапан жүйесі және білікпен газ тарату, жоғары вольтты тұтану жүйесі жоқ. Егер қозғалтқыш дәл және дұрыс жасалған болса, онда ол бүкіл жұмыс кезінде түзетуді және реттеуді қажет етпейді. Үшіншіден, дизайнның қарапайымдылығы оның қызмет ету мерзімін ұлғайтады, тығыздағыш пен жылу алмастырғыш материалын дұрыс таңдау оны 20 мың сағатқа жөндеусіз өткізуге мүмкіндік береді, бұл оның дербестігін қамтамасыз етеді. Төртіншіден, бөлшектердің бірнеше есе аз болуы үлкен мотор ресурсын және майдың минималды шығынын қамтамасыз етеді, оның жұмысын арзан етеді.

Қазақстан Республикасының ауылды аймақтарында сыртқы қозғалтқышы бар жылу электр станцияларын пайдаланудың бірнеше артықшылықтарын бөліп қарастыруға болады:

- көмірсутегі отынының бағасынан тәуелсіздік, сондай-ақ оны сақтау мен тасымалдау шығындарынан бас тарту;
- кез-келген отын түрін пайдалана алу қабілеті. Жергілікті шығарылатын отынды өндіру өнеркәсібін салу перспективасы;
- электр желілерін салудан бас тарту және оларды ұстауға байланысты шығындардың болмауы.
- когенерациялық қондырғыны қолдана отырып өндірілген электр энергиясының 1 кВт / сағ құны 3-тен 5 теңгеге дейін болады, бұл қолданыстағы тарифтерге қарағанда 2-3 есе арзан.
- отынды жағу кезінде пайдаланылған газдардағы СО мөлшері қарапайым жағдайдан 3 есе төмен, ал NO және СН мөлшері әлдеқайда төмен, бұл ең қатаң халықаралық экологиялық стандарттарға сәйкес келеді.
- когенерациялық қондырғылардың өтелу мерзімі – 2-3 жыл.

Мақалада дамыған механикалық қуаттың әртүрлі қысым мәндеріндегі иінді біліктің айналу санына тәуелділігі, сондай-ақ моменттің цилиндрлердегі қысымға иінді біліктің айналу жылдамдығының әртүрлі мәндеріндегі тәуелділігі көрсетілген. Ұсынылған графиктердің негізінде қорытынды жасалған.

Түйін сөздер: жылу электр станциясы, Стирлинг қозғалтқышы, когенерация, электр энергиясы, жылу энергиясы, жылумен қамтамасыз ету, альтернативті энергетика, жылу қозғалтқышы, электрқоректендіру, комплексті өндіріс.

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МИКРОТЕПЛОВАЯ ЭЛЕКТРОСТАНЦИЯ КОГЕНЕРАЦИОННОГО ТИПА ДЛЯ ЭНЕРГООБЕСПЕЧЕНИЯ УДАЛЕННЫХ СЕЛЬСКИХ ПОТРЕБИТЕЛЕЙ

Аннотация. Проблема эффективного электроснабжения не решена в полном объеме до сих пор. Одним из путей решения данной проблемы является разработка микротепловой электростанции, способной функционировать практически на любом топливе. Использование собственного источника энергии позволит снизить затраты на ее производство. Существенно повышаются показатели надежности электроснабжения и обеспечивается ее бесперебойная поставка потребителю. Предложенная нами электростанция приводится в действие тепловым двигателем с внешним подводом теплоты. Целью является создание альтернативного когенерационного источника энергии для удалённых потребителей сельской местности, способного работать практически на любом виде топлива или отходах, подверженных горению. Это позволит сельскому жителю производить на месте без оплаты транспортных потерь электроэнергию, производить электрическую и тепловую энергию в комплексе. В своей работе мы учитываем положительные результаты, опыт и достижения зарубежных стран для создания собственной конструкции.

Решением проблемы эффективного электроснабжения сельских потребителей может быть внедрение микротепловых электростанций. Основой микротепловой электростанции является двигатель с внешним подводом теплоты, работающий по принципу Стирлинга. Выполнен анализ уровня современных достижений

в области микроэлектростанций. Установлено направление развития научных исследований по разработке двигателя с внешним подводом тепла. Задача сводится к тому, чтобы она была способна функционировать на местном низкокалорийном топливе. Необходимо полностью исключить использование дизельного топлива, угля, мазута и другого привозного топлива, которое не позволяет добиться низкой стоимости произведенной энергии.

Можно выделить ряд преимуществ конструктивных особенностей микротепловых электростанций. Во – первых, это его так называемая всеядность, любой источник тепловой энергии от древесины до ядерного топлива. Лабораторные модели работали от тепла нагретой воды, пламени свечи и газовой горелки, а также нами опробованы бытовые отходы подверженные горению различные органические топливные смеси из высушенных остатков растений, смешанных с отходами животноводства. Во-вторых, есть возможность изготовить более простую конструкцию теплового двигателя, так как в нем нет системы клапанов и газораспределения с валом, система высоковольтного зажигания. Если точно и правильно изготовить двигатель, то он не будет требовать настройки и регулировки в течении всей эксплуатации. В третьих, простота конструкции позволит повысить срок его эксплуатации при правильном выборе уплотнений и материала теплообменника позволят пройти ему без ремонта около 20 тыс. часов, что обеспечит его автономность. В – четвертых, меньшее в несколько раз количество деталей обеспечит большой моторесурс и минимальный расход масла, делает недорогой его эксплуатацию.

Преимущества использования в сельской местности когенерационных МТЭС с двигателями внешнего сгорания на местном топливе в регионах Республики Казахстан можно выделить:

- независимость от цены на углеводородное топливо, а также отказ от затрат на его хранение и транспортировку;
- многотопливность и использование доступного топлива для данной местности, а также перспектива создания предприятий по его переработке;
- отказ от прокладки электрических линий и затрат, связанных с их обслуживанием;
- стоимость 1 кВт/ч производимой электроэнергии с помощью когенерационной установки будет составлять от 3 до 5 тенге, что в 2–3 раза дешевле существующих тарифов;
- при сгорании топлива содержание CO в отработанных газах в 3 раза ниже, чем у ДВС и значительно ниже содержание NO и CH, что соответствует самым жестким мировым экологическим стандартам.
- срок окупаемости когенерационных установок 2 - 3 года.

В статье приведена зависимость развиваемой механической мощности от числа оборотов коленчатого вала при различных значениях давления, также зависимость крутящего момента от давления в цилиндрах при различных значениях частоты вращения коленчатого вала. Сделан вывод на основе представленных графиков.

Ключевые слова: тепловая электростанция, двигатель Стирлинга, когенерация, электрическая энергия, тепловая энергия, комплексное производство, электроснабжение, теплоснабжение, альтернативная энергетика, тепловой двигатель.

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**GEOPHYSICAL METHODS CAPABILITIES IN PROSPECT
EVALUATION AND DETECTION OF COPPER-BEARING
LOCALISATIONS OF WESTERN PRE-BALKHASH**

Abstract. In the Western Pre-Balkhash region, deposits of iron, tin, lead, zinc, copper, bismuth, fluorite and wollastonite, as well as copper, silver and gold occurrences are known. All listed ore fields are assigned to Sholpan and Pre-Balkhash formation types. Study covers territories of the famous Bie and potential Besoba ore fields. The aim of the article is to study the prospect evaluation capabilities and sensitivity levels of geophysical methods in the detection of copper ore of the Western Pre-Balkhash. For this purposes, published and archive materials were used, and the results of gravimagnetic studies of recent years were analyzed together with lithogeochemical data.

Two arbitrary areas were assigned to predict distribution of statistical-probability parameters of gravi-magnetic fields. They were selected according to geochemical data based on the presence-absence of copper ore concentrations. Two arbitrary areas were assigned for prediction of statistical-probability parameters of gravity-magnetic fields distribution. Calculation of statistical parameters determines the rate of reflection of ore-concentrating bodies in each of observed fields. Statistical parameters are capable of choosing a rational set of geophysical methods for solving problems and optimize the size of search areas. It has been confirmed that granitoids are the most promising bodies in the exploration of copper ore mineralization. For further detailing of their spatial position, a set of geophysical methods is recommended: magnetic, electrical exploration - vertical electrical sounding (dipole modification) + induced polarization method, using geochemistry data.

The following conditions of application this technique for evaluation geophysical data sensitivity based on the detailed study of gold-bearing ore bodies of the region are listed below: an additional analysis of geological and geophysical data and detailed study of the petrophysical parameters of ore and ore-bearing rocks are required.

Key words: Western Pre-Balkhash, intrusions, copper bearing, gravimagnetic field, geochemistry, statistical processing.

Introduction. Geological exploration in the Western Pre-Balkhash region began at the end of the 19th century and had rare small-scale path intersections nature. In subsequent years, issues of stratigraphy, magmatism, tectonics and hydrogeology were studied; the tungsten-bismuth-tin deposit Karaoba and the tungsten deposit Karakamys (1946) and deposits of tin - Sholpan, Shakshagayly, Karaungir, Korgasyndy, Ayakzhartas group, tungsten – Oktyabrsky, lead and zinc – area XIV, lead-zinc and zinc-tin; area XVIII, copper – Saryshagan were discovered; summary maps (or sets of maps) were compiled, stratigraphy, magmatism and tectonics aspects were correlated, typification of geological and ore formations were revised, tectonic and metallogenic zoning were considered, and a qualitative and quantitative forecast assessment of ore-bearing areas and individual objects (1977-2000 years) was given.

Exploration and prospecting studies were accompanied by geochemical and geophysical surveys, such as: lithogeochemical, magnetic, gravity and small-scale electrical surveys. Consequently, as the result of regional and local researches, deposits of lead and zinc – Bie Vostochny; tin – Pre-Balkhash, Kazarinovskoe, Bie; bismuth – Dvuhmetallnoe, as well as a large number of occurrence and mineralization areas of non-ferrous and rare metals: gold, fluorspar, and etc. were discovered.

Problem statement. Data analysis of previously executed geological-geophysical and geochemical materials of the study area indicate necessity to choose specific set of methods (internal – integrated geophysical methods, and external – geophysical, geochemical and other methods) for further evaluation work. Therefore, the sensitivity of geophysical data within ore-concentration structure must be examined. The solution to the problem is possible by predicting the statistical distribution of physical fields across the study area.

The problem solution. In terms of geology, the field of Bie-Besoba located in an extremely complex structure. It is located at the junction of the Buryltas meganticlinorium, which is part of the Shu-Ili fold zone, and the Mointy synclinorium, which is a substructure of the West Pre-Balkhash megasynclinorium of the Central Kazakhstan Devonian volcanic belt. The northwestern part of the study area hasn't been properly investigated, the undervaluation of the region by economic reasons (lack of large field deposits, poor infrastructure), occurrence of a fresh approaches and development of modern models and distribution (mounting) of non-ferrous deposits and rare metals, are the main factors that determined boundary of the study area.

According to the state of exploration, the Bie's field is considered as an ore, the Besoba's field as a prospective ore-bearing deposits [1]. The ore belts of the Bie site are evenly distributed over its territory and have an isometric or slightly elliptical shape. Their diameter ranges from 2 to 12 km. The Besoba's site is located in the western part of the Bie field and includes a significant number of copper ore occurrences. It is controlled by the Balateniz massif and has slightly angular isometric shape, whose diameter is 14-22 km.

Copper-porphyrific mineralization is spatially and genetically associated with small-scale subalkaline intrusions, which is moderately composed of the Early Permian Torangylyk complex. In the host rocks, following hydrothermal changes are observed: silicification, sericitization, berezization, argillization, vein-disseminated pyritization, kalifeldsparization. Disseminated mineralization is concentrated in brecciation and fractured zones or in vein-vein silicification areas. Typical representatives of copper-porphyrific ore deposits are the Saryshagan field [1].

The data of the previous studies were analyzed to evaluate the possibilities of geophysical data application in allocating of copper-porphyrific mineralization. According to Kashafutdinov V. Kh. et.al (1985, 1992), the density of ore-bearing complex is varying 2.57-2.61 g/cm³, the average is 2.60 g/cm³; magnetic susceptibility – 0-3000·10⁻⁶ CGSM units, average – 630·10⁻⁶ CGSM units [1]. Magnetic and gravitational anomalous fields' values in the region vary from -50 to 500 nTl and -4.5-5 mGal, respectively.

Study area includes different geological features. Geophysical fields' anomalies are similar in shape and sign. Sensitivity assessment of magnetic and gravitational fields in the allocation of ore sites was resolved into prediction of statistical-probability parameters of gravi-magnetic fields distribution (ΔT , nTl and Δg , mGal). Thus, two arbitrary areas were assigned (figures 1 and 2). The contours were drawn on the basis of litho-geochemical data, which is distinguishing zones of copper-ore concentration. Continuously, some distinguished zones are perspective, while others are not. They must be originating from false anomalies. In the first case, there is a non-zero hypothesis (target detection), in the second - the null hypothesis (false target). The reliability of target detection by geophysical (petrophysical) data can be estimated by the method described in [2].

An error of the first kind (false target) arises when H_1 hypothesis is accepted, but in fact there is no signal. There is interference similar to a signal. The probability of such an error is estimated by the area α :

$$\alpha = \int_{S_1} P(F / H_0) dF = \int_h^{\infty} P(F / H_0) dF \quad (1)$$

An error of the second kind (missed target) occurs when the measured value is accepted as interference. That is, H_0 hypothesis is accepted (the null hypothesis), but in fact there is a signal. A similar situation occurs when the interference distorts the signal that becomes similar to interference. The probability of an error of the second kind is determined by β :

$$\beta = \int_{S_0} P(F / H_1) dF = \int_{-\infty}^h P(F / H_1) dF \quad (2)$$

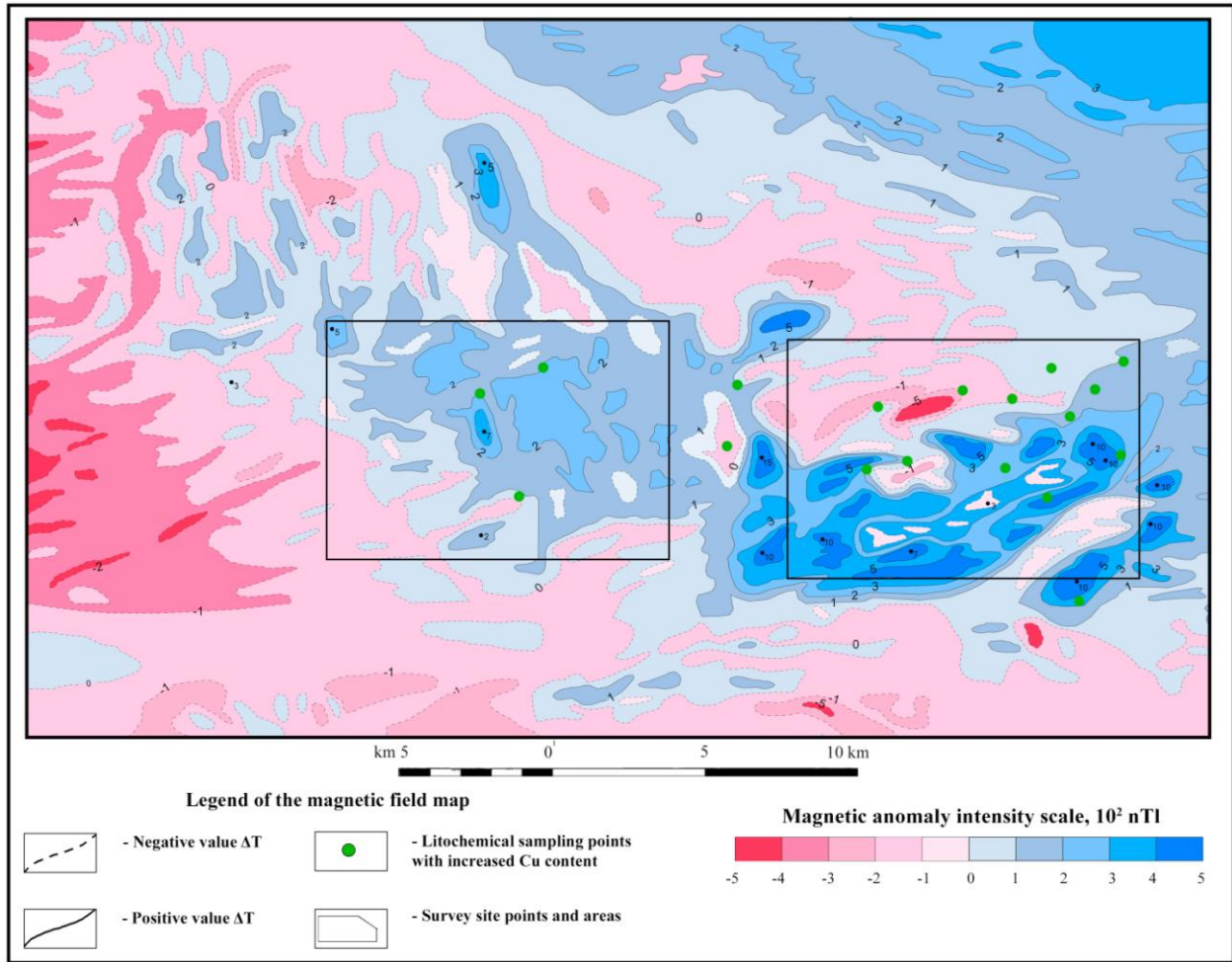


Figure 1 – Map of magnetic field ΔT , 10^2 nTl, of study area in western Pre-Balkhash part with litho-geochemical data

If a priori probabilities of the hypotheses P_0 and P_1 inserted, then we can calculate q - the total unconditional probability error, which associated with false target and missed target.

$$q = P_0 \cdot \alpha + P_1 \cdot \beta \quad (3)$$

Then the reliability (probability of correct selection) of dividing targets into classes (zero or non-zero hypotheses)

$$\gamma = 1 - q \quad (4)$$

As a special case, the probability of correct signal selection is considered

$$\gamma = 1 - \beta \quad (5)$$

Mentioned above method of calculating statistical parameters was used for each of the observed fields. A quantitative probability assessment of the correct targets dividing into classes showed that magnetic exploration data is more informative for distinguishing bodies of copper mineralization. They were objectively reproduced in the values of the calculated statistical parameters: $\gamma=0.723$ – in magnetic, and $\gamma=0.572$ – in gravitational field (according to formula 5).

As the experience of using geophysical methods in studying the areas of sulfide mineralization shows, the results of magnetic studies require further detailing by an electrical exploration complex - vertical electrical sensing (including in dipole modification) and induced polarization. The parameters of electrical resistivity (ρ) and polarizability coefficient (η), jointly obtained using modern hardware systems, and a comprehensive interpretation of the data ΔT , ρ , η will allow to clarify the spatial (deep) positions of ore-bearing objects [3].

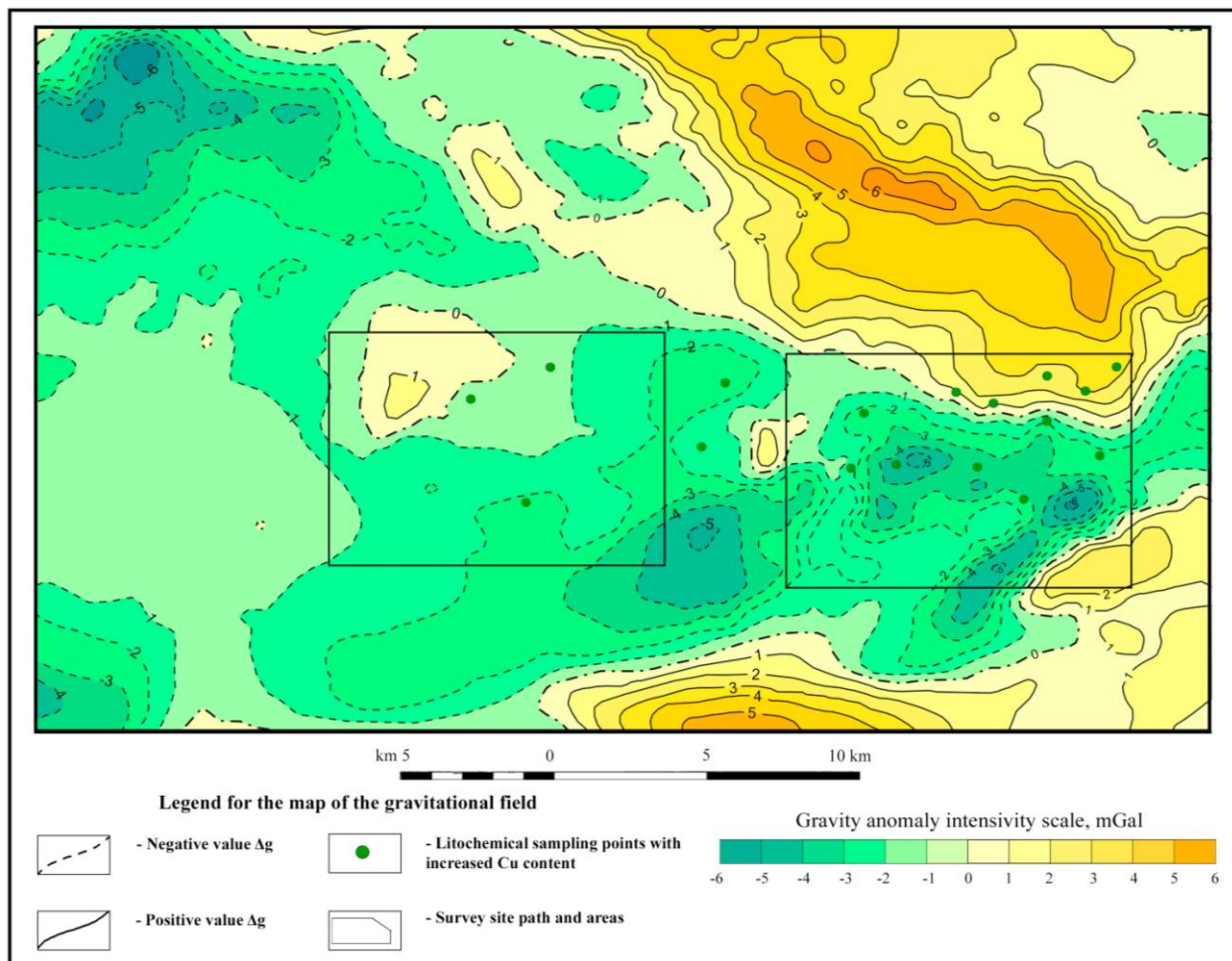


Figure 2 – Map of gravitational field Δg , mGal, of study area in western Pre-Balkhash part with litho-geochemical data

Research prospects. The geological features of the Bie-Besoba's ore field are sufficiently delineated in gravi-magnetic fields. In the northwestern part of the Zhastar's fault zone (outside the study area), it is distinguished by an integration of geological and geophysical data and represents a set of gradients in magnetic and gravitational fields. According to gravity data, elliptical and round minima are distinguished in it, which can be interpreted as untapped stocks by erosion or roots of granitoids lying above basement massifs, characterized by lack of mass (density up to 2.58 g/cm). The Zhastar's zone controls the gold-bearing ore structures of the Zheltau formation (Mynaral).

According to geological and geophysical data, two east-west trending fault zones are distinguished: Karaungir and Usembay. Width of the zones varies from 1.5 to 15 km, and length more than 80 km. Fault zones are distinguished by magnetic and gravitational gradients. They correspond to zones of increased fracturing, folded at a depth by rocks with excessive density. Often zones are accompanied by belt dikes of the dolerite series. Probably, they are relicts of diffuse continental riftogenesis zones, actively operated in the Mesozoic era. Accordingly, it is assumed that they are ore-concentrating structures, which contain ore regardless of its mineragenic type. The intersection of these faults with north-west trending gold ore-bearing faults (Zhastar's zone) determines location of the gold ore mineral areas. Within the study area, most of the small-scale intrusive bodies and snouts composed of felsic rocks have not been properly studied. Among them, ore-bearing granitoids can be found, which previously have not been emphasized into separate complexes. It is most likely that weakly eroded Mesozoic granitoids may be missed: subalkaline leucogranites with equal amounts of alkalis (Be, Mo, Nb, Li), alkaline alaskites (TR, Sn, Nb, F, Zn, Pb), subalkaline Na-K bicarbonate leucogranites (Sn, Nb) and amazonite microcline-albite leucogranites (W, Sn, Mo, Bi, Be, Ta). It's necessary to perform additional analytical studies to investigate granitoids, which consist of small-scale bodies [1].

Conclusion. The results of the research revealed that 1) more detailed study requires investigate ore-bearing granitoids, as well as a detailed analysis of their magnetic and electrical properties; 2) integrated analysis of gravi-magnetic and litho-geochemical data is useful in determining ore-bearing deposits, especially copper-bearing. Statistical estimation showed that the efficiency of using magnetic data ($\gamma = 0.723$) is higher compared to gravitational, where $\gamma = 0.572$; 3) in studying the sulfide mineralization, the results of magnetic data require further prospecting by integrated electrical surveying – vertical electrical sounding (including in dipole modification) and induced polarization. The parameters of electrical resistivity (ρ) and polarization coefficient (η), acquired by using modern hardware systems, and integrated interpretation of ρ , η allows to clarify the spatial position of ore-bearing bodies; 4) Belt of dolerite series dykes may prove to be ore-concentrating features of gold and additional study and analysis is required, including statistical analysis of petrophysical parameters and/or geophysical fields of ore and non-metallic objects using the above methodology.

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БАТЫС БАЛҚАШ МАҢЫНДАҒЫ МЫСТЫ РУДАШОҒЫРЛАНУДЫ АНЫҚТАУДА ГЕОФИЗИКАЛЫҚ ӘДІСТЕРДІҢ ІЗДЕУ-БАҒАЛАУ МҮМКІНДІКТЕРІ

Аннотация. Мақала зерттелетін аудан Батыс Балқаш маңы Шу-Іле қатпарлы белдеуі жүйесіне енетін Бурылтас мегантиклинорийі мен Мойынты синклинорийінің (Орталық Қазақстан девон жанартау белдеуі Батыс Балқаш мегасинклинорийінің құрылымы) біріккен тұсында орналасқан. Батыс Балқаш маңында геологиялық зерттеулер ХІХ ғасырдың соңында басталған, темір, қалайы, қорғасын, мырыш, мыс, висмут, фторит және волластонит кен орындары, сонымен қатар мыс, күміс және алтынның рудалары белгілі. Олар 2 формациялық типтерге қатысты: Шолпан және Балқаш маңы. Іздеу-барлау жұмыстары алдын ала немесе бірге жүргізілген геофизикалық (магниттік, гравитациялық, кейбір жерлерде электрлік барлау) және геохимиялық (литогеохимия) зерттеулермен толықтырылған.

Соңғы жылдары зерттеулер белгілі Бие және әлеуетті Бесоба рудалы алаңдарының территорияларын қамтиды. Зерттеу ауданының контурын анықтайтын факторлар қатарына территорияның солтүстік батыс бөлігінің салыстырмалы түрде зерттелуін, экономикалық себептерге байланысты (ірі кен орындардың болмауы, инфрақұрылымның жеткіліксіздігі) жете бағаланбауын, түсті және сирек металдардың пайда болуы мен кен орындарының орналасу заңдылықтарында жаңа көзқарастардың пайда болуын жатқызуға болады.

Мақаланың мақсаты – Бие-Бесоба алаңындағы мысты кенденудің мысалында геофизикалық әдістердің іздеу-барлау мүмкіндіктерін, ақпараттық деңгейін зерттеу. Ол үшін зерттеу ауданы бойынша жарияланған және фондтық материалдардың қолданылды, соңғы жылдарғы гравимагниттік зерттеулердің нәтижелері литогеохимия мәліметтерімен бірге сараптаудан өтті.

Зерттеудегі гравимагниттік өрістердің рудалы учаскелерді анықтаудағы ақпараттық бағалау олардың бақыланған мәндерінің (ΔT , nTl и Δg , $mGal$) таралуының ықтималды-статистикалық параметрлерін есептеумен орындалды. Есептеулерді орындау үшін 2 учаске таңдалды. Олар геохимия жұмыстарының нәтижелеріндегі мыстың шоғырлану деңгейі бойынша контурланған. Сонымен, 1-объектіде іздеу жұмыстарының перспективасы бар, 2-сінде жоқ. Себебі мұндағы геологиялық объектілер жалған аномалияларды құрайды. Бірінші жағдайда – нөлдік емес гипотеза (объект бар), екіншісінде нөлдік гипотеза орын алады. Сонымен қатар рудалы және рудалы емес геологиялық объектілердің геофизикалық өрістер аномалиялары пішіні мен таңбасы жағынан ұқсас. Фактілік материалдар бойынша объектілердің физикалық қасиеттері мен гравимагниттік өрістерінің кернеуліктері келесі сандық сипаттамаларға ие: тығыздық мәндері $2,57-2,61 \text{ г/см}^3$ арасында өзгереді, орташа мәні – $2,60 \text{ г/см}^3$; магнит қабылдағыштық 0-ден $3000 \cdot 10^{-6}$ CGSM бірліктеріне дейін ауытқиды, орташасы $630 \cdot 10^{-6}$ CGSM бірліктеріне тең; магниттік және гравитациялық аномалиялы өрістер мәндерінің аудан бойынша өзгерістері, тиісінше, -50-ден 500 нТл-ға дейін және -4.5-тен 5 мГал-ға дейінгі аралықта.

Сарапталатын өрістердің статистикалық параметрлерін есептеулер рудашоғырланушы орталардың магниттік өрісте жоғарырақ деңгейде тіркелетінін көрсетті. Есептеулер нәтижелері тапсырмаларды орындауда қолданылатын барынша тиімді геофизикалық әдістер кешенін құрауға және іздеу алаңдарының өлшемдерін ықшамдауға мүмкіндік берді. Нәтижесінде: мысты кенденген алаңдарды контурлауға магниттік барлау әдісі, ары қарай рудашоғырланудың тереңдік орнын анықтауды нақтылауға электрлік барлау әдісі – верти-

каль электрлік зондтау (дипольдік модификациясы) мен табиғи поляризация тәсілдерін бірге қолдану ұсынылды. Зерттеулер геохимия нәтижелерін қолдану арқылы жүргізіледі. Сонымен қатар мысты руда шоғырлануларды іздеуге ең перспективалы объектілерге шағын денелі гранитоидтар жататыны нақтыланды.

Бие-Бесоба кенді алаңы бойынша қазіргі кезде бар геологиялық-геофизикалық, геохимиялық түсірулердің фактілік материалдары, оған қоса түсті және басқа металлдар мөлшерлерін сынамалау мәліметтерінің жеткілікті көлемі осы әдістемені басқа объектілерді іздеуде геофизикалық әдістерді таңдауда да қолдануға мүмкіндік береді. Мысалы, ауданның алтынрудалы объектілерін нақты зерттеулерде геофизикалық әдістердің мүмкіндіктерін осы әдістеменен бағалау шарттары келтірілген: геологиялық-геофизикалық материалдарды қосымша сараптау және алтынды, алтынсыз тау жыныстарының петрофизикалық параметрлерін барынша нақты сараптау қажеттігі.

Түйін сөздер: Батыс Балқаш маңы, интрузиялар, мыстылық, гравимагниттік өріс, геохимия, статистикалық өңдеу.

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ПОИСКОВО-ОЦЕНОЧНЫЕ ВОЗМОЖНОСТИ ГЕОФИЗИЧЕСКИХ МЕТОДОВ ПРИ ВЫДЕЛЕНИИ МЕДЕНОСНЫХ РУДОЛОКАЛИЗАЦИЙ ЗАПАДНОГО ПРИБАЛХАШЬЯ

Аннотация. Район исследования – Западное Прибалхашье – находится на сочлениии Бурылтасского мегантиклинория, входящего в систему Шу-Илийского складчатого пояса, и Моинтинского синклинория – структурой Западно-Балхашского мегасиклинория Центрально-Казахстанского девонского вулканического пояса. Геологические исследования в Западном Прибалхашье были начаты в конце XIX века, известны месторождения железа, олова, свинца, цинка, меди, висмута, флюорита и волластонита, а также проявления меди, серебра и золота. Они отнесены к двум формационным типам: шолпанскому и прибалхашскому. Поисково-съёмочные исследования сопровождались опережающими или одновременными геофизическими и геохимическими работами – литогеохимическими съёмками, магниторазведкой, гравиразведкой, локально электроразведкой.

В последние годы исследованиями охвачены территории известного Биеского и потенциального Бесобинского рудных полей. Относительно слабая опоскованность северо-западной части территории, недооцененность района по экономическим причинам (отсутствие крупных месторождений, слабая инфраструктура), возникновение новых взглядов и разработка современных моделей образования и размещения месторождений цветных и редких металлов – основные факторы, которые определили контур площади исследования.

Целью статьи является изучение поисково-оценочных возможностей, уровней информативности геофизических методов при выявлении рудных площадей на примере медного оруденения в Бие-Бесобинском поле. Для этого были использованы опубликованные и фондовые материалы по району исследования, проанализированы результаты гравимагнитных исследований последних лет совместно с данными литогеохимических работ.

Оценка информативности гравимагнитных полей при выделении рудных участков сводилась к расчету вероятностно-статистических параметров распределения их наблюдаемых значений (ΔT , нТл и Δg , мГал). Для проведения расчетов выделены 2 участка. Они выбраны по данным геохимических работ по признаку уровня концентраций в них меди. Таким образом, один участок представляет поисковый интерес, другой поискового интереса не представляет, так как геологические тела являются источниками ложных аномалий с точки зрения меденосности. В первом случае имеет место ненулевая гипотеза (объект обнаружения), во втором – нулевая гипотеза (ложный объект). При этом аномалии геофизических полей рудных и безрудных объектов сходны по форме и знаку. По фактическим материалам их физические свойства и напряженности гравимагнитных полей имеют следующие количественные характеристики: значения плотности для рудоносного комплекса пород находятся в пределах 2,57-2,61 г/см³, среднее – 2,60 г/см³; магнитной восприимчивости – 0-3000·10⁻⁶ ед. CGSM, среднее – 630·10⁻⁶ ед. CGSM; значений магнитного и гравитационного аномальных полей по району варьируют в диапазонах, соответственно, от -50 до 500 нТл и от -4.5 до 5 мГал.

Расчеты статистических параметров анализируемых полей показали более высокую степень отражения рудоконцентрирующих сред в магнитном поле. Результаты расчетов позволили определить наиболее рациональный комплекс геофизических методов для решения задачи и оптимизировать размеры поисковых

площадей. Так, для оконтуривания площадей медных оруденений, как более информативный метод, предложена магниторазведка, для дальнейшей детализации глубинного положения рудоконцентраций рекомендована электроразведка – вертикальное электрическое зондирование (дипольная модификация) совместно с методом вызванной поляризации, с использованием данных геохимии. Подтверждена, что к наиболее перспективным объектам в поисках медных рудолокализаций относятся гранитоиды, слагающие малые тела.

Имеющиеся на данное время фактические материалы геолого-геофизических, геохимических съемок по Бие-Бесобинскому рудному полю, а также объемы данных опробования на содержание цветных и других металлов позволяют применить данную методику при решении задачи выбора геофизических методов для других объектов поиска. Так, в статье изложены условия её применения для оценки возможностей геофизических методов при исследованиях золоторудных объектов района: необходимость дополнительного анализа геолого-геофизических материалов и более детального изучения петрофизических параметров рудных и безрудных горных пород по участкам исследования.

Ключевые слова: Западное Прибалхашье, интрузии, меденосность, гравимагнитное поле, геохимия, статистическая обработка.

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**ESTIMATION OF THE CHANGES IN WATER SURFACE AREA
BASED ON THE USE OF ARCHIVES SATELLITE IMAGES
OF LANDSAT SATELLITES
(ON THE EXAMPLE OF THE ERTIS RIVER)**

Abstract. Conservation of the surface waters and their rational use is one of the pressing problems throughout the world. In our country, monitoring the regulation of the flow and flooding of the floodplains is also an actual issue. This article examines the remote sensing processing technique for studying the water surface, reflecting the changes that occurred in size and in time, which allows the assessment at a new level.

To determine the technique for studying the surface water researches, the analysis of published materials on modern methods of monitoring the natural water bodies based on data from the use of satellite imagery archives was carried out, and the possibilities of their application to study floodplain flooding dynamics were studied. As a result of the analysis, a technique based on the use of global surface water research data (Global Surface Water Explorer) of the European Commission research center was determined. The global surface water data set (GSWE) uses three million archival satellite images of Landsat to quantify flooding over 32 years (from 1984 to 2015) with a spatial resolution of 30 m.

The analysis of the results obtained showed the presence of the problem for their use in the technique of monitoring the areas of the water surface of the river Ertis floodplain associated with a large number of raster cells with a NoData value (no data) for individual months of individual years. Despite the problems, as a result of analyzing the data of the annual level (Yearly Water Classification), the areas of the water surface were determined, which consists of the area of permanent (permanent water) and seasonal water surface (seasonal water) of the Ertis river floodplain plots.

The purpose of the article is to obtain water surface data by using Landsat satellite imagery archives to monitor area dynamics.

The presented results demonstrate a high potential for various applications requiring the information on the dynamics of the surface waters.

Key words: Landsat, global data, surface waters, remote sensing.

Introduction. Water is a vital natural resource. Water reserves in natural and artificial reservoirs are useful for increasing the available water resources for human society; therefore, water flow should be the main direction in the assessment of water resources [1]. Surface water is an important variable in hydrological, climatic as well as in biodiversity studies [2-4]. The surface waters in rivers and lakes are important both for the existence of an ecosystem and for humans [5-6]. Therefore, the most urgent problem at the present time is the conservation of surface waters and their rational use [7]. For monitoring

the changes in the surface waters [8] and assessing the flooding of floodplain areas [9] recently, satellite images are used, global databases are mapped and created, modeling is conducted [5,8,10].

The important advantages of the remote sensing methods are the ability to regularly monitor the state of the earth's surface, the greater visibility, the high efficiency of obtaining information about the area of interest and the integration into geographic information systems. The latest advances in remote sensing, GIS will help ensure and process a large range of data simultaneously in real time [11].

The remote sensing has become an important source of information in the analysis and getting the data on the changes in various terrestrial resources, and in particular, the surface waters. The sensing and application of GIS technologies for the water resources include the assessment of the risk of flooding and their management [12-13].

Analysis of foreign experience of a similar study. At present, the issue of monitoring the flooding of floodplain territories becomes relevant. There are many methods of floodplains research offered by the scientists from different countries. Considering the global water deficit, the satellite images are used to monitor the changes in surface waters and to assess the flooding of floodplain areas, the global databases are mapped and created. The automatic mapping of the surface waters, their dynamics over seasons or several years and over large areas is becoming increasingly important for quantifying the impact of factors on surface waters, which is necessary for making management decisions [14].

One of the recommended global datasets to use is the Global Surface Water Exploration Data Set (Global Surface Water Explorer) of the Joint Research Center (JRC) of the European Commission, created by using the Landsat 5TM, Landsat 7ETM +, Landsat 8 OLI satellite images archived from March 16, 1984 to October 10, 2015 [8].

The Global WaterPack dataset. The Global WaterPack time series (GWP), which is processed in the German Remote Sensing Data Center (DFD) DLR, quantifies the daily dynamics of global inland waters with daily time resolution. The daily temporal resolution and global coverage of the Global WaterPack (GWP) has a great potential for identifying the effects of climate change, meteorological variability and human activity on the surface water dynamics [15-16].

Using the satellite images, you can determine the state of the surface waters. One of these works is made by Australian scientists; they developed the Water Observation from Space (WofS) product. Observing the Water from the Space (WofS) is a web service that displays the historical surface water observations from the Landsat 5 and Landsat 7 satellite images archives for all of Australia from 1987 to the present [17-18].

Despite the rapidly growing number of large-scale and long-term surface water (SW) records (Pekel et al., Klein et al., 2017; Mueller et al., 2016;), there are currently no proven methods to quantify the dynamics of surface water (SW) according to Landsat resolution and regular time step of 8 days or less. To achieve this goal and eliminate the space-time resolving limitations in Landsat and MODIS based on the mapping of large-scale floodplain flooding dynamics, Australian scientists applied a generalized additive model regression (GAM) [19].

Recently, in world practice, when assessing the river flow and rivers floodplains, the mathematical models of floodplain processes are most effective, which allow reproducing various hydrological phenomena in a wide range of geomorphological and hydrological conditions [20].

Methods. As a result of the analysis, the method based on the use of the data from global studies of the surface waters (Global Surface Water Explorer) of a research center of the European Commission was determined. The Global surface water research data are publicly available. For global studies, the Landsat satellite images archives for the 32-year period 5TM, Landsat 7ETM +, Landsat 8OLI, received in the interval from March 16, 1984 to October 10, 2015, were used. These images contain the information on the water surface for the period of March 1984 - October 2015, the data sets for 8 months (the snowless period from March to October) [8,21]. For the study, the methods of processing and decoding the multi-zone space images.

Results. To monitor the water surface of the Ertis floodplain the pre-processing of the raster datasets of global studies of the surface waters and the created floodplain layer was carried out

The preprocessing stage included the processes of preparing the database, bringing the dataset to a common projection, clipping (Clip Raster) extra territory, converting the vector layer of the river Ertis floodplain in raster, building and updating of raster attribute tables (Build Raster Attribute Table), creating mosaic datasets (Create Mosaic Dataset).

The process and its stages, as well as the preparation of input data sets for the classification and ensuring compliance with the requirements of the data format, metadata and raster fields for analyzing the changes in the area of water bodies are shown in (figure 1).

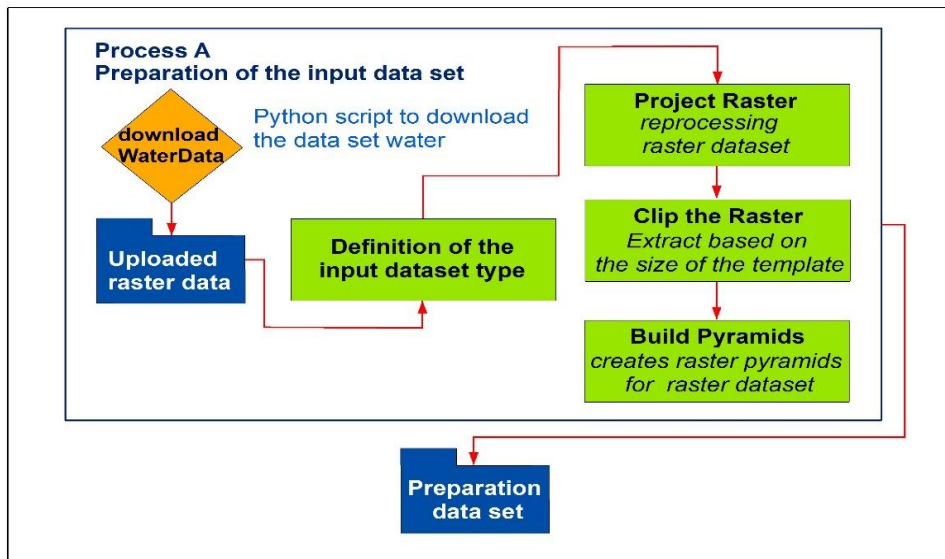


Figure 1 – Preparing the input dataset

To extract quantitative data on the dynamics of the river Ertis surface water area from the corresponding global surface water research datasets the Zone Statistics toolkit of the ArcGIS desktop program was used. Zone statistics is the calculation of statistical data (by pixels) within a specific zone (s). As zones, a mask in the sections of the Ertis floodplain was used. Using the methods of zonal statistics, the maximum area of the floodplain, the area of constant water and the area of seasonal water were determined.

When the source datasets were prepared, raster layers were classified by assigning them unique values. Table 1 presents the attribute characteristics of the objects and their key values, which are used to create and analyze the information on detected changes in surface water bodies for the purpose of mapping. These fields provide the necessary information, such as weights for each class (output data) and labels for each class (range labels).

For the "Yearly Water Classification" collection containing the raster datasets by year based on the repeatability of values detected during the year, the unique values from 0 to 4 are assigned (0 = no data, 1 = not water, 2 = seasonal water, 3 = permanent water).

Table 1 – Characteristics of object attributes for annual data (Yearly Water Classification)

Band Name	Description	Label
Yearly_Water	Classification of seasonality of water throughout the year	0 = no data, 1 = not water, 2 = seasonal water, 3 = permanent water

The next step was to restore the gaps and redefine the cell classes (figure 2). In the "Yearly Water Classification" raster dataset collection, the indication "No data" (0 = no data) is an omission due to the lack of data or due to heavy clouds.

In order to ensure the proper coverage of water bodies, the "Water Recurrence" raster set (Water Recurrence Map) was used to eliminate a small imperfection in the annual raster data. The water recurrence map reflects the interannual variability of water availability. This map shows how often water returns from year to year (expressed as a percentage). Recurring water at 100% means that water is present every year from the beginning of the year of water observations. On the contrary, low percentages characterize the variability of water. Therefore, we believe that if the sum of repetitions of the observed

pixels is more than 75%, then the presence of water gives sufficient confidence that the water returned annually. Conversely, below 74%, the lack of the observation of the water is enough to demonstrate the seasonality of water or its absence.

In the presence of the water indication "NoData" in the year of observation, the following transitions were displayed:

- Permanent water surfaces equal to a value greater than 75%;
- Seasonal water surfaces are from 11 to 74%;
- Lost water surfaces with a value below 10%.

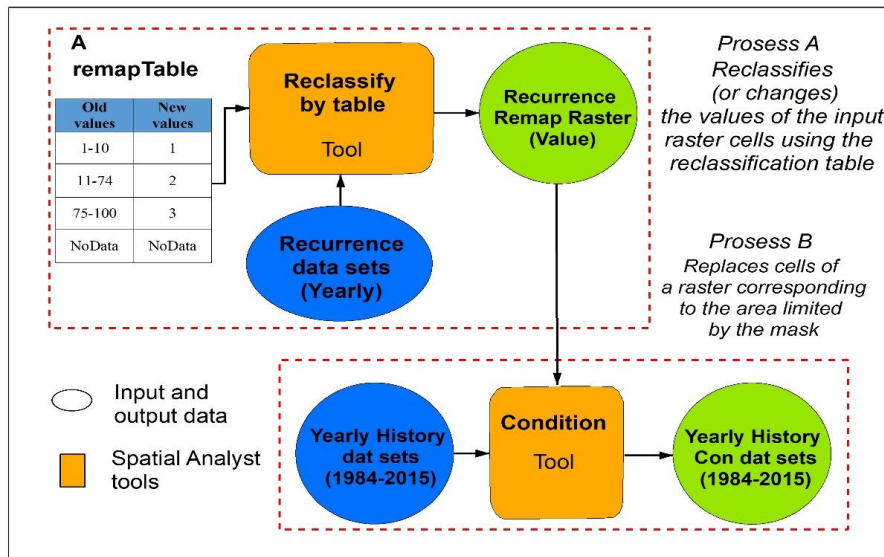


Figure 2 – Process “Restore Missing Pixels”

To eliminate the gaps in the source data, the RemapValue tool in conjunction with the Con tool was used, which allows you to change the NoData values in the raster to any desired value while maintaining the original values, other than NoData (figure 3), for the remaining cells. To reclassify the output raster of the raster dataset RemapValue, Reclassify (Spatial Analyst) was used as follows:

1. reclassfield = "Value"
2. remap = RemapValue ([[0,10,1],
3. [11,74,2],
4. [75,100,3]])
5. rasterlist = []

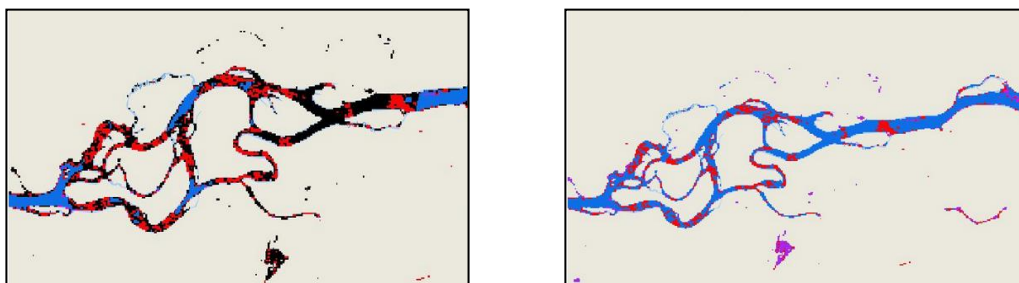


Figure 3 – The example of a raster after restoration (on the left - the original; on the right - the result of the restoration); black color indicates missing pixels

For example, to create a raster where the NoData areas (figure 3) were assigned to a specific value from the data set, while the other (NoData) cells retain their values, the procedure would be as follows:

1. inRaster1 = "Yearly_Water"
2. inRaster2 = "year2_2015",

3. inRaster3 = "Yearly_recurrence"
4. outCon = "C: / ArcGIS / output / outcon"
5. # Process: Con
6. arcpy.gp.Con_save (inRaster1, inRaster2, outCon, inRaster3, "Value = 0")

Calculation of surface water bodies areas. To study the temporal variability of surface water bodies, the Tabulate Area tool was used, which calculates a cross table of areas between two data sets and provides an area table as quantitative characteristics (table 2).

The principle of the "Tabulate Area" tool: If you know the size of the grid cell, then you can easily calculate the area occupied by each object (figure 4).

- In table 2: Z1 - nominal input layer - objects
- Z2 - new scalar type layer - area of objects

Table 2 – «Tabulate Area»

Z2 = objectArea (Z1)	the value in the cell of the Z2 layer is equal to the area of the object from the Z1 layer that includes this cell
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For example: let the cell have a size of 100m * 100m = 1 hectare, then we get the area in hectares

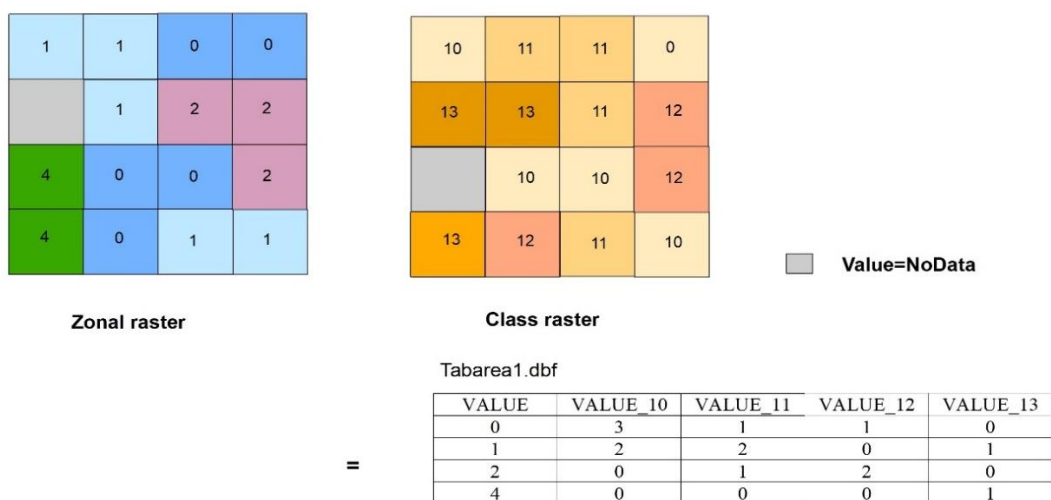


Figure 4 – Example of statistics “Tabulate Area”

As a result of the study, the method of monitoring the water surface area of the Ertis floodplain was defined in terms of annual average data based, from which the data of permanent (Min) and seasonal water (Max) areas were extracted from 2000 to 2015 (figure 5).

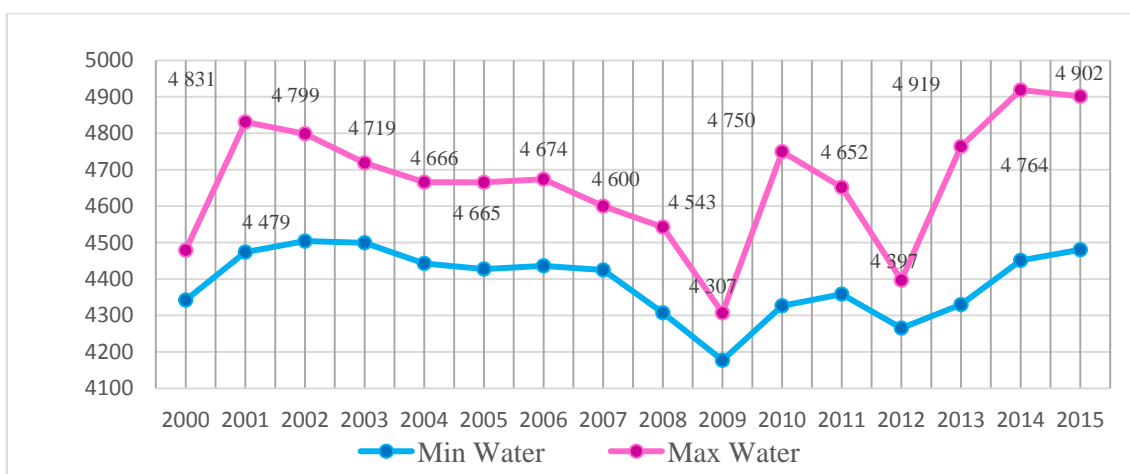


Figure 5 – Dynamics of the changes in the Ertis river water surface based on the archives of satellite images of Landsat satellites, (from the PRC border to the Bukhtarma water reservoir, km²)

Discussion. The analysis of the results showed that there is a problem for their use in the method of monitoring the surface area of the Ertis river floodplain associated with a large number of raster cells with a NoData value for individual months of individual years. Most of the raster cells with a NoData value is associated with the absence of separate Landsat 5 images for the territory of Kazakhstan for the period from 1984 to 1990 in the used remote sensing archive. Space images (from 1984 to 1999), which were characterized by high clouds, do not allow their use for assessing and monitoring the water surface.

Conclusion. Despite the above problems, for the data set "Yearly Water Classification" from 2000 to 2015 we got the water surface area of the floodplain areas of Ertis river (min = permanent water and max = seasonal water). With enough professional study of the water surface area of the floodplain, it is possible to get quite understandable, clear picture. The obtained results allow to analyze the distribution and changes of water bodies in Kazakhstan, including unexplored water bodies.

In view of the vastness of the river floodplains and the speed of its flooding processes, remote sensing data can be used to solve the problem. For land modeling and water management, it is advisable to have daily or more frequent information about water. The satellite remote sensing is only technology available to obtain such information over large areas.

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LANDSAT АРХИВТІК ҒАРЫШТЫҚ ТҮСІРІЛІМДЕРІНІҢ НЕГІЗІНДЕ СУ БЕТІНІҢ ӨЗГЕРІСІН БАҒАЛАУ (ЕРТІС ӨЗЕНІ НЕГІЗІНДЕ)

Аннотация. Жер беті суларын сақтау және оларды тиімді пайдалану дүние жүзі бойынша ең өзекті мәселелердің бірі болып отыр. Әртүрлі елдердің ғалымдары ұсынған, жайылманы зерттеудің көптеген әдістемелері бар. Ғаламдық су тапшылығына байланысты, жер беті суының өзгеруін бақылау және жайылмалық аумақты судың басуын бағалау мақсатында ғарыштық түсірілімдерді пайдалана отырып, жер беті суларының картасы жасалып, ғаламдық база құрылып келеді. Қашықтықтан зондаудың мониторингтік деректерін өңдеудің негізінде құрылған ғаламдық деректер жыйынтығы су ресурстарының жылдар мен маусым арасындағы өзгеру динамикасын түсінуге мүмкіндік береді.

Біздің елімізде де ағындыға мониторинг жасау мен жайылма аумақтарындағы суды басу – өте маңызды сұрақтардың бірі. Бұл мақалада жерді қашықтықтан зондауда су бетін зерттеу үшін болып жатқан өзгерістерді көлемі мен уақыттық белгілерімен бейнелейтін, бағалауды жаңа деңгейде жүргізуге мүмкіндік беретін өңдеу әдістемесі қарастырылады.

Бұл мақаланың мақсаты – Жер беті сулары ауданының динамикасына мониторинг жасау мақсатында Landsat архивтік ғарыштық түсірілімдерін пайдалана отырып, деректер алу.

Жер беті суларын зерттеудің әдістемесін анықтау үшін, архивтік ғарыштық түсірілімдерді пайдалану кезіндегі мәліметтерді негізге ала отырып, табиғи су нысандарына мониторинг жасаудың қазіргі заманғы әдістері бойынша жарияланған мәліметтерге талдау жасалды, оларды жайылма аумақтардағы суды басу динамикасын зерттеу үшін қолдану мүмкіндіктері қарастырылды.

Талдау нәтижесінде Еуропалық комиссияның зерттеу орталығының жер беті суларын ғаламдық зерттеу (Global Surface Water Explorer) деректерін пайдалануға негізделген әдістеме анықталды. Жер беті суларын ғаламдық зерттеудің деректері жалпы қолжетімді.

Ғаламдық зерттеулер үшін Landsat 5TM, Landsat 7ETM+, Landsat 8OL жер серігінен алынған 1984 жылдың 16 наурызынан – 2015 жылдың 10 қазанына дейінгі 32 жылдық кезеңді қамтитын ғарыштық түсірілімдердің архиві пайдаланылды. Бұл түсірілімдердің кеңістік дәлдігі – 30 метр, 1984 жылдың наурыз айынан – 2015 жылдың қазан айына дейінгі жер беті сулары жайлы ақпараттардан тұрады, деректер жинағына 8 ай кіреді (наурыздан қазан айына дейінгі қар жоқ уақыттар).

Ертіс өзені жайылмасының су бетіне мониторинг жасау үшін жер беті суларының ғаламдық зерттеу деректері мен жайылманың құрылған қабытына алдын ала өңдеу жасалды.

Алынған нәтижелерді талдау, Ертіс өзені жайылмасының су бетінің ауданына мониторинг жасау әдістемесінде оларды пайдалануда проблемалар туындайтынын көрсетті, олар растрда жекелеген жылдар мен жекелеген айлардағы NoData (деректер жоқ) мәні бар ұшықтар санының көптігімен байланысты. Растрларда NoData (деректер жоқ) мәні бар ұшықтар санының көп болуы, жерді қашықтықтан зондтаудағы архивтік түсірілімдерде 1984 жылдан 1990 жылдар арасындағы кезеңде Қазақстан аумағында жоғары бұлттылықпен сипатталатын Landsat 5 жекелеген түсірілімдерінің болмауымен байланысты, су бетіне бақылау жасап, бағалауға мүмкіндік бермейді.

Жоғарыда айтылған мәселелерге қарамастан, біз «Yearly Water Classification» деректер жинағын пайдаланып, Ертіс өзені жайылмасының жекелеген участкелері бойынша 2000-2015 жылдар аралығындағы тұрақты (min=permanent water) және маусымдық (max =seasonal water) жер беті суларының аудандарын беретін су бетінің ауданын алдық.

Жеткілікті деңгейде кәсіби түрде зерттесе, жайылма участкелеріндегі су бетінің ауданы жайлы нақты, түсінікті бейнені алуға болады. Алынған нәтижелер Қазақстанның су нысандарының өзгеруі мен таралуына талдау жасауға, әсіресе, аса зерттелмеген су нысандары жайлы да деректер алуға жақсы мүмкіндік береді. Ұсынылып отырған нәтижені жер беті суларының динамикасы жайлы ақпараттарды қажет ететін көптеген жерлерге қолдануға болады.

Спутниктік қашықтықтан зондтау – үлкен аумаққа мұндай ақпараттарды алуда қолданылатын бірден-бір технология. Өзен жайылмасының кеңдігі мен онда болатын су басу процестерінің жылдамдығын ескере отырып, туындайтын проблемаларды шешуде жерді қашықтан зондтау (ЖКЗ) деректерін пайдалану керек.

Түйін сөздер: ғаламдық деректер, қашықтан зондтау, Landsat, жер беті сулары, су басу.

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ОЦЕНКА ИЗМЕНЕНИЯ ПЛОЩАДИ ВОДНОЙ ПОВЕРХНОСТИ НА ОСНОВЕ ИСПОЛЬЗОВАНИЯ АРХИВОВ КОСМИЧЕСКИХ СНИМКОВ СПУТНИКОВ LANDSAT (НА ПРИМЕРЕ Р. ЕРТИС)

Аннотация. Сохранение поверхностных вод и их рациональное использование является одним из актуальных проблем во всем мире. Существует множество методик исследования поймы, предлагаемые учеными разных стран. Учитывая глобальный дефицит воды для мониторинга изменения поверхностных вод и оценки затопления пойменных территорий, используются космические снимки, картируются и создаются глобальные базы данных. Наборы глобальных данных, созданных на основе обработки мониторинговых данных дистанционного зондирования, позволяют понять особенности межгодовой и внутрисезонной динамики водных ресурсов.

В нашей стране мониторинг регулирования стока и затоплений пойменных территорий также является актуальным вопросом. В данной статье рассматривается методика обработки дистанционного зондирования для исследования водной поверхности, отражающих произошедшие изменения в величине и во времени, которая позволяет произвести оценку на новом уровне.

Цель этой статьи – получение данных водной поверхности путем использования архивов космических снимков спутников Landsat с целью мониторинга динамики площадей.

Для определения методики изучения исследований поверхностных вод был проведен анализ опубликованных материалов по современным методам мониторинга природных водных объектов на основе данных использования архивов космических снимков, изучены возможности их использования для исследования динамики затопления поймы.

В результате анализа была определена методика, основанная на использовании данных глобальных исследований поверхностных вод (Global Surface Water Explorer) исследовательского центра Европейской комиссии. Данные глобальных исследований поверхностных вод являются общедоступными.

Для глобальных исследований были использованы архивы космических снимков спутников Landsat за 32-летний период 5TM, Landsat 7ETM+, Landsat 8 OLI, полученные в интервале от 16 марта 1984 года до 10 октября 2015 года. Эти изображения содержат информацию о водной поверхности за период март 1984 - октябрь 2015 года, наборы данных за 8 месяцев (бесснежный период с марта по октябрь) с простран-

ственным разрешением 30 м. Использовали методы обработки и дешифрирования многозональных космических снимков.

Для мониторинга водной поверхности поймы р. Ертис была проведена предварительная обработка растровых наборов данных глобальных исследований поверхностных вод и созданного слоя поймы.

Анализ полученных результатов показал наличие проблемы для их использования в методике мониторинга площади водной поверхности поймы р. Ертис, связанные с большим количеством ячеек растров со значением NoData (нет данных) за отдельные месяцы отдельных годов. Большая часть наличия ячеек растров со значением NoData связана с отсутствием в использованном архиве ДДЗ отдельных снимков Landsat 5 на территории Казахстана за период с 1984 по 1990 гг. Космоснимки (с 1984 по 1999 гг.), которые характеризовались высокой облачностью, не позволяют их использование для оценки и мониторинга водной поверхности.

Несмотря на вышеизложенные проблемы, по набору данных «Yearly Water Classification» с 2000 по 2015 гг. мы получили площадь водной поверхности по участкам поймы р. Ертис, которая состоит из площади постоянной (min=permanent water) и сезонной водной поверхности (max =seasonal water) поймы р. Ертис по участкам.

При достаточно профессиональном изучении площади водной поверхности участков поймы можно получить вполне объяснимую, ясную картину. Полученные результаты позволяют анализировать распределение и изменение водных объектов Казахстана, в том числе и неизученных водных объектов. Представленные результаты демонстрируют высокий потенциал для различных применений, требующих информации о динамике поверхностных вод.

Для получения такой информации на большие территории спутниковое дистанционное зондирование является единственно возможной технологией. Учитывая обширность речных пойм и быстроту протекающих на них процессов затопления, для решения проблемы можно использовать данные дистанционного зондирования земли (ДДЗ).

Ключевые слова: глобальные данные, дистанционное зондирование, Landsat поверхностные воды, затопление.

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COMPARATIVE ANALYSIS OF THE APPLICATION OF STEEP CONVEYOR LINES ON QUARRIES

Abstract. The aim of the research is to identify methods of adaptation of cycle and flow technology, using steeply inclined conveyors, in the development of ore deposits in an open way.

Determination of efficiency and conditions of preferable application of steeply inclined conveyor lifting is carried out using scientifically based principles of versions comparison taking into account relationship of adjacent links of cycle-flow technology according to selected evaluation criteria trying to calculate according to economic and mathematical model, taking into account operation mode, technical parameters and operational characteristics of equipment.

Analysis of dependencies of change of evaluation criteria on the main influencing factors when using traditional and steeply inclined belt conveyors in systems of cycle-flow technology has been carried out.

Influence of inclination angle of conveyor lift route and height of rock mass lifting on main indices of crushing-conveyor complexes is determined. Results of technical and economic analysis of application of cycle-flow technology complexes with steeply inclined conveyor lifts and conventional ones are given. Comparative values of capital and operating costs are determined at different angles of installation of steeply inclined conveyor lift at lifting height of transported material 100 - 600 m and lifting angles up to 50 - 60 °.

Effective conditions for the application of steeply inclined belt conveyors were established on the basis of an analysis of estimated indicators including total and specific capital costs, total and specific operating costs, labor productivity, specific metal consumption and specific heat saturation, which were determined in general for the complex of cycle-flow technology.

The results of the studies show that the steeply inclined conveyor lifts at the angles of their installation are more than 35° more efficient than conventional belt conveyor lifts, which under the conditions makes it possible to reduce total capital costs by 20-100 million rubles, and total operating costs - by 3.5-4.5 million rubles per year.

Key words: cycle and flow technology, deep quarries, mobile crushing and reloading plants, steeply inclined conveyor, concentration horizon, unit costs, research.

The problem and its relationship to scientific and practical tasks. Development of open extraction of mineral raw materials is accompanied by continuous increase of quarries depth, deterioration of mining-geological and mining technical conditions of development, concentration of mining operations. The main volume of a production of ores is the share of large pits of 250-300 m in depth and more which final design depth of development of 700-800 m. In the long term the main volume of dredging of mountain weight on pits will be carried out by development of deep horizon [1-6].

With increasing depth of quarries, conditions of transportation from lower horizons are complicated, which are characterized by increase of range and height of rock mass lifting, increase of weighted average slopes and limitation of capacity of intracarrier transport communications and reduction of reliability of mining and transport equipment. The reduction of equipment productivity for every 100 m reduction of mining operations is: in excavating and automobile complexes, excavators - 10-15%, trucks - 25-39%; In excavator-railway complexes - 17- 19% excavators, locomotive units - 8.5-20%. Height of working zone

increases to 250-300 m, width of working platforms decreases, availability of reserves ready for extraction decreases to 0.4-1.0 months, angle of repayment of quarry sides increases [7]. Research confirms that it is possible to compensate for the negative impact of the factor of increasing the depth of development on the economic indicators of mining enterprises, to ensure maintenance and increase of ore production volumes by reconstruction of mining and transport systems of quarries and introduction of flexible technological schemes of development with high-manmade and productive mining and transport equipment, which is as adapted as possible to the intra-car infrastructure[8-10].

The efficiency of further development of large quarries is determined by the correctness of the strategy of selection of technology and technology during mining works on deep horizons. For most quarries the priority direction of development of deep horizons of quarries is cycle-flow technology (CFT), the efficiency of which is proved by numerous scientific and design developments, experience of operation of systems of cycle-flow technology on foreign quarries[11-14].

One of the main ways to increase work efficiency is to use cyclic-flow technologies based on automobile conveyor transport, using the flow link of cyclic-flow technologies of a steeply inclined conveyor. Currently, the use of cyclic-flow technologies in a quarry in Muruntau (Republic of Uzbekistan) is 30-40%, and by dump trucks by 50-70%, and dump trucks by 30% [15].

Application of cycle-flow technology(CFT) in conditions of continuous deepening of open developments makes it possible to achieve high concentration of production, to improve indicators of use of mining and transport equipment, to provide high degree of automatic control of technological processes and to increase efficiency of mine operation as a whole. The studies carried out have so far shown that the specific energy consumption of cycle-flow technology used in the quarries of Russia and Ukraine is lower by 14 - 16% compared to cycle technology. Distribution of power consumption by the main technological processes of cycle-flow technology on average provides: transportation of mining mass 75 - 80%, crushing 8 - 10%, excavation 16 - 18% [7].

Analysis of research and publications. When analyzing the work of various quarries of the countries, it was revealed that the following complexes of cyclic-flow technologies with steeply inclined conveyors are currently used. The history of the development and use of the steeply inclined «sandwich» conveyor is known in the «Maidanpek» quarry and in Canadian diamond quarries[16-17].

Previously performed by the Institute of Mining of the Ural branch of the Russian Academy of Sciences of scientific research defined parameters of a steeply inclined belt conveyor with a pressure belt and tubular steeply inclined belt conveyors in relation to conditions of deep mining quarries. The results of the design work showed that the tubular steeply inclined belt conveyor is significantly lower in the main parameters than the steeply inclined belt conveyor with pressure belt: in the maximum lifting height by 2-3 times (the limit lifting height - 80-85 m); 1.8-3.2 times (maximum performance is 6.5-7.0 million tonnes/year. In addition, the construction of the tubular conveyor involves the use of special cables with increased abrasion resistance, Limitations on minimum permissible values of spiral vertical curve radii along the conveyor route require the arrangement of horizontal platforms in the quarry to accommodate conveyor loading units up to 75-80 m wide. Taking into account the set of said factors, As well as a number of complex design solutions for individual components of the conveyor, Elimination of possibility of effective application of tubular steeply inclined belt conveyors in deep quarries.

Studies have found that for quarries, the most preferred type of steeply inclined lifting of the rock mass is double-loop belt conveyors of the sandwich type with forced pressing of the upper run of the belt by special mechanical devices[18-23].

A typical practical application of this conveyor design is the "Muruntau" gold mine (Republic of Uzbekistan), where since 2011 the crushing and conveyor complex with a steeply (CCC) inclined belt conveyor of sandwich type.

The commissioning of the steeply inclined belt conveyor in March 2011 reduced the distance of transportation of the rock mass by road on average by 3,5 km, lifting height by 285-320 m.

As the practice of Muruntau 's quarry shows, the use of the complex with a steeply inclined belt conveyor allows to increase the productivity of motor vehicles by 30%, reduce the annual mileage of cars by 30.4%, reduce the number of motor vehicles, drivers and repair workers by 27.2%, the consumption of petrol and lubricants - by 37% [4]. Thus, the introduction of a cycle-flow technology scheme with a

steeply inclined conveyor has low running costs associated with reduced demand for dump trucks, drivers, and maintenance personnel [15].

Presentation of material and results. The results of the technical and economic comparison are given below, which give a general idea of the feasibility of using steeply inclined conveyors in comparison with traditional belt conveyors in cycle-flow technology complexes. Double-loop conveyor with moving pressure elements is considered as steeply inclined lift.

Determination of the field of rational application of steeply inclined conveyors is carried out for conditions of use of cycle-flow technology complexes in process load flows of rocks and ores with volume of 5-30 million tons per year at height of lifting of transported material of 100 - 600 m and angles of lifting up to 50 - 60°. At selection of conveyor equipment parameters rational speed of conveyor belt movement 3.15 m/s is accepted at movement of rock large-rolled rock mass. The selection of the assembly road transport equipment was carried out on the basis of the rational lifting height of the rock mass by the motor trucks equal to 60 - 80 m at the weighted average transportation distance of not more than 2 km.

The conditions for effective application of steeply inclined belt conveyors were determined on the basis of an analysis of estimated indicators including total and specific capital costs and operating costs, labor productivity, specific metal consumption and energy saturation, which were determined in general for the complex of cycle-flow technology (table).

Analysis of the structure of capital expenditures for cycle-flow technology (CFT) complexes shows that in the total cost of equipment the main share of expenditures is accounted for by assembly road transport, which reaches 40 - 60% depending on the annual volume of transportation and height of lifting of transported material by conveyors. Capital costs for excavating link equipment 15 - 20%, for crushing-conveyor equipment 20 - 45% of total costs for main equipment of cycle-flow technology complexes. The share of costs for crushing and conveyor equipment increases significantly (1.6 - 1.7 times) with increasing height of mining mass rise (from 100 to 600 m) and decreases (by 20 - 23%) with increasing volume of traffic (from 5 to 30 million tons per year).

It should be noted that in the total costs of complexes the costs of mining and capital works related to the placement of crushing and reloading points and conveyor lifts in the quarry are very significant. The general trend of changing the share of costs for them is a significant increase in them with the increase in the height of rise of the transported material and a less intense decrease with the increase in the annual volume of transportation of the mountain mass. In this connection, the share of the passive part of capital investments in the cycle-flow technology with conventional belt conveyors is 14-78%, and with steeply inclined conveyor lift - within the limits of 12.5 - 47%.

The operating costs of cycle-flow technology (CFT) complexes are similar to those of capital expenditures.

The studies have established trends and intensity of change of specific indicators depending on the annual volume of transportation and height of lifting to conveyor transports of mountain mass. In systems of cycle-flow technology (CFT) with conventional belt conveyors with capacity of 5 - 30 million tons per year with increase of height of mining mass lifting from 100 to 600 m, specific capital costs for main equipment change by 4.9 - 2.1 times, and specific operating costs by 2.1 - 1.6 times. When used in systems of cycle-flow technology (CFT) of steeply inclined conveyors, the intensity of change of specific capital costs and specific operating costs is significantly lower and is, respectively, 3.3 - 1.7 and 1.8- 1.5 times (figure 1).

For every 100m increase in lift height the specific values are increased: when conventional belt conveyors are used in conveyor lines, respectively, by 35 - 16% and 16 - 10%; When used in conveyor lines, steeply inclined conveyors, respectively, by 25 - 12 and 12 - 8%. The intensity of increasing costs decreases with the growth of annual productivity of cycle-flow technology complexes.

On the other hand, with the increase in the volume of transport of the rock, the specific capital and operating costs are reduced (figure 2): when conventional belt conveyors are used in conveyor lines, respectively, by 1.4 - 3.0 and 1.3 - 1.7 times; When used in conveyor lines, steeply inclined conveyors are 1.3 to 2.5 and 1.2 to 1.5 times respectively. Intensity of cost reduction increases with increase of height of transported material.

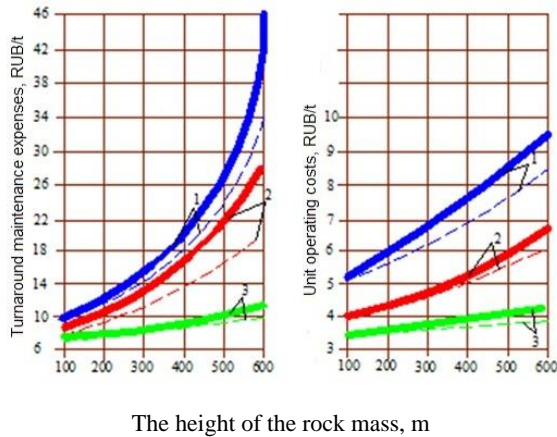


Figure 1 –

Change in specific capital costs and operating costs for cyclic-flow technology complexes depending on the height of the rock mass: 1,2,3, - respectively, with the annual productivity of the complex 5, 10, 30 million tons; solid lines - with conventional conveyors, dashed lines - with steeply inclined double-circuit conveyors

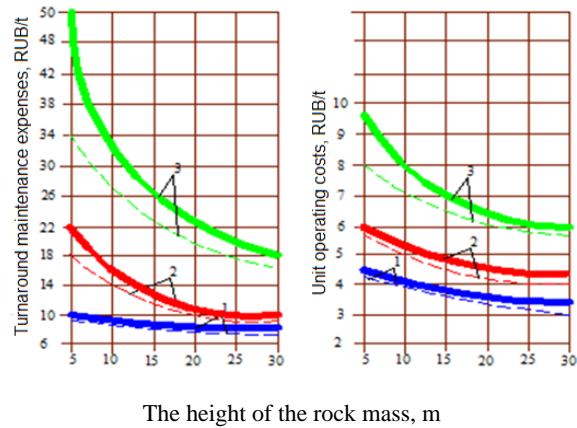


Figure 2 –

Change in specific capital costs and operating costs for cyclic-flow technology complexes depending on annual productivity: 1,2,3, - respectively, when the height of the rock mass is 100, 300, 600 m; solid lines - with conventional conveyors, dashed lines - with steeply inclined double-circuit conveyors

The total energy saturation of cycle-flow technology (CFT) complexes, determined by the required installed capacity of the main technological equipment, increases significantly with the increase in the height of mining mass rise and annual productivity. The most energy-saturated is the link of road transport, the largest share of which in the total installed capacity of equipment of systems of cycle-flow technology reaches 77% and slightly decreases (to 51 - 57%) with increase of height of mining mass lifting by conveyor transport and increase of installed capacity of equipment of the complex. The share of the latter in the total installed capacity of equipment of cycle-flow technology (CFT) complexes varies within 13 - 37% depending on the height of mining mass lifting and annual productivity. The least energy intensive process is mining and loading. The share of excavating link in the total installed capacity of investigated complexes of cycle-flow technology is 8-15%.

Specific energy saturation per 1 t of rock mass developed using cyclic-flow technology varies within the range of 1.3 - 1.9 W/t. The value of this indicator increases with the height of the rise and is practically independent of the annual volume of traffic. The influence of the inclination angle of the belt conveyors on the specific energy saturation of the cycle-flow technology complexes has not been established. When completing cycle-flow technology complexes, equipment with lower installed capacity should be accepted. This determines less power consumption during operation.

Annual productivity of one operating complex of cycle-flow technology is 28 - 87 thousand tons of mining mass. To a large extent it depends on the volume of transported rock mass and used equipment in the excavating and automobile complex. Thus, the increase in the annual volume of traffic from 5 to 20 million tons when used in the excavating and automobile complex of excavators ECC-5 and trucks with a load capacity of 42 tons gives an increase in labor productivity per worker by 28 - 32%. On the other hand, the increase in the annual volume of traffic under the cycle-flow technology from 20 to 30 million tons and the use of excavators on the loading of the mountain mass is ECC-8E, and as an assembly transport of trucks with a load capacity of 100 - 110 tons allows to increase labor productivity by almost 2 times.

At the height of rock lifting by conveyor and 100 m, the number of workers in the excavating and automobile complex reaches 76-90% of the total number of workers in the complexes of cycle and flow technology. With the increase of the height of the mountain mass rise to 600 m, the share of the service personnel of excavating and automobile complexes decreases to the 60 - 82% of the total number of workers, at the same time the link of assembly road transport serves the 45 - 65% of all working in the system of cycle-flow technology. Number of maintenance personnel of crushing-conveyor complexes varies slightly with increase of annual volume of transportation and increases with increase of height of lifting of rock mass by conveyor lift up to 6 - 7%.

Parameters of compared conveyor's types

Production, million t /year	Lifting height, m	Capital expenses, RUB/t	Exploit. expenses, RUB/t	Productivity of labor, t per 1	Specific metal-capacity, kg/t	Specific energy saturation, W/t	Weight of equipment, t		CCC	Installed power, kW	
							autotransport	excavator			
5	100	11,3	4,6	37037	0,33	1,25	590,2	351,6	825	4416	990
	200	10,8	4,5	37879	0,36	1,27	588,1	351,6	925	4416	990
	300	15,4	5,3	35211	0,35	1,39	728,4	351,6	1525	4416	990
	400	13,4	5,0	37037	0,38	1,34	675,3	351,6	1275	4416	990
	500	21,4	6,0	33557	0,40	1,45	828,6	351,6	1825	4416	990
	600	17,2	5,6	36232	0,39	1,51	779,4	351,6	2215	4416	990
	100	29,2	9,6	32051	0,43	1,63	931,8	351,6	2725	4416	990
	200	21,9	6,3	37514	0,40	1,75	858,6	351,6	2625	4416	990
	300	39,1	8,2	29240	0,42	1,61	1078,9	351,6	3325	4416	990
	400	27,9	7,1	34965	0,30	1,72	948,8	351,6	3215	4416	990
	500	51,1	9,6	28090	0,03	1,72	1049,8	673,9	1600	8464	1650
	600	35,1	8,1	34247	0,31	1,17	1088,6	673,9	1600	8464	1650
100	8,9	4,1	44643	0,31	1,17	1077,1	673,9	1600	8464	1650	
200	8,7	4,1	45045	0,31	1,27	1234,4	673,9	2540	8464	1650	
300	11,1	4,4	43290	0,31	1,26	1212,3	673,9	2530	8464	1650	
400	10,1	4,3	44643	0,33	1,38	1431,6	673,9	3650	8464	1650	
500	14,2	4,9	40486	0,32	1,37	1347,4	673,9	3540	8464	1650	
600	12,2	4,7	44053	0,34	1,45	1562,8	673,9	4430	8464	1650	
100	18,2	5,4	39370	0,34	1,53	1520,6	732,5	4410	9200	1980	
200	14,9	5,3	39841	0,37	1,68	1816,9	703,2	6320	8832	1650	
300	23,5	6,2	36232	0,36	1,61	1642,8	732,5	5250	9200	1650	
400	17,9	5,7	39370	0,41	1,78	1959,2	732,5	6650	9200	1980	
500	29,9	7,1	32468	0,27	1,73	1790,8	1318,5	6430	9200	1650	
600	21,5	6,2	38911	0,27	1,14	1647,8	1318,5	2865	16560	3300	
100	7,4	3,7	48426	0,29	1,17	1624,8	1377,1	2805	17296	3300	
200	9,2	4,1	45352	0,28	1,27	1939,5	1377,1	4755	17296	3300	
300	8,3	4,0	46948	0,32	1,25	1832,1	1406,4	4755	17664	3300	
400	11,1	4,5	43384	0,33	1,46	2598,9	1465,0	7080	18400	3300	
500	10,3	4,6	42827	0,34	1,49	2929,1	1406,4	8800	17664	3300	
600	13,2	4,8	42735	0,35	1,53	2825,3	1465,0	8600	18400	3300	
100	11,7	4,8	42644	0,37	1,65	3237,8	1465,0	10900	18400	3630	
200	16,2	5,5	39293	0,37	1,74	3234,8	1552,9	11740	19504	3630	
300	13,7	5,3	40242	0,39	1,80	3568,9	1523,6	13300	19136	3630	
400	19,5	6,1	37383	0,38	1,80	3374,4	1552,9	12850	19504	3630	
500	15,5	5,6	40000	0,21	1,18	1586,3	1914,0	3450	25476	3640	
600	7,8	3,6	87464	0,23	1,14	1602,0	1972,0	3710	26248	4160	
100	8,1	3,7	83333	0,24	1,22	1956,4	1914,0	6150	26248	4160	
200	9,0	3,9	79365	0,24	1,29	2088,0	2088,0	6730	27792	4160	
300	10,3	4,1	77320	0,25	1,36	2370,4	2088,0	9500	27020	4160	
400	9,8	4,2	75188	0,27	1,39	2310,5	2088,0	9750	27792	4160	
500	12,0	4,6	70423	0,29	1,48	2750,4	2262,0	12350	27792	4160	
600	11,3	4,7	69444	0,32	1,60	2719,2	2262,0	13100	30108	4680	
100	14,2	5,2	65934	0,32	1,63	3231,1	2204,0	15200	29336	4160	
200	12,4	4,9	69124	0,3	1,68	2988,8	2262,0	15500	30108	4680	
300	16,7	5,7	61728	0,32	1,79	3692,1	3692,1	18950	30108	4680	
400	14,1	5,4	65076	0,32	1,86	2378,0	3479,1	19350	31652	4680	

Note. In the numerator are indicators of conventional conveyors, in the denominator are indicators of steeply inclined conveyors.

Analysis of the calculated data showed that the annual productivity of one operating complex of cycle-flow technology with steeply inclined conveyor lift in most cases is higher than that of complexes of cycle-flow technology (CFT), conveyor lines of which are equipped with conventional belt conveyors. The general trend of reduction of labor productivity (by 10-25%) with increase of lifting height from 100 to 600 m will continue regardless of annual volumes of processing of mining mass by complexes of cycle-flow technology (CFT). It has been found that at their annual capacity of up to 10 million tonnes, steeply inclined conveyors should be used at a rock lifting height of more than 100 - 200 m. Under these conditions, at lower specific operating costs (per 5-15%), the specific capital costs of cycle-flow technology complexes with steeply inclined conveyors are significantly lower (per 13-30%) than with conventional belt conveyors. In addition, the use of steeply inclined conveyors is preferable in productivity per worker (higher per 8 - 20%). With increase of productivity of cycle-flow technology (CFT) complexes up to 20 - 30 million tons per year, it is expedient to use steeply inclined conveyors at height of rock mass lifting more than 200 - 300 m. Under these conditions, at practically equal specific operating expenses, specific capital costs for cycle-flow technology (CFT) complexes with steeply inclined belt conveyors are lower by 6 - 20%.

From the point of view of environmental protection, the use of steeply inclined double-loop conveyors on quarries is also more preferable: additional volumes of rock mass are reduced by 1.4 - 1.6 times along the extension of quarries sides, and therefore the need for land withdrawal for empty rocks is reduced; Dust and gas emissions to the atmosphere are significantly reduced.

Conclusions and further directions of research.

1. The results of the performed studies show high efficiency of application on deep quarries of complexes of cycle-flow technology with steeply inclined conveyors.

2. Technological parameters and composition of the equipment should be determined taking into account the dynamics of mining operations and the transport system of the quarry as a whole.

3. When selecting the equipment of the crushing-conveyor complex, priority should be given to the equipment of the block-modular open design, which will allow to ensure technological flexibility of the used complexes of cyclic-flow technology in changing mining technical conditions.

4. In the future, the development of personal and flow technology on deep quarries should be based on progressive technological and technological solutions, ensuring increased efficiency, competitiveness, as well as expansion of the sphere of its application.

5. The solution of the problem of development of deep horizons of quarries is closely connected with improvement of technological schemes in cycle-flow technology, transition to flexible technologies. The requirements of deep pit development are best met by cycle-and-flow technology (CFT) systems using mobile crushing and reloading plants and steeply inclined belt conveyors, which ensure rapid installation and dismantling of complexes. Technical and economic calculations and data on foreign firms show high efficiency and prospects of cycle-flow technology with application of steeply inclined conveyor lifting.

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ТІК ЕҢКІШТІ КОНВЕЙЕРЛЕРДІ ҚАРЬЕРДЕ ҚОЛДАНУДЫ САЛЫСТЫРМАЛЫ ТАЛДАУ

Аннотация. Зерттеулердің мақсаты – кенді кенорындарын ашық тәсілмен қазу кезінде тік еңкішті конвейерлерді қолдана отырып, үзілмелі-толассыз технологияның бейімделу әдістерін анықтау.

Тік еңкішті конвейерлі көтерудің тиімділігі мен қолдану жағдайларының артықшылығы таңдалған бағалау критерийлері бойынша үзілмелі-толассыз технологияның іргелес бөлімшелерінің өзара байланысын ескере отырып, ғылыми негізделген қағидалардың нұсқаларын салыстыра отырып анықталады. Тік еңкішті конвейерлі көтерудің тиімділігі жабдықтың жұмыс режимін, техникалық параметрлерін және пайдалану сипаттамаларын ескере отырып, экономика-математикалық модельдеу арқылы есептеледі.

Бағалау критерийлерінің өзгеруінің әдеттегі және тік еңкішті конвейерлі үзілмелі-толассыз технологияның кешендерінде пайдалану кезіндегі негізгі әсер етуші факторларға тәуелділігі талданған.

Қысқыш ленталы тік еңкішті конвейерлер мен құбырлы тік еңкішті конвейерлердің параметрлері кен өндірудің терең аршықтарда қолдану жағдайларына сәйкес анықталған.

Конвейерлі көтергіш трассасының еңкею бұрышы мен кен массасын көтеру биіктігінің, ұсатқыш-конвейерлі кешендерінің негізгі көрсеткіштеріне әсері анықталған.

Тік еңкішті конвейерлі көтергіштермен жабдықталынған үзілмелі-толассыз технологиялық кешендер мен әдеттегі конвейерлі көтергіштермен жабдықталған үзілмелі-толассыз технологиялық кешендерді пайдаланудың техника-экономикалық талдау нәтижелері келтірілген.

Терең кенді аршықтар, қолдану жағдайларына сәйкес, қысатын таспалы тік еңкішті конвейерлер мен құбырлы тік еңкішті конвейерлердің шама шарттарын салыстыру нәтижелері келтірілген.

Ғылыми-техникалық және патенттік ақпаратты талдау нәтижелері, кен массасын және басқа да сусымалы материалдарды тік еңкішті көтеру үшін қолданылатын таспалы конвейерлердің құрылмасының түбегейлі айырмашылығы жүкті 18 °-тан жоғары шамада көтеру барысында, оларды домалап кетпеуін сақтау үшін қабылданған техникалық шешімде жатады. Кенді көтеру тәжірибесінде келесі таспалы тік еңкішті конвейерлерді қолданады: кенді 25-27 ° бұрышпен көтеруді қамтамасыз ететін кедір-бұдырлы конвейерлер; көлденең бөгеттері бар (90 ° дейін); түрлі құбырлы (30-50 ° дейін); қысым таспасы бар (50-90 ° дейін).

Ресей ғылыми академиясының Орал бөлімшесінің тау-кен институты алғашқыда жүргізген ғылыми зерттеулерде, терең кен өндіру аршықтарының жағдайларына сәйкес, қолдануда қысатын таспалы тік еңкішті конвейерлер мен құбырлы тік еңкішті конвейерлердің шама шарттары анықталған.

Құрылымдаушы зерттеулерінің нәтижелері көрсеткендей, құбырлы тік еңкішті конвейерлер, қысатын таспалы тік еңкішті конвейерінен негізгі шама шарттары бойынша едәуір төмен екені анықталды, яғни көтерудің максималды биіктігі – 2-3 есе (көтерудің максималды биіктігі – 80-85 м); өнімділігі бойынша 1,8-3,2 есе (мүмкін болатын максималды өнімділігі жылына 6,5-7,0 млн. тонна) төмен.

Сонымен қатар құбырлы конвейердің құрылмасы қажалуға төзімділігі жоғары арнайы сым арқанды қолдануды қарастырады.

Аталған факторларды және конвейердің жеке құрамдас бөліктерін ескере отырып, терең аршықтарда құбырлы тік еңкішті конвейерлерін тиімді пайдалану мүмкіндігі жоққа шығарылады.

Тік еңкішті конвейерлі көтергіштердің әртүрлі орнату бұрыштарына сәйкес 50-60° және тасымалданатын материалдың көтеру биіктігі 100-600 м аралығындағы, күрделі және пайдалану шығындарының салыстырмалы шамалары анықталынған.

Тік еңкішті конвейерлерін пайдаланудың тиімді жағдайлары күрделі үлесті шығындар мен жалпы шығындар, пайдалану үлесті шығындар мен жалпы шығындар, еңбек өнімділігі, үлесті металсыйымдылығы және үлесті энергиясыйымдылығын қосқандағы есептік көрсеткіштерді талдау негізінде анықталды.

Зерттеу нәтижелері көрсеткендей, тік еңкішті конвейерлі көтергіштердің орнату бұрыштары 35°-тан жоғары болған жағдайда, әдеттегі конвейерлік көтергіштерден гөрі тиімді және зерттеу жағдайларда жалпы күрделі шығындарды жылына 20-100 млн.руб., ал жалпы пайдалану шығындарды жылына 3,5-4,5 млн.руб. азайтуға мүмкіндік береді.

Түйін сөздер: үзілмелі-толассыз технология, терең аршықтар, мобильді ұсақтау және қайта-тиееу қондырғылары, тік еңкішті конвейер, шоғырлау денгейжик, үлестік шығындар, зерттеу.

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СРАВНИТЕЛЬНЫЙ АНАЛИЗ ПРИМЕНЕНИЯ КРУТОНАКЛОННЫХ КОНВЕЙЕРОВ НА КАРЬЕРАХ

Аннотация. Целью исследования является определение методов адаптации циклично-поточной технологии с применением крутонаклонных конвейеров при разработке рудных месторождений открытым способом.

Установление эффективности и условий предпочтительного применения крутонаклонного конвейерного подъема проводится с использованием научно обоснованных принципов сравнения вариантов с учетом взаимосвязи смежных звеньев циклично-поточной технологии по выбранным критериям оценки, рассчитываемых по экономико-математической модели, учитывающей режим эксплуатации, технические параметры и эксплуатационные характеристики оборудования.

Проведён анализ зависимостей изменения оценочных критериев от основных влияющих факторов при использовании в комплексах циклично-поточной технологии традиционных и крутонаклонных ленточных конвейеров.

Приведены результаты сравнения параметров крутонаклонных конвейеров с прижимной лентой и трубчатых крутонаклонных конвейеров применительно к условиям глубоких горнорудных карьеров.

Результаты анализа научно-технической и патентной информации свидетельствуют, что принципиальное отличие в конструктивном исполнении ленточных конвейеров, используемых для крутонаклонного подъема горной массы и других сыпучих материалов, заключается в принятом техническом решении по удержанию груза от скатывания при углах подъема более 18°. Существуют следующие виды крутонаклонных ленточных конвейеров с рифлеными лентами, обеспечивающими подъем груза под углом до 25-27°; с поперечными перегородками (до 90°); трубчатого типа (до 30-50°); с прижимной лентой (до 50-90°).

Одним из главных направлений повышения эффективности работы глубоких карьеров является применение циклично-поточной технологии на основе автомобильно-конвейерного транспорта, с использованием в поточном звене ЦПТ крутонаклонного конвейера. В настоящее время применение ЦПТ на карьере Мурунтау (Республика Узбекистан) позволило сократить расстояние транспортировки руды автотранспортом на 30-40%, снизить высоту её подъема автосамосвалами на 50-70%, сократить количество автосамосвалов, работающих на карьере и уменьшить загазованность на 30%.

В ранее выполненных Институтом горного дела Уральского отделения Российской академии наук научных исследованиях определены параметры крутонаклонного ленточного конвейера с прижимной лентой и трубчатых крутонаклонных ленточных конвейеров применительно к условиям глубоких горнорудных карьеров. Результаты конструкторских проработок показали, что трубчатый крутонаклонный ленточный конвейер по основным параметрам значительно уступает крутонаклонному ленточному конвейеру с прижимной лентой: по максимальной высоте подъема в 2-3 раза (предельная высота подъема - 80-85 м); по производительности в 1,8- 3,2 раза (максимально возможна производительность – 6,5-7,0 млн т/год. Кроме того, конструкция трубчатого конвейера предполагает использование специальных тросов с повышенной устойчивостью на истирание, а ограничения по минимально допустимым величинам радиусов переходных вертикальных кривых по трассе конвейера требуют устройства в карьере горизонтальных площадок для размещения узлов загрузки конвейера шириной до 75-80 м. С учетом совокупности указанных факторов, а также ряда сложных конструктивных решений по отдельным составным частям конвейера исключается возможность эффективного применения трубчатых крутонаклонных ленточных конвейеров в глубоких карьерах.

Определено влияние угла наклона трассы конвейерного подъемника и высоты подъема горной массы на основные показатели дробильно-конвейерных комплексов. Приведены результаты технико-экономического анализа применения комплексов циклично-поточной технологии с крутонаклонными конвейерными подъемниками и обычными. Определены сравнительные величины капитальных и эксплуатационных расходов при различных углах установки крутонаклонного конвейерного подъемника при высоте подъема транспортируемого материала 100 - 600 м и углах подъема до 50 - 60°.

Эффективные условия применения крутонаклонных ленточных конвейеров устанавливались на основании анализа оценочных показателей, включающих суммарные и удельные капитальные затраты, суммарные и удельные эксплуатационные расходы, производительность труда, удельную металлоемкость и удельную энергонасыщенность, которые определялись в целом для комплекса циклично-поточной технологии.

Результаты исследований показывают, что крутонаклонные конвейерные подъемники при углах их установки более 35° эффективнее обычных ленточных конвейерных подъемников, что в рассматриваемых условиях дает возможность уменьшить суммарные капитальные затраты на 20–100 млн руб., а суммарные эксплуатационные расходы – на 3,5-4,5 млн рублей в год.

Ключевые слова: циклично-поточная технология, глубокие карьеры, мобильные дробильно-перегрузочные установки, крутонаклонный конвейер, концентрационный горизонт, удельные затраты, исследование.

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zyekudayeva@gmail.com, yissekeshev@gmail.com, nuraksulu72@mail.ru**POLYNOMIAL TIME ALGORITHMS
FOR SOLVING NP-COMPLETE PROBLEMS**

Abstract. The paper proposes algorithms with a polynomial time complexity and memory for solving the Subset Sum problem. The algorithm is obtained by using a combination function and mapping, the arguments of which are input data with a given length and a certificate. The work with indices of the input data is based on combination function and the combination generation algorithm. Mapping and combination function help to deal with an exponential time complexity of existing algorithms and solve combinatorial problems with constraints. In fact, the proposed algorithms solve the Millennium problem posed by S.A. Cook in a polynomial time. The proposed algorithms are applicable for input data with a given length together with the certificate with a given value.

Key words: polynomial algorithms, the Subset Sum problem, NP-complete problems.

Introduction. One of the most important problems in computer science is the equality of classes P and NP. This problem was formulated in 1971 and still remains unsolved. Currently, the completeness of more than 3000 problems from the NP class has been proved. In addition, P vs NP is one of the seven Millennium Prize Problems, which emphasizes the problem's enormous complexity and fundamental nature.

The main idea of NP-complete is that NP problems can be reduced to NP-complete in polynomial time. Examples of NP-complete problem are the Knapsack problem and the Subset Sum problem among others. The Knapsack problem is a combinatorial optimization problem with constraints. Moreover, the Subset Sum problem is a subproblem of the Knapsack problem. A pseudo-polynomial algorithm exists to solve the Knapsack problem, the algorithm using dynamic programming. Therefore, all NP-complete problems are important.

Let us cite the famous S.A. Cook's problem setup: Could the verification of the correctness of a solution to the problem take longer (in terms of time) than the time it takes to find that solution, regardless of the verification algorithm. In other words, Cook's problem states that the time for the verification of any solution is less than the time required to solve the problem.

In [1] algorithms of combinatorial problems were divided into verification and solving problems, with the possibility to study their complexity. In addition, it implies dependence on the input data X and certificate S in Boolean form, $A(X,S)=1$.

The complexity of the algorithm disclosed in [1,2] is determined based on the function $f(n) = O(g(n)) \leftrightarrow \exists(C > 0), n_0: \forall(n > n_0) f(n) \leq Cg(n)$. The function $f(n)$ is asymptotically upper bounded by $g(n)$ by up to a factor C . An algorithm is polynomial if the complexity of function $f(n)$ can be represented by $f(n) = O(n^k)$, where k is a constant regardless of the length of the input data n . This is equivalent to $f(n) = O(p(n))$, in which the degree of the polynomial $p(n)$ does not exceed k .

The aim of this paper is to solve any NP-complete problem in a reasonable time, but not the proof of Cook's problem.

First of all, we should find algorithms which can solve the problem in a reasonable (polynomial) time. Let us note that the verification algorithms have polynomial time complexity.

The solution to the problem. As a basic problem of the NP-complete class, let us consider the Subset Sum problem. The computational complexity of the Subset Sum problem depends on the size of the input data n and the accuracy p (defined as the number of binary bits in the numbers that make up the set and certificate S). This exponential dependency on the input size was established when solving the Knapsack problem in [3,4].

The aforementioned algorithms are considered the best among the known exponential time algorithms for solving the Subset Sum problem.

However, these algorithms do not handle the indices of the original sets for defining subsets, whose sum of elements is equal to the certificate S , and only later on the Gray code is supposed to be used. In addition to that, an exponential growth complicates their application in practice. In the process of solving the problem, additional information embedded in the certificate S was not used.

Questions always arise to address these limitations. In [5], a new approach was proposed for solving the Subset Sum problem.

The idea of the approach is as follows:

- determine a range to which the certificate S belongs;
- determine the dimension m of the subset X_m over that range;
- define mapping $\tau(x, S)$ of the original set X^n into another set Y^n : $y_i = \tau(x_i, S), x_i \in X^n, i = 1, 2, \dots, n$;
- check the condition $y_i = y_j, i \neq j$, that verifies the certificate $S = x_i + x_j$;

We propose new algorithms for the Subset Sum problem X_m with dimensions two, three and four ($m=2, m=3, m=4$) belonging to the n -dimensional set X^n , with the advantage of time and memory optimization. For larger dimensions including four or more, we consider the composition of the Subset Sum algorithms X_m with dimensions two, three and more.

In the next paper [6] we further develop the proposed approach, where variable m could take even numbers 4,6,8,10 or more.

The idea of developing the approach is as follows:

- construct the subset $Z^l = \{z_1, z_2, \dots, z_l\}$ consisting of k elements $x_i \in X^n$ with indices determined by the generation algorithm of the combination C_n^k from the set $X^n, l = C_n^k, k \leq m/2$;
- define the mapping $\tau(z, S)$ of the subset Z^l into the set Y^l : $y_i = \tau(z_i, S), z_i \in Z^l, i = 1, 2, \dots, n$;
- the condition $y_i = y_j (i \neq j)$ guarantees that a subset $X_m = \{z_i\} \cup \{z_j\}$ with mismatching indices and automatic implementation of certificate $S = \sum_k \{z_i\} + \sum_k \{z_j\}$.

In other words, this corresponds to forming subsets X_m with parameters $m=4, m=6$ and more. Here, the certificate calculations $S = \sum_k \{z_i\} + \sum_k \{z_j\}$ and the complexity of the algorithm is reduced at least twice. The inequality $i \neq j$ means that you can always choose the indices i, j to form a subset of X_m with mismatching indices (which follows from the combination generation algorithm). This is the underlying essence of the proposed algorithms for solving the Subset Sum problems. The formation of subsets X_m with odd values for the parameter m was fully described in [5].

The algorithm is summarized as follows:

$$X^n \rightarrow C_n^k \rightarrow Z^l \rightarrow \tau(z, S) \rightarrow Y^l \rightarrow y_i = y_j \rightarrow X_m = \{z_i\} \cup \{z_j\}, l = C_n^k, k \leq \frac{m}{2}.$$

Further formation of these subsets with parameter $m > \frac{n}{2} + 1$ is not necessary. This follows from the basic properties of the combination function. The form of the map $\tau(z, S)$ is given in [5].

Methods of reducing complexity of the proposed algorithms. *Method 1.* For the value $S_i'' = \sum_k \{z_i\}$, a subset $\{z_i\}$ is formed from Z^l . The value of S_i' is found by the equation $S_i' = S - S_i''$. The subset $\{z_j\}$ corresponding to S_i' is found by the algorithm using the set X^n or via the subset Z^l using a binary search. Moreover, these quantities allow us to form the subsets $X_m = \{z_i\} \cup \{z_j\}$ with mismatching indices from the original set X^n based on $S = S_i' + S_i''$. The complexity of the algorithms is stepwise reduced by two or more times.

Method 2. Dividing the set X^n into k subsets with lower dimension. Then, combinations of subsets are considered to form X_m . The complexity of the algorithms is stepwise reduced by two or more times.

Method 3. Parallelization of the necessary operations generated by a simple software implementation of algorithms for solving the Subset sum problem in order to use all the existing capabilities of computing devices and hardware. The complexity of the algorithms is stepwise reduced by two or more times.

Thus, a scientific direction for the study of problems from the NP-complete class has been developed.

Let us give an example to show how the algorithm works. Suppose there is a set $X^8 = \{17, 43, 38, 14, 20, 10, 36, 47\}$ with dimension $n=8$. The problem asks to determine if there exists a subset $X_m = \{x_i, x_j, x_k, x_h\}$, where the sum of the subset's elements fulfils $S=120$. Here the certificate S is $S \in [S_{min}^4, S_{max}^4] = [61, 164]$. Therefore, the parameter $m=4$. Let's sort the original set X^8 in ascending order, then the sorted $X^8 = \{10, 14, 17, 20, 36, 38, 43, 47\}$. Next, form a subset $Z^l = \{z_1, z_2, \dots, z_l\}$, consisting of two elements x_i with indices defined based on C_n^k , from the set X^n , $l = C_n^k, k = \frac{m}{2}, l = 28$. Now, now apply the algorithm from [5] or the algorithm given above to the subsets to form subsets. Then, apply the algorithm from [5] or the algorithm given above to the subset Z^l to form subsets $X_4 = \{x_1, x_4, x_7, x_8\}$ or $X_4 = \{x_3, x_4, x_5, x_8\}$, where the sum of elements of each of them is 120.

Now we show the possibility of applying these algorithms to any set X^n and any subset X_m , for example, X^{1024} , X_{60} , S . We divide the sorted set X^n into 32 subsets with dimension 32. Then we get a subset Z^l based on the combination C_{32}^{30} , $l = 486$. The number of subsets X_{30} will be $C_{32}^2 = 486$ to form the subset X_{60} . Thus, to construct a subset X_{60} with an arbitrary certificate S , 234196 combinations are required. This means that we have shown the possibility of solving the Subset Sum problem in a reasonable time, more precisely, solving the problem of the sum of subsets with modern computers.

It is easy to determine the upper bound for the run time of the algorithm and the required memory. Then the running time of the algorithm from the second approach will be $T = O(C * l)$, for some constant C , the required memory is $M = O(l)$, $l = C_n^k, k \leq \frac{m}{2}$.

These estimates allow us to state that the Subset Sum problem is solvable on modern computers, and the brute force approach for the Subset Sum problems even using modern computers is not reasonable.

Conclusion. We conclude that although the question of the equality of classes P and NP has not yet been solved, many scholars tend to believe that they are not equal. This statement is valid for the problem posed by Cook and it follows from the proposed algorithms. But the final point in the dispute will be set only by rigorous mathematical proof.

However, the effectiveness of the proposed polynomial-time algorithms found on the basis of the developed approach to solve the Subset Sum problems, including NP-complete problems, confirms the existence of a solution to the same problem in a reasonable amount of time. This conclusion is very important for practice and computer science. In fact, a method is proposed for solving the Millennium problem posed by Cook with a polynomial time algorithm. A patent [7] for a computer system with a high processing speed of big data was obtained.

Finally, we note possible applications

The application scope of the results
in practice:

1. Big data;
2. Search engines;
3. Encryption systems;
4. Coding systems;
5. Banking systems;
6. Payment systems;
7. Intelligent systems;
8. Medical diagnostic systems;
9. Many other systems.

The application scope of the results
in theory:

1. Search problem;
2. Satisfiability problem;
3. Theory of algorithms;
4. Decision problem;
5. Encipherment problem
6. Encryption problem;
7. Knapsack problem;
8. Traveling salesman problem;
9. Many other problems.

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NP-COMPLETE КЛАСЫ ПРОБЛЕМАЛАРЫНА АРНАЛҒАН ПОЛИНОМИАЛДЫ АЛГОРИТМДЕР ТУРАЛЫ

Аннотация. Мақалада жиынтықтар есебін шешуге арналған көпмағыналы уақыт пен жадқа тәуелділігі ұсынылған алгоритмдер сипатталған. Бұл көпмүшелік тәуелділік біріктірілген және дисплей функциясын енгізу арқылы алынады, олардың дәлелі берілген ұзындықтағы және куәлікпен енгізілетін мәліметтер болып табылады. Кіріс деректерінің индекстерімен жұмыс комбинация функциясы мен құрама алгоритмге негізделген. Енгізілген карта мен үйлесімділік функциялары экспоненциалды алгоритмдердің күрделілігіндегі өсудің жарылғыш сипатын және шектеулермен комбинаторлық оптимизация мәселелерін шешеді. Шын мәнінде, Кук жасаған көпжылдық алгоритммен мыңжылдық проблемасын шешудің әдісі ұсынылған. Бұл әдіс берілген мәні бар сертификат болған кезде ақырлы ұзындықтағы мәліметтерді енгізу үшін қолданылады. Нәтижелер жиынтықтар есебін шешудің ұсынылған нақты алгоритмдері осы алгоритмдердің жұмыс істеу уақытын едәуір қысқартады, сонымен қатар компьютерлердің, серверлердің және басқа пайдаланылған есептеу құрылғыларының жабдықтарына қойылатын талаптарды азайтады. Өзірленген алгоритмдердің негізгі тұстарын суреттейтін мысалдар келтірілген. Жиындар есебін шешуге арналған ұсынылған математикалық теория көптеген теориялық және практикалық есептерді шешуге мүмкіндік береді. Бұл NP-complete класы проблемаларды зерттеуге арналған ғылыми бағыттың мәні.

Экспоненциалды алгоритмдердің басты кемшілігі - ақпаратты өңдеуге қажетті уақыт пен жад экспонент арқылы көрсетіледі, атап айтқанда $T^*M = O(2^n)$ уақытының жады (өңделген мәліметтердің n саны). Соңғы ескерту аппараттық құралдарға және ақпаратты өңдеудің басқа құралдарына қатаң талаптар қояды. Біз қолданыстағы алгоритмдердің қолданылу шегін анықтаймыз. Қойыңыз $n = 128$. 2^{64} элементтің ішкі жиынын сұрыптау үшін уақыты қажет $O(2^{70})$. Қазіргі компьютерлер мен ақпараттық технологиялар 2^{66} дерек көлемінде жұмыс істей алатыны белгілі. Осылайша, тіпті осындай ішкі жиынын сұрыптау қиын.

Түйін сөздер: полиномиальды алгоритм, жиынтықтар есебі, NP-complete класы.

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О ПОЛИНОМИАЛЬНЫХ АЛГОРИТМАХ ДЛЯ ЗАДАЧ ИЗ КЛАССА NP-COMPLETE

Аннотация. В работе описаны предложенные алгоритмы с полиномиальной по времени и памяти зависимостью по решению задачи о сумме подмножеств. Эта полиномиальная зависимость получена путем введения функции сочетания и отображения, аргументами которого являются входные данные с заданной длиной и сертификат. Работа с индексами входных данных осуществлена на основе функции сочетания и алгоритма генерации сочетаний. Введенные отображения и функции сочетания сглаживают взрывной характер роста трудоемкости экспоненциальных алгоритмов и решения задач комбинаторной оптимизации с ограничениями. Фактически предложен метод решения задачи тысячелетия, поставленной Куком, с полиномиальным временем работы алгоритма. Метод применим для входных данных конечной длины при

наличии сертификата с заданным значением. Полученные результаты показывают, что предложенные точные алгоритмы для решения задачи о сумме подмножеств существенно сокращают время работы этих алгоритмов, а также уменьшают аппаратные требования к мощности компьютеров, серверов и других используемых вычислительных устройств. Приведены примеры, иллюстрирующие основные положения разработанных алгоритмов. Предлагаемая математическая теория по решению задачи о сумме подмножеств позволит решить многие теоретические и практические задачи. Таков смысл разрабатываемого научного направления по исследованию проблем из класса NP-complete.

Основным недостатком экспоненциальных алгоритмов является то, что требуемое время и используемая память для обработки информации выражается через экспоненту, а именно время, умноженное на память $T \cdot M = O(2^n)$ (n -количество обрабатываемых данных). Последнее замечание налагает очень жесткие требования на аппаратные и другие средства обработки информации. Определим границу применимости существующих алгоритмов. Положим $n=128$. Для сортировки подмножества, состоящего из 2^{64} элементов, необходимо время $O(2^{70})$. Известно, что современные компьютеры и информационные технологии могут работать с количеством 2^{66} данных. Таким образом, даже сортировка такого подмножества затруднительна.

Ключевые слова: полиномиальный алгоритм, задача о сумме подмножеств, класс NP-complete.

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**THE DEVICE FOR MULTIPLYING POLYNOMIALS MODULO
WITH ANALYSIS OF TWO LEAST SIGNIFICANT BITS
OF THE MULTIPLIER PER STEP**

Abstract. We consider a device for multiplying polynomials modulo where two bits of the polynomial multiplier are analyzed per multiplication step. Such a device can serve as the basic unit for building cryptosystems based on non-positional polynomial number systems, where the binary representation of the polynomial multiplicand can show a fragment of the encrypted text, and the binary representation of the polynomial multiplier can serve as a secret key. The module is a binary representation of the irreducible polynomial of these two polynomials.

Key words: cryptosystem based on a polynomial number system, irreducible polynomials, polynomial multiplier modulo irreducible polynomials, remainders.

Introduction. Modern computing devices mainly operate in a positional number system. In such devices, when performing arithmetic operations on multi-bit numbers, it becomes necessary to take into account inter-bit transfers, which significantly slows down the calculation speed and complicates the structure of the computer.

In order to significantly improve the performance of computing devices, it is necessary to use number systems devoid of the disadvantages of a positional number system. Today, such a number system is the so-called "non-positional number systems", one of which is the "system of residual classes (RNS)" [1]. The use of RNS is an effective way of performing with a large discharge data. In particular, the use of RNS allows increasing the speed of the operation due to the lack of transfer. These features provide significant advantages of the RNS over the positional number system when performing modular operations of addition, subtraction and multiplication. This is especially true if multi-bit numbers act as operands. In this case, the multi-bit number is grouped into smaller blocks and each block is processed in parallel, which leads to faster execution of operations on the multi-bit number.

In Kazakhstan, the The Institute of Information and Computational Technologies (of the Ministry of Education and Science of the Republic of Kazakhstan conducts research and implementations of cryptographic information protection algorithms based on the non-positional polynomial number system (NPNS) [2–5]. In particular, algorithms for block symmetric data encryption based on the NPNS were developed and implemented. Of particular interest are the hardware-software and hardware methods for implementing NPSS, which can significantly accelerate the process of encryption and decryption of data due to parallel processing at the level of individual modules and bits inside the module, and key generation allows for integrity.

The main hardware/software and hardware cryptosystems are polynomial multipliers modulo irreducible polynomials, where routine calculations are performed to encrypt and decrypt data. In [6–11], multipliers of polynomials modulo irreducible polynomials were considered, where at each step of multiplication, the least significant or most significant bit of the polynomial multiplier was analyzed.

In this paper, we consider a device for multiplying polynomials modulo with an analysis of two bits of a polynomial multiplier, which allows to accelerate the process of multiplication.

Main part. The functional diagram of the considered polynomial multiplier is shown in figure 1. The device includes:

- a shift register RgB that shifts two bits in the direction of the least significant bit;
- a register RgP for storing the module $P(x)$;
- partial remainder formers PRF1 and PRF2;
- a register of partial remainders of the RgPR;

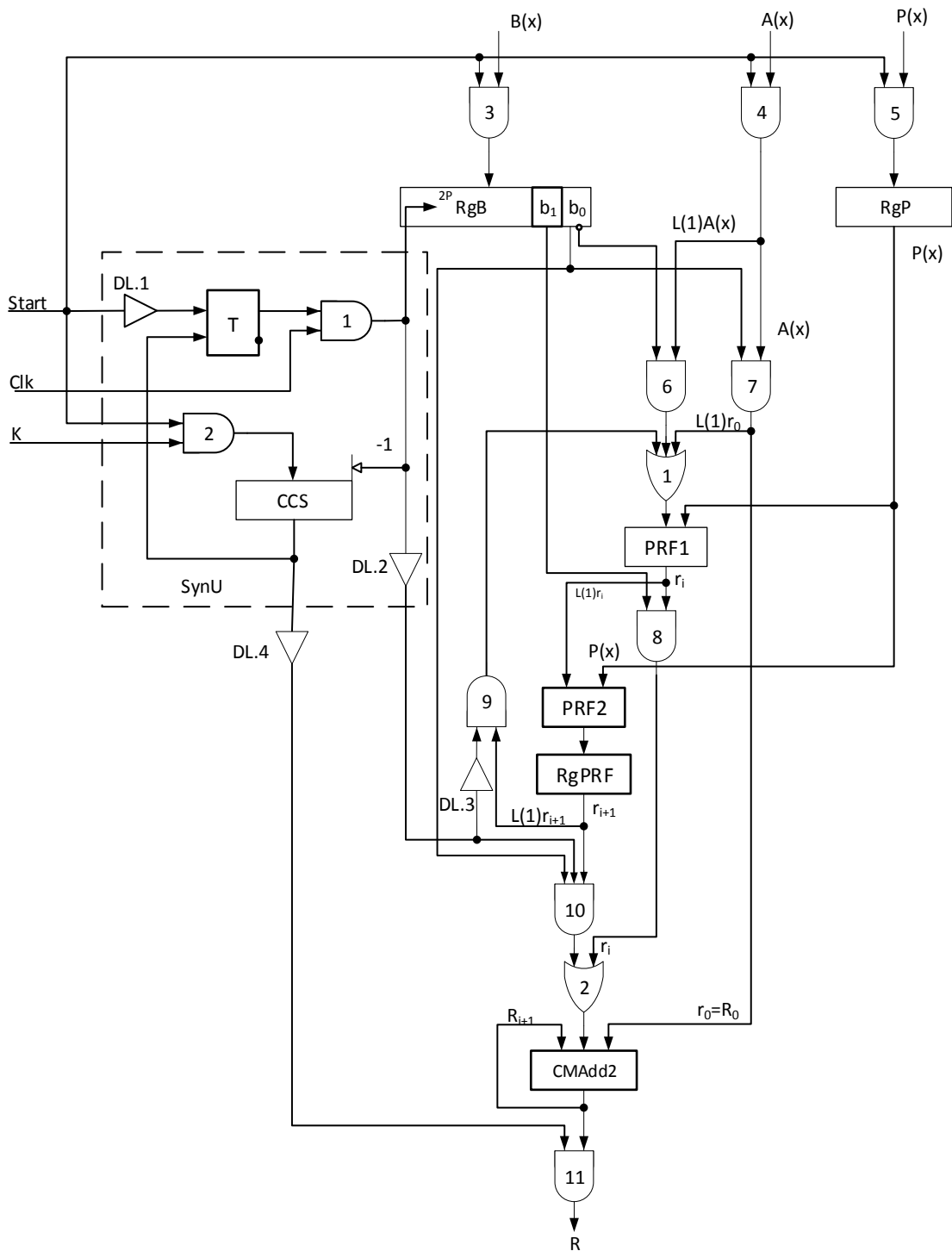


Figure 1 – The device for multiplying polynomials modulo with analysis of two bits of the polynomial multiplier per step

logical circuits And3 ÷ And11 gates;
 logical circuits OR1 and OR2 gates;
 delay lines DL.3, DL.4;
 cumulative adder modulo two (CMAAdd2);

a synchronization unit (SynU), which contains a flip-flop T, a counter of clock signals of the CCS, logical circuits And2 gates, delay lines DL.1 and DL.2.

The “Start” signal, the clock signals Clk, and the binary representation of the number of shifts K are fed to the SynU inputs. The polynomial of the multiplier B(x) is fed to the input of the RgB register through the block of circuits And3, the polynomial of the multiplicand A(x) through the block of circuits And4, and the irreducible polynomial P(x) is fed through a block of circuits And5.

Figure 2 shows the structure of the PRF, which consists of an modulo adder two and a multiplexer MS, containing blocks of circuits And1', And2' and OR', the inverter NOT of which is input to the most significant bit order bit (MS) of the doubled value of the remainder r_{i-1} . The inverter NOT output is connected to the control input of the block of circuits And2' and the control bit of the circuit block And1' is supplied with the most significant bit MS, the value of the doubled remainder $2r_{i-1}$, without inversions. The information inputs of the block of circuits And2' are supplied with the bits of the doubled remainder $2r_{i-1}$, and the information inputs of the block of circuits And1' are connected to the outputs of MAdd2.

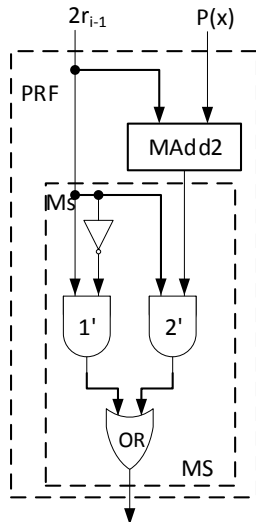


Figure 2 – Functional diagram of PRF

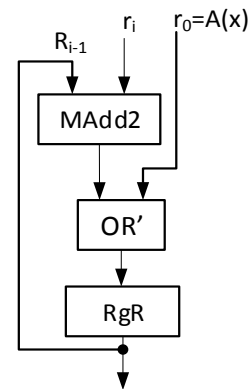


Figure 3 – Functional diagram CMAAdd2

When $M_S = 1$ ($2r_{i-1} > P(x)$), the result of summing $2r_{i-1} \oplus P(x)$ is fed through And1' to the output of the block OR'. In this case, a partial remainder $r_i = 2r_{i-1} \bmod P(x) = 2r_{i-1} \oplus P(x)$ is formed. At $M_S = 0$ ($2r_{i-1} < P(x)$), the value $2r_{i-1}$ is output through the blocks of And2' and OR' circuits, a partial remainder $r_i = 2r_{i-1}$ is formed.

The structure of the cumulative adder modulo two (CMAAdd2) is shown in figure 3, which consists of an adder modulo two (MAdd2), an intermediate remainder register RgR, where the values $R_i = R_{i-1} \oplus r_i$ are stored. As well as the values $r_0 = A(x)$, which is formed by the “Start” level at $b_0 = 1$ (where b_0 -bit of the binary representation of the polynomial multiplier B(x)).

The operation of the multiplication begins with the input to the input SynU signal “Start”. By this signal, the polynomial multiplier B(x) is received in the RgB register through the And3 circuit block, and the binary representations of the polynomial-irreducible polynomial module P(x) are received into the RgP register through the And5 circuit block. The binary representations of the polynomial A(x) are received through the block of circuits And4. The “Start” signal also writes the binary representations of the number of shifts – K to the CCS. After receiving the binary representations of the polynomial B(x) in the least significant bits of the register RgB, the values of the representations b_1 and b_0 are fixed. The positive output of the flip-flop, where the value of the bits b_0 is fixed, is connected to the inputs of the blocks of circuits And7 and And10, and the inverse output of this flip-flop is connected to the input of the block of

circuits And6. The positive output of the flip-flop, where the value of bit b_1 is recorded, is connected to the inputs of the block of circuits And8. The value of the multiplicand $A(x)$ with a shift by one bit in the direction of the most significant bits ($L(1) A(x)$) is fed to the inputs of the block of circuits And6 and without a shift, it is fed to the inputs of the block And7. With a value of $b_0 = 1$, the binary representations of the polynomial $A(x)$ without a shift is fed to the input of the register RgR CMAdd2 and with a shift by one bit in the direction of the most significant bit, it is fed to the moves of the block of circuits OR1. The outputs of OR1 are connected to the first inputs of the PRF1, and to its second inputs are fed binary coefficients of the polynomial $P(x)$. At the same time, the value of the first partial remainder r_1 is formed at the outputs of PRF1. With a value of $b_1 = 1$, the value of r_1 is fed to the inputs of the CMAdd2 through the blocks of circuits And8 and OR23. At the same time, at the its outputs, the value of the intermediate remainder $R_1 = R_0 \oplus r_1$ is formed, which is stored in the register RgR.

In parallel with the formation of the intermediate remainder R_1 , the value of the partial remainder r_1 with a shift by one bit in the direction of the most significant bit one is fed to the inputs of the PRF2. The value of the remainder r_2 is generated at the outputs of the PRF2, which is stored in the register RgPRF2. Since the time of formation and r_1 fixations in RgPRF2 is longer than the time of formation and fixations of the intermediate remainder R_1 , the delay time on the DL.1 of the “Start” signal is determined by the total delay of PRF1, PRF2 and the registers RgB and RgPRF2. Thus, before the “Start” signal arrives at the input of the flip-flop T from the output DL.1, the partial remainder r_2 is fixed in the register RgPRF2, and the intermediate remainder R_1 is registered in the register RgR CMAdd2.

After the formation of r_2 and R_1 , the “Start” signal from the output of DL.1 is fed to the input of flip-flop T and puts it in a single state, which allows the first clock signal Clk11 to go to output And1. Clk1 from the output of And1 is fed to the input of the RgB register and shifts it by two bits to the right, and in its lower bits the value of bits b_3 and b_2 of the polynomial $B(x)$ is fixed. At the same time, the Clk1 decreases the value of the counter by one. Clk1, after a delay by the time of shifting the register RgB, the element DL.2 is fed to the input of the block of circuits And10. At $b_2 = 1$ the value r_2 from the outputs of RgPRF2 is supplied through the blocks of circuits OR3 to the inputs of the circuit CMAdd2, where the value of the intermediate remainder $R_2 = R_1 \oplus r_2$ is calculated and it is stored in RgR CMAdd2.

At the same time, the partial remainder r_2 is shifted by one bit toward the higher one with the clock signal Clk1 through the block of circuits And9 with a delay for the time of writing R_2 in RgR in DL.3 is fed to the inputs of the PRF1 through the block of circuits OR1. At the outputs of PRF1, a partial remainder $r_3 = 2r_2 \bmod P(x)$ is formed, which with a value of $b_3 = 1$ is fed through the blocks of circuits And8 and OR3 to the inputs of CMAdd2, where an intermediate remainder $R_3 = R_2 \oplus r_3$ is formed. During the formation of intermediate remainder R_3 , the value of the remainder r_3 from the outputs of the PRF1 with a shift by one bit to the higher side is fed to the inputs of the PRF2 and the intermediate remainder forms the output of which $r_4 = 2r_3 \bmod P(x)$, which is stored in the register RgPRF2. Thus, before entering the next pulse of Clk2 in the circuit in the register RgPRF2 we have a partial remainder r_4 , in the register RgR CMAdd2 the value of the intermediate remainder R_3 .

Other remainders are similarly formed in RgR and RgPRF2. After the last clock signal is supplied to RgR, the final result $\frac{R_{N-1}}{2}$ is generated. At the same time, the CCS generates a signal “End of operations”, which is delayed by the DL.4 elements for the time the remainder $\frac{r_{N-1}}{2}$ and $\frac{R_{N-1}}{2}$ are PRFs, we are able to increase the speed.

Consider the example of multiplication of polynomials modulo.

Let $A(x) = x^5 + x^4 + x + 1$; $B(x) = x^5 + x^3 + x^2 + 1$; $P(x) = x^6 + x + 1$. Binary representations of these polynomials: $A = 110011_2$ $B = 101101_2$ and $P = 1000011_2$. The calculation results are given in table 1.

To implement the device “for multiplying polynomials modulo with analysis of two bits of the polynomial multiplier per step” was used FPGAs from the company Xilinx, family Artix-7. Table 2 shows the total number of Artix 7 FPGAs (xc7a100t). The work of this device for polynomials with a power of $m = 6 \div 12$ was tested on it.

Figure 4 shows the timing diagram of the device for polynomials $A(x) = 110011_2$, $B(x) = 101101_2$ and $P(x) = 1000011_2$, which implement the operation $R(x) = A(x) * B(x) \bmod P(x)$ with power $m = 6$. As can be seen from the timing diagram, the output data are the values of partial remainders (r_i, r_{i+1}) and

Table 1 – The sequence of operations

Clock signals	Start	Clk1	Clk2
b_i	$b_1=0, b_0=1$	$b_2=1, b_3=1$	$b_5=1, b_4=0$
PRF1	$r_0=b_0 \cdot A(x)=110011;$ $r_1=2r_0 \bmod P(x)=$ $\begin{array}{r} 1100110 \\ \oplus \\ 1000011 \\ \hline 0100101 \end{array}$ $r_1 > P(x)$	$r_3=2r_2 \bmod P(x)=$ $\begin{array}{r} 0010010 \\ \oplus \\ 1000011 \\ \hline 0010010 \end{array}$ $r_3 < P(x)$	$r_5=2r_4 \bmod P(x)=$ $\begin{array}{r} 1001000 \\ \oplus \\ 1000011 \\ \hline 0001011 \end{array}$ $r_5 > P(x)$
PRF2 RgPRF2	$r_2=2r_1 \bmod P(x)=$ $\begin{array}{r} 1001010 \\ \oplus \\ 1000011 \\ \hline 0001001 \end{array}$ $r_2 > P(x)$	$r_4=2r_3 \bmod P(x)=$ $\begin{array}{r} 0100100 \\ \oplus \\ 1000011 \\ \hline 0100100 \end{array}$ $r_4 < P(x)$	$r_6=2r_5 \bmod P(x)=$ $\begin{array}{r} 0010110 \\ \oplus \\ 1000011 \\ \hline 0010110 \end{array}$ $R_6 < P(x)$
CMAdd2	$R_0=0 \oplus r_0=110011$ $R_1=R_0 \oplus (r_1 \cdot b_1)=$ $\begin{array}{r} 110011 \\ \oplus \\ 000000 \\ \hline 110011 \end{array}$	$R_2=R_1 \oplus (r_2 \cdot b_2)=$ $\begin{array}{r} 001001 \\ \oplus \\ 110011 \\ \hline 111010 \\ R_3=R_2 \oplus (r_3 \cdot b_3)= \\ \begin{array}{r} 111010 \\ \oplus \\ 010010 \\ \hline 101000 \end{array}$	$R_4=R_3 \oplus (r_4 \cdot b_4)=$ $\begin{array}{r} 101000 \\ \oplus \\ 101000 \\ \hline 001011 \\ R_5=R_4 \oplus (r_5 \cdot b_5)= \\ \begin{array}{r} 001011 \\ \oplus \\ 100011 \\ \hline 100011 \end{array}$

Checking:

$$(x^5+x^4+x+1) \cdot (x^5+x^3+x^2+1) = x^{10}+x^9+x^8+x^2+x+1;$$

$$\begin{array}{r} x^{10}+x^9+x^8+x^2+x+1 \\ \oplus \\ \underline{x^{10}+x^5+x^4} \\ x^9+x^8+x^5+x^4+x^2+x+1 \\ \oplus \\ \underline{x^9+x^4+x^3} \\ x^8+x^5+x^3+x^2+x+1 \\ \oplus \\ \underline{x^8+x^3+x^2} \\ x^5+x+1, \text{ which corresponds to } 100011_2 \end{array}$$

Table 2 – Total number of Artix 7 FPGA resources (xc7a100t)

Resources	Number
LUT	63 400
FF	126 800

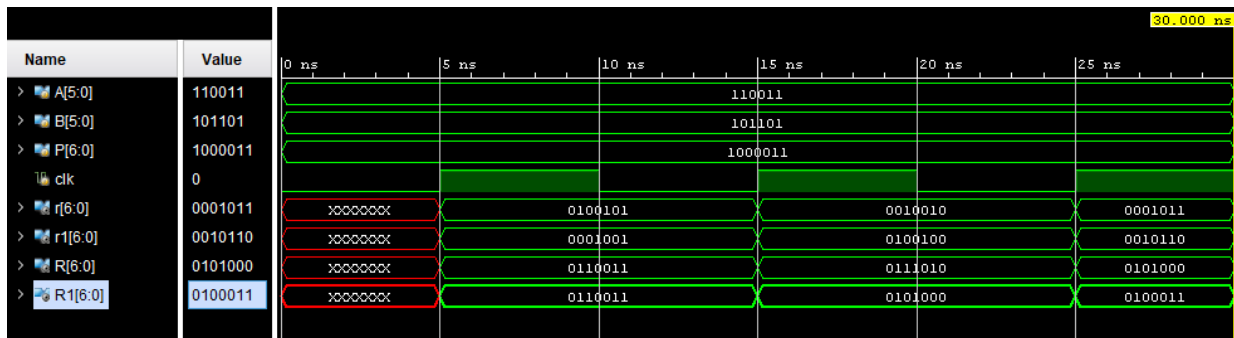


Figure 4 – Diagrams of the formation of intermediate remainders for polynomials with power m = 6

intermediate remainders (R_i, R_{i+1}). In this case, after applying the “Start” level, the value $r_0 = A(x)$ with the value $b_0 = 1$ through the block of circuits And7 is recorded in PrR CMAdd2 as $r_0 = R_0 = 110011$. At the same time, the value of r_0 with a shift by one bit to the left is fed to the input of PRF1 and $r_1 = 0100101$ is formed at the output of PRF1. With a value of $b_1 = 1$, the value r_1 is fed to the input of CMAdd2, where the operation is performed then $R_1 = R_0 \oplus r_1 * b_1 = 110011$. Then, at the same time, r_1 with a shift by one bit to the left is fed to the input of PRF2 at the output of which an intermediate remainder $r_2 = 2r_1 \bmod P(x) = 0001001$ is formed, which is stored in RgPRF2. This ends the action of the “Start” signal. With a clock signal Clk1 with a value of $b_2 = 1$, the contents of RgPRF2 are transmitted to the inputs of CMAdd2. Where $R_2 = R_1 \oplus r_2 * b_2 = 111010$ is formed. At the same time, r_2 from the outputs of RgPRF2 with a left shift by one bit is fed to the input of the PRF1 at the output of which a partial remainder $r_3 = 2r_2 \bmod P(x) = 0010010$ is generated, which is fed to the inputs of CMAdd2, forming $R_3 = R_2 \oplus r_3 * b_3 = 101000$. At the same time, r_3 with a shift by one bit to the left is fed to the inputs of the PRF2, forming $r_4 = 2r_3 \bmod P(x) = 0100100$, which is stored in RgPRF2. After applying the clock signal Clk2 as the value is $b_4 = 0$, then $R_4 = R_3 \oplus r_4 * b_4 = 101000$. Also the signal Clk2 doubles the value r_4 is transmitted to the inputs of the filter 1 at the output of which the value $r_5 = 2r_4 \bmod P(x) = 0001011$, which is fed to the inputs of CMAdd2, where the final balance $R_5 = R_4 \oplus r_5 * b_5 = 100011$ is formed.

Table 3 – The amount of resources spent

m, bit	LUT	%	FF	%
6	202	0.32	130	0.10
8	271	0.43	185	0.15
10	398	0.63	252	0.20
12	591	0.93	332	0.26

Table 3 shows the amount of the main resources LUT and FF used and their percentage of the total for polynomials with power $m = 6 \div 12$.

Conclusion. As can be seen from the considered the device for multiplying polynomials modulo with analysis of two bits of the polynomial multiplier per step, the multiplication process can be accelerated almost twice. Similarly, to accelerate the multiplication of polynomials modulo per step of multiplication, you can analyze more than two bits of the multiplier.

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ҚАДАМ САЙЫН КӨБЕЙТКІШТЕРДІҢ ЕКІ РАЗРЯДТАРЫН ТАЛДАУ АРҚЫЛЫ ПОЛИНОМДАРДЫ МОДУЛЬ БОЙЫНША КӨБЕЙТЕТІН ҚҰРЫЛҒЫ

Аннотация. ҚР БЖҒМ ҒК қарасты Ақпараттық және есептеуіш технологиялар институтында бейпозициялық көпмүшеліктер есептеу жүйесі (БКЕЖ) негізінде деректерді шифрлаудың симметриялық алгоритмі жасалынып, ол программалық жолмен іске қосылған. Деректерді шифрлау және кері шифрлау жылдамдығын арттыру үшін аталған криптожүйе программалық-аппараттық немесе аппараттық жолмен іске қосылуы мүмкін. Мұндай БКЕЖ негізінде құрылған криптожүйеде деректерді шифрлау жылдамдығының өсірілуі оның құрамындағы аппараттық модульдердің параллель жұмыс жасауымен байланысты. БКЕЖ-ге сүйеніп құрылған криптожүйелердің негізгі блогына көпмүшеліктері келтірілмейтін көпмүшеліктер модулі арқылы көбейтетін құрылғылар жатады. Мұндай құрылғыларда деректерді шифрлауға және кері шифрлауға қажет арифметикалық амалдар орындалады.

Аталған көбейту құрылғысында көбейгіш ретінде шифрланатын мәтіннің бір бөлігі болып табылатын көпмүшеліктің екілік коэффициенттері, ал көбейткіш ретінде құпия кілт рөлін атқаратын көпмүшеліктің екілік коэффициенттері бола алады. Модуль ретінде жоғарыдағы көпмүшеліктегі келтірілмейтін көпмүшеліктерінің бірінің екілік коэффициенттері алынады.

Көпмүшеліктерді модуль бойынша көбейтудің екі тәсілі бар. Біріншісінде көпмүшеліктердің екілік коэффициенттерін бір-біріне көбейтіп, одан соң көбейтіндіні модульге келтіреміз. Мұнда көбейту уақыты көпмүшеліктерді көбейтуге кететін уақытпен және оны модульге келтіру уақыттарымен анықталады. Оның үстіне көбейтінді разрядтары модуль разрядтары санынан асып кетеді. Мұндай жағдайда көбейту құрылғысының құрамы күрделіленеді.

Екінші тәсілінде көпмүшеліктерді модуль бойынша көбейту үстінде көбейту амалы бірнеше кадам арқылы орындалады. Қадам саны көбейткіш болып табылатын көпмүшеліктің екілік коэффициенттерінің санымен (разрядтарымен) анықталады.

Көбейтудің әр қадамында бұрынғы алынған жекеленген g_i-1 қалдық жоғары разрядқа қарай бір разрядқа жылжытылып (яғни екіге көбейтіліп), жекелеген қалдық қалыптастырғыш (ЖҚК) кірісіне беріледі. ЖҚК екіге көбейтілген $2g_i-1$ қалдықты модульге келтіріп g_i қалдығын қалыптастырады. Одан әрі g_i қалдығы одан бұрын алынған аралық R_i-1 қалдығына екілік модульмен қосындыланып, R_i аралық қалдығын қалыптастырады. Жоғарыдан көрініп тұрғандай, көбейтудің әр қадамында қалдықтарды жекеленген қалыптастыру үстінде көпмүшеліктерді көбейту және оларды модульге келтіру операциялары бір кадамда орындалады.

Мақалада көбейтудің әр қадамында көбейткіш көпмүшеліктерінің екі разрядтарын талдау арқылы көпмүшеліктерді модуль бойынша көбейтетін құрылғы қаралады. Көбейту құрылғысының құрылымдық сұлбасы, оның жұмыс жасау реті, көбейту құрылғысының құрамына кіретін жекеленген қалдықтар қалыптастырғышы, құрамында жинақтағышы бар екі модульмен жұмыс жасайтын қосындылағышы қаралады. Қаралған көпмүшеліктерді модульмен көбейту құрылғысының жұмысы Хіпх компаниясының ПЛИС-ін (Artix-7) іске қосу арқылы тексерілген.

Түйін сөздер: бейпозициялық көпмүшеліктер есептеу жүйесі, келтірілмейтін көпмүшеліктер, көпмүшеліктерді келтірілмейтін көпмүшеліктер арқылы көбейту, қалдықтар қалыптастырғышы.

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УСТРОЙСТВО УМНОЖЕНИЯ ПОЛИНОМОВ ПО МОДУЛЮ С АНАЛИЗОМ ЗА ШАГ ДВУХ МЛАДШИХ РАЗЯДОВ МНОЖИТЕЛЯ

Аннотация. В Институте информационных и вычислительных технологий КН МОН РК разработаны и программно реализованы алгоритмы блочного симметричного шифрования данных на базе непозиционной полиномиальной системы счисления (НПСС). Особый интерес представляют программно-аппаратные и аппаратные способы реализации НПСС, которые позволяют существенно ускорить процесс шифрования и расшифрования данных за счет параллельной обработки данных на уровне отдельного модуля и разрядов внутри каждого модуля.

При программно-аппаратной и аппаратной реализаций криптосистем на базе НПСС основным блоком является множитель полиномов по модулю неприводимых полиномов, где производятся сложные вычисления по шифрованию и расшифрованию данных. В таких множителях в качестве множимого выступает фрагмент шифруемого текста, а множителем является полином, который служит секретным ключом, а модуль выбирается из множества неприводимых полиномов.

Существует два подхода к умножению полиномов по модулю. В первом подходе двоичные коэффициенты полинома множителя и множимого умножаются на устройстве умножения полиномов, затем это произведение приводится по модулю неприводимого полинома. При таком подходе время умножения полиномов по модулю складывается из времени умножения полиномов и времени приведения произведения полиномов по модулю неприводимого полинома. Кроме этого, результат умножения полиномов выходит за разрядной сеткой модуля, что усложняет структуру устройства умножения.

Во втором подходе умножение полиномов по модулю операция разбивается на шаги, число которых определяется числом двоичных коэффициентов (разрядностью) полинома – множителя. При этом на каждом шаге предыдущий частичный остаток g_i-1 передается со сдвигом на один разряд в сторону старшего разряда этого остатка (g_i-1 умножается на два) на входы следующего формирователя частичных остатков (ФЧО) и производится его приведение по модулю неприводимого модуля, формируя частичный остаток g_i . Остаток g_i при единичном значении анализируемого разряда множителя подается на входы накапливающего сумматора по модулю два, где вычисляется промежуточный остаток путем сложения по модулю два частичного остатка g_i с промежуточным остатком R_i-1 . При этом подходе умножения нетрудно заметить, что при формировании очередного частичного остатка операция умножения полиномов совмещается с операцией приведения по модулю.

В данной работе рассматривается множитель полиномов по модулю, где на каждом шаге умножения анализируется два разряда полинома – множителя, что позволяет ускорить процесс умножения. В работе приводятся функциональные схемы множителя и его компонентов, пример умножения. В заключении приводится реализация рассмотренного устройства умножения на ПЛИС фирмы Xilinx (семейства Artix-7). Работа предложенного устройства умножения опробована для полиномов, имеющих степень $m=6\div 12$, и определено для них количество затраченных ресурсов.

Ключевые слова: криптосистема на основе полиномиальной системы счисления, неприводимые полиномы, множитель полиномов по модулю неприводимых полиномов, формираторы остатков.

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**EROSION HAZARD ANALYSIS IN THE LIMBOTO LAKE
CATCHMENT AREA, GORONTALO PROVINCE, INDONESIA**

Abstract. Damages to the land resources, mainly those happening on drainage basin at Alo, Gorontalo occur in consequence of degradation of the ground surface layer as hit by raindrops and rainwater flow that carry soil surface. This issue becomes quite serious due to illegal logging and agricultural land conversion, mostly for maize fields as one of Gorontalo's top commodities. The purpose of this study is to determine the level of erosion hazard in the Limboto Lake catchment area. In order to achieve these objectives two methods are used namely the field survey and documentation. The research material used includes of socio-biogeophysical characteristics of Alo drainage basin and analyzes the level of soil surface erosion. The result shows that 98.75 percent of erosion hazard is classified into low to moderate, covering approximately 6,874.721 hectares. Meanwhile, 1.25 percent of the high to extreme level of erosion hazard are 98.79 hectares wide. This suggests that inappropriate use of land is more likely to increase the erosion hazard rate.

Key words: Erosion Hazard, Limboto Lake, Alo, Gorontalo.

Introduction. Preserving conservations sites from threats is quite a duty these days. The treats are from various illegal activities, such as logging, hunting, kinds of land conversion, mineral exploration and exploitation, or conflict of land use [1]. It is important to manage land resources in the context of development in Indonesia years ahead, as now more complex challenges begin to emerge. These challenges are pressures from local people, land conversions and working shifts, forest degradation and land damages, and environmental damages and natural disasters. Therefore, a sustainable concept of land resources management focusing on tackling the challenges needs to be designed and formulated on local, regional and national scale [2].

Damages to land resources in watersheds are the after effect of loss of soil surface by rain drops and rainwater's carrying capacity, eventually creating a critical land zone. It is caused by over exploitations of productive lands and careless activities towards environment preservation. Some of the main factors to damage the catchment area are deforestation and cultivation with less or no appliance of soil conservation principles. As reported by State Ministry of Environment and Forestry, in entire Indonesia, floods in 2006 only affected 124 districts in total. The number increased to 240 districts in 2007. This was aggravated by pervasive spread of damaged catchment areas over Indonesia and nearly 4.2 percents of land conversion rate per year [3].

Limboto Lake is a natural lake located in Gorontalo regency, Indonesia. Stretched approximately 3.000 hectares wide, it is the estuary of 5 main rivers, namely Bone Bolango, Alo, Daenaa, Bionga, and Molamahu River. As an icon of both Gorontalo regency and province, Limboto Lake possesses a significant role, either as an ecological and hydrological function, or socio-economical support to the locals [4]. Research on Lake Limboto has been carried out mainly on microfacies and uplift rate of limestone. There are three limestone microfacies in the slope to toe of slope depositional environment. While the rate of uplift limestone 0.0669-0.0724 mm/year [5,6].

Alo drainage basin is among the largest watersheds nearby Limboto Lake catchment area, having an area of 48.828 hectares, covering 52 percents of Limboto Lake catchment area, making it a benchmark when analyzing Limboto Lake catchment area entirely. One major quest needs to be solved the tendency of land functional shift by local people. Most of the locals are farmers. Thus they tend to explore land in the upstream area of the watershed, resulting in gradual deforestation. The forest is cut down then replaced by farms (mainly maize fields), as an effort of industrial extensification, without scrutiny analysis on the watershed's environmental support capacity. There is not enough intensive management and technology used in maize farms located in a hilly area of the watershed. As mentioned in [7], there was a decrease in the size of forests in Alo watershed, from 5,587 hectares on 2003 to 4,478 hectares two years later. By that, Alo watershed has more dry farmland and wide open ground than other sub-watersheds, also, most lands have a slope of 49.3 percent. On the other hand, farmlands expanded significantly from 1,398 hectares on 2003 to 30,338 hectares on 2005. This might trigger an increase in surface flow rate in the rainy season, being very prone to erosion. Lihawa then asserted that erosions in Alo were categorized as heavy ones, rated 190.36 tons/hectares/year or 9,294,695.62 tons/year in total. Meanwhile, as claimed in [8-10], erosion level of Limboto.

Lake catchment area has met the number of 9,902,588.12 tons/year. As per 2006, the area of the lake has shrunk into less than 3,000 hectares, with an average depth of 2.5 meters. The shrinkage occurred as a result of illegal logging and agricultural land conversions to maize fields. [4,10] also blamed the existence of water hyacinth, causing lake sedimentation and also damaging ecosystems of the lake. With that in mind, there is a bigger probability that flood might happen in high rainfall. It is worsened by the high rate of air humidity in Gorontalo, having 80.17 percents on average. The maximum rainfall with 24 rainy days is in December [3]. This evidence is enough as a proof of urgency to conserve Limboto Lake to reduce the rate of lake degradation. Hence, one needs to conduct a study on the level of erosion hazard on Limboto Lake catchment area.

Research Method. The research took place in Alo drainage basin, Tibawa District, Gorontalo Regency, Gorontalo Province, precisely at the west of Limboto District. Tibawa District is at the longitude of $122^{\circ}46'56'' - 122^{\circ}53'47''E$ and latitude of $00^{\circ}45'51'' - 00^{\circ}39'14''N$. Alo river is a river with most sediment deposits of 124.83 tons/hectares flowing to Limboto Lake. Alo drainage basin covers six villages, namely Datahu, Iloponu, Buhu, Isimu Utara, Labanu, and Motilango village, all under the administration of Tibawa District. This is shown in figure 1 as follows:

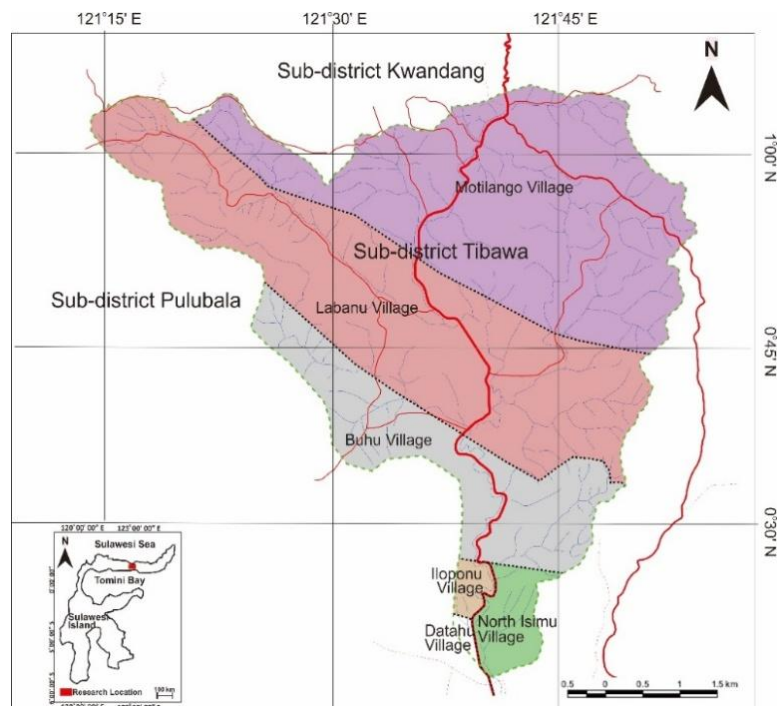


Figure 1 – Map of Alo drainage basin

Data Collection. This study encompasses socio-biogeophysical characters of Alo watershed and involves the rate of surface erosion and tolerable erosion rate. Field observation and documentation were conducted to collect data of slope length and area, land use by the locals, varieties of plants, conservations completed, sufficient depth of soil, soil color and texture, land cover, and soil sampling.

The main climate data of the research are rainfall and air temperature. Data of rainfall are obtained from four rainfall stations, i.e., the meteorological station of Djalaluddin Airport, Alo station, Kwandang station, and Biyonga station. The obtained data then are converted into isohyetal map and rain erosivity map to acquire data of spatial rainfall and erosivity spread. The mock approach is preferred to extract data of the air temperature obtained from the meteorological station at Djalaludin Airport of Gorontalo.

Data Analysis. A descriptive analysis is performed to break down and present data of environmental condition of and land use in Alo watershed in forms of the table. The spatial and ecological approach is undergone by using Geographical Information System (GIS) to observe the spatial spread of environmental situation of the watershed, i.e., the condition of the hillside, soil, land use, socio-economy, and culture. The impact of actual land use towards erosion and land degradation is measured by comparison ratio of real soil erosion value (A) and tolerable soil erosion (T). Actual land use will not trigger land degradation if $A < T$, and vice versa. The impact is then classified into three categories, safe ($A < T$), unsafe ($T < A < 2T$), and highly unsafe ($A > 2T$). The data gathered is then set as a benchmark to measure erosion hazard rate. The parameters of measurement are the value of erosion rate and soil solum. The rate of erosion hazard is then arranged based on five criteria of level: extremely low, low, moderate, high, and extremely high [11].

Research Results and Discussion. Erosion Level. Erosion is a process of movement of the soil or its parts from a place to another by natural media [12]. There is a parametric model to predict the rate of erosion of a plot of a land developed by [13-14] called Universal Soil Loss Equation (USLE). The next step is to interpolate calculations result of every rain station by EI30 to gather rain erosivity value of every land unit by ArcView 3.3 software, to be then overlapped by a map of a land unit.

Alo watershed has C, D, and E climate type with rain intensity of 1,100-1,400 mm/year. It determines the power of raindrops toward the ground, a number of raindrops, rain spread area, and rate of soil erodibility. The highest rate of erosivity in Alo watershed is 1,102,000 tons-m ha⁻¹ cm⁻¹ occurring on a land unit of structural hills of granite rocks (S1IVPt) with an area of 5.4 hectares, with class IV slope steepness and land use of shrubs. Concurrently, the lowest rate of erosivity, 47,000 tons-m ha⁻¹ cm⁻¹, took place on unit S1IPt with an area of 165.24 hectares.

Prediction of Soil Surface Erosion. here are three groups of erosion rate; group I with A value more than 100 tons/hectare/year, group II having A value of 10-100 tons/hectare/year, and group III with less than 100 tons/hectare/year of value. All land units of karst hills have a value below 10 ton/hectare/year. The erosion rate is low, owing to low rate of rain erosivity.

Measurement of Tolerable Erosion Rate (T) and Erosion Hazard Rate (EHR). The result of which is presented in table 1. According to table 1, five land units are included in extremely unsafe category, by reason of A value more than T value those are: D1IIIPt (89.599 tons/ha/year), S1IIIPt (21.244 tons/ha/year), S1IVB (67.652 tons/ha/year), S1IVPt (102.608 tons/ha/year), and S1IVPc (40.456 tons/ha/year).

The parameters can help when determining five levels of erosion hazard; extremely low, low, moderate, high, and extremely high. The result is shown in table 2. The table shows that four land units, D1IIIPt (89.599 ton/ha/year), D1IVPc (15.657 ton/ha/year), S1IVB (67.652 ton/ha/year), and S1IVPt (102.608 ton/ha/year) are in the critical zone. These units are scoring high to extremely high EHR value. This results from the slope steepness and CP value as the key factors. In particular, land unit D1IVPt is in class IV steepness. However, its use as dry farmland makes it under bad caretaking and accordingly has CP value of 0.007. Besides, soil solum of the unit is shallow, only 35 cm, by that, the actual erosion exceeds tolerable erosion rate. Further, figure 2 displays spread map of EHR in Alo drainage basin.

Table 1 – Calculation of tolerable erosion rate and conservation need

Land unit	Area (hectare)	Erosion rate (ton/year)	T (ton/ha/year)	A (ton/ha/year)	Need of Conservation
D2IB	76.36	10,698	0.475	0.140	Conservation not needed
D1IIIB	31.82	38,841	0.19	1.221	Conservation needed
D1IIIPc	77.77	164,024	0.15	2.109	Conservation needed
D1IIIPt	4.08	365,114	0.2	89.599	Conservation needed
D1IIPc	154.83	10,698	0.3	0.069	Conservation not needed
D1IIPt	49.09	164,024	0.09	3.341	Conservation needed
D2Ipc	486.63	10,698	0.5	0.022	Conservation not needed
D2Ipm	27.78	365,114	0.09	13.144	Conservation needed
D2Ipt	301.32	20,771	0.5	0.069	Conservation not needed
D1IVB	252.30	38,841	0.45	0.154	Conservation not needed
D1IVPc	548.75	351,420	0.5	0.640	Conservation needed
D1IVPt	30.99	100,821	0.4	3.253	Conservation not needed
D1VB	9.26	145,105	0.225	15.679	Conservation needed
D1VPc	35.36	553,680	0.285	15.657	Conservation needed
F1Ipk	58.14	25,745	0.255	0.443	Conservation needed
K2IB	59.19	42,604	0.24	0.720	Conservation needed
K1IIIB	63.58	19,490	0.045	0.307	Conservation needed
K1IIIPc	98.75	19,490	0.21	0.197	Conservation needed
K2Ipk	52.00	42,604	0.27	0.819	Conservation needed
K2Ipm	3.60	2,835	0.27	0.788	Conservation needed
K1IVB	118.19	19,490	0.5	0.165	Conservation not needed
K1IVPc	101.36	231,824	0.105	2.287	Conservation needed
S3IB	153.20	461,999	0.2	3.016	Conservation needed
S1IIB	231.61	461,999	0.18	1.995	Conservation needed
S1IIIB	57.18	461,999	0.33	8.080	Conservation needed
S1IIIPc	424.00	461,999	0.11	1.090	Conservation needed
S1IIIPt	17.19	365,114	0.225	21.244	Conservation needed
S1IIPc	312.08	149,705	0.11	0.480	Conservation needed
S3Ipc	1,010.54	1700,510	0.195	1.683	Conservation needed
S3Ipm	15.86	100,865	0.12	6.360	Conservation needed
S3Ipt	165.24	107,252	0.18	0.649	Conservation not needed
S1IVB	6.83	461,999	0.06	67.652	Conservation needed
S1IVPc	600.53	149,705	0.08	0.249	Conservation needed
S1IVPt	5.40	554,494	0.09	102.608	Conservation needed
S1VB	67.20	461,999	0.075	6.875	Conservation needed
S1VPc	47.12	1,906,223	0.035	40.456	Conservation needed
S4IB	255.00	460,730	0.2	1.807	Conservation needed
S2IIIB	201.46	610,514	0.135	3.031	Conservation needed
S2IIIPc	439.54	100,865	0.255	0.229	Conservation not needed
S4Ipc	126.55	100,865	0.425	0.797	Conservation needed
S2IVB	24.73	461,999	0.15	18.682	Conservation needed
S2IVPc	138.27	461,999	0.15	3.341	Conservation needed
S2VB	32.91	461,999	0.075	14.037	Conservation needed

Table 2 – Erosion hazard rate at Alo watershed

Land unit	Soil solum	EHL
D2IB	95	Extremely Low
D1IIIB	95	Extremely Low
D1IIIPc	75	Extremely Low
D1IIIPt	100	High
D1IIPc	100	Extremely Low
D1IIPt	30	Extremely Low
D2IPc	100	Extremely Low
D2IPm	45	Low
D2IPt	100	Extremely Low
D1IVB	90	Extremely Low
D1IVPc	60	Low
D1IVPt	80	Low
D1VB	75	Moderate
D1VPc	95	High
F1IPk	85	Extremely Low
K2IB	80	Extremely Low
K1IIIB	45	Moderate
K1IIIPc	70	Moderate
K2IPk	90	Extremely Low
K2IPm	90	Extremely Low
K1IVB	100	Moderate
K1IVPc	35	Moderate
S1IB	100	Low
S1IIIB	60	Low
S1IIIB	75	Low
S1IIIPc	75	Low
S1IIIPt	75	Moderate
S1IIPc	55	Extremely Low
S3IPc	65	Moderate
S3IPm	60	Low
S3IPt	60	Low
S1IVB	30	High
S1IVPc	40	Extremely Low
S1IVPt	45	Extremely High
S1VB	75	Low
S1VPc	35	High
S4IB	40	Moderate
S2IIIB	45	Moderate
S2IIIPc	85	Low
S4IPc	85	Low
S2IVB	75	Moderate
S2IVPc	75	Low
S2VB	75	Low

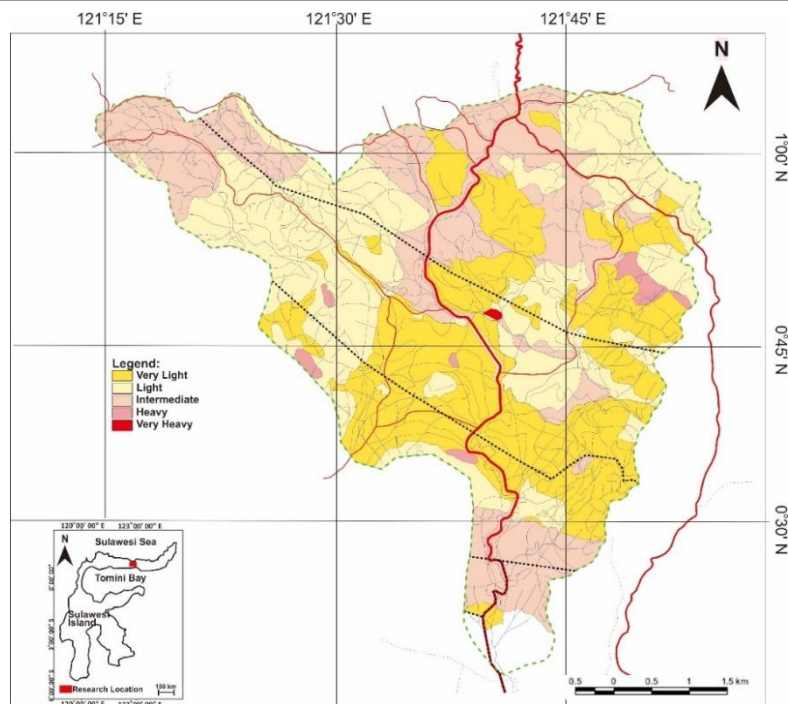


Figure 2 – Map of Erosion Hazard Rate in Alo drainage basin

It shows that 98.75 percents of land units (a total of 6,874.21 hectares) in Alo watershed are in classified as extremely low to moderate. The remaining 1.25 percents are in high – extremely high rate. The maximum erosion hazard rate of Alo basin takes place in some land units. In total, land units categorized in extremely low hazard rate have accumulated area of 2,200.53 ha, those in the low category have a total of 2,776.64 ha, unit in the moderate class have 1,896.99 hectares, units in high and extremely high have a total area of 93.86 and 5.50 hectares in order. The analysis of erosion hazard spread points out that inappropriate land use in Alo watershed has brought the land capacity to the limit, if not taken care of, it will eventually increase the hazard rate.

Conclusion. Slope length and its steepness are the key factors to contribute the value of erosion rate on a given land unit. 32 of 43 units of lands in Alo watershed have a value that exceeds tolerable erosion rate, by that, such actions of land conservation are needed. It mostly occurred on structural hills with class III, IV, and V slope steepness. The land units categorized in extremely low hazard rate have an overall area of 2,200.53 ha, while those in the low category are 2,776.64 hectares in total. Also, land units in the moderate class have a total of 1,896.99 ha, and units included in high and extremely high are of 93.86 and 5.50 hectares in order. The result of analysis asserts that improper land use is more likely to trigger an increase of the erosion level hazard.

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ЛИМБОТО КӨЛІ, ГОРОНТАЛО, ИНДОНЕЗИЯ АЙМАҒЫНДАҒЫ ЭРОЗИЯ ҚАУШПН ТАЛДАУ

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АНАЛИЗ ОПАСНОСТИ ЭРОЗИИ В ОБЛАСТИ ОЗЕРА ЛИМБОТО, ГОРОНТАЛО, ИДОНЕЗИЯ

Аннотация. Повреждения земельных ресурсов, в основном те, которые происходят в водосборном бассейне в Ало, Горонтало, происходят в результате деградации поверхностного слоя грунта в результате попадания дождевых капель и потока дождевой воды, несущейся по поверхности почвы. Эта проблема

становится довольно серьезной из-за незаконных рубок деревьев и переустройства сельскохозяйственных земель, в основном для кукурузных полей, как одного из главных товарных продуктов Горонтало.

Целью данного исследования является определение уровня эрозионной опасности в водосборном бассейне озера Лимбото. Для достижения этих целей используются два метода, а именно полевое обследование и документация. Используемые материалы исследования включают социально-биогеофизические характеристики водосборного бассейна Ало и анализ уровня эрозии поверхности почвы. Результат показывает, что 98,75% опасности эрозии классифицируется как от слабой до умеренной, охватывая приблизительно 6 874 721 га. В то же время, 1,25 процента от высокой до крайней степени эрозионной опасности имеют ширину 98,79 га. Это говорит о том, что ненадлежащее использование земли с большей вероятностью увеличивает риск эрозии.

Ключевые слова: опасность эрозии, озеро Лимбото, Ало, Горонтало.

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ELECTROPHYSICAL PROPERTIES OF CARBON MATERIAL BASED ON COAL OF “SARYADYR” DEPOSIT

Abstract. The article presents the results of heat treatment (carbonization) of grade G coal of the «Saryadyr» deposit («Pyatimetrovyy» layer) in the temperature range 250–550 °C at a heating rate of 10–15 °C/min and holding at 550 °C for 1, 2 and 3 hours. As a result of carbonization, carbon materials (CM) were obtained. Using the methods of thermogravimetric, energy dispersive X-ray spectroscopy, electron microscopy, we studied the technical, elemental composition, and surface morphology of the obtained products. The electrophysical characteristics of the CM were determined by measuring the electrical resistance (R), electric intensity (C), and dielectric constant (ϵ) of the samples in the temperature range 293–483 K. Based on the data obtained, the band gap (ΔE) of the samples was calculated. The carbon material obtained at 550 °C for 3 hours has a dielectric constant of 740 thousand at 293 K and will increase to 1.1 billion at 453 K, i.e. up to 109 degrees to colossal values and is a very attractive material for microelectronics, i.e. at 453 K, ϵ CM is higher than the reference BaTiO₃ by about 540 thousand times.

Key words: carbon material (CM), chemical composition, electrophysical properties, electrical resistance, electrical intensity, dielectric constant.

Introduction. Recent decades have been marked by a surge of scientific activity in the development and study of carbon materials (CM). This is reflected in the targeted synthesis of allotropic forms of carbon (carbohydrates, fullerenes, nanotubes, compasses, etc.), as well as in the creation of a wide range of porous materials in a series of mixed (transitional) forms of carbon, which are of practical interest as adsorbents, catalysts, and carriers for catalysts, substrates in new generation current sources (lithium-ion batteries, supercapacitors, ionistors and fuel cells) etc. [1-7].

Promising devices for the accumulation and storage of electrical energy, combining both high energy intensity and relatively high output power, are supercapacitors (SC) and capacitive deionization systems capable of reversibly accumulating charge on the surface of electrode material [8-11]. In [12-14], based on the porous - carbon material of carbon nanotubes, the production of materials with pore sizes up to angstroms for flexible and printing devices with a short response time, as well as nanoparticles of transition metal oxides and nitrides for pseudo-capacitors, which are the latest achievements, was developed and organized in the field of supercapacitors. Natural materials, such as coconut shells, wood, resins, coals, or synthetic materials, such as polymers, are commonly used as precursors. Carbon materials used in capacitors are usually pretreated to remove moisture and most of the functional groups present on the carbon surface to increase stability during cycling, since they can cause wilting of the capacitance and aging of the capacitor [15].

Electrophysical properties is as the main indicator of the carbon material used in electrothermal processes [16], as well as for the manufacture of superconducting materials, capacitors and fuel cells from them. The aim of this work is to study the electrophysical properties of a carbon material based on coal from the Saryadyr deposit (Pyatimetrovyy layer) (Kazakhstan). Coal belongs to high-ash, gas grade "G".

Research methodology. Samples of carbon material were obtained at the “Institute of Coal Chemistry and Technology” LLP (Nur-Sultan) by heat treatment in a tube furnace in the temperature range of 250-550 °C at a heating rate of 10-15 °C/min and holding at 550 °C for 1, 2 and 3 hours.

The elemental composition, structure, and dimensionality of the samples were studied by energy dispersive X-ray spectroscopy on an SEM instrument (*Quanta 3D 200i*) with an attachment for energy dispersive analysis from EDAX. The energy of the exciting electron beam in the analysis was 15 keV.

The heat of combustion of coal and the resulting products was determined by the calorimetric method on the device "Calorimeter V08MA K"

Results and its discussion. The results of the elemental analysis, presented in table 1, show that after heat treatment of coal, most of the heteroatoms (oxygen, hydrogen, sulfur, nitrogen) are removed in the form of gaseous products. Accordingly, the carbon concentration decreases from 82.98 to 67.80 wt. % and the structure of flat aromatic rings developing, uniting into basic structural units or elementary graphite crystallites, develops.

Table 1 – The chemical composition of the carbon material from coal of the «Saryadyr» deposit («Pyatimetrovyy» layer)

Indicators	Content			
	Initial coal	CM, 1 hour exposure	CM, 2 hours exposure	CM, 3 hours exposure
Humidity, W^a , %	1.68	1.36	1.64	2.24
Ash content, A^d , %	37.33	23.72	26.13	27.92
Volatility, V^{daf} , %	26.35	14.11	10.57	8.48
Sulfur per working mass, S^{daf} , %	0.59	0.32	0.27	0.28
Carbon content, C^{daf} , %	82.98	67.97	68.17	67.80
Hydrogen content, H^{daf} , %	5.59	3.07	1.78	0.68
Oxygen content, O^{daf} , %	7.88	3.58	2.45	2.09
Nitrogen content, N^d , %	1.38	1.34	1.20	1.23
Aluminum content, Al, %	2.30	1.90	2.12	2.36
Silicon content, Si, %	5.48	4.50	4.12	4.03
Calorific value, Q_i , kcal/kg	5215	6271	5987	5689

The data from table 1 show that a noticeable effect of the exposure time of coal during heat treatment affects the calorific value of the obtained product [17]. At the shortest time ($t = 1$ hour), the calorific value is the highest and amounts to 6271 kcal/kg, which significantly exceeds the same parameter of the initial coal (5215 kcal/kg). With a further increase in the exposure time, this parameter decreases.

Figures 1–2 show micrographs of samples of the initial coal and carbon materials (with an increase of 5,000 and 50,000 times).

When analyzing the surface morphology of the samples, it was found that the cleaved surface is represented by heterogeneity of the structure and has dense formations with strong agglomerates. Despite the presence of an increased content of the mineral component, the structure is characterized by flocculent inclusions in the carbon matrix; it is also seen that there are elevations and depressions on the surface. This is due to the heterogeneity of the composition and the natural origin of coal.

The results of the analysis of micrographs show that after heat treatment the surface structure changes with smaller particle sizes (up to ~ 170 nm). In CM products, crystallites are arranged irregularly, the gaps between them are filled (or blocked) with amorphous carbon, which is formed upon decomposition of resinous substances. As a result of carbonization, volatile (moisture and partially resin) substances are released from raw materials. At the same time, primary macroporous structures with a diameter of 2 to 30 microns are formed in it.

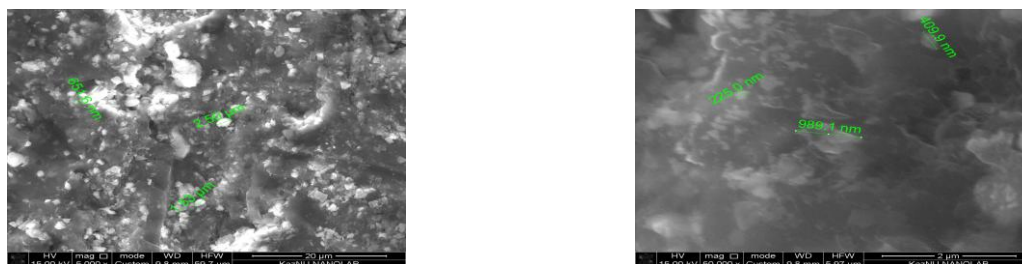


Figure 1 – Electron microscopic images of the Initial coal of the “Saryadyr deposit”

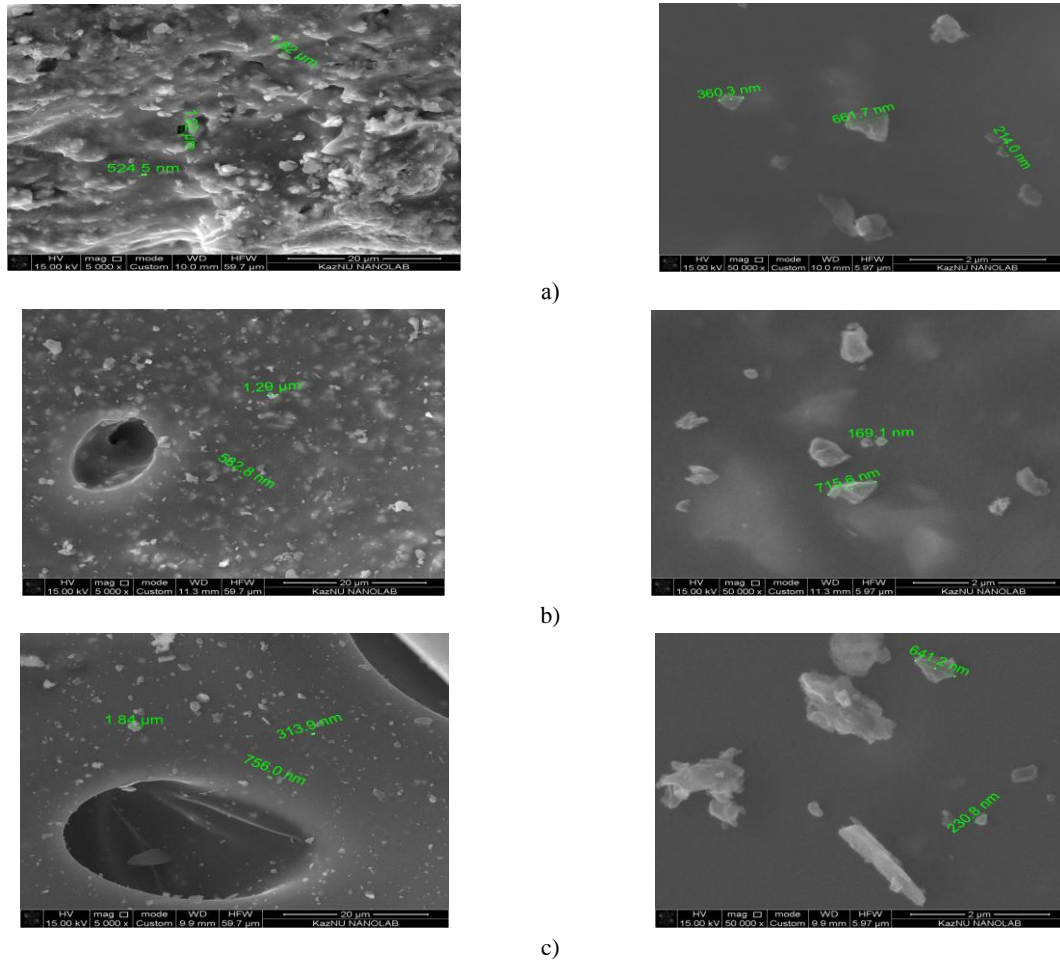


Figure 2 – Electron-microscopic images of CM from coal of the Saryadyr deposit:
a) 1 hour exposure, b) 2 hours exposure, c) 3 hours exposure

An analysis of micrographs (figure 2) at various magnifications indicates that the surface of the CM is represented by an inhomogeneous structure with local clusters of cluster-like (dendritic) and isometric shapes, overlays (secondary textures) are interspersed and streaked. The figures show that finely dispersed carbon nanoparticles with diameters from ~ 100 to 700 nm were formed on the surface of the sample, this may be due to the fact that, as a result of carbonization, the reactive radicals forming interact with each other with the formation of new substances. The most likely cause of the appearance of nanoparticles on the surface layer is synthesis from the gas phase. The nucleation and growth of ordered carbon during the heat treatment of coal can occur through self-organization of carbon nanoparticles without the participation of the mesophase. Measurements of the electrophysical properties were carried out according to the procedures [18,19].

The study of electrophysical properties (dielectric constant and electrical resistance) was carried out by measuring the electric capacity of the samples on a LCR-800 serial device (Taiwan) at an operating frequency of 1 kHz continuously in dry air in thermostatic mode with a holding time at each fixed temperature.

Plane-parallel samples were preliminarily made in the form of disks with a diameter of 10 mm and a thickness of 5 – 6 mm with a binder additive ($\sim 1.5\%$). Pressing was carried out under a pressure of 20 kg / cm^2 . The resulting disks were fired in a silica furnace at 200 °C for 6 hours. Next, they were thoroughly double-sided grinding.

The dielectric constant was determined from the electric capacity of the sample at known values of the thickness of the sample and the surface area of the electrodes. To obtain the relationship between the electric induction D and the electric field E was used a Sawyer-Tower circuit. Visual observation of the D (E -hysteresis loop) was carried out on a $CI-83$ oscilloscope with a voltage divider consisting of a resistance of 6 mOhm and 700 kOhm, and a reference capacitor of 0.15 μF . The frequency of the

generator is 300 Hz. In all temperature studies, the samples were placed in a furnace, the temperature was measured with a chromel-alumel thermocouple connected to a B2-34 voltmeter with an error of ± 0.1 mV. The rate of temperature change is ~ 5 K / min. The value of the dielectric constant at each temperature was determined by the formula: $\varepsilon = C/C_0$, where C_0 is the capacitance of the capacitor without the test substance (air).

Below are the results of measurements of the electrophysical characteristics of carbon materials from coal of the Saryadyr deposit.

Table 2 – Electrical properties of CM based on Saryadyr coal (Pyatimetrovyy layer)
($\tau = 1$ hour) (C - capacity, R - electrical resistance, ε - dielectric constant)

T, K	C, nF	R, Ohm	ε	lg ε	lgR
293	0.24402	2220000	1335	3.13	6.35
303	0.26692	2101000	1460	3.16	6.32
313	0.33632	1860000	1840	3.26	6.27
323	0.43216	1622000	2364	3.37	6.21
333	0.48451	1535000	2650	3.42	6.19
343	0.50585	1508000	2767	3.44	6.18
353	0.51147	1483000	2798	3.45	6.17
363	0.50135	1489000	2742	3.44	6.17
373	0.53663	1458000	2935	3.47	6.16
383	0.61584	1315000	3369	3.53	6.12
393	1.0248	1025000	5605	3.75	6.01
403	1.8592	716400	10169	4.01	5.86
413	3.3245	504000	18184	4.26	5.70
423	4.7521	387200	25993	4.41	5.59
433	6.5738	317000	35957	4.56	5.50
443	8.5247	276200	46628	4.67	5.44
453	11.202	245900	61273	4.79	5.39
463	13.877	230500	75904	4.88	5.36
473	17.703	219700	96837	4.99	5.34
483	21.427	211300	117201	5.07	5.32

CM obtained at 550 °C for 1 hour, in the entire studied temperature range exhibits semiconductor conductivity. The dielectric constant at the indicated ΔT is also low.

The calculation of the band gap was determined by the formula 1:

$$\Delta E = \frac{2kT_1T_2}{0.43(T_2 - T_1)} \lg \frac{R_1}{R_2}, \quad (1)$$

where k - is the Boltzmann constant; for calculating ΔE , it is $8.6173303 \cdot 10^{-5}$ eV·K⁻¹.

The calculation of ΔE was performed in the range 293–483 K. At a temperature of 293 K, the electrical resistance is 6.35, and at 483 K, $\log R = 3.32$.

$$\Delta E = \frac{2 \times 0.000086173 \times 293 \times 483}{0.43(483 - 293)} \lg \frac{6.35}{5.32} = \frac{24.3902}{81.7} \times 1.1936 = 0.36eV$$

This carbon material can be attributed to narrow-gap semiconductors.

Table 3 presents the dependence of electrical resistance (R), electric capacity (C) and dielectric constant (ε) on temperature (CM based on Saryadyr coal (Pyatimetrovyy layer) ($\tau = 2$ hours).

As can be seen from the data in the table, a CM with up to 383 K exhibits a low dielectric constant, then at 463 K it exhibits a relatively high dielectric constant (1.89 million). In the temperature range under study, the CM exhibits semiconductor conductivity; there are small temperature jumps at 333–373 K, which can be neglected. Calculation of the band gap, at $T = 293$ K, $\log R = 6.62$; $T = 483$ K, $\log R = 4.85$.

$$\Delta E = \frac{2 \times 0.000086173 \times 293 \times 483}{0.43(483 - 293)} \lg \frac{6.62}{4.85} = \frac{24.3902}{81.7} \times 1.3649 = 0.41eV$$

Table 3 – Electrical properties of CM based on Saryadyr coal (Pyatimetrovyy layer) ($\tau = 2$ hours)
(C - capacity, R - electrical resistance, ϵ - dielectric constant)

T, K	C, nF	R, Ohm	ϵ	$lg\epsilon$	lgR
293	0.05706	4160000	452	2.65	6.62
303	0.03489	4512000	276	2.44	6.65
313	0.03116	4173000	247	2.39	6.62
323	0.0299	4417000	237	2.37	6.65
333	0.02452	4645000	194	2.29	6.67
343	0.02557	4403000	202	2.31	6.64
353	0.05134	3217000	406	2.61	6.51
363	0.07499	3481000	594	2.77	6.54
373	0.04192	4031000	332	2.52	6.61
383	1.0483	730600	8299	3.92	5.86
393	6.2496	342500	49477	4.69	5.53
403	11.135	255300	88154	4.95	5.41
413	19.302	195500	152810	5.18	5.29
423	32.592	162100	258024	5.41	5.21
433	69.704	111500	551833	5.74	5.05
443	113.14	86600	895707	5.95	4.94
453	194.56	70440	1540293	6.19	4.85
463	239.31	65340	1894570	6.28	4.82
473	60.347	104200	477755	5.68	5.02
483	133.0	71250	1052935	6.02	4.85

This CM can also be attributed to narrow-gap semiconductors. Figures 3 and 4 below show the temperature dependence of the samples in the range 293–483 K.

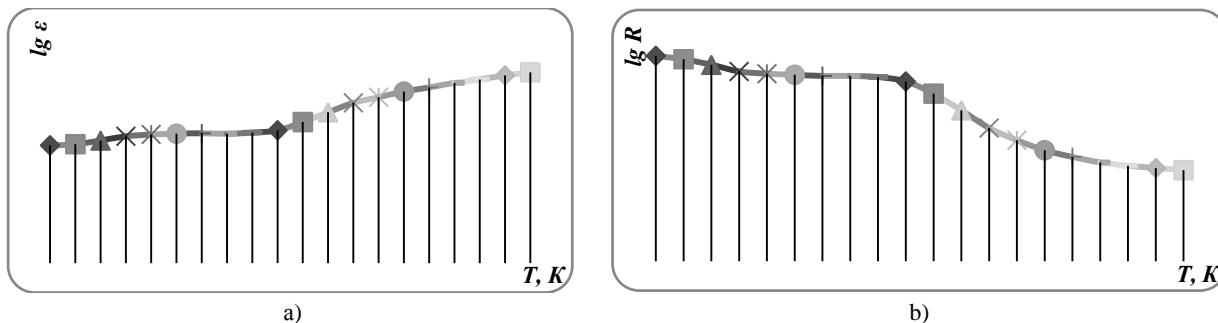


Figure 3 – Temperature dependence of CM based on coal from the Saryadyr deposit ($\tau = 1$ hour) in the range 293–483 K: a) dielectric constant; b) electrical resistance

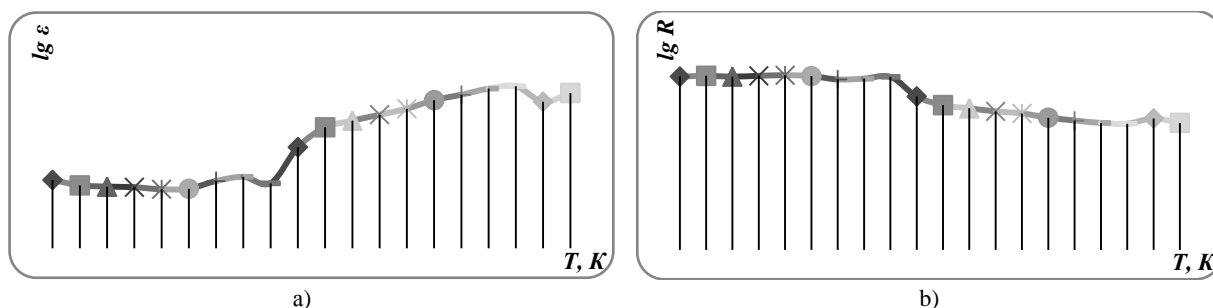


Figure 4 – Temperature dependence of CM based on coal from the Saryadyr deposit ($\tau = 2$ hours) in the range 293–483 K: a) dielectric constant; b) electrical resistance

Table 4 below shows the results of measuring the electrophysical characteristics of CM based on coal from the Saryadyr deposit, at a holding temperature of 3 hours.

Table 4 – Electrical properties of CM based on Saryadyr (Pyatimetrovyy layer) ($\tau = 3$ hours) (C - capacity, R - electrical resistance, ϵ - dielectric constant)

T, K	C, nF	R, Ohm	ϵ	$lg\epsilon$	lgR
293	65.899	148600	739879	5.87	5.17
303	15.198	234800	170635	5.23	5.37
313	217.17	42510	2438268	6.39	4.63
323	1927.1	15120	21636446	7.34	4.18
333	2529.8	11450	28403239	7.45	4.06
343	3630.1	8885	40756817	7.61	3.95
353	4884.2	7061	54837180	7.74	3.85
363	6286.9	5780	70585944	7.85	3.76
373	8504.2	4963	95480600	7.98	3.70
383	11653	3991	130833639	8.12	3.60
393	15050	3385	168973335	8.23	3.53
403	22778	2764	255739177	8.41	3.44
413	31371	2290	352216776	8.55	3.36
423	44725	1833	502148332	8.70	3.26
433	61763	1469	693441866	8.84	3.17
443	77146	1212	866153946	8.94	3.08
453	97302	1103	1092454712	9.04	3.04
463	2156.9	20030	24216517	7.38	4.30
473	1383.4	23290	15532074	7.19	4.37
483	2454.3	18670	27555565	7.44	4.27

As can be seen from the data obtained, the CM in the interval 293–453 K exhibits semiconductor properties, at $\Delta T = 453$ –473 K - metal and at $\Delta T = 473$ –483 K - the semiconductor nature of conductivity.

Figure 5 below shows the temperature dependence of the CM Saryadyr (Pyatimetrovyy layer) ($\tau = 3$ hours) in the range 293–453 K.

The calculation of ΔE was performed in the range of 293–453 K. At a temperature of 293 K, the electrical resistance is 5.17, and at 453 K, $\log R = 3.04$.

$$\Delta E = \frac{2 \times 0,000086173 \times 293 \times 453}{0.43(453 - 293)} \lg \frac{5.17}{3.04} = \frac{22.8753}{68.8} \times 1.7007 = 0.57 eV$$

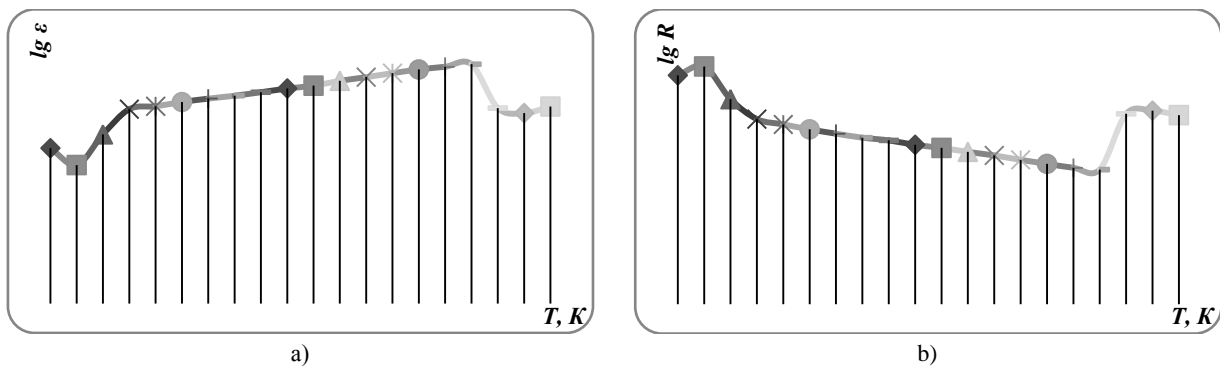


Figure 5 – Temperature dependence of UM based on coal from the Saryadyr deposit ($\tau = 3$ hours) in the range 293–483 K: a) dielectric constant; b) electrical resistance

The obtained carbon material in the range 293–453 K exhibits semiconductor conductivity characteristic of narrow-gap semiconductors. This CM have large values of dielectric constant, which from 740 thousand at 293 K reaches up to 1.1 billion at 453 K, i.e. up to 10^9 degrees to a colossal value and is very attractive as a promising material for microelectronics, i.e. at 453 K, ϵ of CM exceeds the reference $BaTiO_3$ by about 540 thousand times.

This is explained by a phase transition and the formation of carbon nanoparticles ranging in size from 100–700 nm on the surface of the sample, which is evidenced by electron microscopic images (3 hours exposure) (figure 2).

Conclusion. Thus, a chemical analysis of carbon materials from coal from the Saryadyr deposit (Pyatimetrovy layer) was carried out in the work. In the temperature range 293–483 K, their electrophysical characteristics C , R , ϵ were determined. The analysis showed that the obtained carbon material from Saryadyr coal is promising as a capacitive material, fuel cell and semiconductor, as well as for the manufacture of electrodes.

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«САРЫАДЫР» КЕН ОРНЫНЫҢ КӨМІРІ АРҚЫЛЫ АЛЫНҒАН КӨМІРТЕКТІ МАТЕРИАЛДЫҢ ЭЛЕКТРОФИЗИКАЛЫҚ ҚАСИЕТТЕРІ

Аннотация. Мақалада «Сарыадыр» («Пятиметровый») қабаты кен орнындағы Г маркалы көмірді 250–550 °C температурада 10–15 °C/мин жалдамдықта және 550 °C-та 1, 2 және 3 сағат көлемінде термиялық өңдеудің (карбонизация) нәтижелері келтірілген. Карбонизация нәтижесінде көміртекті материалдар (КМ) алынды. Термогравиметриялық, энергодисперсиялық рентгендік спектроскопия, электронды микроскопия әдістерін қолдана отырып, алынған өнімнің техникалық, элементтік құрамы мен беттік морфологиясы зерттелді. КМ-дың электрофизикалық сипаттамалары 293–483 К температура диапазонындағы үлгілердің электрлік кедергісін (R), электр сыйымдылығы (C) және диэлектриктік өткізгіштігін (ϵ) өлшеу арқылы анықталды. Алынған мәліметтер негізінде үлгілердің тыйым салынған аймақ ені (ΔE) есептелінді. 3 сағат ішінде 550 °C температурада алынған көміртегі материал үлкен диэлектрлік тұрақты мәнге ие, оның мәні 293 К-де 740 мыңнан 453 К кезінде 1,1 млрд.-қа дейін жетеді, яғни 10^9 дейінгі үлкен мәнге ие және микроэлектроника үшін перспективті материал болып табылады, яғни 453 К кезінде диэлектрлік өткізгіштігі ϵ эталон $BaTiO_3$ -тен шамамен 540 мың есе асады. Үлгілердің элементтік құрамы, құрылымы және өлшемі SEM (Quanta 3D 200i) құралында энергия дисперсиялық талдау EDAX көмегімен энергиялық дисперсиялық рентгендік спектроскопия көмегімен зерттелді. Талдаудағы электронды сәуленің энергиясы 15 кэВ. Элементтік талдау нәтижелері көмірді термиялық өңдеуден кейін гетероатомдардың көп бөлігі (оттегі, сутегі, күкірт, азот) газ тәрізді өнімдер түрінде бөлінеді. Тиісінше, көміртегі концентрациясы 82,98-ден 67,80 мас. %-ға дейін төмендейді және қарапайым құрылымдық блоктарға немесе қарапайым графит кристаллиттеріне біріктірілген ароматты сақиналардың құрылымы дамиды. Микросуреттерді талдау нәтижелері термоөңдеуден кейін беттік құрылымында кіші бөлшектер (~ 170 нм дейін) пайда болғанын көрсетеді. КМ өнімдерінде кристаллиттер тұрақты емес орналасады, олардың арасындағы саңылаулар шайырлы заттардың ыдырауы кезінде пайда болатын аморфты көміртегімен толтырылған. Карбонизация нәтижесінде ұшқыш заттар шикізаттан бөлініп, диаметрі 2-ден 30 мкм-ге дейінгі бастапқы макропорлы құрылымдар пайда болады. Электрлік қасиеттерді (электр өткізгіштік пен электр кедергісі) зерттеу LCR-800 сериялы қондырғысындағы (Тайвань) үлгілердің электр сыйымдылығын 1 кГц тұрақты жиіліктегі құрғақ ауада термостатикалық режимде әр белгіленген температурада ұстап тұру уақытымен өлшеу арқылы жүргізілді. 550 °C температурада 1 сағатта алынған КМ, зерттелген температура диапазонында жартылай өткізгіштік қасиет көрсетеді. Көрсетілген ΔT диэлектрлік константаның мәні де төмен. Бұл көміртекті материалды тар аймақты жартылай өткізгіштерге жатқызуға болады. 550 °C температурада 2 сағат ішінде 383 К дейін алынған КМ төмен диэлектрлік тұрақты, ал 463 К кезінде салыстырмалы түрде жоғары диэлектрлік тұрақты (1,89 млн) көрсетеді. Зерттеліп жатқан температура диапазонында КМ жартылай өткізгіштік қасиетке ие, 333–373 К температурада кішігірім ауытқулар байқалады, оларды ескермеуге болады. $T = 293$ К, $\lg R = 6.62$ $T = 483$ К, $\lg R = 4.85$ кезінде тыйым салынған аймақ ені есептелінді (ΔE). Бұл КМ-ды жартылай өткізгіштерге де жатқызуға болады. 3 сағат ұстау температурасында алынған 293–453 К диапазонында жартылай өткізгіштік қасиеттері бар, $\Delta T = 453$ –473 К - металлдық және $\Delta T = 473$ –483 К кезінде - жартылай өткізгіштік. ΔE есептеу 293–453 К аралығында жүргізілді, 293 К температурада электр кедергісі 5,17, ал 453 К температурада $R = 3.04$. Алынған көміртегі материалдар 293–453 К диапазонында жартылай өткізгіштікке ие. Бұл КМ диэлектрлік өткізгіштік мәні өте жоғары, олар 293 К-де 740 мыңнан 453 К 1,1 миллиардқа жетеді, яғни 10^9 дәрежесіне дейінгі үлкен мәнге ие және микроэлектроника үшін перспективті материал болып табылады. Мұны фазаның ауысуымен және үлгінің бетінде мөлшері 100–700 нм-ге дейін болатын көміртекті нанобөлшектердің түзілуімен түсіндіріледі, электронды микроскопиялық суреттермен дәлелденеді. Сонымен, жұмыс

барысында «Сарыадыр» кен орны көмірінен («Пятиметровый» қатпары) алынған көміртекті материалға химиялық талдау жүргізілді. 293–483 К температуралық диапазонда олардың электрофизикалық сипаттамалары C , R , ϵ анықталды. Талдау нәтижесі Сарыадыр көмірінен алынған көміртекті материал сыйымдылық материал ретінде, отын элементі және жартылай өткізгіш ретінде, сондай-ақ электродтар өндірісі үшін перспективті материал екенін көрсетті.

Түйін сөздер: көміртекті материал (КМ), химиялық құрамы, электрофизикалық қасиеттер, электркердегі, электрсыымдылық, диэлектриктік өткізгіштік.

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ЭЛЕКТРОФИЗИЧЕСКИЕ СВОЙСТВА УГЛЕРОДНОГО МАТЕРИАЛА НА ОСНОВЕ УГЛЯ МЕСТОРОЖДЕНИЯ «САРЫАДЫР»

Аннотация. В статье приведены результаты термической обработки (карбонизации) угля марки Г месторождения «Сарыадыр» (пласт «Пятиметровый») в интервале температур 250–550 °С при скорости нагрева 10–15 °С/мин и с выдержкой при 550 °С в течение 1, 2 и 3 часов. В результате карбонизации получены углеродные материалы (УМ). Методами термогравиметрического, энергодисперсионной рентгеновской спектроскопии, электронной микроскопии изучены технический, элементный состав, морфология поверхности полученных продуктов. Определены электрофизические характеристики УМ путем измерения электросопротивления (R), емкости (C) и диэлектрической проницаемости (ϵ) образцов в интервале температур 293–483 К. На основании полученных данных рассчитаны ширина запрещенной зоны (ΔE) образцов. Углеродный материал, полученный при 550 °С в течение 3 часов, обладает большими значениями диэлектрической проницаемости, которая от 740 тыс. при 293 К достигает до 1.1 млрд при 453 К до 10^9 степени до колоссального значения и является очень привлекательным в качестве перспективного материала для микроэлектроники, при 453 К ϵ УМ превышает эталонного BaTiO₃ примерно в 540 тыс. раз. Исследование элементного состава, структуры и размерности образцов проводили методом энергодисперсионной рентгеновской спектроскопии на приборе SEM (*Quanta 3D 200i*) с приставкой для энергодисперсионного анализа от EDAX. Энергия возбуждающего пучка электронов при анализе была 15 кэВ. Результаты проведенного элементного анализа показали, что большая часть гетероатомов (кислород, водород, сера, азот) удаляется в виде газообразных продуктов. Соответственно уменьшается концентрация углерода с 82,98 до 67,80 мас. % и развивается структура плоских ароматических колец, объединяющихся в основные структурные единицы или элементарные графитовые кристаллиты. Результаты анализа микроснимков показывают, что после термической обработки поверхностная структура изменяется с меньшими размерами частиц (до ~170 нм). В продуктах УМ кристаллиты расположены нерегулярно, промежутки между ними заполнены (или блокированы) аморфным углеродом, который образуется при разложении смолистых веществ. Как известно, в результате карбонизации из сырья выделяются летучие (влага и частично смолы) вещества. Одновременно в нем образуются первичные макropористые структуры диаметром от 2 до 30 мкм. Исследование электрофизических свойств (диэлектрической проницаемости и электрического сопротивления) проводилось путем измерения емкости образцов на серийном приборе LCR-800 при рабочей частоте 1кГц непрерывно в сухом воздухе в термостатном режиме со временем выдержки при каждой фиксированной температуре. УМ, полученный при 550 °С в течение 1 часа, во всем исследуемом интервале температуры проявляет полупроводниковую проводимость. Диэлектрическая проницаемость также при указанном ΔT невысокая. Данный углеродный материал можно отнести к узкозонным полупроводникам. УМ, полученный при 550 °С в течение 2 часов, до 383 К проявляет низкую диэлектрическую проницаемость, далее при 463 К он проявляет относительно высокую диэлектрическую проницаемость (1.89 млн.). УМ проявляет в исследуемом интервале температуры полупроводниковую проводимость, есть небольшие скачки температуры при 333–373 К, которыми можно пренебречь. Рассчитана ширина запрещенной зоны при $T = 293$ К, $\lg R = 6,62$; $T = 483$ К, $\lg R = 4,85$. Данный УМ можно также отнести к узкозонным полупроводникам. УМ, полученный при температуре выдержки 3 часа в интервале 293–453 К, проявляет полупроводниковые свойства, при $\Delta T = 453$ –473 К – металлическую и при $\Delta T = 473$ –483 К – полупроводниковый характер проводимости. Расчет ΔE произведен в интервале 293–453 К. При температуре 293 К электросопротивление составляет 5.17, а при 453 К $\lg R = 3.04$. Полученный углеродный материал в интервале 293–453 К проявляет полупроводниковую проводимость, характерную узкозонным полупроводникам. Данный УМ обладает большими значениями диэлектрической проницаемости, которая от 740 тыс. при 293 К достигает до 1.1 млрд при 453 К, т.е. до 10^9 степени до колоссального значения и является очень привлекательным в качестве перспективного материала для микроэлектроники. Это объясняется фазовым переходом и образованием углеродных наночастиц размером от 100–700 нм на поверхности образца, о чем свидетельствуют электронно-микроскопические снимки. Таким образом, в работе проведен химический анализ углеродных материалов из угля месторождения «Сарыадыр» (пласт «Пятиметровый»). В интервале температур 293–483 К определены их электрофизические характеристики C , R , ϵ . Проведенный анализ показал, что полученный углеродный материал из Сарыадырского угля представляется перспективным в качестве емкостного материала, топливного элемента и полупроводника, а также для изготовления электродов.

Ключевые слова: углеродный материал (УМ), химический состав, электрофизические свойства, электросопротивление, емкость, диэлектрическая проницаемость.

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FORMATION OF SELENIUM POWDER AT REDUCTION OF SELENITE IONS IN HYDROCHLORIC ACID SOLUTION ON THE SURFACE OF COPPER ANODE

Abstract. The article shows the possibility of reduction of selenite ions in the presence of copper (II) ions with the formation of dispersed selenium powders. The effect of the concentration of hydrochloric acid, copper (II) ions, the current density at the copper anode and the solution temperature on the current efficiency (CE) of the formation of selenium powder has been studied. The current efficiency of selenium powder was calculated by the weight of the powder formed. It was found that with increase in concentration of copper (II) ions and the solution temperature, the current efficiency of the formation of elemental selenium in the form of a powder increases. It was shown that at the current density below 75 A/m², the current efficiency of selenium powder exceeds 100%. Previous studies have shown that titanium (IV) ions cannot be used in the recovery of selenite ions. Using an electron microscope, micrographs of selenium powder were obtained. They indicate the formation of a finely dispersed selenium powder of spherical shape with an average particle size of 0.252 μm.

Key words: electrochemistry, selenium powder, selenite ion, copper (II) chloride, reduction, electrolysis, current density, hydrochloric acid.

Selenium powders have various applications, for example, 23.9% in the metallurgy of ferrous and non-ferrous metals. Thus, the presence of a small amount (0.2-0.3%) contributes to production of fine-grained structure in cast steel, freeing it from casting defects and giving good ductility. The additive of selenium to certain grades of stainless steel improves their ability to be machined. In magnesium-manganese alloys, an admixture of 0.5-3% selenium increases the corrosion resistance. Another field of application of powdered selenium is the glass and ceramic industries (25.7%). A small additive gives the glass a different beautiful color. In an elementary colloidal form, selenium stains glass (depending on the added amounts) from pink to red-orange and dark red. Glass thus painted is widely used for light signaling in the form of light filters. The composition of black glass, which has the best light absorbing properties, includes 0.6% Se and 0.1% CoC₃. Thus, the glass, ceramic and chemical industries, as well as electronics, have been the main consumers of selenium for a long time [1-3].

A method for producing powdered selenium, which was previously used in industry, based on the recovery of selenite ions (SeO₃²⁻) is known [4]. As a reducing agent the sulfur dioxide (SO₂) is used, which reduces selenite ion by the reaction:



The disadvantage of this method is that the use of toxic sulfur dioxide in the reduction process complicates the process, since a number of problems arise during its production and storage, in addition, special sealed equipment is required that ensures maximum allowable concentration in working rooms of no more than 0.02 mg/l. In this regard, this method is not used in industry.

The most efficient are electrochemical methods for producing selenium from industrial products. In this regard, a number of scientific research is devoted to the study of the electrochemical behavior of selenium and its compounds [1, 5-15].

This paper [16] shows the possibility of producing selenium powder upon polarization by a cathodic impulse current of selenite ions (SeO_3^{2-}), in which the selenium oxidation rate is “plus four”. It was shown that in a sulfuric acid solution at a cathodic current density of 100–2500 A/m², selenium powders with average particle sizes of 7–16 μm are formed. It was found that cathodic reduction of selenium proceeds according to the reaction:



It is also shown that at high cathodic current densities, the formed selenium powders interact with atomic hydrogen and, as a consequence, there is co-formation of toxic gas - hydrogen selenide:



We previously showed that it is possible to reduce selenate ions, in other words, anions in which selenium is in the oxidation rate of “plus six” – (SeO_4^{2-}), in the presence of Ti^{4+} ions and copper (II) [1,13,18]. The possibility of electrocatalytic reduction of selenate ions on a lead electrode was also established [17].

Our preliminary studies showed that Ti^{4+} ions cannot be used in the reduction of selenite ions, because interacting with each other, they form an insoluble compound - titanium selenite, with the approximate composition $4\text{TiO}_2 \cdot \text{SeO}_3 \cdot 13\text{H}_2\text{O}$ or $\text{TiO}_2 \cdot \text{SeO}_3$, which precipitates.

The purpose of our work is to produce finely dispersed powders of selenium by reducing selenium (IV) using cuprous copper ions formed in hydrochloric acid solutions at anodic polarization.

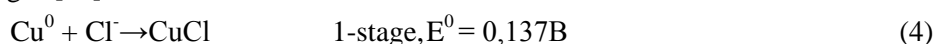
Experimental technique. The experiments were carried out in a thermostatically-controlled electrolyzer with a volume of 100 ml, the electrode spaces were separated by an MA-40 anion exchange membrane. A copper plate (99.99%) was used as the anode, and VT-1 titanium was used as the cathode. The following reagents were used: selenium (IV) oxide of chemically pure grade, copper (II) chloride – pure grade. The composition of the initial electrolyte: hydrochloric acid, copper (II) chloride and selenite ions. The effect of the concentrations of hydrochloric acid and copper (II) ions, the current density at the copper anode and the solution temperature on the current efficiency of the formation of selenium powder has been studied. The current efficiency of selenium powder was calculated by the weight of the powder formed.

Results and their discussion. We believe that if certain metals, under certain conditions (i.e., in solutions), dissolve anodically to form their lower oxidation ions, which are the reducers of selenite ions, due to the formation of a redox system with a negative potential relative to the Se(IV)-Se system, then the selenite ion should be reduced to the elemental state on the surface of this metal.

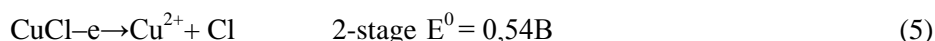
To establish the correctness of this idea, we conducted preliminary studies on the recovery of selenite ions on the surface of a copper anode in a hydrochloric acid solution. The results of the experiments clearly showed that in this case, the reduction of selenite ions on the surface of the copper anode occurs with the formation of elemental selenium in the form of a dispersed powder.

The reason for this is that the standard potential (E^0) of the Cu (I) - Cu (II) redox system in the hydrochloric acid solution is -0.54 V, and the potential of the Se-Se (IV) system is 0.77 V (as is known from the reference guide [19]), i.e. the standard potential of the first system has a more negative value compared to the value of the second one. In this regard, copper ions Cu^+ reduce selenite ions to form elemental selenium, while they themselves are oxidized to Cu^{2+} .

In theoretical terms, the anodic oxidation of copper in a chloride solution, i.e. in a solution of sodium chloride proceeds in two stages [20]:



further



At low current densities, copper is ionized only to form copper (I) ions. Besides, in this case there is a reaction of disproportionation, i.e. a copper electrode interacts with copper (II) ions to form copper (I) chloride:



Copper (I) chloride is very soluble in hydrochloric acid solution to form copper (I) ions and chlorine.

The copper (I) ions formed by the reactions (4) and (6), according to the potentials of the above redox systems Cu(I)-Cu(II) and Se-Se(IV), will instantly enter into the chemical reaction of reduction (7) on the surface of the copper anode, since the equilibrium constant (K-value) of this reaction is 10^{15} and the reaction equilibrium is strongly shifted to the right.



It may be noted that the ions in the solution, as well as copper (II) ions formed by the reaction (7) at low cathodic current densities, are also reduced only to copper (I) by the reaction:



The Cu^+ ions formed on the cathode surface as well may participate in the reduction of selenite ions to elemental powdered selenium by the reaction (7). But in this study, we have established the patterns of formation of selenium powder only in the anode space.

As can be seen in figure 1, an increase in the concentration of hydrochloric acid first leads to a sharp increase in the current efficiency of selenium powder formation. This effect of hydrochloric acid is due to the fact that, with an increase in its concentration, the stability of copper (I) ions - reducing agent increases, and in this regard, the ionization rate of the copper electrode in the first stage increases, as well as the process of formation of selenium powder by chemical reaction (7). On the other hand, the formed copper (I) ions bind in a complex with chlorine ions of the CuCl_n^{n-} type, where the "n" number increases with increasing concentration of hydrochloric acid and, accordingly, this leads to a decrease in the reducibility of cuproions according to the reaction (7). All this in total leads to a more delayed increase in the CE of the formation of selenium powder.

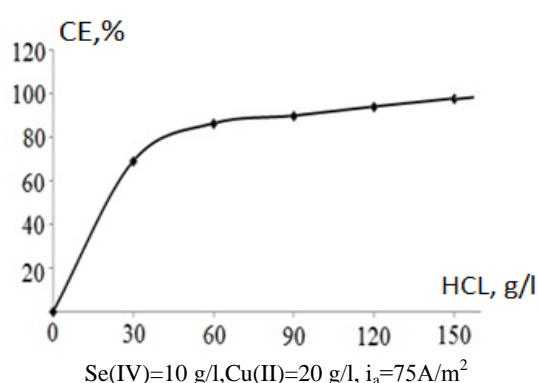


Figure 1 – Reduction of selenite ions to form selenium powder depending on the concentration of hydrochloric acid

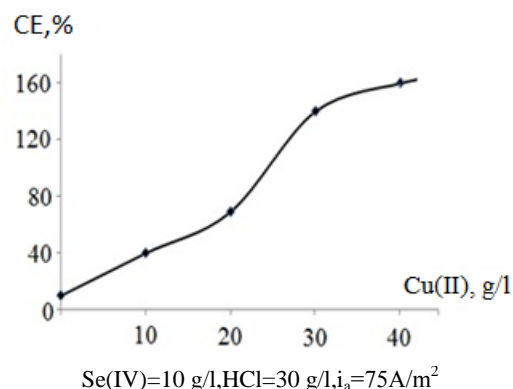


Figure 2 – Reduction of selenite ions to form selenium powder depending on the concentration of copper (II) ions

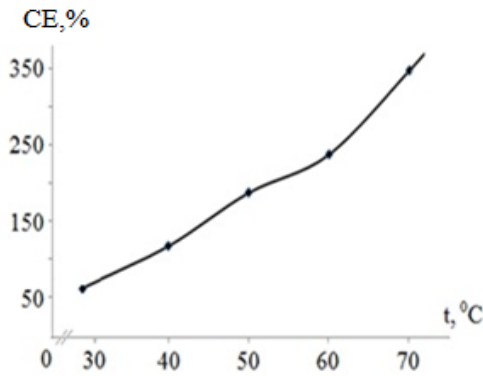
Increase in the concentration of copper (II) ions in solution leads to a proportional increase in the current efficiency of selenium powder formation (figure 2). This is due to the formation of additional amounts of copper (I) ions due to the well-known chemical reaction (6). As can be seen in figure 2, with an increase in the concentration of copper (II) ions, the rate of formation of copper (I) ions increases.

Besides, in this case, the fraction of copper ionization reaction in the first stage increases, i.e. mainly to form copper (I) ions. Additional experiments showed that in the absence of copper (II) ions in solution, the reduction of selenite ions proceeds with a low current efficiency (CE does not exceed 10%).

As the solution temperature rises, the current efficiency of powder formation sharply increases (figure 3), which is due to an increase in the rate of formation of copper (I) ions by the chemical reaction of re-disproportionation (9).

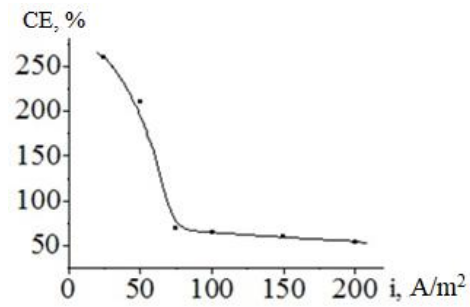
Using the Arrhenius dependence, the apparent activation energy of 38.5 kJ/mol was calculated, which is typical for processes with a mixed diffusion-kinetic nature.

With an increase in the current density at the copper electrode, a decrease in the CE of the formation of selenium powder is observed (figure 4).



Se(IV) = 10 g/l, HCl = 30 g/l, Cu(II) = 20 g/l, $i_a = 75 \text{ A/m}^2$

Figure 3 – Reduction of selenite ions to form selenium powder depending on the temperature of the electrolyte



Se(IV) = 10 g/l, HCl = 30 g/l, Cu(II) = 20 g/l

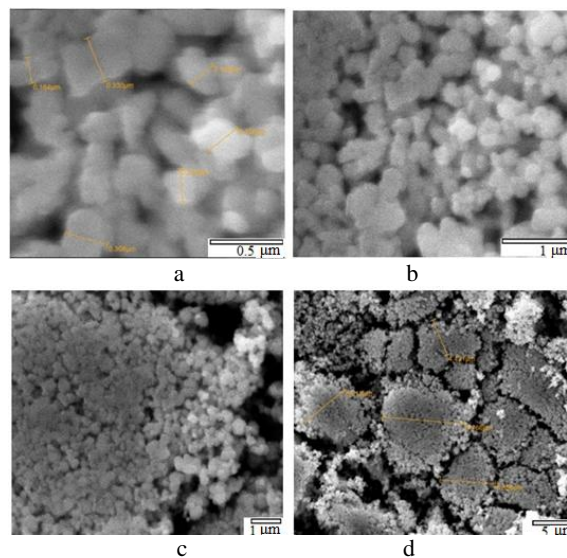
Figure 4 – Reduction of selenite ions to form selenium powder depending on the current density

This is due to the fact that, with an increase in the anode current density, according to the Tafel equation, the electrode potential shifts to the positive side, in this regard, the rate of the second stage increases, i.e. the formation of copper (II) ions, which cannot participate in the reduction reaction, i.e. in the formation of selenium powder. This leads to a decrease in CE of powder formation. It should be noted that up to a solution temperature of 60°C red amorphous selenium powders are formed, and above that - gray selenium.

We note that the excess of CE of selenium powder by 100% in all cases is due to the participation in the reaction of copper (I) ions formed owing to the chemical reaction of repropotionation (6). Thus, in the presence of selenium (IV) anions in solution, they are reduced on the surface of the copper anode due to cuprous copper ions formed as a result of the anodic electrochemical reaction and chemical reaction (6). But the fraction of the latter decreases with increasing current density at the copper anode to a certain value.

It should be noted that in this case, copper selenide is formed in small amounts on the surface of the copper anode.

Figure 5 shows microphotographs of the selenium powder produced on the surface of a copper anode obtained using a JSM6610W electron microscope. As can be seen in the above microphotographs, the particles of the produced selenium powder have mainly spherical shapes, the average particle sizes of which are 0.252 μm .



Se(IV)=10 g/l; Cu(II)=10 g/l; $i=75 \text{ A/m}^2$; HCl=30 g/l

Figure 5 – Microphotographs of selenium powder produced in the anode space, magnified: a) 50,000 times; b) 25,000 times; c) 10,000 times; d) 3000 times

Conclusions. We for the first time showed the possibility of reducing selenite ions in hydrochloric acid solutions on the surface of a copper anode. It was found that an increase in the concentration of hydrochloric acid and copper (II) ions, as well as an increase in the solution temperature leads to an increase, and an increase in the current density at the copper anode leads to a decrease in the current efficiency of selenium powder formation.

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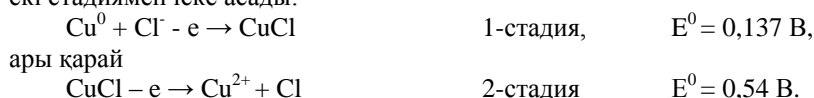
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ТҰЗ ҚЫШҚЫЛЫ ЕРІТІНДІСІНДЕ СЕЛЕНИТ-ИОНДАРЫН ТОТЫҚСЫЗДАНДЫРУ КЕЗІНДЕ МЫС АНОДЫНЫҢ БЕТІНДЕ СЕЛЕН ҰНТАҚТАРЫНЫҢ ТҮЗІЛУІ

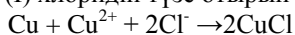
Аннотация. Зерттеулер мыс электродын тұз қышқылды ерітінділерде анодтық поляризациялау кезінде түзілетін мыстың бір валентті иондарының қатысуымен селенит иондарын тотықсыздандыруға арналған. Тәжірибелер нәтижелері осы жағдайда селенит иондарының дисперсті ұнтақ күйде түзілетін элементті селенге дейін тотықсыздануы мыс анодының бетінде және анод жанындағы кеңістікте жүретінін біржақты көрсетті.

Болған жағдай тұз қышқылындағы Cu (I) - Cu (II) тотығу-тотықсыздану жүйесінің стандарттық потенциалының (E^0) мәні $-0,54$ В құрайтынымен, ал Se-Se (IV) жүйесінің потенциалы $-0,77$ В құрайтынымен, демек, бірінші жүйенің стандарттық потенциалының мәні екінші жүйенің потенциалының мәніне қарағанда терістеу болуымен түсіндіріледі. Осыған байланысты Cu^+ -иондары селенит-иондарын элементті селен түзе тұра тотықсыздандырады да, өздері Cu^{2+} - ге дейін тотығады.

Теориялық тұрғыдан мыстың хлоридті ерітіндіде, демек, натрий хлориді ерітіндісінде анодтық тотығуы екі стадиямен іске асады:

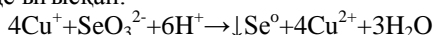


Ток тығыздықтарының төменгі мәндерінде мыс тек мыс (I) иондарын түзе отырып тотығады. Осыдан басқа, бұл жағдайда компропорциялану реакциясы орын алады, демек, мыс электроды мыс (II) иондарымен мыс (I) хлоридін түзе отырып әрекеттеседі:

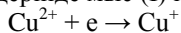


Мыс (I) хлориді тұз қышқылды ерітіндіде өте жақсы ериді, бұл кезде мыс (I) иондары және хлор түзіледі.

Жоғарыда келтірілген реакциялар бойынша түзілген мыс (I) иондары жоғарыда келтірілген Cu(I)-Cu(II) және Se-Se(IV) тотығу-тотықсыздану жүйелерінің потенциалдарының мәндеріне сәйкес тез арада мыс анодының бетінде селен (IV) иондарын химиялық жолмен тотықсыздандыру реакциясына түседі, себебі бұл реакцияның біз есептеген тепе-теңдік константасы ($K_{T-т}$) 10^{15} құрайды және тепе-теңдік оңға қарай мардымды түрде ығысқан.



Айта кететін мәселе, ерітіндіде түзілген мыс (II) иондары да катодтық ток тығыздықтарының төменгі мәндерінде мыс (I) иондарын түзе, келесі реакция бойынша тотықсызданады:



Түзілген бір валентті мыс иондары да селенит-иондарды катод бетінде және катодтық кеңістікте элементті ұнтақ түріндегі селенге дейін тотықсыздандыруға қатысады. Бірақ бұл зерттеуде біз ұнтақ түріндегі селеннің тек анодтық кеңістікте түзілу заңдылықтарын анықтадық.

Селен ұнтақтарының түзілуінің ток бойынша шығымына (ТШ) тұз қышқылы концентрациясының, мыс (II) иондарының концентрациясының, мыс анодындағы ток тығыздығының және ерітінді температура-сының әсерлері зерттелді. Селен ұнтақтарының түзілуінің ток бойынша шығымы түзілген ұнтақтың массасы бойынша есептелді. Мыс (II) иондарының концентрациясының және ерітінді температурасының өсуімен элементті селен ұнтақтарының түзілуінің ток бойынша шығымы артатындығы анықталды. 75 A/m^2 -ден төмен ток тығыздықтарында селен ұнтақтарының түзілуінің ток бойынша шығымы 100 %-дан асатындығы көрсетілді.

Электронды микроскоп көмегімен селен ұнтақтарының микросуреттері түсірілді. Бұл нәтижелер сфера пішінді бөлшектердің орта өлшемі $0,252 \text{ мкм}$ болып келетін майда дисперсті селен ұнтақтарының түзілгенін көрсетті.

Түйін сөздер: электрохимия, селен ұнтақтары, селенит-ион, мыс (II) хлориді, тотықсыздану, электролиз, ток тығыздығы, тұз қышқылы.

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ФОРМИРОВАНИЕ ПОРОШКА СЕЛЕНА ПРИ ВОССТАНОВЛЕНИИ СЕЛЕНИТ-ИОНОВ В СОЛЯНОКИСЛОМ РАСТВОРЕ НА ПОВЕРХНОСТИ МЕДНОГО АНОДА

Аннотация. Исследования посвящены восстановлению селенит-ионов в солянокислых растворах с участием ионов одновалентной меди, образующейся при анодной поляризации медного электрода. Результаты опытов однозначно показали, что в данном случае восстановление селенит-ионов происходит с образованием элементного селена в виде дисперсного порошка на поверхности медного анода и в прианодном пространстве.

Это объясняется тем, что стандартный потенциал (E^0) окислительно-восстановительной системы Cu (I) - Cu (II) в солянокислом растворе равен $-0,54 \text{ В}$, а потенциал системы Se-Se (IV) – $0,77 \text{ В}$, т.е. стандартный потенциал первой системы имеет более отрицательное значение по сравнению со значением второй. В этой связи ионы меди Cu^+ восстанавливают селенит-ионы с образованием элементного селена, а сами при этом окисляются до Cu^{2+} .

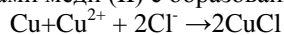
Теоретически анодное окисление меди в хлоридном растворе, т.е. в растворе хлорида натрия протекает в две стадии:



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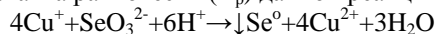


При невысоких плотностях тока медь ионизируется только с образованием ионов меди (I). Кроме того, в данном случае имеет место реакция компрпорционирования, т.е. медный электрод взаимодействует с ионами меди (II) с образованием хлорида меди (I):

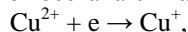


Хлорид меди (I) очень хорошо растворяется в солянокислом растворе с образованием ионов меди (I) и хлора.

Образовавшиеся по вышеуказанным реакциям ионы меди (I), согласно величинам потенциалов вышеуказанных окислительно-восстановительных систем Cu(I)-Cu(II) и Se-Se(IV), будут моментально вступать в химическую реакцию восстановления селена (IV) на поверхности медного анода, так как рассчитанная нами константа равновесия (K_p) данной реакции равна 10^{15} и равновесие сильно смещено вправо.



Следует отметить, что имеющиеся в растворе ионы меди (II) при невысоких катодных плотностях тока также восстанавливаются с образованием ионов меди (I) по реакции:



Образовавшиеся одновалентные ионы также могут участвовать в реакции восстановления селенит-ионов до элементного порошкообразного селена на поверхности катода и в прикатодном пространстве. Но в данном исследовании нами установлены закономерности формирования порошка селена только в анодном пространстве.

Исследовано влияние концентрации соляной кислоты, ионов меди (II), плотности тока на медном аноде и температуры раствора на выход по току (ВТ) образования порошка селена. Выход по току порошка селена рассчитывали по весу образовавшегося порошка. Установлено, что с увеличением концентрации ионов меди

(II) и температуры раствора повышается выход по току образования элементарного селена в виде порошка. Показано, что при плотности тока ниже 75 A/m^2 кажущийся выход по току порошка селена превышает 100%.

С помощью электронного микроскопа получены микрофотографии порошка селена. Они свидетельствуют о формировании мелкодисперсного порошка селена с частицами сферической формы со средними размерами 0,252 мкм.

Ключевые слова: электрохимия, порошок селена, селенит-ион, хлорид меди (II), восстановление, электролиз, плотность тока, соляная кислота.

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n_kozyukova@list.ru, mbruyako@yandex.ru,**DETERMINATION OF THE DURABILITY PARAMETERS
OF SAND SOILS UNDER COMPRESSION**

Abstract. Arrangement of sand and ground cushions in the foundations, a widespread method of reinforcing, increasing bearing capacity and strengthening weak, structurally unstable soils, especially in seismic areas. 7 regions of Kazakhstan, this is more than 6 million people and 40% of the country's industrial potential are located in areas of increased seismic activity, so the issue of strengthening the foundations in these areas is relevant and requires further study. The article presents the results of experimental studies carried out according to the methods developed by the authors on modified devices equipped with measuring equipment (hard voltage sensors - pressure gauges).

The article presents the results of experimental studies carried out according to the methods developed by the authors on modified devices equipped with measuring equipment (hard voltage sensors - pressure gauges). Studies includes sandy soils of various densities, humidity, particle size distribution and various methods of sample formation. Strength parameters determined by the research results are necessary for calculating the bearing capacity, determining the characteristics of the base soil under dynamic and static loads. These comparative tests were carried out on a compression device with side pressure measurement and a shear bench. During the formation of soil samples, uniform boundary conditions were created according to their physical properties. The main prerequisite for such comparative tests was the law of C. Coulomb on the condition of limiting equilibrium in soils. Assessment of stress states under compression and shear was carried out by the graph-analytical solution of Mohr and Coulomb's law.

Key words: physical properties, soil strength, ultimate stress state, angle of internal friction, adhesion, lateral pressure, vertical pressure, graph-analytical solution.

Introduction. When building foundations on weak structurally unstable soils, especially in seismic areas [1,2], one of the most common methods of increasing the bearing capacity of bases is the installation of soil and sand cushions. Therefore, the question of studying the physicommechanical properties of sandy soils, their dependence on indicators of the physical state and strength parameters, the method of formation and compaction of the sand cushion, is very relevant [3].

The authors conducted a set of experimental studies to study the influence of the method of soil formation, its physical properties, methods for determining the strength parameters, on the bearing capacity of sand.

According to the current design standards in Kazakhstan [4,5], and abroad [6,7], the design resistance of the base soil depends on the physical characteristics (density, humidity, etc.) and strength properties (adhesion-s and the angle of internal friction- φ) The soil strength parameters c and φ are determined from the condition of the limit equilibrium of C. Coulomb [8, 9], in which the slightest additional increase in force affects the balance existing at the point of the array and sets the mass in motion (destruction) with a different intensity. [10] The experimental implementation of the Coulomb equilibrium state scheme is possible only under conditions that create the development of maximum holding horizontal force, which is ensured under conditions of compression compression with rigid stationary side walls. Based on the Coulomb scheme, the second way of realizing the equilibrium conditions of a caving wedge, retained by

its adhesion and friction, is to apply the maximum shear load, while the rigidity of this load should be much higher than the stiffness of the soil. [11] In both cases, the maximum horizontal force, according to C. Coulomb, is a function of both external and internal stress states.

During shear, the reaction to an external force action, which is modeled by lateral pressure σ_b , is the ultimate shear resistance $\tau_{pre.}$, because of the “connectivity and friction” [12]. In this case the state of ultimate equilibrium is described by the Coulomb law, which establishes a relationship between the tangential stress τ_{pre} and the normal stress σ .

$$\tau = \sigma \operatorname{tg}\varphi + c$$

Under conditions of compression the response to external sealing pressure is the maximum horizontal force, which will decrease, in the case of the slightest compliance of the system. Assessment of the stress state of the soil during compression was carried out by the method of Mohr. [8,13] The use of Mohr’s graph-analytical solution to determine the parameters of the stress state during compression under conditions of the impossibility of lateral expansion is based on the following.

1. The condition of limiting equilibrium formulated by Coulomb or the state of stability is the stress state of the array at rest. The maximum horizontal force is required in order to preserve it. In the case of compression without the possibility of lateral expansion - this is a horizontal spacer.

2. The concept of the equality of the conditions of Coulomb and Mohr [8,9], adopted in soil mechanics, allows to distribute them for comparing stress states during shear and compression.

3. The physical premise of such a comparison is the mechanism of the compression process. The compaction process is associated with microshear of particles, the possibility of which is due to the porosity of the soil, its density, moisture composition. In this case, self-hardening of the soil occurs under the action of a compaction load. Mohr's solution allows comparing the parameters of the Coulomb strength with the parameters of the stress state under self-hardening of the soil under compression conditions.

In Kazakhstan and abroad, an experimental study of the parameters of ultimate equilibrium is currently carried out according to standard methods [15,16,17] using triaxial compression devices or shear devices [18,19]. In both cases, the evaluation criterion is the value of the relative deformation (vertical volumetric or shear), which allows rather conditional assessment of the stress state in the soil and the moment of the onset of a progressive course of deformations. In this connection, experimental studies were performed on improved compression and shear devices equipped with strain gauges [20]. A thorough metrological examination of the equipment was carried out, the factors affecting the values of the measured indicators were determined [21].

Based on the foregoing provisions, shear tests [22] were used as the main criterion for assessing the limiting state of soils, as a generally accepted method for determining the strength parameters, which were subsequently compared with the parameters obtained by the graph-analytical solution of Mohr from the results of compression tests with measurement of lateral pressure. A series of tests were carried out on sandy soils with different densities and particle size distributions.

The fine loose sands of medium density. Loose sand samples ($\rho_d = 1.44 \text{ g/cm}^3$) were formed by layer-by-layer sanding, medium density ($\rho_d = 1.60 \text{ g/cm}^3$) with insignificant force impact. Studies have shown that the method of samples forming significantly affects the test results. According to the data obtained, Mohr diagrams were constructed (for compression tests with the measurement of σ_b) and shear (figure 1). The discrepancies in the value of the angle of internal friction φ_m were about 1%. φ_m (the angle of internal friction according to the Mohr diagram) was 17.3 degrees for loose sand and φ_k (according to the results of shear tests) - 17.1 degrees. For sand of medium density, φ_m was 21.6 and φ_m was 21.8 for shear tests. In addition, a relationship has been established between the lateral pressure coefficient and the strength properties of soil that does not have an internal stress state (due to formation). $\xi = \operatorname{tg}2(45 - \varphi/2)$.

Similar tests were carried out for other types of sandy soils that differ in grain size and moisture. The discrepancies in the values of the angles φ_m and φ_k ranged from 1% to 1.5%. Thus, the conducted studies allowed us to conclude that the Coulomb limit state is realized under the conditions of the impossibility of lateral expansion and the applicability of Mohr's solutions to describe the limit state under compression conditions.

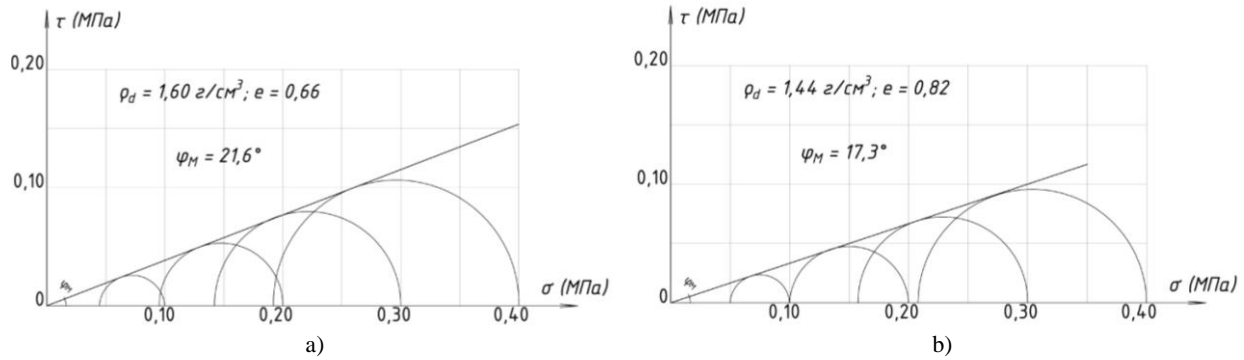


Figure 1 – Mora diagrams from compression tests with lateral pressure measurements:
 a) fine sand, loose; b) fine sand of medium density

Analysis of the results of studies of dense sandy soils. The significant influence of the stress state created during the formation of samples of dense sandy soils is confirmed by the results of compression and shear tests. The particle density was $\rho_d = 1.67 \text{ g/cm}^3$ and $\rho_d = 1.75 \text{ g/cm}^3$. It was noted that during the formation of samples of this density by shock compaction, a lateral spacer was created, the residual value of which was 0.010-0.0120 MPa for sand with a density of 1.67 g/cm^3 and 0.018-0.02 MPa for sand with a density of 1.75 g/cm^3 . The vertical load was applied in steps of 0.05 MPa. It was found that in the graph of the dependence $\sigma_b = f(\sigma_v)$ there are two linear sections with different increment intensities σ_b , with a fracture point corresponding to $\sigma_v = 0,098 \text{ MPa}$ (figure 2) for sand with a density of 1.67 g/cm^3 and 0.11 MPa for sand with a density of 1.75 g/cm^3 , which confirms the presence of two stress states, the first of which is the ultimate equilibrium, the second is the equilibrium stress state provided by the condition of pure compression.

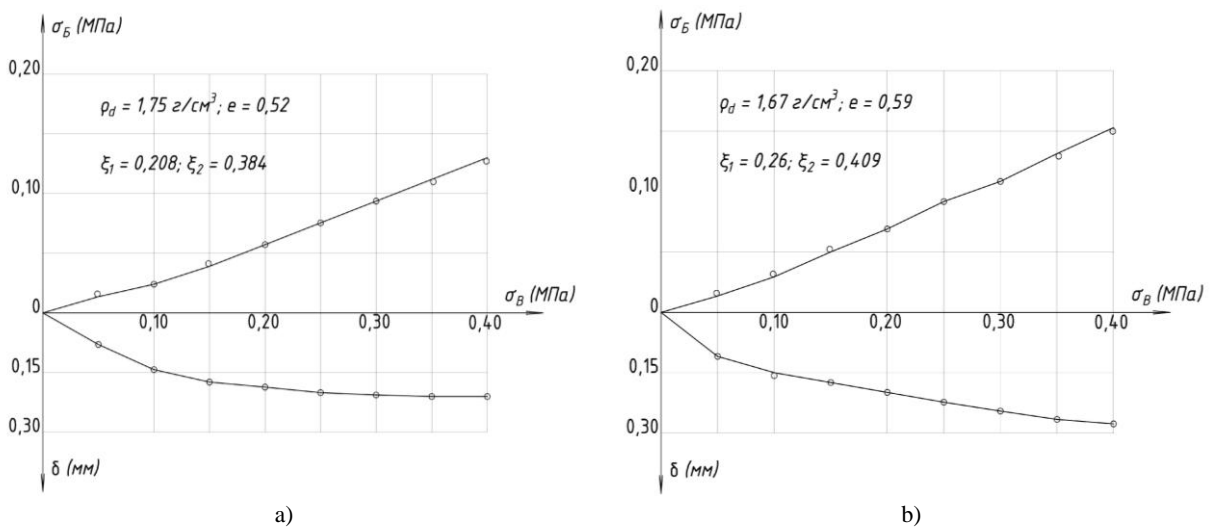


Figure 2 – The results of compression tests of fine sandy soil: a) fine sand, loose; b) fine sand of medium density

The uniqueness of stress states under compression and shear conditions can be estimated by comparing the intensity of shear stresses with an increase in vertical load and a similar change in lateral pressure increments in the same $\Delta\sigma_v$ intervals (figure 3). So, for loose sand ($e = 0.82$), the lateral pressure coefficient decreases from 0.56 (in the range where $\Delta\sigma_v$ is from 0 to 0.1 MPa) to 0.52 (in the range where $\Delta\sigma_v$ is from 0.10 to 0, 20 MPa), decreasing with subsequent compaction to 0.48 (at the range where $\Delta\sigma_v$ is from 0.30 to 0.40 MPa). The ratio $\Delta\tau/\Delta\sigma_v$ in the same intervals varies from 0.296 to 0.40. The lateral pressure coefficient ξ is the angle of inclination α (of dependence $\sigma_b = f(\sigma_v)$) and in the case of a linear dependence, $\tan \alpha = \sigma_b / (\sigma_v)$.

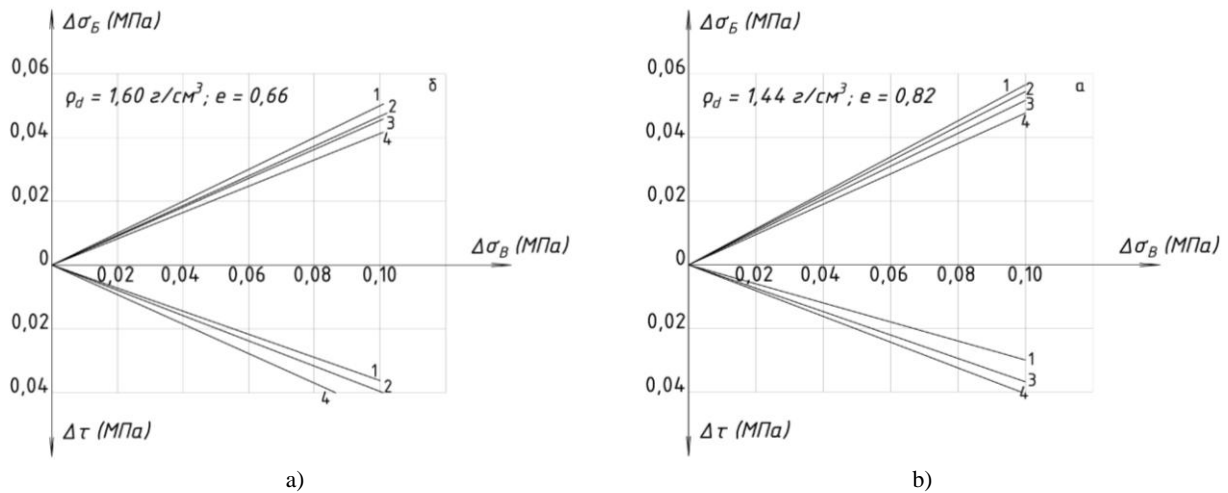


Figure 3 – Graphs of changes in the intensities of increments:
 a) fine sand, loose; b) fine sand of medium density; 1- $\Delta\sigma_h$ from 0 to 0.10 MPa; 2- $\Delta\sigma_h$ from 0.1 to 0.20 MPa; 3- $\Delta\sigma_h$ from 0.2 to 0.30 MPa; 4- $\Delta\sigma_h$ from 0.3 to 0.40 MPa

The change in the angle α in the indicated pressure range was 4.6° , the angle of internal friction in the same range of vertical loads increased by 5.8° . For medium-density sand, the corresponding changes in the angles φ and α were 2.5° and 2° , respectively. To confirm the conclusion about the influence of the method of soil sample formation on the parameters of ultimate equilibrium and lateral pressure coefficient, tests were carried out on sand of medium density, compacted by repeated loading. Initial soil density $\rho_d = 1.54 \text{ g/cm}^3$, porosity coefficient was 0.72. The samples were formed by layer-by-layer filling, with a 6-fold loading and unloading cycle. Sealing was carried out in the chamber of the compression device with the measurement of lateral pressure (figure 4).

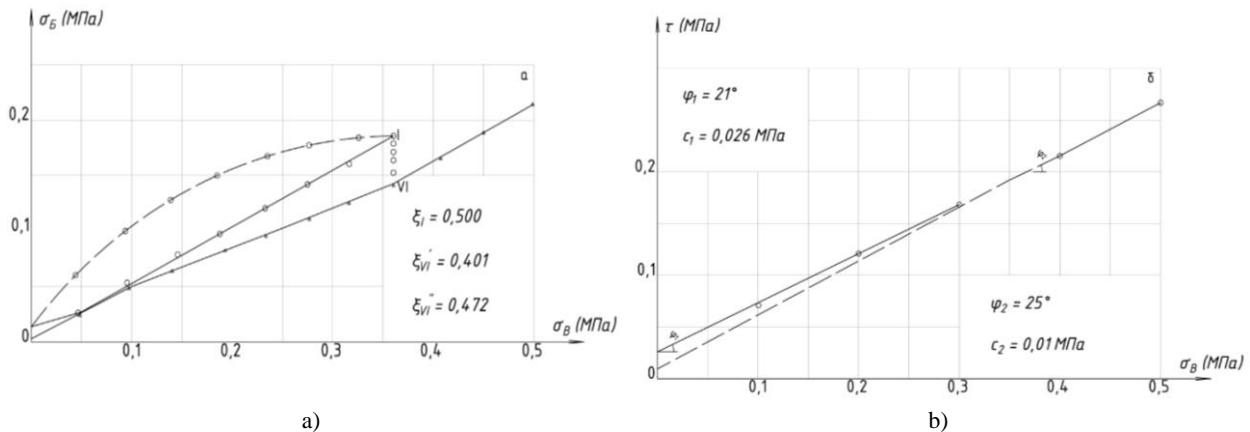


Figure 4 – a) dependence $\sigma_b = f(\sigma_v)$ upon repeated loading of sand with a density of 1.54 g/cm^3 ;
 b) sand shear diagram with a density of 1.54 g/cm^3 compacted by repeated loading

After the 6th loading cycle, a residual lateral pressure of 0.012 MPa was recorded, and the sand density increased to 1.57 g/cm^3 . The graph of the $\sigma_b = f(\sigma_v)$ dependence after 6 cycles of compaction and unloading is characterized by 2 linear sections, similar to the dependences $\sigma_b = f(\sigma_v)$ defined for dense sand. The fracture in the graph reflects the transition of soil from one equilibrium state to another, and the fracture point characterizes the ultimate stress state when they change and also appears to be a function of the initial stress state due to its formation. In the same initial conditions (the density, 6 loading-unloading cycles) shear tests were performed, the purpose of which was to determine the strength parameters depending on their stress state. The tests were carried out by the method of step loading with a constant rate of shear force application (figure 4).

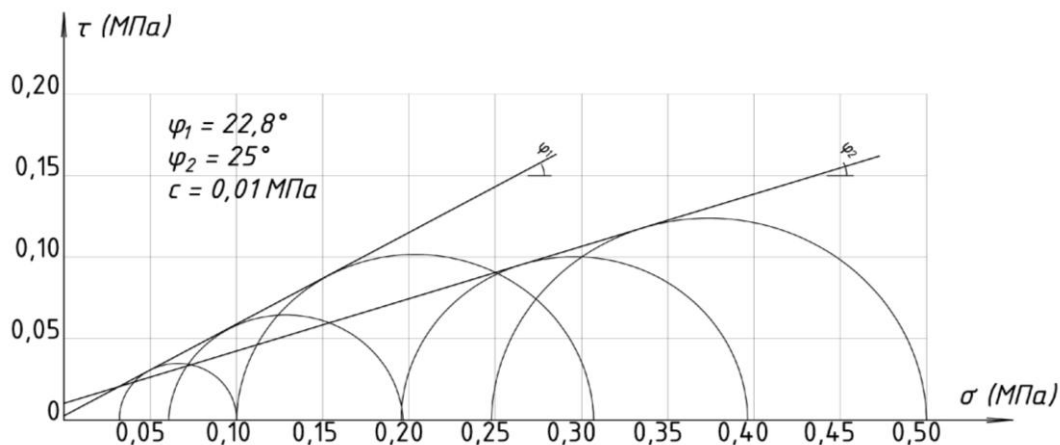


Figure 5 – Mora diagrams based on the results of compression tests of sandy soils (with repeated loading)

The Mohr diagram, based on the results of compression tests (figure 5), is represented by two sections with an angle $\varphi_m = 22.8^\circ$ and a 0.010 MPa adhesion which was recorded on the τ -axis. The limiting envelope of Mohr's circles at σ_{δ} and σ_{β} values within the limits of repeated loading (up to 0.37 MPa), and coming from the origin, made up an angle $\varphi_m = 25^\circ$. Thus, it was found that in sandy soils formed by external force (shock compaction or repeated loading), two sites are presented, depending on the vertical and lateral pressures obtained during compression compression.

Conclusion. A comparative analysis of the results of sandy soils testing for compression and a straight cut leads to the following conclusions:

1. When a stress field acts on a discrete medium, like a sandy soil, particle mutual displacements occur regardless of the type of stress state, which are displayed by the law of Coulomb. This physical model explains the identity of soil conditions under various influences of force fields - compression under the conditions of the impossibility of lateral expansion and a direct cut.

2. The realization of the limit state of Coulomb under conditions of the compression and the shear cut is confirmed by the equality or rather close convergence of the angles of internal friction obtained from the shift test diagrams and the graph-analytical solution of Mohr. The compression loading trajectories of loose and medium density sand characterize the limiting surfaces. In this case, the lateral pressure coefficient, determined by the ratio of the increments of the principal stresses, is described by the condition of ultimate Coulomb-Mohr equilibrium.

$$\xi = \operatorname{tg} 2 (45^\circ - \varphi/2).$$

3. For dense sands formation which requires the application of force influences, typical residual lateral pressure appears which causes a different dependence $\sigma_{\delta} = f(\sigma_{\beta})$. The parameters of the limiting state obtained by the Mohr's graph-analytical solutions and the results of compression tests are close to the strength parameters φ and C obtained from shear tests.

4. A significant influence of the method of compacted sandy soils formation on the dependence $\sigma_{\delta} = f(\sigma_{\beta})$ is observed. Under the same boundary conditions: the methods of sample formation, loading intensity and strain stabilization time, both under compression and shear conditions, the Coulomb-Mohr limit equilibrium condition is unambiguously performed in both cases, which is associated with the process of development of irreversible deformations during compaction, which are close to Coulomb displacements at the micro level and confirms the assumption of K.Terzaghi about the possibility of reaching the limit state of the soil mass in resting conditions [23,24].

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КОМПРЕССИЯ ЖАҒДАЙЫНДА ҚҰМДЫ ТОПЫРАҚТЫҢ БЕРІКТІК ПАРАМЕТРЛЕРІН АНЫҚТАУ

Аннотация. Құм және топырақ төсеніштерді негізде орналастыру – әлсіз, құрылымдық-тұрақсыз топырақты күшейтуге, көтеру қабілетін арттыруға және нығайтуға, әсіресе сейсмикалық аудандарда кеңінен қолданатын әдіс. 6 миллионнан астам адамды қамтитын Қазақстанның 7 облысы елдің өнеркәсіптік әлеуетінің 40% жоғары сейсмикалық белсенділік аймағында орналасқан, сондықтан осы аудандарда негіздерді күшейту мәселесі өзекті болып саналады және одан әрі зерттеуді талап етеді. Мақалада авторлар әзірлеген әдістемелер бойынша өлшеуіш аппаратурамен (қатаң кернеу датчиктері-месдоздар) жабдықталған, түрлендірілген аспаптарда орындалған тәжірибелік зерттеулердің нәтижесі келтірілген.

Түрлі тығыздықтағы, ылғалдықтағы, гранулометриялық құрамды құмды топырақ пен үлгілерді қалыптастырудың түрлі әдістері зерттелді. Зерттеу нәтижелері бойынша анықталатын беріктік параметрлері динамикалық және статикалық жүктемелер әсер еткенде негіз топырағының көтергіш қабілетін есептеу және сипаттамаларын анықтау үшін қажет. Осы салыстырмалы сынақтар бүйірлік қысымды өлшейтін компрессиялық аспапта және ығыстыру стендінде жүргізілді. Топырақ үлгілерін қалыптастыру кезінде олардың физикалық қасиеттері бойынша бірыңғай шектік жағдай жасалды. Мұндай салыстырмалы сынақтарды жүргізудің негізгі алғышарты ретінде топырақтағы шектік тепе-теңдік шарты туралы Ш. Кулонның заңы қолданылды, онда күш әсерінің шамалы қосымша ұлғаюы массив нүктесіндегі тепе-теңдікті бұзады және массивті қозғалысқа (қирауға) әкеледі. Кулонның тепе-теңдік күй сұлбасын эксперименталды іске асыру тек қозғалмайтын қатаң бүйір қабырғалары кезінде, компрессиялық қысу жағдайында қамтамасыз етілетін әрі жоғары ұстап тұратын горизонтальды күштің даму үдерісін тудыратын жағдайда ғана мүмкін.

Кулон сұлбасын негізге ала отырып, іліну және үйкелу негізінде ұсталатын құлау сынақтарының тепе-теңдік шарттарын іске асырудың екінші тәсілі ең жоғары ығысу жүктемесі болып саналады, бұл ретте осы жүктеменің беру қатаңдығы топырақ қатаңдығынан әлдеқайда жоғары болуы тиіс. Екі жағдайда да Ш.Кулон заңы бойынша максималды горизонтальды күш сыртқы және ішкі кернеулік күйдің функциясы болып саналады. Кесілетін кезде, бүйірлік қысыммен σ_6 модельделетін сыртқы күштік әсерге реакция «байланыс пен үйкеліске» негізделген ығысудың шектік кедергісі $\tau_{пред}$ болып есептеледі. Бұл жағдайда шектік тепе-теңдіктің күйі Кулон заңымен сипатталады әрі жанама кернеу τ мен тік кернеу σ арасындағы байланысты орнатады. Жүргізілген салыстырмалы сынау мен талдау нәтижесінде кернеу өрісінің, құмды топырақ сияқты дискретті ортаға әсері кезінде кернеудің түріне қарамастан бөлшектер өзара ығысады, олар топырақты шектік тепе-теңдік жағдайына әкелуі мүмкін және Ш.Кулон заңымен өрнектеледі.

Бұл физикалық модель күш өрісінің түрлі әсері (бүйірлік кеңейту мүмкін болмаған жағдайда қысу және тікелей кесілу) кезінде топырақ жағдайының ұқсастығын түсіндіреді. Компрессиялық қысу және кесу жағдайында Ш.Кулонның шекті күйін іске асыру жылжу сынақтарының диаграммалары және Мордың графо-аналитикалық шешімі бойынша (бүйірлік қысымы өлшенген компрессиялық сынақтардың нәтижелері бойынша) алынған ішкі үйкеліс бұрыштарының теңдігімен немесе жеткілікті жақын ұқсастығы арқылы анықталады. Тығыз құмды топырақ үлгілерін қалыптастыру үдерісінде пайда болған кернеулік күйдің елеулі әсері жүргізілген сынақтардың нәтижесі негізінде расталады. Бөліктердің тығыздығы: $\rho_d = 1,67 \text{ г/см}^3$ және $\rho_d = 1,75 \text{ г/см}^3$ құрады. Соққы тығыздау жолымен осы тығыздықтағы үлгілерді қалыптастыру барысында бүйірлі қысым пайда болды, оның қалдық шамасы, тығыздығы $1,67 \text{ г/см}^3$ құм үшін $0,010-0,0120 \text{ Мпа}$ және тығыздығы $1,75 \text{ г/см}^3$ құмда $0,018-0,02 \text{ Мпа}$ құрайды. Тік жүктеме $0,05 \text{ Мпа}$ сайын беріліп тұрды. $\sigma_6 = f(\sigma_6)$ -қа байланысты графикте түрлі өсу қарқындылығы σ_6 екі сызықты учаскесі мен сыну нүктесі бар, тығыздығы $1,67 \text{ г/см}^3$ құмда тиісті $\sigma_6=0,098 \text{ Мпа}$ (сурет.25) және тығыздығы $1,75 \text{ г/см}^3$ құмда $\sigma_6=0,11 \text{ Мпа}$, бұл екі кернеулік күйдің болатынын айқындайды, біріншісі, шектік тепе-теңдік, екіншісі, таза компрессия шартымен қамтамасыз етілген тепе-теңді кернеулік күй.

Компрессия және кесілу жағдайында кернеулік күйдің бір мағыналығын жанама кернеудің қарқындығын тік жүктеменің ұлғаюымен және сол аралықтарда бүйірлік қысымның өсуінің ұқсас өзгеруімен салыстыра отырып бағалауға болады. Осылайша, тығыздалған құмды топырақты қалыптастыру тәсілінің бүйірлік және тік қысымның $\sigma_6=f(\sigma_6)$ және беріктік параметрлеріне тәуелдік сипатына әсері байқалды. Бірыңғай шекаралық шарттарды сақтағанда: үлгілерді қалыптастыру әдістемесі, жүктеу қарқындығы және

деформацияны тұрақтандыру уақыты компрессия жағдайында да, кесу кезінде де, Кулон-Мордың шекті тепе-теңдігінің шарты екі жағдайда да сөзсіз орындалады, бұл микродеңгейде кулондық ығысуға жақын және К.Терцагидің тыныштық жағдайында топырақ массивінің шектік күйіне қол жеткізу мүмкіндігі туралы болжамын алғаш рет анықтайды.

Түйін сөздер: физикалық қасиет, топырақтың беріктігі, шекті кернеулі жағдай, ішкі үйкеліс бұрышы, ілінісу, бүйірлік қысым, тік қысым, графикалық-аналитикалық шешім.

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ОПРЕДЕЛЕНИЕ ПАРАМЕТРОВ ПРОЧНОСТИ ПЕСЧАНЫХ ГРУНТОВ В УСЛОВИЯХ КОМПРЕССИИ

Аннотация. Устройство песчаных и грунтовых подушек в основаниях, широко распространенный метод усиления, повышения несущей способности и укрепления слабых, структурно-неустойчивых грунтов, особенно в сейсмических районах. 7 областей Казахстана, это более 6 млн. человек и 40% промышленного потенциала страны находятся в зонах повышенной сейсмической активности, поэтому вопрос усиления оснований в этих районах, является актуальным и требует дальнейшего изучения. В статье приведены результаты экспериментальных исследований, выполненных по разработанным авторами методикам на модифицированных приборах, оснащенных измерительной аппаратурой (жесткие датчики напряжений – месдозы). Исследованы песчаные грунта различной плотности, влажности, гранулометрического состава и разными методами формирования образцов. Данные сравнительные испытания проводились на компрессионном приборе с измерением бокового давления и сдвигом стенде. При формировании образцов грунта создавались единые граничные условия по их физическим свойствам. Основной предпосылкой для проведения таких сравнительных испытаний послужил закон Ш.Кулона об условии предельного равновесия в грунтах, при котором малейшее добавочное увеличение силового воздействия нарушает существующее в точке массива равновесие и приводит массив в движение (разрушение). Экспериментальная реализация схемы равновесного состояния Кулона возможна лишь в условиях, создающих развитие максимальной удерживающей горизонтальной силы, что обеспечивается в условиях компрессионного сжатия при жестких неподвижных боковых стенках. Исходя из схемы Кулона, вторым способом реализации условий равновесия клина обрушения, удерживающегося своим сцеплением и трением, является приложение максимальной сдвигающей нагрузки, при этом жесткость приложения этой нагрузки должна быть намного выше жесткости грунта. В обоих случаях, максимальная горизонтальная сила, по Ш.Кулону, есть функция как внешнего, так и внутреннего напряженных состояний. При срезе, реакцией на внешнее силовое воздействие, которое моделируется боковым давлением, является предельное сопротивление сдвигу τ пред., обусловленное «связностью и трением». Состояние предельного равновесия в этом случае описывается законом Кулона, устанавливающим связь между касательным напряжением τ пред и нормальным напряжением σ . В результате проведенных сравнительных испытаний и анализа установлено, что при воздействии поля напряжений на дискретную среду, каковой является песчаный грунт, независимо от вида напряженного состояния, происходят взаимосмещения частиц, которые могут привести грунт в состояние предельного равновесия и отображаются законом Ш.Кулона. Данная физическая модель объясняет идентичность состояний грунта при различных воздействиях силовых полей – сжатий в условиях невозможности бокового расширения и прямом срезе. Реализация предельного состояния Ш.Кулона в условиях компрессионного сжатия и среза подтверждается равенством или достаточно близкой сходимостью углов внутреннего трения, полученных по диаграммам сдвиговых испытаний и графо-аналитическому решению Мора (по результатам компрессионных испытаний с измерением бокового давления). Существенное влияние напряженного состояния, созданного в процессе формирования образцов плотных песчаных грунтов, подтверждается результатами проведенных испытаний. Плотность частиц составляла: $\rho_d = 1,67 \text{ г/см}^3$ и $\rho_d = 1,75 \text{ г/см}^3$. Отмечено, что в процессе формирования образцов данной плотности путем ударного уплотнения создавался боковой распор, остаточная величина которого, составила 0,010-0,0120 Мпа, для песка плотностью $1,67 \text{ г/см}^3$ и 0,018-0,02 Мпа для песка плотностью $1,75 \text{ г/см}^3$. Вертикальная нагрузка прикладывалась ступенями по

0,05 Мпа. Установлено, что в графике зависимости $\sigma_b = f(\sigma_v)$ имеется два линейных участка с разной интенсивностью приращения σ_b , с точкой перелома, соответствующей $\sigma_v = 0,098$ Мпа (рис.25) для песка плотностью $1,67 \text{ г/см}^3$ и $0,11$ Мпа для песка плотностью $1,75 \text{ г/см}^3$, что подтверждает наличие двух напряженных состояний, первое из которых – предельное равновесие, второе – равновесное напряженное состояние, обеспеченной условием чистой компрессии. Однозначность напряженных состояний в условиях компрессии и среза можно оценить сравнением интенсивности касательных напряжений с увеличением вертикальной нагрузки и аналогичным изменением приращений бокового давления в тех же интервалах. Таким образом, доказано существенное влияние способа формирования уплотненных песчаных грунтов на характер зависимости бокового и вертикального давлений $\sigma_b = f(\sigma_v)$ и параметры прочности. При соблюдении единых граничных условий: методики формирования образцов, интенсивности нагружения и времени стабилизации деформаций как в условиях компрессии, так и при срезе, условие предельного равновесия Кулона-Мора, однозначно выполняется в обоих случаях, что связано с процессом развития необратимых деформаций при уплотнении, которые на микроуровне близки кулоновским смещениям и впервые подтверждает предположение К.Терцаги о возможности достижения предельного состояния массива грунта в условиях покоя.

Ключевые слова: физические свойства, прочность грунта, предельное напряженное состояние, угол внутреннего трения, сцепление, боковое давление, вертикальное давление, графо-аналитическое решение.

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**THE DETERMINATION OF THE BASE MATRIX
OPTIMAL COMPOSITION WITH USE
OF TEST ORGANISMS *TETRAHYMENA PYRIFORMIS***

Abstract. The use of accelerated biotesting in combination with chemical-analytical and microbiological methods allows evaluating quality and safety of dairy products fully and reliably without significant increase in costs. The relative biological value and the optimal range of fat and protein mass fractions ratio in normalized milk mixtures amounted to 0.36 - 0.89 were determined by means of the biotest analysis express method on protozoa. Milk normalization by fat mass fraction in indicated range contributed to the achievement the maximum relative pasteurized milk biological value (162 ± 7) %. The efficiency protein assimilation was higher in the presence of a certain amount of fat. It was established the influence of methodological techniques during experimental work, in particular, the degree of samples dilution (0.05; 0.15; 0.3 mg nitrogen/ml) on the dynamics of number of test cultures depending on fat mass fraction in the medium was established and was selected the optimal milk dilution for testing up to 0.15 mg nitrogen/ml.

Key words: normalized milk, *Tetrahymena pyriformis*, relative biological value.

Introduction. Multicomponent food formulations development is aimed at ensuring optimal composition and ratio of the main components. At the same time, biological value and good product quality are undoubtedly one of the main criteria for formulations optimality and process efficiency. Formulation optimization is associated with restrictions introduction on finished product composition (for certain types of raw materials and ingredients used, protein, fat, carbohydrates content, etc.).

It is known that the quantitative proteins and fats ratio in product composition affects the digestibility of both. Fat and protein in diet should be balanced, because while reducing fat intake, the body uses excess protein for energy purposes. Fat lack in diet leads to energy malnutrition, exacerbates proteins deficiency in food: proteins begin spending on covering body's energy consumption. In addition, the protein digestion, received with food is worsening, protein metabolism products are accumulating - uric acid, etc., the acid-base balance is shifted to acid side [1].

The ratio of protein, fat and carbohydrates plays major role in food products biological value formation, which necessitates scientific approach to rational use of these nutrients in high-quality food products formulations development. The most reliable method of product quality integral assessment from nutritional point of view is biological method using higher animals [2, 3], application of which is very difficult for products continuous monitoring, raw materials evaluation, various processing methods and new technologies.

Recently, several authors [4–10] have developed the concept of “whole cell biosensors” (WCB) as an alternative to classical methods. Prokaryotic or eukaryotic cells are used as biosensors. Previous studies have shown that eukaryotic ciliates cells are similar to higher organisms in terms of genome and number of basic metabolic parameters [11,12], which allows interspecific extrapolation of assessing food products biological value results [13-15].

The *Tetrahymena pyriformis* ability to use intact proteins as nutrient substrate has practical importance in assessing food product biological value, and correlation coefficient of experimental results when comparing *T.pyriformis* ciliates and white rats is 0.93–0.98 and is estimated as high. The bioavailability of food product proteins in this case is characterized by rate of vital processes of indicator organism depending on food object quantity and quality, which can be estimated by increase dynamics in ciliates number [16].

Statement of the problem. The aim of the work is to study methodological aspects of accelerated dairy products biological assessment using test organisms *Tetrahymena pyriformis*. Based on the results of applying express method to determine indicators of dairy products relative biological value, it is planned to develop methodology for assessing technological processes effectiveness for dairy products production, which will exclude an empirical approach to biological value formation developed products.

The subject of this study was to determine effect of fat and protein ratios in the food matrix on dairy products relative biological value.

Methods. The object of the study was pasteurized normalized milk with fat mass fractions of 0.05% и 8.0%; protein mass fractions 2.8% и 3.6%. The normalized milk with various fat and protein mass fraction ratios (from 0.02 to 2.7:1) was obtained by mixing skimmed milk and cream. Normalized milk was homogenized at temperature of 60 °C and pressure of (17.5 ± 2.5) MPa, pasteurized at (92 ± 2) °C, cooled and prepared dilutions. The following parameters were measured in the normalized milk samples: the fat – by Gerber butyrometric method (ISO 2446:2008); the total protein - by Kjeldahl method with use of KJELTEC automatic system (ISO 8968-1:2014). The milk with various fat mass fraction was investigated in dilutions providing the amount of milk protein in the medium in terms of nitrogen: 0.05; 0.15 and 0.3 mg/ml. Reference samples in the analysis were samples containing skimmed milk.

The experiments repetition is 3-4 times. The obtained experimental data were processed by the methods of mathematical statistics (regression analysis) using applied service programs (Statistica, Mathcad). The confidence level of probability was taken equal to 0.95 with relative error of ±5%.

Biological experiment at *Tetrahymena pyriformis*. Comparative biological studies of the product were performed by biotesting methods on test organisms *Tetrahymena pyriformis* [17-22]. Cell counts were performed using the BioLaT-3 analytical complex (Europolitest LLC) according to the Operation Manual. The ciliates were counted 10 times in 0.02 ml of culture medium from each tube. Each milk sample was examined in triplicate. For biotesting, a less dense, pure tetrachimen culture was used (in the range of 50-100 thousand cells per 1 ml).

A pure culture of ciliates was subcultured into bacteriological tubes with 4 cm³ peptone medium (2.0 g of peptone, 0.1 g of yeast extract, 0.5 g of glucose, 0.1 g of sodium chloride, distilled water (pH 7.1) up to 100 ml) every 7-10 days. Cultivation was carried out for 3 days in an incubator at temperature of 25 °C, shaking 2-3 times a day. Before culture introducing, milk samples were diluted with distilled water. In 1 ml of diluted milk, 1 ml of CSY (carbohydrate-salt yeast) medium was added (1.5 g of glucose, 0.1 g of yeast extract, 0.1 g of sodium chloride, distilled water (pH 7.1) up to 100 ml). Tubes with prepared samples were heat treated to inactivate microflora. After cooling to (25±2) °C, 0.02 ml of a 3-day-old tetrachimene culture, grown on peptone medium was added to each tube. The ciliates were cultured for 4 days in an incubator at 25 °C until stage of the stationary growth phase, shaking periodically 2-3 times a day. After 96 hours of cultivation, one drop of 5% alcohol solution of iodine was added to the vials, thoroughly shaken, diluted 2-4 times with water, and the grown cells were counted taking into account the dilution.

Relative biological value (RBV) was determined by cells number ratio, grown on test product to the ciliates number, grown on the control product, expressed as a percentage. Protein efficiency ratio (PER) was determined as ratio of the gain in live weight of test organisms to consumed protein, the protein relative effectiveness ratio (PRE) as ratio of protein efficiency of the experimental product to protein effectiveness of the control product, expressed in % ($PRE_e \times 100/PRE_c$).

Results. A visual analysis of *T.pyriformis* population state, grown in cultivation media based on the studied milk did not reveal noticeable differences in these populations, as well as any morphological and functional disorders. Organisms death during 4-day cycle of population study was not observed.

Table 1 shows the results, obtained when testing pasteurized milk samples with different fat content and diluting samples to 0.05 mg nitrogen/ml.

From table 1 data it follows that in medium with 0.05 mg nitrogen/ml with an increase in fat mass fraction in range of 1-1.7%, the ciliates number increases by 2-2.3 times. In interval of fat mass fraction of 1.7-3.3%, an increase in test organisms was observed and, accordingly, an increase in RBV by 2.3-2.8 times. In range of fat mass fraction of 3.3–8%, the difference between their average abundance in almost all samples was statistically insignificant. The obtained results indicate that this concentration of protein in absence of fat in medium significantly limits reproduction of protozoa. The population increases when certain fat amount appears in culture medium. Thus, the use of milk dilution to protein concentration in terms of nitrogen of 0.05 mg/ml does not provide test organisms with sufficient amount of nutrients in all samples.

Table 1 – The number of *Tetrahymena pyriformis* cells grown on normalized milk with different ratio of fat and protein mass fractions, and RBV indicators (0.05 mg nitrogen/ml of medium)

i – number of factor level	Fat, %	The ratio of fat: protein in normalized milk, factor x	The number of living cells, parameter y (the number of repetitions of experience, n = 3)	Standard deviation, σ	Average error of the mean	RBV, %
1	0.05	0.02	2346	14	8	100
2	1.0	0.3	4668	913	528	198
3	1.7	0.6	5362	56	32	229
4	2.6	0.8	6381	110	64	272
5	3.3	1.1	6596	71	41	281
6	3.6	1.2	6563	244	141	280
7	4	1.3	5682	524	303	242
8	5	1.7	6548	789	456	279
9	6.6	2.3	6586	397	229	281
10	8	2.7	6431	131	76	274

Table 2 shows results, obtained when testing pasteurized milk samples with different fat content and diluting samples to nitrogen mass fraction of 0.3 mg/ml.

From the data of table 2 it follows that when diluting milk to 0.3 mg/ml in terms of nitrogen, nutrients concentration in medium did not limit growth of ciliates in all samples. At the same time, milk fat did not play a significant role in overall metabolism, judging by the fact that with an increase in its content in medium, change in cells number did not exceed the maximum standard deviation. Thus, milk dilution to 0.3 mg N/ml in conditions of our experiment did not allow us to reveal the effect of fat mass fraction in environment for protozoa growth.

Table 2 – The number of *Tetrahymena pyriformis* cells grown in normalized milk with different ratio of fat and protein mass fractions, and indicators of RBV (0.3 mg nitrogen/ml of medium)

i – number of factor level	Fat, %	The ratio of fat: protein in normalized milk, factor x	The number of living cells, parameter y (the number of repetitions of experience n = 3)	Standard deviation, σ	Average error of the mean	RBV, %
1	0.05	0.02	6526	1498	866	100
2	1.0	0.3	6142	774	447	94
3	1.7	0.6	5854	392	227	90
4	2.6	0.8	6426	158	91	98
5	3.3	1.1	5047	499	288	77
6	3.6	1.2	6450	665	384	99
7	4	1.3	6471	519	300	99
8	5	1.7	7147	80	46	110
9	6.6	2.3	6672	60	35	102
10	8	2.7	6583	267	154	101

Table 3 shows results, obtained by testing pasteurized milk samples with various fat mass fractions and diluting samples to nitrogen content of 0.15 mg/ml. Judging by total cells number, grown in media with different milk concentrations, dilution to 0.15 mg N/ml contributed to the best growth of test culture. From the data of table 3 it follows that in an environment with milk diluted to 0.15 mg N/ml, with an increase in fat content, the number of protozoa increases by 1.5 times, and with ratio of fat and protein mass fractions 0.3:1.1 exceeds cells number of grown in medium with high milk protein content (0.3 mg N/ml). An increase in fat: protein ratio to 1.2 and higher led to decrease in grown cells number. This allows to conclude that protein use efficiency is higher in presence of certain fat amount.

Table 3 – The number of *Tetrahymena pyriformis* cells grown on normalized milk with different ratio of fat and protein mass fractions, and indicators of RBV (0.15 mg nitrogen/ml of medium)

i – number of factor level	The ratio of fat: protein in normalized milk, factor x	The number of living cells, parameter y (the number of repetitions of experience n = 4)	Standard deviation, σ	Average error of the mean	RBV, %
1	0.02	4714	1509	755	100
2	0.3	6929	932	466	147
3	0.6	7784	656	328	165
4	0.8	7518	499	250	159
5	1.1	7312	640	320	155
6	1.2	6350	210	105	135
7	1.3	6318	557	279	134
8	1.7	6606	105	53	140
9	2.3	6604	505	253	140
10	2.7	6475	1538	768	137

The values of PER and PRE for various dilutions were also calculated and analyzed (table 4, figure 1).

Table 4 – The number of test culture cells, grown on normalized milk with different ratio of fat and protein mass fractions and PER, PRE indicators

The ratio of fat: protein in milk	Milk dilution to mg nitrogen/ml:					
	0.05		0.15		0.3	
	The number of cells, units	PER/PRE, %	The number of cells, units	PER/PRE, %	The number of cells, units	PER/PRE, %
0.02	2346	0.28/100	4312	0.17/100	5466	0.11/100
0.3	4002	0.47/170	6589	0.26/153	6689	0.13/118
0.6	5322	0.63/228	7685	0.3/176	6131	0.12/109
0.8	6459	0.76/275	7402	0.29/171	6314	0.12/109
1.1	6546	0.77/279	7206	0.28/165	4694	0.09/82
1.2	6735	0.79/286	6592	0.26/153	5980	0.12/110
1.3	5311	0.62/225	6642	0.26/153	6838	0.13/118
1.7	5990	0.7/254	6663	0.26/153	7203	0.14/127
2.3	6305	0.74/268	6360	0.25/147	6714	0.13/118
2.7	6524	0.77/279	6656	0.26/153	6394	0.13/118

From the data in table 4 and figure 1, it can be seen that with an increase in samples dilution degree, the values of PER and PRE are increase. When milk is diluted to 0.3 mg nitrogen/ml, the values of PER and PRE are minimal and increase to 1.0–8.0% in presence of fat in 1.1:1.3 times. Correlation with fat mass fraction is practically absent, which indicates protein excess in the medium and, obviously, insignificant fat consumption.

When milk is diluted to 0.05 mg nitrogen/ml, the values of PER and PRE were maximum and most dependent on fat presence in medium. At the same time, the number of cells, grown in medium with

comparison sample (skimmed milk) was the lowest and with an increase in fat mass fraction in the medium it increased most significantly (1.74÷2.8 times). With further fat mass fraction increase (over 3.6%), the values of PER and PRE are slightly decreased. Obviously, protein lack in the medium was compensated by consumption of fat certain proportion.

The use of milk dilution up to 0.15 mg nitrogen/ml made it possible to reveal a certain dependence of PER and PRE on fat mass fraction in the medium, maximally expressed at a ratio of fat and protein mass fraction of 0.3÷1.1.

Thus, dilution of milk for testing up to 0.15 mg nitrogen/ml provides a fairly balanced intake of protein and fat by infusoria in all samples, which allows to identify the effect of their ratio on growth of test organisms and determine its optimum.

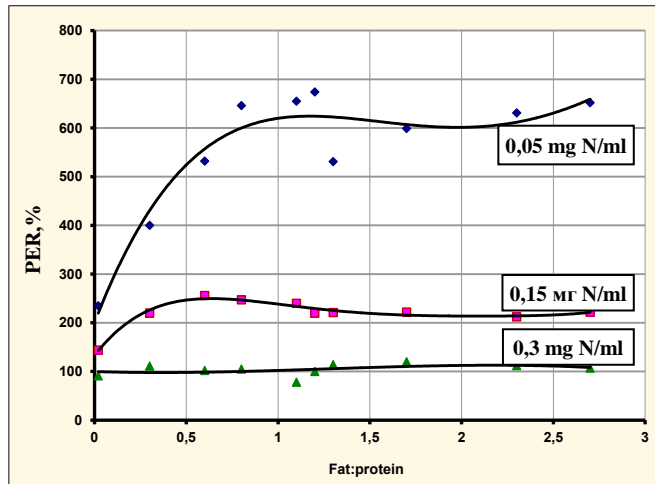


Figure 1 – PER dependence on the ratio of fat and protein mass fraction in normalized milk when using different dilutions

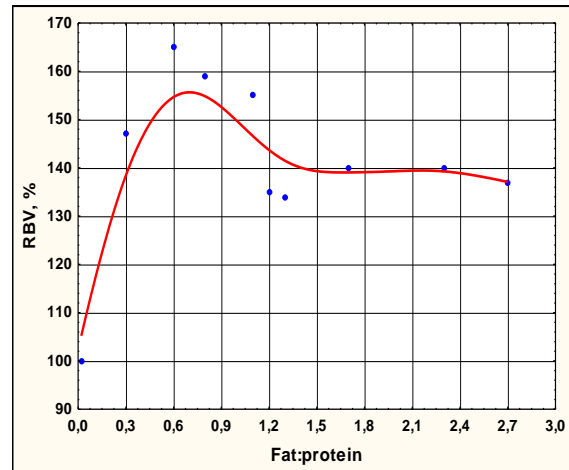


Figure 2 – Dependence of normalized milk RBV on the ratio of fat and protein mass fraction

Considering the obtained data, further studies were carried out using samples dilution to protein content in terms of nitrogen of 0.15 mg/ml.

Analysis of the data in table 3 for presence of gross errors showed, that calculated values of maximum relative deviation are less than table quantile value distribution of maximum relative deviation, therefore, there are no grounds for dropping out the extreme results of the sample.

The formalization of obtained experimental data (Table 3) by least-squares method allowed obtain an empirical mathematical dependence:

$$y = 239.65x^5 - 2927.5x^4 + 12059x^3 - 20942x^2 + 14284x + 4388.4$$

Determination factor $R^2 = 0.923$; standard error of the regression equation – 354.3. $F_{\text{fact.}} = 9.6$; $F_{\text{theor.}}(0.05, 5, 4) = 5.2$. Since $F_{\text{fact.}} > F_{\text{theor.}}$, the equation adequately describes the identified dependence.

Thus, a close relationship was found between the number of grown test organisms and the ratio of fat and protein mass fraction in culture medium and nonrandomness of their joint change.

Based on obtained experimental data, the RBV of normalized milk was calculated. The dependence of milk RBV on the ratio of fat and protein mass fraction was correspondingly similar (figure 2).

Regression equation:

$$y = 5.18x^5 - 62.69x^4 + 256.76x^3 - 444.3x^2 + 302.46x + 93.14$$

where y – RBV, %; x – the ratio of fat and protein mass fraction in normalized milk.

$R^2 = 0.925$. Standard error of the regression equation – 7.36. $F_{\text{fact.}} = 9.97$; $F_{\text{theor.}}(0.05, 5, 4) = 5.2$. Since $F_{\text{fact.}} > F_{\text{theor.}}$, the equation is adequate.

Determination of maximum function:

$$dy/dx = 25.9x^4 - 250.76x^3 + 770.28x^2 - 880.6x + 302.46 = 0.$$

When $x_0 = 0.6$ maximum function value $y_{\max} = 162 \pm 7$. Given the calculation error, the optimal value $x_0 = 0.36 \pm 0.89$.

Conclusion. During experimental work, the influence of samples dilution degree on dynamics of *Tetrahymena pyriformis* test culture number dependence on the ratio of fat and protein mass fraction in the medium and the value of protein efficiency coefficient was established. The optimal milk dilution for testing was selected - up to 0.15 mg nitrogen/ml. By accelerated biotesting method, the indicators of relative biological value and optimal ratio of fat and protein mass fraction in normalized milk mixtures were determined, intended for whole milk products production, amounting to 0.36 ± 0.89 , contributing to an increase in their relative biological value to $(162 \pm 7) \%$. The obtained data will allow to evaluate the effectiveness of technological regimes for whole milk products production and to choose the optimal parameters that provide high degree of products usefulness that contribute to solving the problem of maintaining human health. It should be noted that the obtained values of protein efficiency coefficient did not characterize protein biological value. Obviously, to characterize protein biological value, it is advisable to use nitrogen metabolism coefficient as the ratio of consumed nitrogen amount by test organisms to amount of total nitrogen introduced into medium. To determine the long-term effect of medium composition on the nature of tetrachimene growth curve and culture life span, longer observations are required.

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БАЗАЛЫҚ МАТРИЦАНЫҢ *TETRAHYMENA PYRIFORMIS* ТЕСТІН ҚОЛДАНУ АРҚЫЛЫ ҚҰРАМЫН ОҢТАЙЛЫ АНЫҚТАУ

Аннотация. Нутрициологияның дамуы мен азық-түлік нарығындағы бәсекелестіктің артуы өнімді түзету және жаңа рецептура әзірлеу арқылы өнім түрлерін үнемі жақсарту қажеттілігіне әкеледі. Көп компонентті тамақ құрамын жасау негізгі компоненттердің оңтайлы құрамы мен арақатынасын қамтамасыз етуге бағытталған. Сонымен қатар, оңтайлылықтың негізгі өлшемдерінің бірі өнімнің биологиялық құндылығы мен жоғары сапасы болып саналады.

Рецептураны оңтайландыру дайын өнімнің құрамына шектеу енгізуге байланысты (шикізат пен қолданылатын ингредиенттердің белгілі бір түрлері, ақуыз, май, көмірсулар және т.б.). Ақуыз, май және көмірсудың қатынасы тамақ өнімінің биологиялық құндылығын қалыптастыру барысында үлкен рөл атқарады әрі жоғары сапалы тағам рецептурасын жасауда осы қоректік заттарды ұтымды пайдалануға ғылыми көзқарасты қажет етеді.

Соңғы уақытта классикалық әдістерге балама ретінде прокариоттық немесе эукариотты жасушаларды қолданатын «тұтас жасушалы биосенсорлар» (WCB) тұжырымдамасы жасалды. Алдыңғы зерттеулер көрсеткендей, эукариотты инфузорий жасушалар геномы және бірқатар негізгі метаболиттік көрсеткіштері бойынша жоғары ағзаларға ұқсас, бұл тамақ өнімдерінің биологиялық құндылығын бағалау нәтижелерін спецификалық экстраполяциялауға мүмкіндік береді. Азық-түлік өнім ақуыздарының биологиялық құндылығы тағам нысанының саны мен сапасына байланысты индикаторлар ағзасының тіршілік әрекетінің маңызды үрдістерінің жылдамдығы негізінде сипатталады, оны инфузорий санының көбею динамикасымен бағалауға болады.

Аталған зерттеудің пәні сүт өнімдерінің салыстырмалы биологиялық құндылығына өнім матрицасындағы май мен ақуыздың қатынасының әсерін анықтау болып саналады.

Зерттеу нысаны ретінде май мен ақуыздың массалық үлесі 0,02-ден 2,7: 1-ге дейін пастерленген қалыпқа келтірілген сүт алынды.

Құрамындағы түрлі массалық үлесі бар сүттің ақуыз мөлшерін 0,05; 0,15 және 0,3 мг/мл. азотпен қайта есептеу арқылы сұйылтыла отырылып зерттелді. Талдауда салыстыру үшін құрамында майсыздандырылған сүті бар үлгілер бар сынамалар қолданылды.

Өнімді салыстырмалы биологиялық зерттеулер *Tetrahymena pyriformis* тест-ағзасымен биотесттеу әдісі арқылы жүргізілді. Тест-ағзаларының саны мен салыстырмалы биологиялық құндылықты (СБК) пайызбен өрнектелетін сынақ үлгілерімен бір ортада өсірілген жасуша санының салыстырылатын үлгілерде өсірілген инфузорий мөлшерінің қатынасымен анықтадық.

Тәжірибелік жұмыс барысында оқыту әдістерінің, атап айтқанда, ортадағы майдың массалық үлесіне байланысты сынама дақылдар санының динамикасына сұйылтылу дәрежесі (0,05; 0,15; 0,3 мг азот / мл)

анықталды. Ақуызды ассимиляциялаудың тиімділігі белгілі бір май мөлшерінің қатысуы негізінде жоғарылады. Сынаққа қажетті сүтті 0,15 мг азот /мл дейін сұйылту жағдайы барлық үлгілерде инфузориядан ақуыз мен майдың жеткілікті теңгерімді қабылдауын қамтамасыз етті, бұл олардың арақатынасының тест-ағзаның өсуіне әсерін анықтауға мүмкіндік береді.

Тәжірибелік мәліметтерді минималды квадраттар әдісімен ресімдеу тестік дақылдардың өлшемі, салыстырмалы биологиялық құндылық СБҚ және өнім матрицасының құрамы арасындағы қатынасты дәл сипаттайтын эмпирикалық математикалық тәуелділікті алуға мүмкіндік берді (анықтау коэффициенті 0,92). Функцияны саралай отырып, қалыпқа келтірілген сүт қоспаларында май мен ақуыздың массалық фракцияларының оңтайлы арақатынасы 0,36-0,89 құрады. Көрсетілген диапазонда майдың үлес салмағы бойынша сүттің нормалануы пастерленген сүттің максималды салыстырмалы биологиялық құндылығына (162 ± 7) % қол жеткізуге ықпал етті.

Жеделдетілген биотестілеуді қолдану химиялық-аналитикалық және микробиологиялық әдістермен бірге шығын өсуінсіз сүт өнімдерінің сапасы мен қауіпсіздігін неғұрлым толық және сенімді бағалауға мүмкіндік береді. Алынған мәліметтер бізге сүт өнімдерін өндірудің технологиялық режимдерінің тиімділігін бағалауға және адамның денсаулығын сақтау мәселесін шешуге ықпал ететін өнімдердің жоғары дәрежелі пайдалылығын қамтамасыз ететін оңтайлы көрсеткіштерді таңдауға септігін тигізеді.

Түйін сөздер: қалыпқа келтірілген сүт, *Tetrahymena pyriformis*, салыстырмалы биологиялық құндылық.

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ОПРЕДЕЛЕНИЕ ОПТИМАЛЬНОГО СОСТАВА БАЗОВОЙ МАТРИЦЫ С ИСПОЛЬЗОВАНИЕМ ТЕСТ-ОРГАНИЗМОВ *TETRAHYMENA PYRIFORMIS*

Аннотация. Развитие нутрициологии, усиление конкуренции на продовольственном рынке приводит к необходимости постоянного совершенствования ассортимента выпускаемой продукции путём коррекции существующих и разработки новых рецептур.

Разработка многокомпонентных рецептур пищевых продуктов имеет целью обеспечение оптимального состава и соотношения основных компонентов. При этом одним из основных критериев оптимальности, несомненно, является биологическая ценность и доброкачественность продукта. Оптимизация рецептур связана с введением ограничений по составу готового продукта (по отдельным видам используемого сырья и ингредиентов, содержанию белка, жира, углеводов и пр.). Соотношение белка, жира и углеводов играет основную роль в формировании биологической ценности пищевых продуктов, что обуславливает необходимость научного подхода к вопросам рационального использования этих нутриентов при разработке рецептур высококачественных пищевых продуктов.

В последнее время в качестве альтернативы классическим методам была разработана концепция «цельноклеточных биосенсоров» (WCB), в качестве которых используются прокариотические или эукариотические клетки. Проведенными ранее исследованиями показано, что эукариотические клетки инфузорий имеют сходство с высшими организмами по геному и ряду основных параметров обмена веществ, что допускает межвидовую экстраполяцию результатов оценки биологической ценности пищевых продуктов. Биологическая доступность белков пищевого продукта при этом характеризуется скоростью протекания процессов жизнедеятельности индикаторного организма в зависимости от количества и качества пищевого объекта, что может быть оценено по динамике прироста количества инфузорий.

Предметом данного исследования являлось определение влияния соотношений жира и белка в продуктовой матрице на относительную биологическую ценность молочных продуктов.

Объектом исследования являлось молоко, нормализованное, пастеризованное с соотношением массовых долей жира и белка от 0,02 до 2,7:1.

Молоко с различной массовой долей жира исследовали в разведениях, обеспечивающих количество молочного белка в среде в пересчете на азот: 0,05; 0,15 и 0,3 мг/мл. Образцами сравнения в анализе служили пробы, содержащие обезжиренное молоко.

Сравнительные биологические исследования продукта выполняли методами биотестирования на тест-организмах *Tetrahymena pyriformis*. Определяли количество тест-организмов и относительную биологическую ценность (ОБИ) по отношению количества клеток, выросших на среде с опытными образцами, к количеству инфузорий, выросших на образцах сравнения, выраженному в процентах.

В ходе экспериментальных работ установлено влияние методических приемов, в частности, степени разведения проб (0,05; 0,15; 0,3 мг азота/мл) на динамику численности тест-культуры в зависимости от массовой доли жира в среде. Эффективность ассимиляции белка была выше в присутствии определенного

количества жира. Разведение молока для тестирования до 0,15 мг азота/мл обеспечивало достаточно сбалансированное потребление белка и жира инфузориями во всех образцах, позволяющее выявить влияние их соотношения на рост тест-организмов. Формализация экспериментальных данных методом наименьших квадратов позволила получить эмпирические математические зависимости, адекватно описывающие взаимосвязь численности тест-культуры, ОБЦ и состава продуктовой матрицы (коэффициент детерминации 0,92). Путем дифференцирования функции был определен диапазон оптимального соотношения массовых долей жира и белка в нормализованных молочных смесях, составивший 0,36-0,89. Нормализация молока по массовой доле жира в указанном диапазоне способствовала достижению максимальной относительной биологической ценности пастеризованного молока (162 ± 7) %.

Применение ускоренного биотестирования в сочетании с химико-аналитическими и микробиологическими методами дает возможность более полной и достоверной оценки качества и безопасности молочных продуктов без существенного увеличения затрат. Полученные данные позволят оценить эффективность технологических режимов производства цельномолочных продуктов и выбрать оптимальные параметры, обеспечивающие высокую степень полезности продукции, способствующей решению проблемы сохранения здоровья человека.

Ключевые слова: нормализованное молоко, *Tetrahymena pyriformis*, относительная биологическая ценность.

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**DEVELOPMENT AND RESEARCH OF A FREQUENCY
CONVERTER WITH INTELLIGENT CONTROL
SYSTEM WITH INDUCTION HEATER**

Abstract. The article has a frequency converter for induction heating of metal. Induction heating is a technology with low cost, high efficiency, low weight and dimensions, it provides a wide range of frequency control of the converter, the choice of the minimum number of power transistors, the establishment of the minimum power. Experienced frequency and inductance converters for metal and wort are designed and manufactured in the work. Experimental studies and tests of a prototype frequency converter were carried out. The issues of using the developed models and methods for controlling induction heating are considered.

Frequency converters are known where transformers are used to reduce voltages. The task is to create such a frequency converter, where the number of transistor modules would be minimum, and the step-down transformer would have the lowest overall dimensions.

An experimental model of a frequency converter and inductor with a power of 6 kW with a frequency of 2 to 20 kHz was developed and manufactured with power supply from one or three-phase voltage. Experimental studies and tests of a prototype frequency converter for induction heating of metal in real conditions were carried out.

In the development of technical documentation for the manufacture of a laboratory sample of the frequency converter and the selection of transistor IGBT modules, the main attention was paid to the topology of the power buses of the module and how to connect electrical circuits and remove heat. Even with the most advanced chips, the design of powerful key modules is extremely important to ensure reliability and efficiency. Distributed conductivity characteristics and parasitic inductance values of communication buses and terminals should have a minimum value to reduce losses and reduce the level of transient overvoltages.

For a more complete analysis, modeling was performed in the environment of MatLab R12 v.6.0, this package is intended for solving mathematical calculations of any complexity, for professional analysis and modeling of processes in electrical and electronic circuits, static processing of measurement results and experiments, as well as building Charts. In the simulation we used the Simulink Library Browsers library, as well as SimPowerSystems.

Key words: frequency converters, induction heater, transistor module, triacs, three-phase rectifier, inverter.

Introduction. Frequency converters (FC) for induction heating of metal consist of IGBT or MOSFET transistor modules connected in a specific configuration with control drivers. At the same time, they have protection against short circuit currents, overloads and protection against excessive temperatures. Currently, the use of inverters for induction heating of metal in the industry of Kazakhstan is practically absent, since the unit cost of existing foreign analogues is very high, so their mass introduction is unprofitable. You should develop your technology with low cost, high efficiency, low weight and size.

Frequency converters can be used in the following technologies:

- for induction heating of metals for stamping,
- for melting metals in induction melting crucible furnaces,
- for induction heating of metals for the purpose of hot volume hardening,
- for induction heating of oil in pipelines and tanks,

- for induction drying of grain, heating of liquid media, drying of wood and coatings and the production of milk powder [1,3,7,12].

The main objectives and goals are to create an inverter production technology, which should: provide the required frequency control range for the inverter, select the minimum number of power transistors, have high efficiency and low prices, minimum installed power of the entire inverter or its individual elements with the same given parameters of heating technology.

Research of a frequency converter with an intelligent control system with an induction heater.

Frequency converters are known where transformers are used to reduce voltages. The task is to create such a frequency converter, where the number of transistor modules would be minimum, and the step-down transformer would have the lowest overall dimensions. The electrical circuit of a frequency converter on two transistors with a single-phase power supply for an induction heater is shown in figure 1, consisting of blocks: a block 1-input triacs, a block 2-three-phase rectifier, a block 3-inverter [5,6].

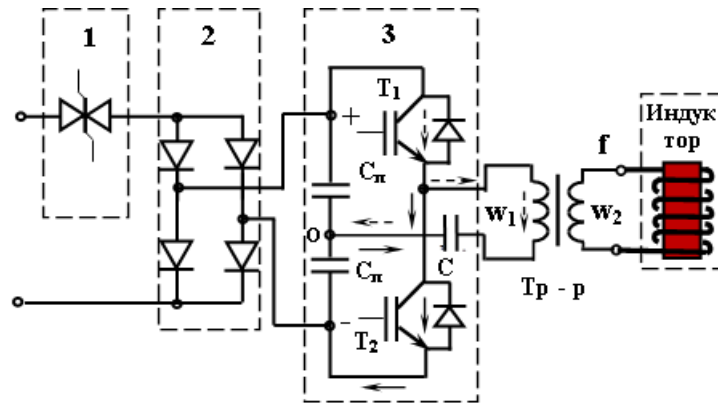


Figure 1 – The electrical circuit of the frequency converter of the induction heater with single-phase power

A feature of the inverter is that it is made on two transistors. The inverter direct voltage is converted to alternating voltage of high intermediate frequency f_{π} (figure 1). Further, from the moment of time $t = 0$, one of the two thyristors T-p1 opens, and the rectified one-half-voltage of a given frequency f_{π} falls into the load, and at the time $t = T / 2$ the first thyristor T-p1 closes.

To form a negative half-wave of the output voltage from the time $t = T / 2$ to $t = T$, the second thyristor T-p2 opens, and the rectified voltage of high intermediate frequency gets into the load and at the time $t = T$ the thyristor T- P2 closes. This forms a negative half-wave of the output voltage. The thyristor control unit in the time interval $t = 0 - T$ will adjust the frequency of the voltage at the load to the desired value [1,7].

Thus, the voltage at the output of the transformerless inverter has the form of a rectified sinusoid, consisting of single-period rectified high-frequency voltages and this frequency of the voltage at the load will be equal to

$$f = \frac{f_{\pi}}{n}, \tag{1}$$

where f_{π} - is the intermediate frequency at the inverter output, n is the number of rectified voltage periods of the intermediate frequency.

As can be seen from the last expression, the formation of voltage on a given load occurs from rectified high-frequency voltages.

For example, with an intermediate frequency at the inverter output $f_{\pi} = 20,000$ Hz and with the number of straightened periods $n = 40$, the frequency of the voltage at the load will be

$$f = \frac{f_{\pi}}{n} = \frac{20000}{40} = 500 \text{ Hz.} \tag{2}$$

Figure 2 shows the electric circuit of the frequency converter of the induction heater with three-phase power supply. The three-phase rectifier of block 2 is designed to convert AC voltage to DC, and the inverter converts direct current into alternating voltage of high frequency [5].

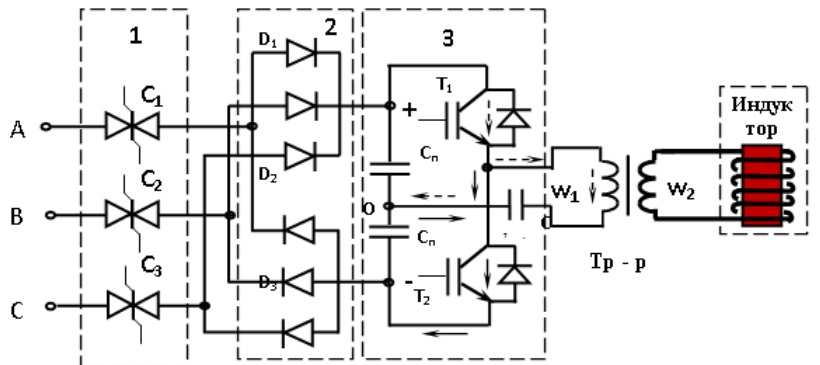


Figure 2 – Electric circuit of the frequency converter of induction heater with three-phase power supply

The inductor is designed to convert high frequency electrical energy into heat energy, and the transformer lowers the voltage to the required value. The rectifier and inverter are presented as a frequency converter. The output transformer is used to coordinate the parameters of the inductor with the workpiece with the parameters of the high-frequency inverter, while the overall dimensions of the transformer are reduced several times.

Input triacs C_1, C_2, C_3 of block 1 are made not only for the non-contact inclusion of the frequency converter in the network, but also for regulating the input voltage. The fact is that during operation of the induction heater, every few minutes it is necessary to disconnect the frequency converter from the mains, since the heated metal (billet) should be removed from the inductor and transferred for stamping. Next, insert the new blank into the inductor and turn on the frequency converter in the network. The half-bridge inverter of block 3, formed on IGBT transistors T_1 and T_2 (figure 1), is connected to a DC voltage source, capacitors C_n (lower and upper) are designed to separate the supply voltage into two equal parts. The capacitor C_n in the inverter output circuit is made to improve the quality of the output voltage and in order to achieve a consistent resonance.

In addition, in block 3, for the formation of a positive half-period of voltage at the inverter output, the transistor T_1 opens, and the transistor T_2 is closed, while the constant current from the voltage source will flow through the transistor T_1 and the primary winding of the transformer. To form a negative half-period at the inverter output, the transistor T_2 opens, and the transistor T_1 closes, and a constant current from the voltage source will flow through transistors T_2 and the primary winding of the transformer in the opposite direction.

Thus, a step voltage is generated at the inverter output. It should be noted that the frequency of the step voltage on the inductor is determined by the switching frequency of transistors and can reach tens of kilohertz. This mode of operation of the inverter with a minimum number of power transistors will increase the frequency range of the current at the inductor and improve their energy performance, as well as increase reliability and reduce the cost of equipment.

The bridge circuit of a three-phase rectifier of block 2 is connected to the triac output (figure 1). As you know, the bridge circuit of a three-phase rectifier provides the least ripple output voltage. In the bridge circuit of a three-phase rectifier, uncontrolled diodes open afterwards with a shift of 60° , and the D_1, D_3 и D_5 diodes open in positive and the D_6, D_2 и D_4 diodes open in negative half-periods of phase stresses. The conduction interval of each diode is 120° , at each moment of time two diodes are open (one in the bridge arm) and the voltage across the load is determined by the phase voltage difference, i.e., whether π -neine voltage. The average value of the voltage at the load with a sinusoidal mains voltage has the following form,

$$U_{cp} = \frac{6\sqrt{2}}{\pi} U_m \sin \frac{\pi}{6} \cos \alpha = 1,35 U_{\pi} \cos \alpha = 2,34 U_{\phi} \cos \alpha \tag{3}$$

where $U_{\pi} = \sqrt{3} U_{\phi}$ is the effective value of the linear voltage of the secondary winding of the transformer.

Test results of the manufactured experimental sample of the frequency converter and inductor, data processing. An experimental model of a frequency converter and inductor with a power of 6 kW with a frequency of 2 to 20 kHz was developed and manufactured with power supply from one or three-phase voltage. Experimental studies and tests of a prototype frequency converter for induction heating of metal in real conditions were carried out.

Figure 3 shows the process of induction heating of a metal billet with a diameter of 44 mm and a length of 80 mm. At the beginning of the induction heating process, the metal did not heat up uniformly, i.e. in the middle of the workpiece, the temperature was lower than at the edges. This meant that the penetration depth of the electromagnetic wave is not significant, so you should choose a lower current frequency, however, this will increase the heating time of the metal. The time of heating the metal with a frequency converter to a temperature of 600-6500C was 3.5 minutes at a frequency of 8 kHz and at a frequency of 10 kHz - 2.41 minutes (figure 4). At the same time, the transistors did not overheat, which is required by the operating conditions.



Figure 3 – Induction heater during the test period

The test results showed that the created induction heater was operational, passed a successful test, and the cooling system of the inductor was working properly. The process of induction heating of the metal can be carried out to the desired temperature.



Figure 4 – The process of induction heating of metal to a temperature of 731⁰ C

In the development of technical documentation for the manufacture of a laboratory sample of the frequency converter and the selection of transistor JGBT modules, the main attention was paid to the topology of the power buses of the module and how to connect electrical circuits and remove heat. Even with the most advanced chips, the design of powerful key modules is extremely important to ensure reliability and efficiency. Distributed conductivity characteristics and parasitic inductance values of

communication buses and terminals should have a minimum value to reduce losses and reduce the level of transient overvoltages.

Figure 5, 6 shows the waveform of the voltage at the inverter output without a capacitor in the primary circuit of the transformer. As can be seen from the graph, the voltage waveform is oscillatory in nature, which means that the transistors are in active mode. In this case, they will heat up and ultimately fail. In order for the transistors to switch to the key mode, it is necessary to turn on the capacitor C_n in series in the output circuit of the inverter, improve the quality of the output voltage and achieve a consistent resonance.

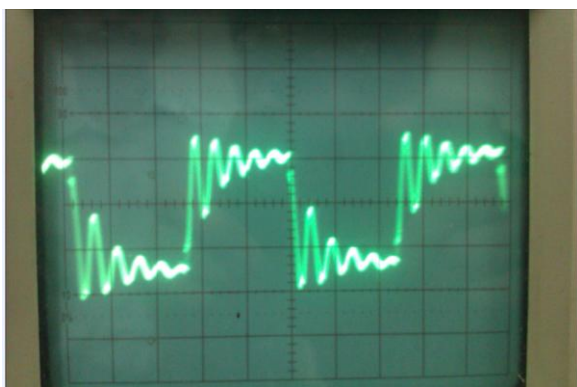


Figure 5 – Voltage waveform at inverter output without capacitor in transformer primary circuit



Figure 6 – Waveform of the voltage at the output of the inverter with a capacitor in the primary circuit of the transformer

Figure 6 shows the waveform of the voltage at the inverter output with a capacitor in the primary circuit of the transformer. As can be seen from the graph, the voltage at the inverter output has a rectangular shape, which means that the transistors work in key mode, while they will not heat up. In addition, by choosing experimentally the value of the capacitor C_n , it is possible not only to improve the quality of the output voltage, but to achieve a consistent resonance. At resonance, the active power of the inverter will be transferred to the inductor, i.e. blank for heating.

Induction heating of metal products is carried out using a special device called an inductor. When an alternating current is passed through an inductor, a magnetic field appears around its wire, the intensity of which periodically changes in time in magnitude and direction. The magnetic field strength, and, consequently, the magnetic flux density - induction - will be greatest inside the coil of the inductor near the wire.

If a metal cylinder is placed inside the inductor, then the alternating magnetic flux penetrating this cylinder will cause the appearance of an induced current in it. The induced current due to the proximity effect will be concentrated under the inductor wire, and its path will have an annular shape. The higher the frequency of the current, the more current flows in the cylinder in a thinner layer, i.e. the stronger the surface effect.

The main part of the inductor is an induction wire, the design of which largely determines the result of heating. The heating time of each element of the surface of the cylinder passing under the induction wire, the longer, the greater the width of the wire and the lower the speed of grain movement relative to the inductor. Therefore, the concept of heating time (formula 3) of a cylindrical surface is similar to the concept of heating time with a simultaneous heating method.

$$t_k = a/v \quad (4)$$

where t_k - is the heating time of the cylindrical surface, s; a - is the width of the induction wire, cm; v - is the speed of movement, cm / s.

The specific power on the surface of the cylinder covered by the inductor is calculated by the formula

$$p_0 = \frac{P_{\text{пч}}}{\pi D_2 a'} \quad (5)$$

where $P_{\text{пч}}$ - is the total power of the frequency converter on the cylinder surface, kW; D_2 ameter of the part, see.

For a given power of the frequency converter for induction heating, we obtain the following relation for determining the maximum width of the induction wire:

$$a = \frac{P_{\text{пч}}}{\pi D_2 \rho_0},$$

or, expressing the power of the cylinder through the power of the frequency converter, we obtain

$$a = \frac{\eta_{\text{H}} \eta_{\text{ТР}} P_{\text{пч}}}{\pi D_2 a}, \quad (6)$$

where $P_{\text{пч}}$ is the power of the frequency converter, kW; η_{H} - the efficiency of the inductor; $\eta_{\text{ТР}}$ - Efficiency of a step-down transformer.

On average, you can take $\eta_{\text{H}} \approx \eta_{\text{ТР}} \approx 0.8$. Then the width of the inductor (cm) will be

$$a = \frac{0,64 P_{\text{пч}}}{\pi D_2 \rho_0},$$

or

$$a = \frac{0,2 P_{\text{пч}}}{D_2 \rho_0}, \quad (7)$$

Estimated values of the heating time and specific power depending on the depth of the heated layer, diameter and frequency can be determined.

Since at a given depth of the heated layer, the heating time is a known quantity, the inductor width can be determined by the formula

$$a = v t_{\text{к}} \quad (8)$$

In this case, the required power of the frequency converter (kW) based on the formula (8) is equal to

$$P_{\text{пч}} = 5 a D_2 \rho_0 \quad (8)$$

The current induced in the surface layers of the cylinder causes it to heat, and the surface temperature and depth of heating depend on the power supplied to the inductor, the frequency and time of heating. On the other hand, the width of the heating strip, its shape and uniformity of surface heating depend on the shape of the inductor.

For example, figure 3 shows the developed transistor - thyristor frequency converter, which can be used depending on the power and productivity of grain drying. The frequency converter operates as follows. The temperature of the grain can be measured with thermometers. The remaining parts are auxiliary, and their construction usually does not cause difficulties.

The bridge circuit of the inverter formed by transistors T1, T2, T3 and T4 (figure 2) is connected to the first voltage source $U_{\text{п}}$. At the time t_1 , transistors T1 and T4 open and direct current from the voltage source $U_{\text{п}}$ will flow through transistors T1 and T4. This is the formation of a positive half-cycle of the stepwise voltage at the load.

To form a negative half-cycle of the stepwise voltage on the load at time $t_1 + T / 2$, where T is the voltage period, transistors T2 and T3 open and the direct current from $U_{\text{п}}$ will flow through transistors T2 and T3, in the opposite direction.

Thus, the formation of a negative half-cycle of voltage and step voltage at the load. It should be noted that the frequency of the step voltage at the load is determined by the switching frequency of the transistors and can reach up to hundreds of kilohertz [11].

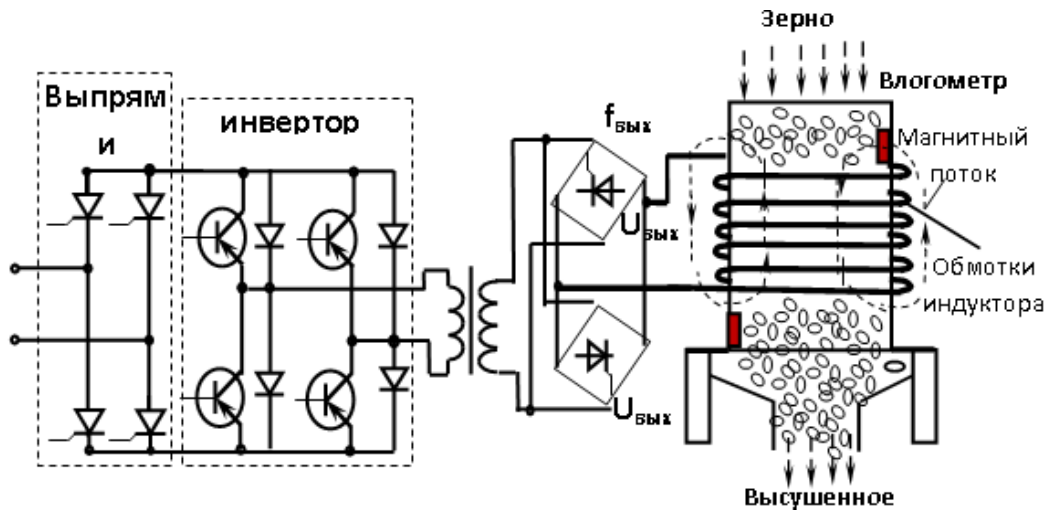


Figure 7 – Transistor-thyristor frequency converter with a higher frequency link for drying grain

Inverter direct voltage is converted into alternating voltage of high intermediate frequency $f_{\text{п}}$ (figure 7). Then, from the moment of time $t = 0$, one T-p1 of two thyristor rectifiers opens, and the rectified two-half-voltage of a given frequency f_{out} falls into the load, and at the time of $t = T / 2$, the first thyristor rectifier T-p1 closes [16,17].

To form a negative half-wave of the output voltage from the time $t = T / 2$ to $t = T$, the second thyristor rectifier T-p2 opens, and the rectified voltage of a high intermediate frequency gets into the load and at the time $t = T$ the second thyristor rectifier T-p2 closes. This forms a negative half-wave of the output voltage. The thyristor control unit in the time interval $t = 0 - T$ will adjust the frequency of the voltage at the load to a predetermined value. The advantage of this circuit is that the output voltage will be twice as high as in the first case (figure 7), since there is a two-half-wave voltage rectification circuit.

For a more complete analysis, modeling was performed in the environment of MatLab R12 v.6.0, this package is intended for solving mathematical calculations of any complexity, for professional analysis and modeling of processes in electrical and electronic circuits, static processing of measurement results and experiments, as well as building Charts. In the simulation we used the Simulink Library Browzers library, as well as SimPowerSystems. Figure 8 shows a simulation circuit of a transistor - thyristor inverter with a purely active load. The simulation results are shown in figure 9 with a net active load. As can be seen from the figure, with a net active load, the voltage and current in the load have a clearly defined graph. The principle of operation of a transistor - thyristor frequency converter with a half-wave voltage rectification circuit is confirmed.

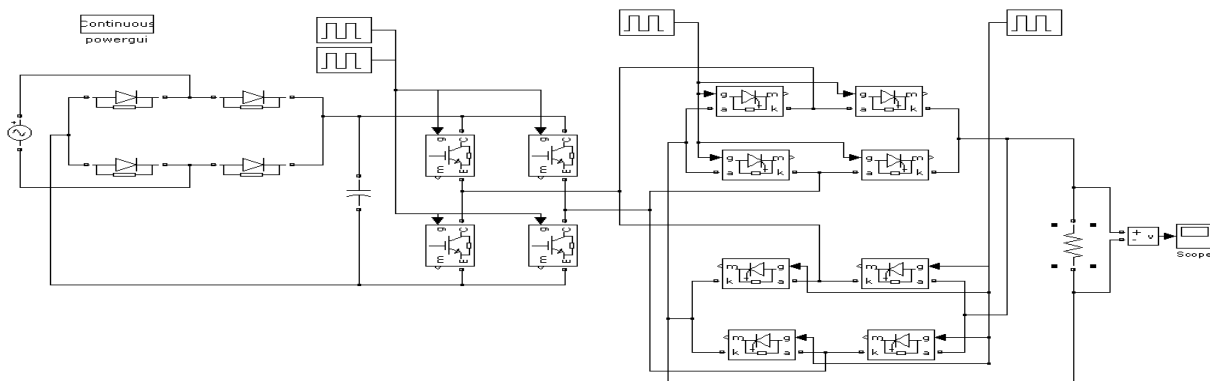


Figure 8 – Simulation scheme of transistor – thyristor frequency converter

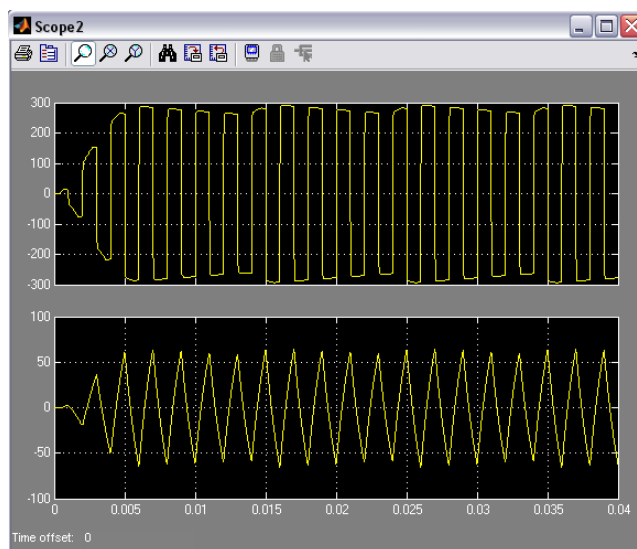


Figure 9 – Results of simulation of a frequency converter under active load

An alternating voltage was applied to the input of the frequency converter. Formation of the voltage form at the inverter input is carried out by dividing into several steps with different voltage levels, and program-controlled switching time. The transistor inverter was assembled by a bridge circuit. The bridge circuit consists of four transistors (figure 7). At certain points in time, at each stage it is necessary to switch a pair of transistors to form a positive and negative half-wave of a sinusoidal voltage. The switching mode of the transistors is organized in such a way as to exclude a short circuit of voltage sources.

Conclusion. SKYPER 52 drivers will be used in transistor frequency converters of induction heating, which is the conversion of a low-current logic controller signal into a gate control signal, the power of which should be sufficient for quick recharging of IGBT shutter capacities. Since the power switches operate at voltages significantly exceeding the potentials of the controller signals, the gate control device must carry out a high-voltage level shift or galvanic isolation of control pulses and pulses arriving at the gates. In addition, the modern SKYPER 52 drivers contain numerous protective and service functions necessary for IGBT uptime in all operating modes, including emergency.

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ТӨМЕНГІ ӨНДІРУ ҰҢҒЫМАЛАРЫНДА МҰНАЙ ҚЫЗДЫРУДЫҢ ИНДУКЦИЯЛЫҚ ӘДІСІ

Аннотация. Мақалада төменгі өндіру ұңғымаларында мұнай қыздырудың индукциялық әдісі қарастырылады. Ол үшін индукциялық қыздырғыш пен жиілік түрлендіргіш пайдалануды ұсынады. 1-1,5 кГц ток жиілігі кезінде индукциялық қыздырғыш және инвертор жиілік түрлендіргіші мұнай ұңғымасының түбінде орнатылуы мүмкін. Инвертор бір мың вольтке дейін кернеу, жүздеген ампер және ондаған киловатт қуат тогы коммутациялайтын JGBT транзисторлық модуляцияларда орындалады.

Мұнайды жылыту үшін шағын, қызмет көрсетуге ыңғайлылық пен арзан электр энергиясы болған кезде пайда болатын электр жылыту құрылғылары қолданылады.

Жүргізілген зерттеулердің мақсаты – мұнайды қажетті температураға дейін жұмсалатын электр энергиясын барынша тиімді пайдалана отырып, ашық отты (пеш, жанарғы) қолданбай, жылу электр қыздырғыш аспаптарынсыз (ТЕН) және ПЭК 60-80% аспайтын жылу алмастырғыш құрылғыларды қолданусыз қыздыру. Бұл индукциялық қыздыру әдісін пайдалану барысында жүзеге асырылады.

Индукциялық қыздыру технологиялық жабдықты (мұнай құбыры, құбыр, сыйымдылық және т.б.) жылыту, сұйық ортаны қыздыру, материалдардың (мысалы, сүрек) жабынын кептіру үшін қолданылады. Индукциялық қыздыру кондырғыларының маңызды параметрі – жиілік. Әрбір үдеріске үздік технологиялық

және экономикалық көрсеткіштерді қамтамасыз ететін оңтайлы жиілік диапазоны бар. Индукциялық қыздыру үшін 50Гц-тен 5МГц-ке дейінгі жиілік қолданылады.

Мұнай өндіруді ұлғайту үшін мұнай жылытуды жүзеге асыру қажет. Бұл көптеген мұнай өндіруші компанияларда маңызды әрі жан жақты мәселе болып саналады. Жылыту үшін су буы, ыстық су, ыстық газ және мұнай өнімдері, электр энергиясы сынды түрлі жылу тасымалдағыштар қолданылады. Жоғары жылу мөлшері мен жылу бергіші бар, жай ғана тасымалданатын және өрт қаупі жоқ су буы көп қолданылады. Мұнай өнімін 80-100°C дейін қыздырып, 0,3 - 0,4 МПа қысымдағы қаныққан буды пайдаланады.

Мұнай ұңғымаларындағы мұнайды қыздырудың мұндай тәсілі Латын Америкасы елдерінде қолданылады. Әдебиеттер мен құжаттаманы шолу әрі талдау жұмыстары көрсеткендей, жылытқыштың шетелдік конструкциясының үлестік құны өте жоғары. Осыған байланысты Қазақстанда шетелдік өндіріс жылытқышын енгізген тиімсіз саналады, өйткені өтелімділік мерзімі он жылға жетеді. Сондықтан индукциялық жылытқышын экономикалық жағынан тиімді болатын өзіне тән әзірлемелер негізінде жетілдіру қажет. Электр энергиясының құны шетелдегі электр энергиясының құнымен салыстырғанда төмен болған жағдайда, сондай-ақ бүкіл қондырғының үлестік құнын төмендету, индукциялық жылытқышты әзірлеу және енгізу өзекті мәселе болып саналады.

Техникалық құжаттаманы әзірлеу кезінде жиілік түрлендіргішінің зертханалық үлгісін жасау және транзисторлық JGBT модульдерді таңдау кезінде басты назар модульдің күштік шиналарының топологиясына және электр тізбектерін қосу және жылыуды бұру тәсілдеріне аударылды. Қазіргі заманғы чиптерді қолданғанда да қуатты негізгі модульдердің конструкциясы сенімділік пен тиімділікті қамтамасыз етуде өте маңызды. Байланыс шиналары мен шығарылған өткізгіштігінің бөлінген сипаттамасы мен паразиттік индуктивтілігінің мәні ысырапты азайту мен ауыспалы кернеудің арту деңгейін төмендету үшін аз мәнге ие болуы тиіс.

Сонымен қатар, тәжірибелік жолмен с конденсаторының мәнін таңдай отырып, шығу кернеуінің сапасын жақсартып қана қоймай, дәйекті резонансқа қол жеткізуге болады. Резонанс кезінде инвертордың белсенді қуаты индукторға беріледі, яғни қыздыру үшін дайын болады.

Түйін сөздер: индукциялық әдіс, ток жиілігі, JGBT транзисторлық модульдері, кернеу, қажетті температура.

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РАЗРАБОТКА И ИССЛЕДОВАНИЕ ПРЕОБРАЗОВАТЕЛЯ ЧАСТОТЫ С ИНТЕЛЛЕКТУАЛЬНОЙ СИСТЕМОЙ УПРАВЛЕНИЯ С ИНДУКЦИОННЫМ НАГРЕВАТЕЛЕМ

Аннотация. В статье рассматривается индукционный способ нагрева нефти в низкодебитных скважинах. Для этого предлагают использовать индукционный нагреватель и преобразователь частоты. Показано, что при частотах тока 1 – 1,5 кГц индукционный нагреватель и инвертор-преобразователь частоты могут быть установлены на дне нефтескважин. Инвертор будет выполнен на JGBT транзисторных модулях, которые могут коммутировать напряжения до тысяча вольт, токи – сотни ампер и десятки киловатт мощности.

Для подогрева нефти используют электронагревательные устройства, которые различаются компактностью, удобством в обслуживании и выгодой при наличии дешевой электроэнергии.

Цель проводимых исследований – нагрев нефти до необходимой температуры, с максимально эффективным использованием затрачиваемой электроэнергии, без применения открытого огня (печи, горелки), без тепловых электронагревательных приборов (ТЭНов) и без использования теплообменных устройств, КПД которых не превышает 60-80%. Это возможно при использовании индукционного способа нагрева.

Индукционный нагрев применяют для обогрева технологического оборудования (нефтепровода, трубопровода, емкости и т. д.), нагрева жидких сред, сушки покрытий материалов (например, древесины). Важнейший параметр установок индукционного нагрева – частота. Для каждого процесса существует оптимальный диапазон частот, обеспечивающий наилучшие технологические и экономические показатели. Для индукционного нагрева используют частоты от 50Гц до 5МГц.

Для увеличения добычи нефти необходимо осуществить подогрев нефти. Это многогранная и серьезная проблема для многих нефтедобывающих компаний. Для обогрева используют разные теплоносители: водяной пар, жаркую воду, жаркие газы и нефтепродукты, электроэнергию. Наибольшее применение имеет водяной пар, обладающий высочайшим теплосодержанием и теплоотдачей, просто транспортируемый и не

представляющий пожарной угрозы. Употребляют насыщенный пар давлением 0,3-0,4 МПа, обеспечивая нагрев нефтепродукта до 80-100 °С.

Такой способ нагрева нефти в нефтескважинах применяется в странах Латинской Америки. Как показывает обзор и анализ литературы, а также технические документации, удельная стоимость существующих зарубежных конструкций нагревателей очень высока. В связи с этим, внедрение нагревателей в Казахстане иностранного производства невыгодно, так как срок окупаемости достигает около десяти лет. Поэтому следует разрабатывать свои индукционные нагреватели на основе собственных разработок, которые будут экономически выгодны. Учитывая, что при низкой стоимости электроэнергии по сравнению со стоимостью электроэнергии за рубежом, а также снижение удельной стоимости всей установки разработка и внедрение индукционных нагревателей является актуальной проблемой.

При разработке технической документации для изготовления лабораторного образца преобразователя частоты и выборе транзисторных JGBT модулей основное внимание было уделено топологии силовых шин модуля и способам подключения электрических цепей и отвода тепла. Даже при использовании самых современных чипов конструкция мощных ключевых модулей имеет чрезвычайно большое значение для обеспечения надежности и эффективности. Распределенные характеристики проводимости и значения паразитных индуктивностей шин связи и выводов должны иметь минимальное значение для уменьшения потерь и снижения уровня переходных перенапряжений.

Кроме того, подбирая экспериментальный путем значение конденсатора С можно не только улучшить качество выходного напряжения, но и добиться последовательного резонанса. При резонансе активная мощность инвертора будет передаваться индуктору, т.е. заготовке для нагрева.

Ключевые слова: индукционный метод, частота тока, транзисторные модули JGBT, напряжение, требуемая температура.

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MICROENCAPSULATION OF PROTEOLYTIC ENZYMES FOR INDUSTRIAL APPLICATION

Abstract. The aim of the present study was to develop the technology of microencapsulation of proteolytic enzymes in the pseudo-boiling layer which based on the diffusion of maltodextrin into an enzyme, which allows maintaining high enzyme activity for a long time in meat products. It was found that maltodextrin provides high strength capsule walls their integrity during long-term storage. It was shown that the maximum activity of the proteolytic enzyme pepsin immobilized in a maltodextrin matrix shifts to the alkaline side with increasing pH of the reaction medium, which is not typical for a free enzyme. The results of determining the cutoff voltage of ham from pork ham confirmed that the immobilized enzyme remained active for 6 months of storage. While pure pepsin after 3 months of storage noticeably lost its proteolytic effect. Considering the results obtained microencapsulation of the proteolytic enzyme pepsin using maltodextrin with a coating thickness of 4 to 6 μm can be recommended which will expand the possibilities of using enzymes in the production of meat products.

Key words: microencapsulation, ham products, pepsin, activity, immobilized enzyme, maltodextrin.

Introduction. The modern food industry aims to increase the biological value of food products. In relation to ham products the scientific and technological problem is to accelerate the ripening and bating of meat which can be solved by the use of proteolytic enzyme preparations.

There are various methods of treating meat with enzyme preparations. The most common are aerosol. It means immersion of portioned meat pieces in an enzyme solution or injection of the drug by syringing. Due to the modern food science it possible to use microencapsulation of enzymes. Microcapsules are made with enzymes that have a directed effect on muscle and connective tissue proteins.

Given these circumstances, researchers have been searching for effective methods of capsulation [1,2,3,4,5]. Often, an extrusion method is used for the production of microcapsules which involves the external gelation of hydrocolloids using various gelling agents (calcium chloride solution for alginate, potassium chloride for carrageenan and tripolyphosphate for chitosan, transglutaminase for caseinate). The suspension of the biologically active substance and the hydrocolloid solution is extruded in separate drops, which are collected in a container for thermal gelation. Then using pressing it can be possible to produce capsules of various diameters [6]. Extrusion technology is recommended for encapsulation of living cells – probiotics [6,7,8].

Encapsulating food substances is proposed using hydrolyzed and modified starches [9]. At the same time, it is noted in the work that hydrolyzed starch does not always ensure the stability of taste. The use of starch modified with octenyl succinate increases the stability of the emulsion.

Studies often come down to finding a protective substance for encapsulation which should have high rheological properties and be easily processed during encapsulation. Also, the protective substance must have emulsion and dispersion properties with high stability, they must be inert with respect to the

encapsulated substance during use and during storage of capsules; have good solubility; be affordable and affordable. It should also be taken into account that the use of the protective substances used in the encapsulation of food ingredients must be approved by state authorities.

The protective substances used for encapsulation cannot always combine all these characteristics, in some cases several substances are used for this, for example, modified cellulose, which has high emulsifying and mechanical properties [10].

A promising method of microencapsulation of enzymes is the application of a protective coating on them in a pseudo-boiling layer of a dispersion of maltodextrin. This treatment allows you to evenly distribute the film-forming substance over the entire surface of the enzyme.

Lipin et al. [11] propose a number of designs of technological devices for gushing action, which make it possible to ensure a uniform carrier gas velocity for stable gushing. The data obtained can be used in the development of industrial plants.

Modern research often boils down to the use of micro-capsules to add value to foods, primarily dietary supplements. In relation to meat products, studies are aimed at increasing their shelf life [12,13,14, 15]. While the use of microcapsules for the tendering of meat products is not well understood. This actualizes the problem of the possibility of using microcapsules for softening ham products.

In this regard, the **aim** of this study is to develop a technology for microencapsulation of proteolytic enzymes in a pseudo-boiling layer and to evaluate their tendering effect in the production of ham products.

To achieve this goal, the following **tasks** were set:

- to develop own technology and device for microencapsulation of pepsin in maltodextrin;
- to evaluate the effect of microcapsules of different diameters and thicknesses of the coating on the activity of pepsin;
- to determine the tendering effect of microencapsulated pepsin on samples of ham products.

Organization and research methods. Encapsulation was carried out in a specially designed glass apparatus by applying a pseudo-boiling layer (PBL) to the surface of the enzyme (figure 1).

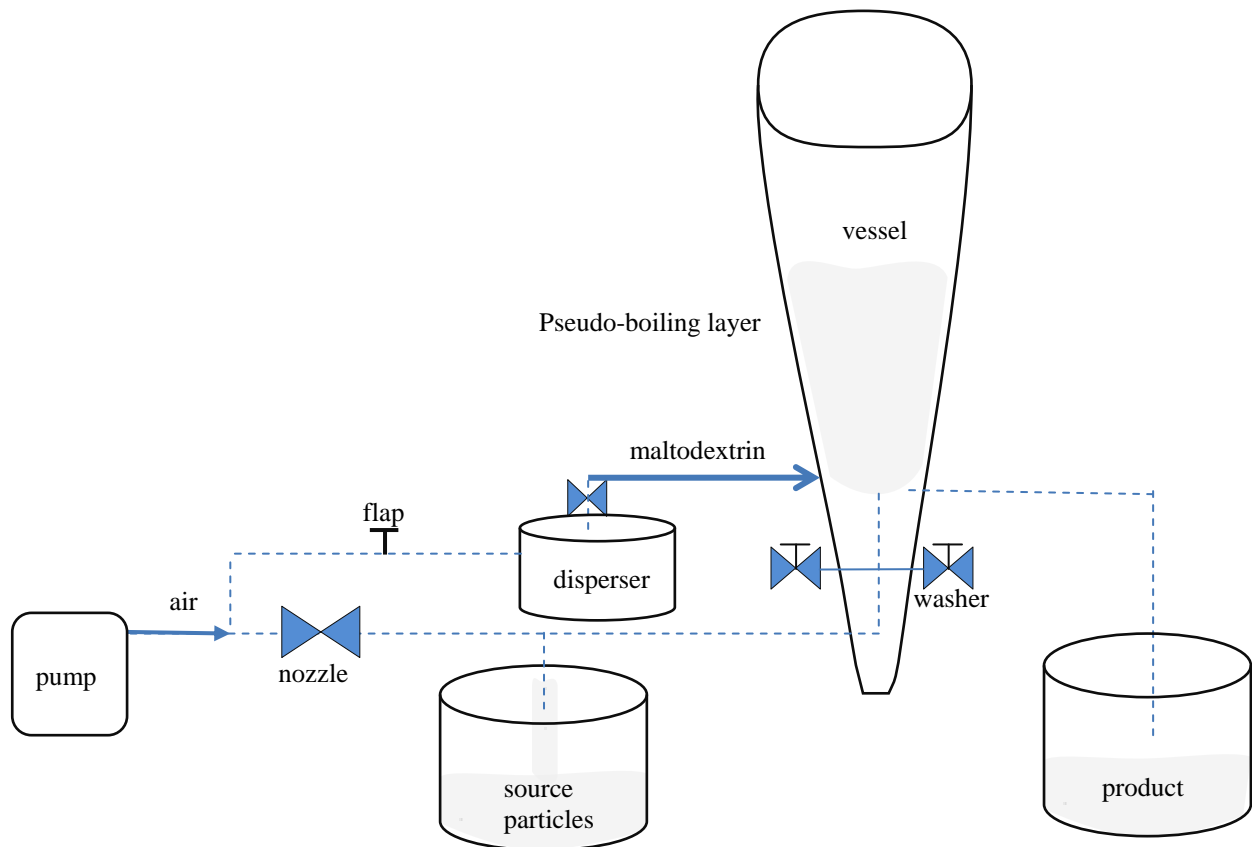


Figure 1 – Scheme of the device for microencapsulation of enzymes

Microencapsulation on the apparatus included the modified of known technology. A container with an enzyme was hermetically connected to the pipe, air was supplied from the pump, which, passing through interchangeable nozzles of various diameters, takes the initial (source) particles. Then, the particles in the turbulent flow are dried and enter the casing of the apparatus with pseudo-boiling layer in the form of gushing flows in the vessel. The correct selection of the velocities of these flows, depending on the properties of the enzyme particles, is ensured by washers of the required hole diameter and the size of the conical body of vessel (height and diameter). After preliminary drying of the particles in the nozzle and in the gushing flows of the apparatus, a washer was opened, and the air entered the dispersant for liquid components, previously filled with a portion of them. The dispersant is equipped with a replaceable nozzle. The choice of nozzle diameter provides dispersion of droplets of the required size, which are introduced through the nozzle into the gushing flows of the bottom of the vessel.

The size of the drops should create the overall surface of liquid components, on a par or even bigger than the consummate surface of the hard particles in the spouted layer of the apparatus. Covering the enzyme with drops should be intensive and fleeting, it comes in hand with the beginning of the desiccation of the glued drops by the spouted layer, which flush the particles from all sides. After all the required components are received, the nozzle is closed. After the desiccation has been made, the bottom throat section is occluded by the batch gate with flapper and the portion of the encapsulated enzyme falls freely in the storage vessel. Drying time was lasted from 5 to 8 minutes. Then the flapper is opened, and the cycle with hard and liquid particles is rehearsed in the same manner.

For the present experiment pepsin was used; as a protective layer, a 10% aqueous solution of maltodextrin obtained by the acid or enzymatic method from corn starch as a result of its partial hydrolysis and equivalent dextrose weight. When heated to 100 °C and a pH of 4.0–5.0, corn starch breaks down, resulting in maltodextrin and corn syrup.

The ratio of solid to liquid (S/L) was kept within $10/1 \div 11.5 / 1$. The fluidizing agent including in the drying mode was room temperature air pumped through the apparatus.

For the experiment, five polished samples of encapsulated enzymes were prepared with a maltodextrin layer thickness of 2 μm , 4 μm and 6 μm . Pure unencapsulated pepsin was taken as a control.

Pepsin activity was determined in the range of pH between 1.5 to 5.0 by the amount of tyrosine as a result of the hydrolysis of casein. Casein was used as a substrate with Gerner method according to Anson's work [16-19]. The amount of tyrosine was determined by the spectrophotometric method at a wavelength of 280 nm on an SF-46 spectrophotometer.

The object of the study was the rear ham of lean, boneless pork from chilled half-carcasses with 6.1 pH. The gammon was injected with brine in an amount of 15% by weight of the raw material with a density of 1077.7 kg / m², containing salt, sodium nitrite, the enzyme pepsin in an amount of 0.15% and granulated sugar. Raw meat filled with brine, was kept in salting for 5 hours. Then the salted samples were molded, poured and heated in accordance with the technology for the ham production. After cooling the shear stress was determined on an Instron 1022 testing machine.

Five groups of ham were developed. Each experimental study was performed in 5 times replicate. Statistical data processing was performed using Statistica 9 software package. The confidence level was 0.95 ($p \leq 0.05$).

Results and discussion. The duration of the processing of maltodextrin in the apparatus for microencapsulation determined the thickness of the protective layer of the capsules. It is defined that the thickness of the defensive coating from maltodextrin linearly depends ($p \leq 0.05$) on the duration of its processing in the apparatus for microencapsulation (figure 2).

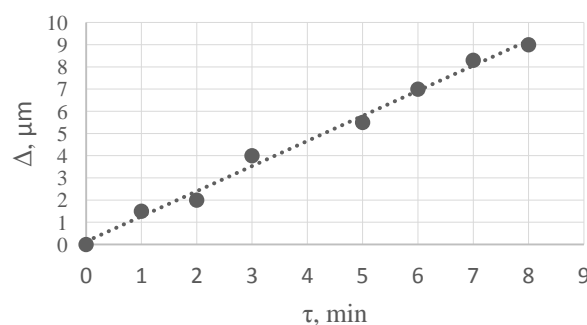


Figure 2 – Layer thickness maltodextrin and its duration on pepsin

After 2 min of processing by the maltodextrin mixture (figure 2) there was more than ¼ of thickness of the surface layer from its average size on the pepsin grain at the end of the experiment, and after 6 min of depositing was 70%. And the rating speed of the air flow with the maltodextrin mixture in the bottle neck of the cone of the working chamber was on a par with the marginal terminal velocity of the large pepsin particles and was about 0,17 m/sec. Due to the equation of the flow continuity and in unison with the terminal velocity and pepsin particle entrainment there was a theoretical size of the belly of the apparatus cone during the depositing of the maltodextrin mixture made:

$$d_w = 4,4 \cdot d_n, \quad (1)$$

where d_w – the diameter of the broad cone part of the working chamber, d_n – the diameter of the narrow cone part of the working chamber.

The analysis of the pepsin activity and the coating thickness of the maltodextrin enzyme showed that the thicker the maltodextrin coating was, the longer the initial pepsin activity lasted (figure 3).

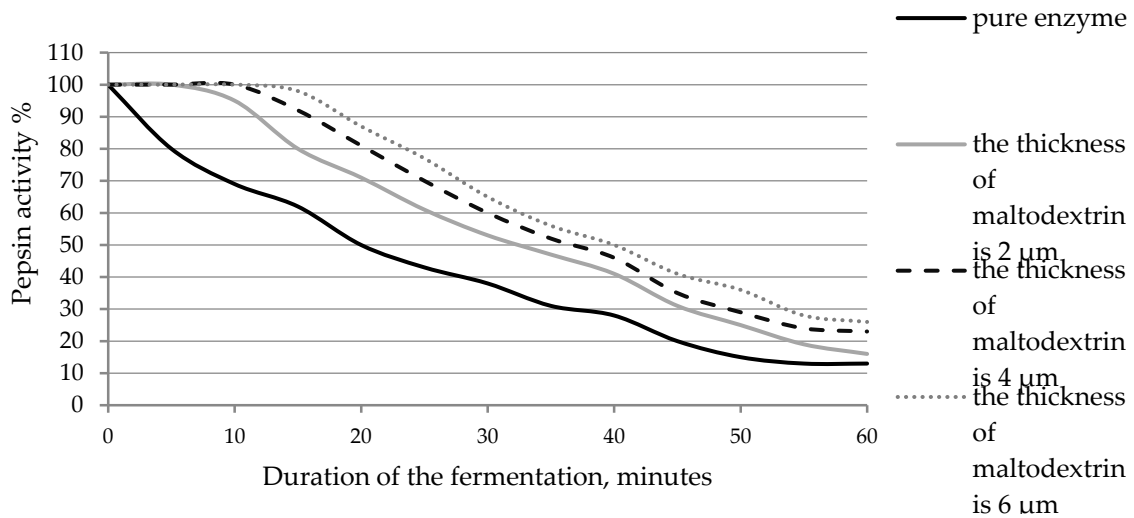


Figure 3 – The impact of the thickness of the maltodextrin on pepsin activity

The coating thickness of maltodextrin affects the activity of pepsin. The pepsin activity was the most stable when the thickness of the maltodextrin coating was 6 μm. As the thickness of the defensive coating decreases, the enzyme quickly loses its initial activity.

It was established that the activity of pepsin in microcapsules with a layer thickness of more than 6 μm was not investigated.

As can be seen in figure 4, maximum activity of the pepsin immobilized in the maltodextrin mixture moved roughly for 2 units pH in the acid direction compared with the free enzyme. It apparently can happen due to the limitation of the initial substance diffusion, when there is a lack of proton dispensation and limitations in diffusion as well.

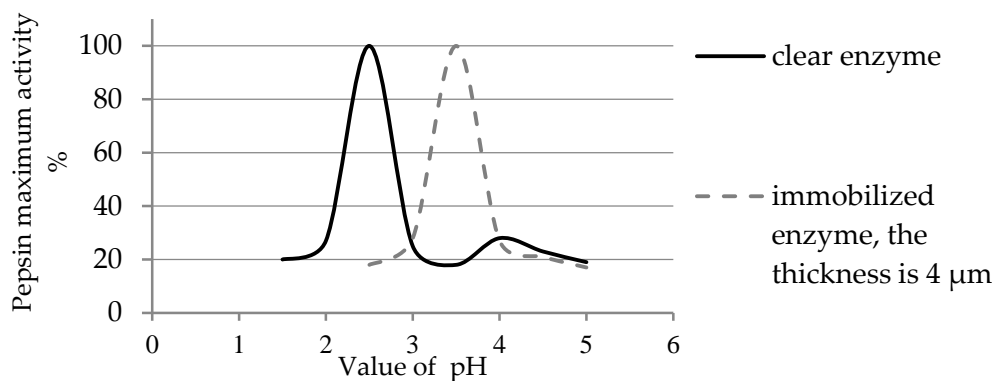


Figure 4 – Dependence of the pepsin activity from pH for the maltodextrin, thickness 4 μm

The results indicate that pepsin activity with the thickness maltodextrin of 4 μm is slightly lower than microcapsules of 6 μm . In this connection, it is advisable to use pepsin with maltodextrin coating of 4 μm . Therefore, in further experiments, an enzyme with the thickness of 4 μm was used.

The experiment of the pepsin proteolytic activity depended on the length of the conservation period under the temperature 0-2 $^{\circ}\text{C}$ revealed (figure 5) that immobilization of the enzyme with the maltodextrin made its activity much more stable practically for 6 months, whereas clear enzyme already started to lose its activity after 3 months.

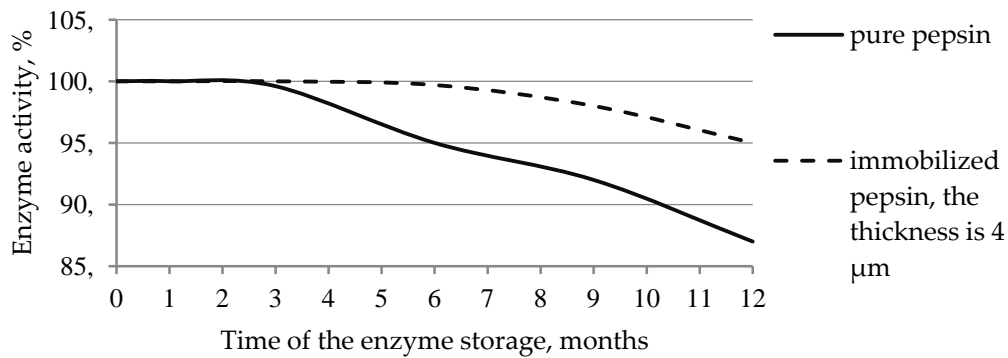


Figure 5 – Dependence of the proteolytic activity of the clear pepsin (Row 1) and the immobilised one, the thickness of the maltodextrin coating 4 μm (Row 2) on the length of conservation

During the experiment there were researches conducted on the connection between the length of the pure and encapsulated pepsin conservation and the structure and physical qualities of the ham. Enzymes microcapsules were stored in a dry, dark place at a temperature not exceeding 2 $^{\circ}\text{C}$ and a relative humidity of not more than 75% in compliance with the technical conditions. The shelf life of pepsin did not exceed 10 months. The immobilized enzyme for 6 months showed a great proteolytic activity (figure 6).

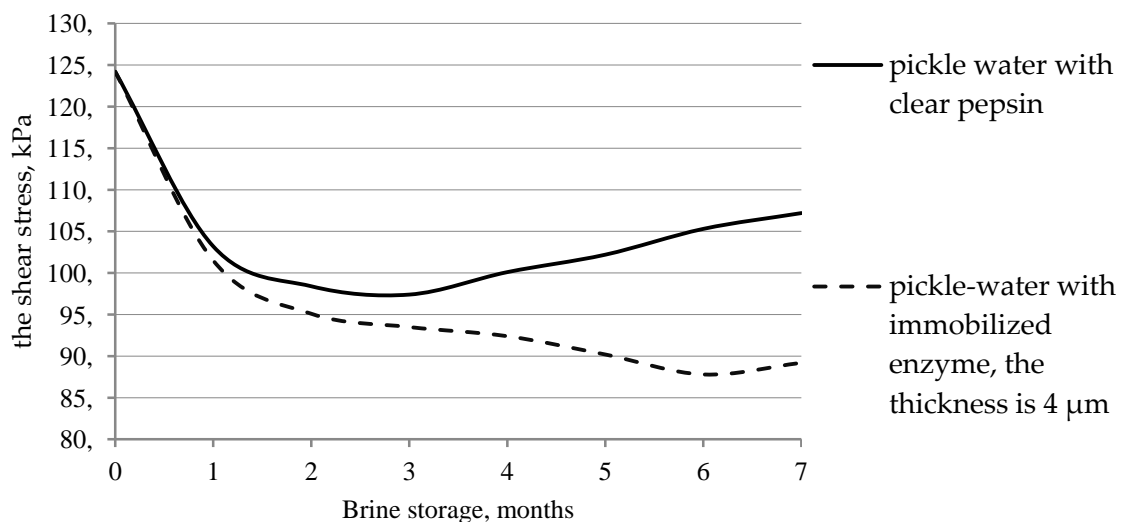


Figure 6 – The impact of the pepsin length of the storage on the structural-physical qualities of the ham pepsin (Row 1- pickle water with clear pepsin, Row 2- pickle-water with immobilized enzyme the thickness of the maltodextrin coating 4 μm)

It should be noted that within 1 month of storage, the proteolytic effect of pure and immobilized enzymes remained almost at the same level, as can be seen from the results of determining the stress value of the slice of ham. At the same time, pure pepsin noticeably lost its activity after 3 months and its proteolytic effect on the product was significantly reduced. This is evident by comparing the stress values of a slice of ham treated with an enzyme stored for up to 3 months and pure pepsin. At the same time, the immobilized enzyme did not lose its activity during 6 months of storage, which is evident from the

decrease in the voltage value of the ham cut. These results indicate the protective action of maltodextrin, preventing the inactivation of pepsin.

In accordance with the experiments upshots there was a way of making pepsin enzyme immobilization based on the annexation of the maltodextrin to the inert matrix. The impact of the thickness of the maltodextrin coating on the enzyme activity was proven; also, it is shown that immobilization of the pepsin by maltodextrin pushed the maximum activity roughly for 2 units in the alkali direction.

It was also proven that the conservation of the immobilized enzyme under the temperature 0-2 °C saved its proteolytic activity 2 times better compared with the clear enzyme.

Conclusion. As a result of the present research the technology for microencapsulation of proteolytic enzymes in a pseudo-boiling layer was developed and it was established:

- the efficiency of the developed microencapsulation technology is ensured by the diffusion of maltodextrin into the enzyme which allows to maintain high long-term activity of the enzyme in meat products;

- maltodextrin provides high hardness of the walls of the capsule during long-term storage the integrity is not broken;

- the maximum activity of pepsin immobilized in a maltodextrin solution, with an increase in the pH of the reaction medium, shifts to the alkaline side, which is not typical for a free enzyme;

- the results of determining the cutoff voltage of the ham confirm that the immobilized enzyme retains its activity for 6 months of storage. While pure pepsin after 3 months of storage had a less proteolytic effect, as evidenced by the magnitude of the shear stress of the finished product;

- Encapsulating the pepsin enzyme can be an effective way to ensure the quality of ham.

Bearing in mind the received outcomes, it is recommended the microencapsulation of the proteolytic pepsin enzyme with the use of maltodextrin with a coating thickness of 4 to 6 µm, which enables to broaden the usage of the immobilized enzymes during the production of meat products.

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ПРОТЕОЛИТТИК ФЕРМЕНТТЕРДІ ӨНЕРКӘСІПТЕ ҚОЛДАНУ ҮШІН МИКРОКАПСУЛДАУ

Андатпа. Мақала ферментке мальтодекстриннің диффузиясына негізделген жалған қайнататын қабатта протеолиттік ферменттерді микрокапсулдау технологиясын әзірлеу бойынша зерттеумен таныстырады, бұл ферменттің жоғары белсенділігін ет шикізатын ұзақ уақыт бойы сақтауға мүмкіндік береді. Микрокапсулдау келесі түрде жүргізілді: патрубқаға ферментпен сыйымдылық герметикалық қосылады және компрессордан ауа беріледі, ол түрлі диаметрлі ауысымды шүмектер арқылы өтіп, бастапқы бөлшектерді алады. Одан әрі турбуленттік ағындағы бөлшектер кептіріледі және фонтандау ағындары түрінде қайнаған қабаты бар аппарат корпусына түседі. Фермент бөлшектерінің диаметріне байланысты осы ағындардың жылдамдығын дұрыс таңдау тесіктердің қажетті диаметрі мен конустық корпусының өлшемі (биіктігі мен диаметрі) бар шайбалармен қамтамасыз етіледі. Бөліктерді патрубқада және аппараттың фонтандау ағынында алдын ала кептіргеннен кейін вентиль ашылады және ауа сұйық компоненттерге арналған ауыспалы шүмегі бар диспергаторға түседі. Шүмектің диаметрі корпусының түптік бөлігінің фонтандаушы ағындарына патрубок арқылы енгізілетін қажетті көлемдегі тамшылардың диспергирленуін қамтамасыз етеді. Тамшылар көлемі аппараттың фонтандау ағынындағы қатты бөлшектер порциясының жиынтық бетіне қарағанда тең немесе бірнеше үлкен сұйық компоненттер порциясының жиынтық бетін қамтуы тиіс. Ферментті тамшылап жабу үдерісі қарқынды және жылдам ағады. Ол фонтандау ағындары, ферменттің бөлшектерін шаятындықтан жабысқан тамшыларды кептірумен бірге жүреді. Сұйық компоненттердің барлық порциясы берілгеннен кейін вентиль жабылады. Кептіру ұзақтығы 5-8 минутты құрайды.

Эксперимент үшін пепсин ферменті таңдалды, қорғаныс қабаты ретінде 10% – мальтодекстриннің сулы ерітіндісі қолданылды. Қатты заттың сұйықтыққа (К/С) арақатынасы 10/1 ÷ 11,5/1 шегінде шыдады. Күйік түсіруші агент, оның ішінде кептіру режимінде бөлме температурасында аппарат арқылы сорылатын ауа болды.

Эксперимент үшін 2 мкм, 4 мкм және 6 мкм мальтодекстрин қабатының қалыңдығы бар капсулаланған ферменттердің бес эксперименталды өңделген үлгісі дайындалды. Бақылау ретінде таза капсулданбаған пепсин алынды. Пепсиннің белсенділігі казеин гидролизінің нәтижесінде пайда болатын тирозин саны бойынша 1,5-тен 5,0 бірлікке дейінгі рН диапазонында анықталды. Субстрат ретінде Гаммерстен бойынша казеин қолданылды. Тирозин мөлшері СФ-46 спектрофотометрінде толқын ұзындығы 280 нм болғанда спектрофотометриялық әдіспен анықталған. Өзірленген технология капсулалардың қорғаныш қабатының қалыңдығы түрлі микрокапсулаларды жасауға мүмкіндік береді. Бұл ретте, жағу ұзақтығына байланысты пепсин түйіршігіне мальтодекстрин ерітіндісін жағудың орташа қалыңдығының сызықтық тәуелділігі ($p \leq 0,05$) тәжірибелік жолмен анықталды. Мальтодекстрин капсула қабырғаларының жоғары беріктігін, ұзақ сақтау кезінде олардың тұтастығын қамтамасыз етеді. Мальтодекстрин қабатының қалыңдығы 4 мкм болатын пепсиннің белсенділігі мальтодекстрин қалыңдығы 6 мкм болатын пепсинге қарағанда шамалы төмен екені анықталды. Осыған байланысты 4 мкм-де мальтодекстриннің қорғаныс қабаты бар пепсинді қолданған жөн. Мальтодекстрин ерітіндісінде иммобилденген пепсиннің протеолитикалық ферментінің ең жоғары белсенділігі реакциялық ортаның рН жоғарылауы кезінде сілтілік жағына жылжиды, бұл еркін ферментке тән емес. Сонымен қатар, иммобилизацияланған фермент 6 ай сақтау кезінде өзінің белсенділігін жоғалтпады, бұл ветчина кесіндісінің кернеу мөлшерінің азаюынан көрінеді. Бұл деректер пепсиннің инактивациясына кедергі келтіретін мальтодекстриннің қорғаныш әсері туралы куәландырады және таза және иммобилизацияланған ферменттің белсенділігін анықтау нәтижелерін растайды. Иммобилизацияланған ферментті 0 – 2⁰С температурада сақтау өңделмеген ферментпен салыстырғанда оның протеолит белсенділігін 2 есе сақтауға мүмкіндік беретіні анықталды.

Алынған нәтижелерді ескере отырып, 4-тен 6 мкм-ге дейінгі жабын қалыңдығы кезінде мальтодекстринді пайдалана отырып пепсиннің протеолитикалық ферментін микрокапсулдауды ұсынуға болады, бұл ет өнімдерін өндіру кезінде ферменттерді пайдалану мүмкіндігін кеңейтуге мүмкіндік береді.

Түйін сөздер: микрокапсулдау, пепсин, белсенділік, жұмсарту, сан еті, ветчина өнімдері.

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МИКРОКАПСУЛИРОВАНИЕ ПРОТЕОЛИТИЧЕСКИХ ФЕРМЕНТОВ ДЛЯ ПРОМЫШЛЕННОГО ПРИМЕНЕНИЯ

Аннотация. Статья знакомит с исследованием по разработке технологии микрокапсулирования протеолитических ферментов в псевдокипящем слое, которая основана на диффузии мальтодекстрина в фермент, что позволяет сохранить высокую активность фермента в течение длительного времени в мясном сырье. Микрокапсулирование проводилось следующим образом: к патрубку герметично подсоединяется емкость с ферментом и подается воздух из компрессора, который проходя через сменные сопла различных диаметров, забирает исходные частицы. Далее частицы в турбулентном потоке подсушиваются и поступают в корпус аппарата с псевдооживленным слоем в виде фонтанирующих потоков. Правильный подбор скоростей этих потоков в зависимости от диаметра частиц фермента обеспечивается шайбами с необходимым диаметром отверстий и размером конического корпуса (высота и диаметр). После предварительной подсушки частиц в трубке и в фонтанирующих потоках аппарата открывается вентиль, и воздух поступает в диспергатор со сменным соплом для жидких компонентов. Диаметр сопла обеспечивает диспергирование капель необходимых размеров, которые через патрубок вводятся в фонтанирующие потоки донной части корпуса. Размер капель должен создать суммарную поверхность порции жидких компонентов, равную или несколько большую, чем суммарная поверхность порции твердых частиц в фонтанирующих потоках аппарата. Процесс покрытия фермента каплями интенсивен и скоротечен. Он сопровождается началом сушки прилипших капель за счет фонтанирующих потоков, омывающих частицы фермента со всех

сторон. После выдачи всей порции жидких компонентов вентиль закрывают. Продолжительность сушки составляет 5-8 минут.

Для эксперимента был выбран фермент пепсин, в качестве защитного слоя использовали 10% - водный раствор мальтодекстрина. Соотношение твердого вещества к жидкому (Т/Ж) выдерживали в пределах 10/1 ÷ 11,5/1. Ожижающим агентом, в том числе и в режиме сушки, был воздух с комнатной температурой, прокачиваемый через аппарат.

Для эксперимента приготавливали пять экспериментальных отшлифованных образцов капсулированных ферментов с толщиной слоя мальтодекстрина 2 мкм, 4 мкм и 6 мкм. В качестве контроля был взят чистый некапсулированный пепсин. Активность пепсина определяли в диапазоне рН от 1,5 до 5,0 ед. по количеству тирозина, образующегося в результате гидролиза казеина. В качестве субстрата использовали казеин по Гаммерстену. Количество тирозина определяли спектрофотометрическим методом при длине волны 280 нм на спектрофотометре СФ-46.

Разработанная технология позволяет изготавливать микрокапсулы с различной толщиной защитного слоя капсул. При этом, опытным путем выявлена линейная зависимость ($p \leq 0,05$) средней толщины нанесения раствора мальтодекстрина на гранулу пепсина в зависимости от продолжительности нанесения.

Установлено, что мальтодекстрин обеспечивает высокую прочность стенок капсулы, их целостность при длительном хранении. Было выявлено, что активность пепсина с толщиной слоя мальтодекстрина 4 мкм незначительно ниже, чем у пепсина с толщиной мальтодекстрина 6 мкм. В связи с этим целесообразно использовать пепсин с защитным слоем мальтодекстрина в 4 мкм. Показано, что максимальная активность протеолитического фермента пепсина, иммобилизованного в растворе мальтодекстрина, при повышении рН реакционной среды сдвигается в щелочную сторону, что нехарактерно для свободного фермента. В то же время иммобилизованный фермент не терял своей активности в течение 6 месяцев хранения, что видно по уменьшению величины напряжения среза ветчины. Эти данные свидетельствуют о защитном действии мальтодекстрина, препятствующем инактивации пепсина и подтверждают результаты определения активности чистого и иммобилизованного фермента. Установлено, что хранение иммобилизованного фермента при температуре 0 - 2 °С позволяет сохранять его протеолитическую активность по сравнению с необработанным ферментом практически в 2 раза.

Учитывая полученные результаты, можно рекомендовать микрокапсулирование протеолитического фермента пепсина с использованием мальтодекстрина при толщине покрытия от 4 до 6 мкм, что позволит расширить возможности использования ферментов при производстве мясных продуктов.

Ключевые слова: микрокапсулирование, пепсин, активность, мячение, окорок, ветчинные продукты.

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**THE «ACTIVATION-LULL» METHOD
FOR MEDIUM-STRENGTH EARTHQUAKES**

Abstract. The analysis of the spatio-temporal patterns of the distribution of medium-strength earthquakes ($K \geq 9.6$) was carried out in order to determine the possibility of using them for the medium-term forecast for 2020. The territory of the Eastern Tien Shan and Dzungaria, encompassed by coordinates $41^{\circ}40' - 45^{\circ}30'$ of the north latitude and $74^{\circ}00' - 81^{\circ}00'$ of the east longitude, was adopted as a test site. The catalog of earthquakes with energy class $K \geq 9.6$ ($M \geq 4.2$) for 1951-2019 and strong earthquakes with $M \geq 5.6-6.0$ (total 16) that occurred during the indicated period was used. Based on a retrospective analysis of the time course of the annual values of the number of earthquakes (parameter N is the number of medium-strength earthquakes with $K \geq 9.6$), determined for the whole observation period with a shift of 3 months, anomalous changes in its behavior were revealed consisting in a successive alternation of activation periods ($N > N_{cr} = N_{av} \pm \sigma$), i.e. the parameter N exceeds certain critical level of N_{cr} and lull ($N < N_{cr}$), which are associated with the times of occurrence of strong earthquakes in the study area.

The fact of the existence of the “activation-lull” process for medium-sized earthquakes during periods of preparation of strong earthquakes is described in many studies on the theory of preparation and practice of forecasting and is used to predict strong earthquakes for various seismically active regions of Eurasia. According to studies, the distribution area of various precursors is so wide in size that it suggests the participation of large areas in the preparation of strong earthquakes.

A juxtaposition of the anomalous periods with the times of occurrence of strong earthquakes indicates the existence of a fairly close relationship between them. Indeed, before fourteen earthquakes out of 16 there was an anomalous lull in the number of earthquakes of medium strength, which is observed after activation. Three false alarms also occurred.

As a result of the study, 3 sites were identified, within or in the immediate vicinity of which earthquakes with $M \geq 5.6-6.0$ in the next one to two years are likely to occur.

Key words: catalog, medium-strength earthquakes, activation, lull, precursor, anomalous period, medium-term forecast.

In the article, the regularities (patterns) of the seismic mode of medium-strength earthquakes with $K \geq 9.6$ are investigated in order to clarify the possibility of using them for a medium-term forecast, which is understood as an assessment of the tendency of the seismic process for the next 1-2 years.

Many studies on the theory of preparation and practice of forecasting indicate the existence of a lull on the earthquakes of medium strength during the preparation of a strong event [1-4]. In [5-14], questions of using this pattern for forecasting purposes for various seismically active regions of Eurasia were considered. According to studies [4,13–16], the distribution area of various precursors is so large that it suggests the involvement of large territories in the preparation of strong earthquakes.

The territory of the Eastern Tien Shan and Dzhungaria, bounded by the coordinates of $41^{\circ}40' - 45^{\circ}30'$ North latitude, $74^{\circ}00' - 81^{\circ}00'$ East longitude, is accepted as the test site. We analyzed earthquakes with an energy class $K \geq 9.6$ (without aftershocks) that occurred on the specified territory in 1951-2019. Figure 1 shows a time series of annual values of the number of earthquakes (N) with $K \geq 9.6$, determined in increments of $\Delta t = 3$ months, the data of which indicates the variability of the studied parameter over time.

The selection of abnormal periods of parameter N was performed by calculating errors in its definition. The calculation is based on the most homogeneous material since 1961 with the exception of intense aftershock sequences. The average annual value of N_{cp} was equal to 21 with a standard deviation of $\sigma = \pm 5.1$. The anomaly was considered to be a parameter value that goes beyond the corridor $-\sigma$ with a confidence probability of 0.7 (the critical level).

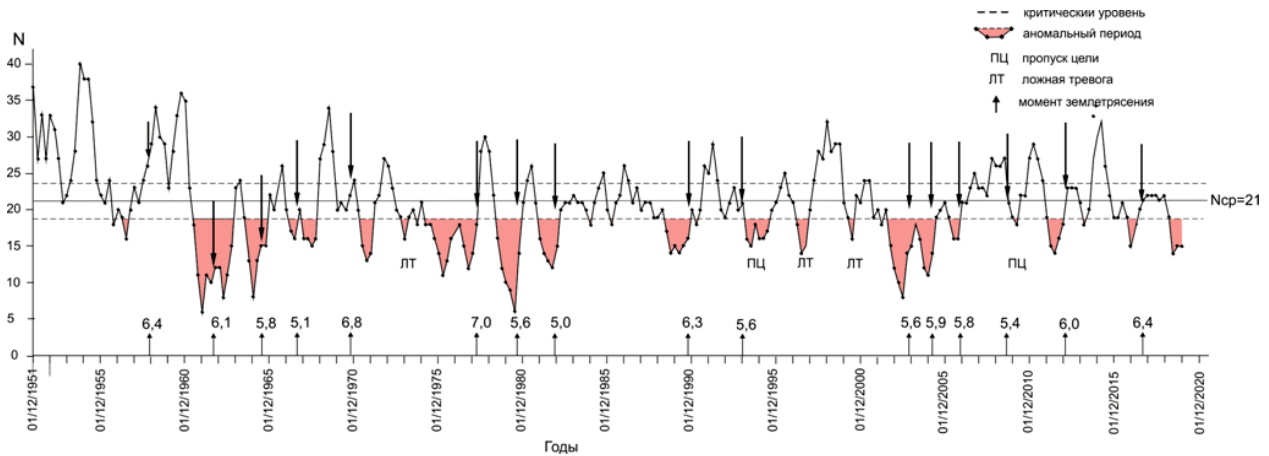


Figure 1 – Diagram of changes in the annual number of the earthquakes of medium strength ($K \geq 9.6$) in the territory of the Eastern Tien Shan and Dzhungaria

Strong earthquakes with $K \geq 15$ ($M \geq 5.8-6.0$) for 1951-2019 were studied, which occurred within the study area or in the immediate vicinity of it (no more than 30-40 km from its external borders). Also, the analysis involved earthquakes with $K = 14$ that occurred in the central part of the territory (figure 2). At the same time, if several strong earthquakes occurred in a short period of time (no more than a year), they were considered as a single event regardless of the epicentral distances. Such groups took place during the time periods from 12.1958 to 11.1959 (3 earthquakes), from 02.1969 to 06.1970 (2 earthquakes), and from 09.1979 to 07.1980 (2 earthquakes). Taking into account these circumstances, in the territory under consideration for the period of 1951-2019, a total of 16 strong earthquakes occurred (table 1), the time of their occurrence is shown by arrows (figure 1).

Table 1 – List of the earthquakes with $K \geq 14$ ($M \geq 5.4$) for the period of 1951-2018 that occurred within the study area or in the immediate vicinity of it

Earthquake name, year	Month	Day	Hour	Min	Sec	Latitude	Longitude	Depth	Energy class	M_s
1 Dzhungarian, 1958	12	21	5	46	29,0	44°48	80° 36	25	16,0	6,4
2 Dzhungarian, 1962	8	19	18	26	38,0	44° 46	81° 16	25	15,0	6,1
3 Kokshaal, 1965	5	4	8	34	41,6	41° 44	79° 15	23	15,0	5,8
4 Saryjaz, 1967	8	20	2	2	5,0	45° 11	80° 00	18	13,8	5,3
5 Kokshaal, 1969	2	11	22	8	52,6	41° 30	79° 18	25	15,0	6,6
6 Sarykamys, 1970	6	5	4	53	6,2	42° 28	78° 48	15	15,6	6,8
7 Zhalanash-Tyup, 1978	3	24	21	5	48,6	42° 52	78° 35	20	16,0	7,0
8 Bakanas, 1979	9	25	13	5	55,0	45° 00	77° 00	40	14,0	5,8
9 Kajisay, 1980	7	5	20	25	22,0	41° 46	77° 30	20	13,6	5,6
10 Novogodneye, 1982	12	31	19	46	46,4	42° 52	77° 22	18	13,7	5,6
11 Baysorunskoe, 1990	11	12	12	28	51,4	42° 56	77° 56	18	14,6	6,3
12 Tekeli-1, 1993	12	30	14	24	6,4	44° 49	78° 46	20	15,0	5,6
13 Syumbinskoe, 2003	12	1	1	38	32,6	42° 55	80° 33	-1	14,3	5,6
14 Kokshaal, 2005	2	14	23	38	9,5	41° 48	79° 11	5	14,3	5,9
15 Tekeli -2, 2009	6	13	17	17	37,9	44° 46	78° 49	15	13,8	5,4
16 Saryjaz, 2013	1	28	16	38	52,4	42° 31	79° 40	10	14,7	6,0

A comparison of the anomalous periods with the moments of the occurrence of strong earthquakes indicates the existence of a fairly close relationship between them. Indeed, before the fourteen earthquakes out of 16 there is an anomalous lull in the number of weak events that is observed after activation. It should be noted that the Tekeli earthquakes of 1993 ($K = 15$, $M = 5.6$) and 2009 ($K = 14$, $M = 5.4$) are poorly diagnosed and are marked as “missed targets” on the diagram, although a decrease in the number of earthquakes of medium strength is noted in front of them. There are also so called “false alarms”.

The duration of the precursors was determined both from the moment of transition of the critical level and from the minimum value of the parameter. So, for the Baysorun earthquake of 1990 with $M = 6.3$, the duration of the precursor from the moment of transition of the critical level was 15 months, and from the minimum value of the parameter was 12 months.

A precursor is considered informative if $P > P_0$ according to [17], where P_0 is determined by the random forecast. Tabular values of P_0 at a confidence level of 0.975 for various values of the input parameters were carried out in [13,17]. According to [18], the forecast is statistically significantly different from random guessing if the value is $J \geq 2.0$, and according to [19] the precursor is considered useful if $q > 0.1-0.2$ and very useful if $q > 0.3-0.5$ ($n > 10-15$).

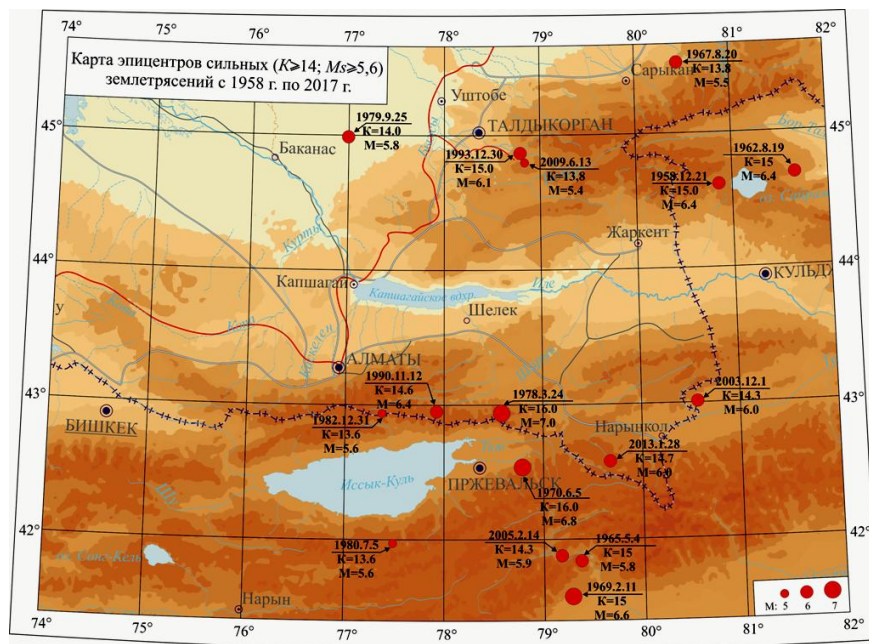


Figure 2 – Map of the epicenters of strong earthquakes for the period 1958-2019

A retrospective analysis of the diagram of changes in the annual numbers of medium-strength earthquakes ($K \geq 9.6$) on the territory of the Eastern Tien Shan and Dzhungaria allowed us to obtain the values of the informativeness coefficients of the method: $P = 0.58$ ($P_0 = 0.36$), $J = 3.44$, $q = 0.66$. In the calculations, the precursor duration, determined from the moment of transition of the critical level ($N_{cp} - \sigma$), was used as the most reliable.

Thus, the obtained data indicate that the coincidence of the time of occurrence of the considered strong earthquakes with the anomalous periods of the parameter N is not accidental.

To estimate the magnitude of the expected earthquake, we can use a generalized "image" of the behavior of the parameter under consideration for two magnitude groups (figures 3a, 3б), which is obtained by combining and averaging data for each earthquake depending on their magnitude [13].

As can be seen from figures 3a, 3б, the type of averaged time course of the parameter N for the considered magnitude groups is quite clearly different: for the magnitude group $M = 5,6-6,1$, it is shorter in time, and the level decrease occurs more sharply than for earthquakes with $M = 6,3-6,8$. To estimate the magnitude of the expected event, we can also use the dependence of the duration of the alarm time on the magnitude of the predicted earthquakes in accordance with the data in table 1 (figure 3в).

The dependence of the duration of the anomalous period (ΔT) on magnitude (M), for two options for determining the duration of the first, has the form:

$$\lg \Delta T (\text{month}) = 0,55M - 2,3 - \text{from the moment the parameter } N \text{ exceeds the critical level;}$$

$$\lg \Delta T (\text{month}) = 0,62M - 2,83 - \text{from the minimum value of the parameter } N.$$

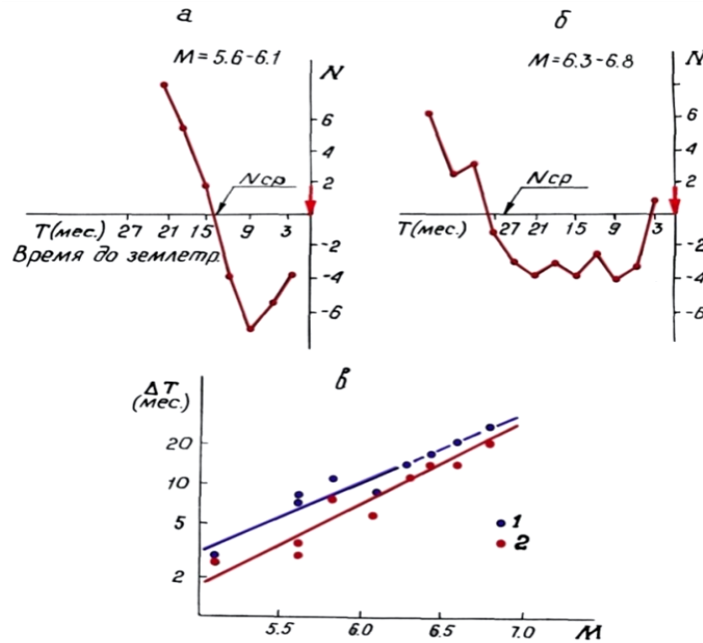


Figure 3 – The generalized time course of the number of earthquakes of medium strength for various magnitude groups (a, б) and the dependence of the duration of the anomalous period on the magnitude of earthquakes (в) [13]. 1 - from the moment of transition of the critical level; 2 - from the minimum value of the parameter N

An analysis of the maps of earthquake epicenters shows that in areas of future foci there is a complete lull ($N = 0$), or the number of earthquakes decreases sharply here. For less strong earthquakes ($K = 14$), such a pattern was not found. Thus, it can be stated that, according to the forecast of the place of occurrence of the earthquake, there is some uncertainty that can be overcome by using other methods. The graph (figure 1) shows that since the end of 2018, there has been a decrease in the parameter N - the number of the earthquakes of medium strength from $K \geq 9.6$ in the study area.

If we consider the seismic process in the near ($R \approx 100-150$ km) and far ($R \approx 150$ km) zones from the source of the future earthquake, then it proceeds differently. So, for 3-5 years before the earthquake in the near zone, activation prevails, and in the far zone lull prevails, and 1-2 years before the shock, the opposite picture is observed. This is clearly demonstrated in Figure 4, which shows the time diagram of the ratio of the number of earthquakes from $K \geq 9.6$ in the far zone ($N1$) to the near zone ($N2$). The area with coordinates $41^{\circ}50' - 43^{\circ}30'$ North latitude and $76^{\circ}30' - 79^{\circ}30'$ East latitude was considered as the near zone, within which the epicenters of strong earthquakes (1970, 1978, 1980, 1982 and 1990) occurred. The graph (figure 4) shows that before all the above-mentioned earthquakes, there is first a drop and then a sharp increase in the parameter $N1/N2$, which, in the vast majority of cases, goes beyond the confidence interval with a width of ± 1.6 at a probability level of 0.7. Note that very low values of $N1/N2$, which are observed immediately after strong earthquakes, are associated with their aftershocks.

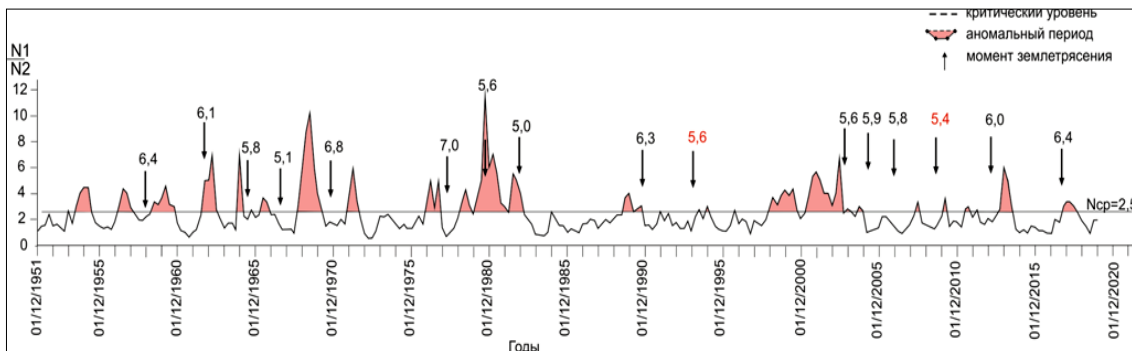


Figure 4 – Diagram of the time course of parameter $N1/N2$

To assess the places of possible occurrence of the expected earthquake, a search was conducted for areas within which the pattern of activation and lull in the number of medium-strength earthquakes is very clear. For this purpose, maps of earthquake epicenters were compared for two periods: for the activation period of 06.2014 - 06.2016, which, according to the data in figure 1, precedes the period of lull, and that for the anomalous period from 06.2016 to 05.2017.

Figure 5 shows that the seismic process under consideration ('activation-lull') occurred in three regions: in the central part of the Zailiysky and Kungei Alatau ridges, South-East of lake Issyk-Kul and in Dzhungaria.

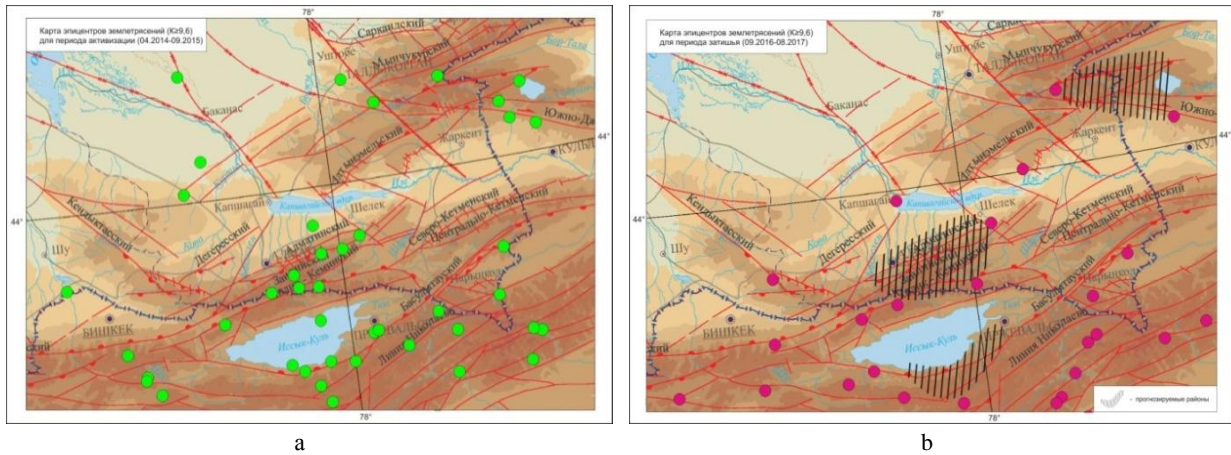


Figure 5 – Maps of earthquake epicenters with $K \geq 9.6$: (a) - for the activation period (06.2014 - 06.2016); (b) - for the lull period (06.2016 - 05.2017)

On August 8, 2017, an earthquake with $M = 6.4$ occurred on the territory of the Xinjiang Uygur Autonomous Region of China (the Dzhungarian section), and a significant number of less severe events ($K = 9.6 - 11.6$) in 2018 occurred on the other two sections (figure 6).

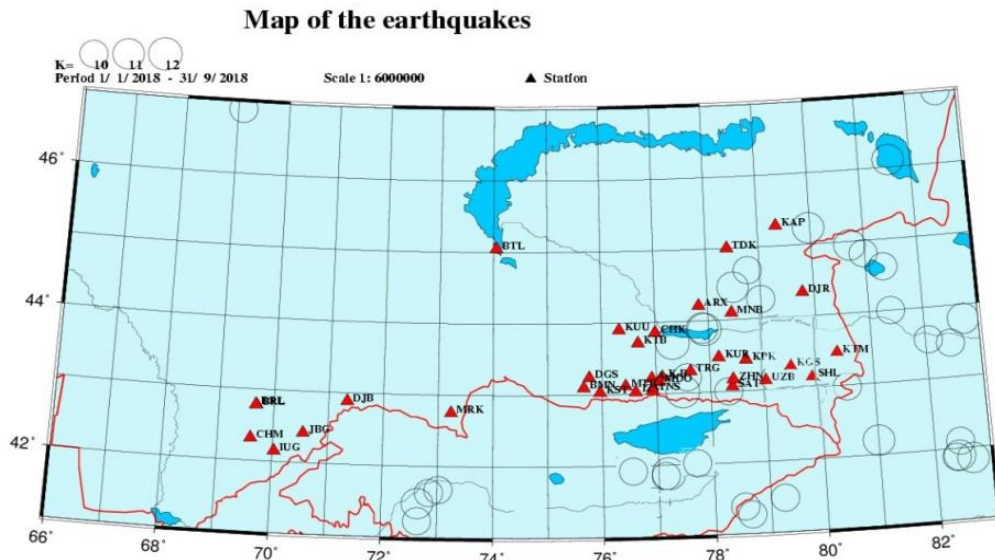


Figure 6 – Map of earthquake epicenters with $K \geq 9.6$ on the territory of South-East Kazakhstan and in its immediate vicinity for 2018

It should be noted that the graph of parameter N in 2019 begins to form a period of lull, which requires close attention to the further development of the time variation of parameters N and $N1/N2$.

The results obtained suggest that the proposed approach in combination with other methods can be used in the practice of medium-term forecasting of strong earthquakes in the Eastern Tien Shan and Dzhungaria regions.

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ОРТА КҮШТІ ЖЕРСІЛКІНІСТЕР БОЙЫНША «БЕЛСЕНДІЛІК-БӘСЕНДІК» ӘДІСІ

Аннотация. 2020 жылдың орта мерзімді болжамын анықтауға қолдану үшін орта күші ($K \geq 9,6$) бар жер сілкінісінің кеңістік-уақыт заңдылығымен таралу жағдайына талдау жүргізілді. Тәжірибелік полигон ретінде Шығыс Тянь-Шань және Жоңғар аймағының солтүстік ендігі $41^{\circ}40' - 45^{\circ}30'$, шығыс бойлығы $74^{\circ}00' - 81^{\circ}00'$ координаттарымен шектелген аудан қарастырылды. 1951-2018 жылдар аралығында магнитудасы $M \geq 5,6-6,0$ (барлығы 16) және энергетикалық класы $K \geq 9,6$ ($M \geq 4,2$) болатын жерсілкініс каталогы қолданылды. Ретроспектр талдау негізінде барлық бақыланып отырған жылдарда жер сілкінісі санының жылдық мәнінің (N параметрі – орта күшті жер сілкіністер саны) 3 ай сайын уақыттық жылжудан белсенділік кезеңінің ($N > N_{кр} = N_{ср} \pm \sigma$) алмасуын көрсететін уақыттық жылжуы кезінде ауытқу өзгерістері байқалды, яғни N параметрінің кейбір критикалық деңгейі $N_{кр}$ жоғарылауы және бәсеңдеуі ($N < N_{кр}$) зерттеліп отырған аудандағы жер сілкінісінің болатын уақытымен байланысты.

Орта күшті жер сілкіністер бойынша жойқын зілзалаға дайындық кезеңі «белсенділік-бәсеңділік» үдерісінің болу фактісі жер сілкінісін болжау тәжірибесінде және жер сілкінісіне дайындық теориясына арналған көптеген зерттеулерде байқалады және Еуразияның түрлі сейсмобелсенді аудандарының күшті жер сілкіністерін болжау үшін пайдаланылады. Зерттеулерге сәйкес, түрлі алғышарттардың таралу ауқымы жағынан аса жоғары болуынан жойқын сілкініске дайындық көлемді территория алатыны байқалды.

Қатты жер сілкінісінің өту және ауытқу кезеңін салыстыру арқылы олардың арасында тығыз байланыс бар екені байқалды, шын мәнінде, 16 жер сілкінісінің ішіндегі он төрт жер сілкінісінің алдында белсенділіктен кейін байқалатын орташа күшті жер сілкініс санының бәсеңділік ауытқуы байқалды. Сондай-ақ қатты жер сілкіністің өту және ауытқу кезеңдері сәйкес келмейтін үш жалған орын бар.

Бір-екі жылға жуық аралықта жер сілкіну магнитудасы $M \geq 5,6-6,0$ болуы ықтимал аумақтар, яғни тікелей жақын немесе зерттеліп отырған аудан шегінде орналасқан 3 аумақ көрсетілді.

Түйін сөздер: каталог, орта күшті жер сілкінісі, белсенділік, бәсеңділік, алғышарттар, ауытқу кезеңі, орта мерзімді болжам.

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МЕТОД «АКТИВИЗАЦИЯ-ЗАТИШЬЕ» ПО ЗЕМЛЕТРЯСЕНИЯМ СРЕДНЕЙ СИЛЫ

Аннотация. Проведен анализ пространственно-временных закономерностей распределения землетрясений средней силы ($K \geq 9,6$) с целью выяснения возможности применения их для среднесрочного прогноза на 2020 год. В качестве опытного полигона принята территория Восточного Тянь-Шаня и Джунгарии, ограниченная координатами $41^{\circ}40' - 45^{\circ}30'$ северной широты, $74^{\circ}00' - 81^{\circ}00'$ восточной долготы. Использован каталог землетрясений с энергетическим классом $K \geq 9,6$ ($M \geq 4,2$) за 1951-2019 гг. и сильные землетрясения с $M \geq 5,6-6,0$ (всего 16), произошедшие за указанный период. На основе ретроспективного анализа временного хода годовых значений количества землетрясений (параметра N – количество землетрясений средней силы с $K \geq 9,6$), определенных для всего периода наблюдений со сдвигом в 3 месяца, выявлены аномальные изменения в его поведении, заключающиеся в последовательном чередовании периодов активизации ($N > N_{кр} = N_{ср} \pm \sigma$), т.е. превышения параметром N некоторого критического уровня $N_{кр}$, и затишья ($N < N_{кр}$), которые связаны с моментами возникновения сильных землетрясений на исследуемой территории.

Факт существования процесса «активизация-затишье» по землетрясениям средней силы в периоды подготовки сильных землетрясений отмечается во многих исследованиях, посвященных теории подготовки и практике прогноза, и используется для целей прогнозирования сильных землетрясений для различных сейсмоактивных районов Евразии. Согласно исследованиям, площадь распределения различных предвестников столь велика по размерам, что позволяет предполагать участие крупных территорий в подготовке сильных землетрясений.

Сопоставление аномальных периодов с моментами возникновения сильных землетрясений свидетельствует о существовании достаточно тесной связи между ними, действительно, перед четырнадцатью землетря-

сениями из 16 имеет место аномальное затишье числа землетрясений средней силы, которое наблюдается после активизации. Также имеют место три ложные тревоги.

В результате проведенного исследования выделено 3 участка, в пределах или в непосредственной близости от которых вероятны возникновения землетрясений с $M \geq 5,6-6,0$ в ближайшие один-два года.

Ключевые слова: каталог, землетрясения средней силы, активизация, затишье, предвестник, аномальный период, среднесрочный прогноз.

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**EFFECT OF 3d-METAL SALTS ON THE ACTIVITY
OF ECOPHOSPHATE SLAG BINDING AGENTS**

Abstract. It has been established that: 3d-metals of a number of manganese are effective at low doses (2 ... 4% by weight), over which the strength of slag stone decreases - the higher the dose, the more the strength decreases; cations $3d^{5-8}$ of which are capable of receiving electrons, effectively activate HFS, while the strength of slag (cement) stone with an addition of 2 ... 4% reaches 61 ... 97 MPa; moreover, manganese salts possess the highest strength, characterized by increased electron-acceptor properties (72 ... 97 MPa), the least - nickel salts (60 ... 72 MPa); with cations of copper ($3d^9$) and zinc ($3d^{10}$) extremely negatively affect the hardening of slag stone (21 ... 40 MPa); with cations whose hydrates have a spatial octahedral configuration, they effectively activate HFS; if cation hydrates have a distorted octahedral or tetrahedral configuration, then they adversely affect the hardening of slag (cement) stone.

Considering that the main elements of tobermorite gel and CSH (I) are Ca^{2+} , SiO_4^{4-} и OH^- (H_2O), ions, we can assume that: cations of 3d metal salts in the structure of calcium hydrosilicates replace Ca^{2+} ions according to the scheme $Me^{2+} \uparrow \downarrow Ca^{2+}$; in addition, impurity ions (Me^{2+}) in calcium hydrosilicates can be located outside structural bonds — in voids; ions SO_4^{2-} in hydrated phases can replace silicon-oxygen radicals according to the scheme $SO_4^{2-} \uparrow \downarrow SiO_4^{4-}$; the ions SO_4^{2-} replacing groups $Si_xO_y^{2-}$ in the structure of calcium hydrosilicates cannot create a continuous series in them; the ions Cl^- in the structure of calcium hydrosilicates can occupy three positions: to replace O^{2-} , OH^- and to be in voids.

Key words: Granulated phosphate slag, chlorides and sulfates of 3d transition metals, cations, electrons, acceptors, donors, strength, stone, calcium silicate hydrates.

Introduction. Works [1–4] show that the most effective way to neutralize granulated phosphate slag (hereinafter - GPS) from harmful gases (PH_3 , H_2S , HF, etc.) and their sources are compounds of some transition 3d metals (Mn, Cu and Fe). Besides, we suggested that: the aforementioned oxides not only neutralize GPS, but can also activate it; the neutralizing activating ability of Mn, Cu, and Fe oxides is associated with the presence of electron-free orbitals on the 3d-sublevel of these elements.

Based on the above considerations, we can assume the following: the third-row elements from Cr to Zn, as well as their salts, can also have both neutralizing and activating GPS properties; the degree of their activity should be related to the number of electrons in 3d orbitals - the less electrons in them, the greater their activity as a neutralizer and activator.

It is known that the influence of the electron content in the 3d-sublevel of transition metals on cement activity was studied in [5–7]. Analyzing the results obtained, it can be stated that metal additives with electronic configuration d^{10} have an adverse effect on the strength of the hardening cement paste, and with configuration d^{2-8} , vice versa, they increase the strength of the cement stone compared to the strength of the control samples.

The adverse effect of d^{10} elements is due to the fact that their electrons, like donors, stop the movement of protons and neutralize active centers of the surface of cement particles, therefore its activity decreases or disappears. Since d^{2-8} elements, as acceptors, take electrons to empty orbitals from the surface of clinker minerals, they help increase the activation of the latter, and thereby increase the strength of the cement stone.

However, it should be noted that cement itself does not need to increase its activity by injecting such expensive additives - there are cheaper and more effective methods for this.

To neutralize harmful gases and their sources that are part of GPS, the relevant neutralizer is a vital measure, since it is associated with the social-environmental and environmental-economic direction of the southern regions of Kazakhstan, and more.

Research methodology. Chlorides and sulfates of a number of manganese were used as a GPS neutralizer, since they, as salts of strong acids, dissolve well in water, dissociating according to the scheme: $\text{MeX} \rightarrow \text{Me}^{2+} + \text{X}^{\text{II}}$, where Me – 3d-metal cation, X^{II} - SO_4^{2-} and Cl^- .

An ecophosphate slag binding agent was prepared with the addition of these salts using the wet method. GPS grinding with the addition of 2...8 % salts of 3d-metals was carried out in a vibratory mill to a specific surface of 500 m²/kg without activating alkaline components in order to establish the degree of activating ability of these salts depending on the number of electrons on the 3d-sublevel. 2x2x2 cm samples were prepared from the test, which were then autoclaved at 180 °C according to the 2+8+2 hr mode and tested for compressive strength.

Results and discussion. It is established that: 3d-metals of a number of manganese are effective at low doses (2...4 % by weight), over which the slag stone strength decreases - the higher the dose, the more the strength decreases; cations 3d⁵⁻⁸ which are capable of receiving electrons, effectively activate GPS, while the strength of slag (cement) stone with an additive of 2...4 % reaches 61...97 MPa; moreover, manganese salts have the highest strength, characterized by increased electron-accepting properties (72...97 MPa), the least - nickel salts (60...72 MPa); with cations of copper (3d⁹) and zinc (3d¹⁰) have an extremely adverse effect on slag stone hardening (21...40 MPa); with cations whose hydrates have a space octahedral configuration, they effectively activate GPS; if cation hydrates have a distorted octahedral or tetrahedral configuration, then they adversely affect the hardening of slag (cement) stone.

Moreover, the increased activating ability of 3d⁵⁻⁸ cations (elements) compared to 3d¹⁰ cations (elements) is explained by the resulting action of the following three factors:

1. In the presence of cations (elements) of 3d⁵⁻⁸-metals, the basicity of the hardening system increases to a greater extent as a result of an increase in the content in the liquid phase of hydroxide groups (OH⁻) accelerating its hydration and hardening;

2. Cations (elements) of 3d⁵⁻⁸-metals with electron-accepting properties attract electrons from the structure (bond) of portland cement and slag, as a result of which these bonds are lengthened (stretched); this contributes to an increase in the coordination number of silicon and the formation of intermediate unstable complexes, which favorably affects the hydration and hardening of hardening systems;

3. By creating $\equiv\text{Si-O-Me}^+$ bonds, cations (elements) of 3d⁵⁻⁸-metals interfere with the polymerization of silicon-oxygen anions to form calcium hydrosilicate nuclei, which increases the activity of the base portland cement and slag binders.

Thus: any additives that are electron acceptors activate portland cement and slag binders; if they are electron donors, then such additives can be inhibitors of hydration and hardening of hardening systems; initially, clinker minerals of portland cement (C₃S, β-C₂S, C₃A, C₄AF, etc.) and vitreous components of granulated slag have electrodonor properties, and the aqueous medium with which they are mixed during hydration and hardening must have electron-accepting properties in order to pull donor electrons from these minerals and glass; this is how hydration processes occur, followed by the transformation of the hardening system into stone.

The results obtained show that: with such a quantity, these additives in the hardening system do not remain in a free state and do not form independent compounds (both adversely affect the properties of cement stone, concrete and products), and will be included in the structure of tobermorite gel (C-S-H) and submicrocrystalline CSH (I); the endoeffect in the thermogram of the tobermorite gel that arose in the reference sample is recorded at 120 °C [8], and in the slag stone - at 140...260°C; the X-ray pattern of the reference sample contains CSH (I) diffraction maxima with interplanar spacings $d = 3.07; 2.8$ and 1.83 \AA [8], and on the X-ray pattern of slag stone, reflections of this phase appear at $\text{\AA}: 3,00...3,12; 2,80...2,82$ and $1,80...1,85$.

Moreover: the endoeffect of the tobermorite gel on DTA shifts toward higher temperatures, which is due to the entry of ions of 3d-metal salts into its structure; in this case, impurity ions positively affect the

state of tobermorite gel, as a result of which its effect appears at elevated temperatures; the exo-effect of CSH (I) on XRF shifts toward lower and higher temperatures compared to the exo-effect of the reference sample; this indicates a weakening of its structure in the first case and strengthening in the second case when ions of 3d-metal salts enter it; the entry of ions of 3d-metal salts into the CSH (I) structure shows both the expansion and the narrowing of interplanar spacings in the area of analytical line 3.03 Å in the X-ray pattern; moreover, impurity ions are more localized on the (220) CSH (I) plane than on the (400) and (040) planes.

Considering that the main elements of tobermorite gel and CSH (I) are Ca^{2+} , SiO_4^{4-} and OH^- (H_2O) ions, we can assume that: cations of 3d-metal salts in the calcium silicate hydrate structure replace Ca^{2+} ions according to the $\text{Me}^{2+} \uparrow \downarrow \text{Ca}^{2+}$ scheme; in addition, impurity ions (Me^{2+}) in calcium silicate hydrates can be located outside structural bonds — in voids; SO_4^{2-} ions in hydrated phases can replace silicon-oxygen radicals according to the $\text{SO}_4^{2-} \uparrow \downarrow \text{SiO}_4^{4-}$ scheme; while SO_4^{2-} ions replacing $\text{Si}_x\text{O}_y^{2-}$ groups in the calcium silicate hydrate structure cannot create a continuous series in them; this is due to the fact that SO_4^{2-} ions have an anisodesmic structure, and SiO_4^{4-} ions have a mesodesmic structure; in addition, in SO_4^{2-} ions, 2/3 of oxygen charge is associated with sulfur, while in SiO_4^{4-} ions only half of the oxygen charge is associated with silicon [9]; Cl^- ions in the calcium silicate hydrate structure can occupy three positions: replace O^{2-} , OH^- and be in voids.

Summary. 1. Sulphates and chlorides of 3d-metals of a number of manganese (metals themselves and their other compounds) used as neutralizing additives from harmful gases and their sources, that present in the composition of granulated phosphate slag, can simultaneously activate this slag.

1. The activating ability of 3d-metal compounds (including metals themselves) depends on the amount of electron-free 3d-orbitals. It is shown that cations (elements) of $3d^{5-8}$ -metals with electron-accepting properties activate mineral binders, while cations (elements) of $3d^{9-10}$ -metals, which have predominantly electron-donating properties, can be inhibitors of hydration of hardening systems.

2. With a small amount (2...4 %) neutralizing additives do not remain in a free state and do not form independent compounds, but enter into the structure of hydrated phases of hardening systems. At the same time, cations of neutralizing additives in the structure of calcium hydrosilicates can mainly replace Ca^{2+} , anions - silicon-oxygen radicals or hydroxide groups.

Confirmation. Scientific results were obtained within self-financing of TseLSIM LLP.

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3d-МЕТАЛЛ ТҰЗЫНЫҢ ЭКОФОСФОҚОЖ ТҮТҚЫР БЕЛСЕНДІЛІГІНЕ ӘСЕРІ

Аннотация. Зерттеу барысында мынадай үдерістер айқындалды: марганец қатарындағы аз мөлшердегі (2...4% салмақ) 3d-металдары тиімді болғандықтан қож тасының қаттылығы төмендейді, доза көп болған сайын беріктігі әлсірей түседі; $3d^{5-8}$ катиондары электрондарды қабылдауға қабілетті, ГФҚ тиімді белсендендіреді, бұл ретте 2...4%-ға қоса қож (цемент) тасының беріктігі 61...97 МПа жетеді; сонымен қатар, жоғары электронды-акцепторлық қасиеттер негізінде сипатталатын марганец тұздары аса берік келеді (72...97 МПа), ең азы – никель тұзы (60...72 МПа); мыс катиондары ($3d^9$) және мырыш ($3d^{10}$) қож тасының қатаюына теріс әсер береді (21...40 МПа); кеңістік октаэдрикалық конфигурациясы бар катион гидраттары ГФҚ тиімді белсендендіреді; егер катион гидраттары бұрмаланған октаэдрикалық немесе тетраэдрикалық конфигурацияға ие болса, онда олар қож (цемент) тастарының қаттылығына теріс әсер етеді.

Зерттеу барысында мына мәселелерді атап көрсеткен жөн: аз мөлшерде берік жүйедегі бұл қоспалар бос күйінде қалмаумен қатар, дербес қосылыс та құрмайды (осы және басқалары цемент тасы, бетон мен бұйым қасиеттеріне теріс әсер етеді) және тоберморитті гель (C-S-H) мен субмикрористал СҢН (I) құрылымына кіреді; эталон үлгісінде пайда болған тоберморитті гелдің термограммасында эндоэффект 120°C кезінде, ал

қож таста 140...260°C болғанда белгіленеді; эталонды үлгінің рентгенограммасында $d=3,07$ жазықаралық қашықтығы СҢН (I) дифракциялық максимумнан тұрады: 2,8 және 1,83Å, ал қож тастарының рентгенограммасында Å: 3,00...3,12; 2,80...2,82 и 1,80...1,85 кезінде осы фаза көріністері пайда болады.

Тоберморитті гель мен СҢН (I) негізгі элементтері Ca^{2+} , SiO_4^{4-} және OH^- (H_2O) ионы екенін ескере отырып, кальций гидросиликат құрылымындағы 3d-металл тұзының катионын Ca^{2+} иондарына $Me^{2+} \uparrow \downarrow Ca^{2+}$ схемасы бойынша алмастыруға болады; сонымен қатар, кальций гидростиликатындағы қоспалы иондар (Me^{2+}) құрылымдық байланыстан тыс – бос жерде мүмкін; гидратты фаздағы SO_4^{2-} иондар $SO_4^{2-} \uparrow \downarrow SiO_4^{4-}$ сызбасы бойынша кремний тотықты радикалдарды алмастыра алады; сонымен қатар SO_4^{2-} иондар кальций гидросиликат құрылымындағы $Si_xO_y^{2-}$ топқа орналасқанда үздіксіз қатар түзе алмайды; кальций гидросиликат құрылымындағы Cl^- иондар O^{2-} орын алмастыру, OH^- және бос қалу сынды үш позиция иеленуі мүмкін.

Түйін сөздер: Түйіршіктелген фосфор қожы, 3d-өтпелі металл хлориді мен сульфаты, катиондар, электрондар, акцепторлар, донорлар, беріктік, тас, кальций гидросиликаттары.

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ВЛИЯНИЕ СОЛЕЙ 3d-МЕТАЛЛОВ НА АКТИВНОСТЬ ЭКОФОСФОШЛАКОВЫХ ВЯЖУЩИХ

Аннотация. Установлено, что 3d-металлы ряда марганца эффективны при малых дозах (2...4 % по массе), сверх которых прочность шлакового камня снижается: чем больше доза, тем больше снижается прочность; катионы, $3d^{5-8}$ которых способны принимать электроны, эффективно активизируют ГФШ, при этом прочность шлакового (цементного) камня с добавкой 2...4 % достигает 61...97 МПа; причем наибольшей прочностью обладают марганцевые соли, характеризующиеся повышенными электронно-акцепторными свойствами (72...97 МПа), наименьшей – никелевые соли (60...72 МПа); с катионами меди ($3d^9$) и цинка ($3d^{10}$) чрезвычайно отрицательно влияют на твердение шлакового камня (21...40 МПа); с катионами, гидраты которых имеют пространственную октаэдрическую конфигурацию, эффективно активизируют ГФШ; если же гидраты катионов обладают искаженной октаэдрической или тетраэдрической конфигурацией, то они отрицательно влияют на твердение шлакового (цементного) камня.

Показано, что при малом количестве эти добавки в твердеющей системе не остаются в свободном состоянии и не образуют самостоятельных соединений (те и другие негативно действуют на свойства цементного камня, бетона и изделий), будут входить в структуру тоберморитового геля (C-S-H) и субмикроструктурного CSH (I); эндоэффект в термограмме тоберморитового геля, возникшего в эталонном образце, фиксируется при 120°C, а в шлаковом камне – при 140...260°C; на рентгенограмме эталонного образца присутствуют дифракционные максимумы CSH (I) с межплоскостными расстояниями $d=3,07$; 2,8 и 1,83Å, а на рентгенограмме шлакового камня появляются отражения этой фазы при Å: 3,00...3,12; 2,80...2,82 и 1,80...1,85.

Учитывая, что основными элементами тоберморитового геля и CSH (I) являются ионы Ca^{2+} , SiO_4^{4-} и OH^- (H_2O), можно допустить, что катионы солей 3d-металлов в структуре гидросиликатов кальция замещают ионы Ca^{2+} по схеме $Me^{2+} \uparrow \downarrow Ca^{2+}$; кроме того, примесные ионы (Me^{2+}) в гидросиликатах кальция могут находиться вне структурных связей – в пустотах; ионы SO_4^{2-} в гидратных фазах могут замещать кремнекислородные радикалы по схеме $SO_4^{2-} \uparrow \downarrow SiO_4^{4-}$; при этом ионы SO_4^{2-} , замещая группы $Si_xO_y^{2-}$ в структуре гидросиликатов кальция, не могут создавать в них непрерывный ряд; ионы Cl^- в структуре гидросиликатов кальция могут занимать три позиции: замещать O^{2-} , OH^- и находиться в пустотах.

Ключевые слова: гранулированный фосфорный шлак, хлориды и сульфаты 3d-переходных металлов, катионы, электроны, акцепторы, доноры, прочность, камень, гидросиликаты кальция.

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**SELECTION OF A BINDER
FOR A ZEOLITE-CONTAINING CRACKING CATALYST
ON AL- PILLARED TAGAN MONTMORILLONITE**

Abstract. It was shown that the strength of Al(2.5) NaHMM + HLaY + NaMM catalysts increases significantly with the introduction of NaMM. The optimal amount of NaMM additive is 10 mass%. With an increase in the calcination temperature of this catalyst, an increase in strength is observed, which reaches a maximum value (223.4 N/sm²) at 600⁰C. A further increase in the amount of introduced NaMM to 15 and 20 wt.% reduces the strength of the catalysts at all studied calcination temperatures. On Al (2.5) NaHMM + HLaY + NaMM catalyst, a large amount (42.5%) of gaseous hydrocarbons is formed at 500⁰ C, which decreases with an increase in cracking temperature to 550⁰ C. The gasoline yield at 500⁰C is 42.0%, light gas oil 5.5%. With an increase in cracking temperature, the yield of gasoline decreases to 39.5%, and light gas oil increases to 15.8%. Under these conditions, a decrease in the yield of gaseous hydrocarbons to 28.8% is observed.

Comparison of the results of VG cracking on catalysts with and without NaMM binder showed that the introduction of NaMM does not significantly affect the yield of gasoline.

Key words: catalytic cracking, montmorillonite, strength, gasoline, zeolite, vacuum gas oil (VG).

Introduction. The matrixes of modern zeolite-containing cracking catalysts are multicomponent systems that should provide a number of requirements for the catalysts during their operation: high activity, optimal porous structure and specific surface area, thermal stability, abrasion resistance [1,2]. The high heat capacity of montmorillonite (MM) promotes heat removal from the zeolite component at the regeneration stage, which leads to increased thermal stability of the catalyst [3]. Obviously, the strength characteristics of the catalysts are determined by their composition and texture properties - porosity, specific surface area, size of primary particles. However, in the literature there are very few works devoted to the study of the relationship of strength with the physicochemical properties of catalytic systems.

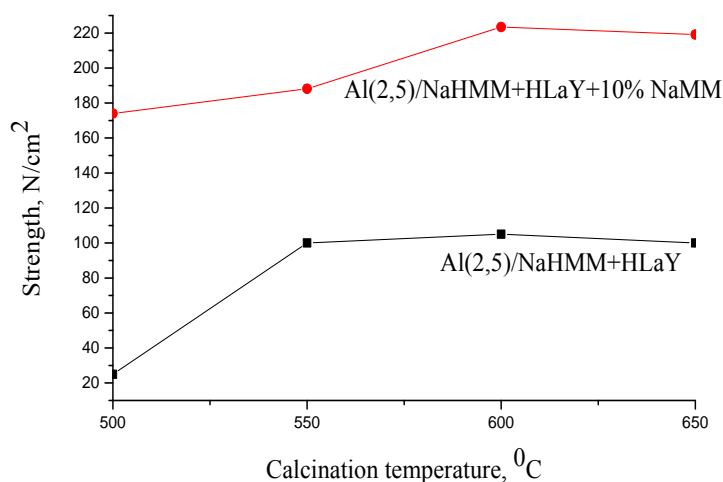
The purpose of the work is to develop new effective additives to increase the mechanical strength of cracking catalysts based on natural clays and zeolites for processing vacuum gas oils in the fuel direction and to identify the relationship of strength with the characteristics of the developed cracking catalysts.

Experimental part. As a raw material for cracking, VG from LLP Pavlodar Oil Chemistry Refinery, trade mark B, type 2 was used with a density of 907.7 kg/m³, with a boiling end of 510⁰C, kinematic viscosity at 50⁰C equal to 27.05 mm²/s, sulfur content of 1.5 mass%, pour point 30⁰C and coking ability of 0.14 wt.%. Montmorillonite activated with a H₂SO₄ solution and pillared Al, as well as the synthesis of zeolite Y modified with lanthanum, were carried out by known methods.

The elemental composition of the catalysts was determined by X-ray fluorescence spectroscopy (INCA - Energy 450 at SEM JSM6610LV, JOEL, Japan). The textural characteristics of the catalysts were determined from isotherms of low-temperature adsorption and desorption of nitrogen on an Accusorb instrument (BET method). The crush strength of the catalyst granules was determined by the compression method ("Prochnomer of catalysts" PK-21-015). The acidity of the catalysts was determined by the thermal desorption of ammonia. The catalytic activity of the samples was determined on a laboratory flow-through installation, corresponding to the standard, with a fixed catalyst layer with a volume of 40 ml

in the temperature range 480-550⁰C. When the catalyzate was distilled, a fraction of gasoline T_{b. b.} - 205⁰C and light gas oil fraction 205-350⁰C were taken. Cracking products were analyzed by GLC with a flame ionization detector and a capillary column 100 m long; temperature 250⁰C; carrier gas - helium (Chromos GC-1000).

Results and discussion. It was shown earlier that the use of montmorillonite in the Na-form as a matrix and a binder of zeolite-containing catalysts leads to an increase in their crushing strength. In this regard, in order to increase the strength of cracking catalysts, various amounts of the initial MM in the Na form were introduced into the zeolite-containing catalysts based on pillared MM as an additive. From figure, where the effect of NaMM additives on the strength of Al (2.5) NaHMM + HLaY is clearly shown, it is seen that the introduction of 10% NaMM increases the strength of the catalyst by 1.9–2.3 times at T_{calc} = 550–650⁰C compared to the strength of the catalyst without NaMM.



Effect of calcination temperature on the strength of Al (2.5) NaHMM + HLaY catalysts with the addition of 10% NaMM

For the cracking tests, catalysts calcined at the optimum temperature and sufficiently strong were taken. So, Al (2.5) NaHMM + HLaY + 10% NaMM catalyst was calcined at 600⁰ C, while the strength of the catalyst increased to 223.4 N/sm² and VG was cracked at temperatures of 500 and 550⁰ ° C with determination of material balance and chromatographic analysis of the resulting gasoline fractions. The gasoline yield at 500⁰ C is 42.0%, light gas oil 5.5%. With an increase in cracking temperature, the yield of gasoline decreases to 39.5%, and light gas oil increases to 15.8%. Under these conditions, a decrease in the yield of gaseous hydrocarbons to 28.8% is observed.

Material balance of VG cracking on Al (2,5) NaHMM + HLaY + 10% NaMM catalyst at various cracking temperatures

VG raw materials	The yield of products, wt.%	
	500 ⁰ C	550 ⁰ C
Cracking temperature	500 ⁰ C	550 ⁰ C
Gas	42,5	28,8
Gasoline (b.b.-205 ⁰ C)	42,0	39,5
Light gas oil (205-350 ⁰ C)	5,5	15,8
Heavy gas oil (> 350 ⁰ C)	5,8	8,6
Coke	2,9	4,5
Losses	1,3	2,8
Product Amount	100	100

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**АЛЮМИНИЙМЕН ПИЛЛАЛИРЛЕНГЕН ТАҒАН МОНТМОРИЛЛОНИТІ
НЕГІЗІНДЕ КРЕКИНГТІҢ ЦЕОЛИТҚҰРАМДЫ КАТАЛИЗАТОРЛАРЫНА
БАЙЛАНЫСТЫРҒЫШ ТАҢДАУ**

Аннотация. Мақалада $Al(2,5) NaHMM + HLaY + NaMM$ катализаторларының беріктігі $NaMM$ енгізгенде едәуір артатыны көрсетілген. $NaMM$ қоспасының оңтайлы мөлшері 10 масса% құрайды. Осы катализатордың қыздыру температурасының жоғарылауы негізінде берік бола түседі, ол максималды мәнге ($223,4 \text{ Н/см}^2$) 600°C жетеді. Енгізілген $NaMM$ мөлшерінің одан әрі артуы 15 және 20 салм.% зерттелген жоғары температурадағы катализаторлардың беріктігін кемітеді. $Al(2.5) NaHMM + HLaY + NaMM$ катализаторында 500°C температурада газ тәрізді көмірсутектер көп мөлшерде (42,5%) түзіледі, ол крекинг температурасының 550°C дейін жоғарылауы негізінде төмендейді. 500°C температурада бензиннің шығымы 42,0%, жеңіл газ 5,5% құрайды. Крекинг температурасының жоғарылауы арқылы бензин шығымы 39,5% дейін төмендейді, ал жеңіл газойль 15,8%-ға дейін артады. Бұл жағдайда газ тәрізді көмірсутектер шығымы 28,8% дейін төмендейтіні байқалды.

Катализаторлардағы ВГ крекинг нәтижелерін $NaMM$ байланыстырғышпен және онсыз салыстырғанда $NaMM$ енгізу бензиннің түсуіне айтарлықтай әсер етпейтінін көрсетті.

Түйін сөздер: каталитикалық крекинг, монтмориллонит, беріктілік, жанар май, цеолит, вакуумды газойль (ВГ).

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**ПОДБОР СВЯЗУЮЩЕГО ДЛЯ ЦЕОЛИТСОДЕРЖАЩЕГО
КАТАЛИЗАТОРА КРЕКИНГА НА АІ- ПИЛЛАРИРОВАННОМ
ТАГАНСКОМ МОНТМОРИЛЛОНИТЕ**

Аннотация. Показано, что прочность $Al(2.5)NaHMM+HLaY+NaMM$ -катализаторов существенно повышается с введением $NaMM$. Оптимальное количество добавки $NaMM$ составляет 10 мас.%. С повышением температуры прокали этого катализатора наблюдается рост прочности, которая достигает максимального значения ($223,4 \text{ Н/см}^2$) при 600°C . Дальнейший рост количества вводимого $NaMM$ до 15 и 20 вес.% снижает прочность катализаторов при всех изученных температурах прокали. На $Al(2.5)NaHMM+HLaY+NaMM$ катализаторе образуется большое количество (42,5%) газообразных углеводородов при 500°C , которое уменьшается с ростом температуры крекинга до 550°C . Выход бензина при 500°C составляет 42,0%, легкого газойля 5,5%. С ростом температуры крекинга выход бензина снижается до 39,5%, легкого газойля растет до 15,8%. В этих условиях наблюдается уменьшение выхода газообразных углеводородов до 28,8%.

Сравнение результатов крекинга ВГ на катализаторах со связующим $NaMM$ и без него, показал, что введение $NaMM$ не оказывает существенного влияния на выход бензина.

Ключевые слова: каталитический крекинг, монтмориллонит, прочность, бензин, цеолит, вакуумный газойль (ВГ).

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ASPHALT CONCRETE WITH NANOCARBON BITUMEN

Abstract. This paper shows the possibility for producing a road asphalt concrete with the improved characteristics with the use of the bitumen with nanocarbon powder we manufactured before compared with the conventionally used asphalt concrete. The paper determines and compares the standard indicators of two types for road asphalt concrete: 1) a hot fine-grained asphalt concrete of Type B, prepared with the use of bitumen with nanocarbon powder; 2) a conventional hot fine-grained asphalt concrete of type B prepared with the use of a neat bitumen of grade BND 70/100. The neat bitumen was produced by the Pavlodar petrochemical plant, a nanopowder (150-200 nm) was manufactured from the coal rock of “Saryadyr” deposit (“Corporation “ON’Olzha” LLP, Akmola region) by three-stage grinding in a mechanical dispergator (up to 2-3 mm), an aerodynamic mill (up to 20 mcm) and a reactor with rotating electromagnetic field (150-200 nm). Modifying of the neat bitumen with nanocarbon powder in the amount of 0.5 % and 2 % has been performed in Kazakhstan Highway Research Institute by continuous mixing of the neat bitumen and the nanocarbon powder for 30 minutes at the temperature of 160 °C.

The asphalt concretes were prepared under standard ST RK 1225-2013, their volumetric characteristics and standard indicators were determined under standard ST RK 1218-2003. To prepare the asphalt concretes a crushed stone was used from the Novo-Alekseyevsk quarry (Almaty region), a sand from the plant “Asphalt concrete-1” (Almaty city) and an activated mineral powder from “Zhartas” LLP (Kordai village, Zhambyl region). It is established that the use of the nanocarbon bitumen improves essentially the standard indicators of the road asphalt concrete. For example, with the content of the nanopowder in bitumen of 2 % the water saturation is decreased for 18 %, shear resistance is increased for 43 %, the strength at the temperature of 20 °C in dry and water-saturated conditions is increased for 9 % and 17 % respectively, the strength at the temperature of 50 °C is increased for 29 %, the strength at the temperature of 0 °C is decreased for 44 % (nearly 2 times).

Key words: bitumen, nanopowder from coal, bitumen with nanocarbon powder, asphalt concrete with nanocarbon bitumen, standard indicators.

1. Introduction. In Kazakhstan, as well as in other countries, it is accepted to evaluate standard indicators of bitumens and asphalt concretes with their use separately. Meanwhile, for optimum mix design it is accepted to use only those bitumens which satisfy the requirements of the current standard. At present in Kazakhstan the standard requirements to road bitumens and asphalt concretes are specified in standards ST RK 1373-2013 [1] and ST RK 1225-2013 [2] respectively.

In our works [3-6] the possibility has been shown for improvement of characteristics for road bitumens by modification with a nanocarbon powder, and their standard and non-standard characteristics have been investigated. This paper is the continuation of our above works, and it shows the possibility for producing of a road asphalt concrete with the improved characteristics at the use of the bitumen with nanocarbon powder we manufactured before.

2. Materials and methods.

2.1. Bitumens and nanopowder. To prepare a conventional road asphalt concrete of type B satisfying the requirements of the standard ST RK 1225-2013 [2] the road bitumen of grade BND 70/100 has been accepted, which satisfies the requirements of the standard ST RK 1373-2013 [1]. The bitumen has been produced by the Pavlodar petrochemical plant from a crude oil of the Western Siberia (Russia) by direct oxidation.

A nanopowder (150-200 nm) was manufactured from the coal rock of “Saryadyr” deposit (“Corporation “ON’Olzha” LLP, Akmola region) by three-stage grinding. A mechanical dispergator (up to 2-3 mm), an aerodynamic mill (up to 20 mcm) and a reactor with rotating electromagnetic field (150-200 nm) were used on grinding stages respectively.

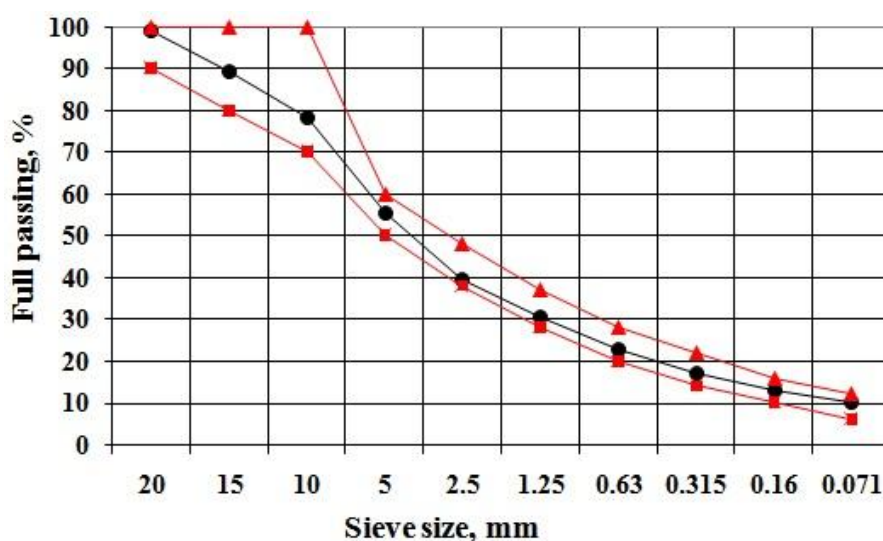
The nanocarbon bitumen with the content of the carbon nanopowder in the amount of 0.5 % and 2.0 % by weight of the neat bitumen was prepared by constant mixing of the neat bitumen and the nanopowder at the temperature of 160 °C for 30 minutes.

The detailed information about the neat bitumen, the nanopowder and the nanocarbon bitumen and their standard and non-standard characteristics is included in our previous works [3-6].

2.2. Asphalt concretes. Conventionally used in the road construction the hot fine-grained asphalt concrete of type B with the use of the neat bitumen of grade BND 70/100 and the similar hot fine-grained asphalt concrete of type B with the use of the nanocarbon bitumen have been prepared under standard ST RK 1225-2003 [2]. To prepare the asphalt concretes a crushed stone (20%) was used from the Novo-Alekseyevsk quarry (Almaty region), a sand of fraction 0-5 mm (49%) from the plant “Asphalt concrete-1” (Almaty city) and an activated mineral powder (7%) from “Zhartas” LLP (Kordai village, Zhambyl region). The content of the neat bitumen and the nanocarbon bitumen in the asphalt concretes was 4.8 % by weight of the dry mineral materials.

The granulometric curve of the mineral part of the asphalt concretes is shown in figure. The standard indicators of the crushed stone, the sand and the mineral powder determined under the standards ST RK 1213-2003 [7], ST RK 1217-2003 [8] and ST RK 1221-2003 [9] respectively are given in tables 1-3.

Volumetric characteristics determined under standard ST RK 1218-2003 [10] are given in table 4. As it is seen, the average and the real densities of the conventional and the nanobitumen asphalt concretes are practically similar. Residual air voids is decreased with the increase of the amount of the nanopowder: with the content of nanopowder 2.0 % by decreasing of residual air voids of the asphalt concrete it reaches 15%. It is possible to improve the standard indicators of the asphalt concrete by decreasing of residual air voids.



Granulometric curve of the mineral part of the asphalt concretes

Table 1 – Standard indicators of the crushed stone

Description of indicator	Norm	Actual results	
		Fraction 10-20 mm	Fraction 5-10 mm
Content of grains of thin flake and needle-shaped form, % Class	up to 15 incl. 1	6.8 1	12.9 1
Strength according to crushability - weight loss, % - grade	up to 10 incl. 1000	6.4 1000	8.9 1000
Wearing quality, - weight loss, % - grade	up to 25 incl. W1	14.1 W1	17.3 W1
Content of grains of soft rocks, %	not more than 10	5.0	6.1
Frost resistance (saturation in solution of sodium sulphate): - number of cycles - weight loss, % - grade	10 not more than 5 F100	10 2.7 F100	10 3.3 F100
Content of dust and clay particles, %	not more than 1.0	0.11	0.2
Content of clay in lumps, %	not more than 0.25	0	0
Content of granulated grains, %	not less than 80	90.0	87.5

Table 2 – Standard indicators of the sand

Description of indicator	Norm	Actual results
Size modulus	above 2.5 up to 3.0 large	2.6 large
General sieve residual with mesh No. 063	above 45 up to 65 large	54.1 large
Content of grains with size, II class: - above 10 mm - above 5 mm - less than 0.16 mm	5 15 15	3.0 10.6 12.0
Content of dust and clay particles, %	not more than 10	6.4
Content of clay in lumps, %	not more than 0.25	0
Content of clay particles by swelling method, %	not more than 0.5	0.21

Table 3 – Standard indicators of the mineral powder

Description of indicator	Norm	Actual results
Grain size, % under mass: - less than 1.25 mm - less than 0.315 mm - less than 0.071 mm	not less than 100 not less than 90 not less than 80	100 98.5 80.1
Air voids, %	not more than 28	21
Swelling of specimens from the mix of filler with bitumen, %	not more than 1,5	0.5
Bitumen content value, g,	not more than 50	38.0
Water content, %	not more than 0.5	0.16

Table 4 – Volumetric characteristics of the asphalt concretes with the neat bitumen and the nanocarbon bitumen

Amount of nanopowder, %	Average density, g/cm ³	Real density, g/cm ³	Residual air voids, %
0	2.39	2.49	4.0
0.5	2.39	2.48	3.6
2.0	2.40	2.49	3.4

3. Results and discussion. The standard indicators of the asphalt concretes with the neat bitumen and the nanocarbon bitumen determined under the standard ST RK 1218-2003 [10] are represented in eable 5. As it is seen, the use of the nanocarbon bitumen improves all the considered standard indicators of the asphalt concrete. With the content of the nanopowder in bitumen 2 % water saturation is decreased for 18 %, shear resistance is increased for 43 %, strength at the temperature of 20 °C in dry and water-saturated conditions is increased for 9 % and 17 % respectively, strength at the temperature of 50 °C is increased for 29 %, strength at the temperature of 0 °C is decreased for 44 % (nearly 2 times).

Table 5 – Standard indicators of the asphalt concretes with the neat bitumen and the nanocarbon bitumen

Indicator	Amount of nanopowder, %			Norm
	0	0.5	2.0	
Water saturation, %	3.4	3.1	2.8	1.5-4.0
Compression strength (MPa) at the temperature (°C):				
-20 °C	3.2	3.3	3.5	not less 2.5
- 20 °C (in water-saturated condition)	3.0	2.9	3.5	–
- 50 °C	1.4	1.6	1.8	not less than 1.3
- 0 °C	6.8	4.5	3.8	not more than 13.0
Shear resistance	0.42	0.44	0.60	not less than 0.38

The considerable increase in the strength at the temperature of 50 °C (29 %) and shear resistance (43 %) shows the increased shear resistance of the asphalt concrete with the nanocarbon bitumen compared with the conventional asphalt concrete. The essential decrease of the strength at the temperature of 0 °C (44 %) informs about the increased resistance of this asphalt concrete to the fatigue and low temperature cracking. Water saturation decrease characterizes its comparatively better frost resistance.

Conclusion. 1. A new road asphalt concrete has been manufactured with the improved standard indicators. It was prepared with the use of a nanocarbon bitumen.

2. With the content of the nanopowder in the bitumen 2 % water saturation is decreased for 18 %, shear resistance is increased for 43 %, the strength at the temperature of 20 °C in dry and water-saturated conditions is increased for 9 % and 17 % respectively, the strength at the temperature of 50 °C is increased for 29 %, the strength at the temperature of 0 °C is decreased for 44 % (nearly 2 times).

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НАНОКӨМІРТЕК БИТУМДЫ АСФАЛЬТБЕТОН

Аннотация. Мақалада дәстүрлі асфальтбетонмен салыстырғанда бұрын өзіміз қол жеткізген нанокөмір ұнтағы бар битумды қолдана отырып, жақсартылған сипаттамалары бар жол асфальтбетонның алу мүмкіндігі көрсетілген. Онда жол асфальтбетонның екі түрінің стандарт көрсеткіштері анықталып, салыстырылған: 1) нанокөміртек ұнтақты битумды пайдаланып дайындалған ыстық майда түйіршікті Б типтік асфальтбетон; 2) МЖБ 70/100 маркалы таза битумды пайдаланып дайындалған ыстық майда түйіршікті Б типтік асфальтбетон. Таза битум Павлодар мұнай-химия зауытында, наноұнтақ (150-200 нм) «Сарыадыр» кен орнының («ОН-Олжа» корпорациясы) ЖШС, Ақмола облысы) көмір жынысынан механикалық диспергаторда (2-3 мм-ге дейін), аэродинамикалық диірменде (90 мкм дейін) және айналма электр-магниттік өрісті реакторда (150-200 нм дейін) үш сатылы ұнтақтау арқылы алынды. Таза битумды 0,5 % және 2 % наноұнтақпен модификациялау Қазақстан жол ғылыми-зерттеу институтында 160 °C

температурада 30 минут бойы таза битум мен нанокөміртек ұнтақты үздіксіз араластыру негізінде жүзеге асырылды.

Асфальтбетондар ҚР СТ 1225-2003 стандарты бойынша дайындалды, олардың көлем сипаттамалары мен стандарт көрсеткіштері ҚР СТ 1218-2003 стандарты бойынша анықталды. Асфальтбетондарды даярлауға Ново-Алексеевск (Алматы облысы) карьерінің шағыл тасы, «Асфальтбетон-1» ЖШС (Алматы облысы) зауытының құмы және «Жартас» ЖШС-нің (Қордай ауылы, Жамбыл облысы) активтендірілген минералдық ұнтағы пайдаланылды. Нанокөміртек ұнтақты битумды пайдалану жол асфальтбетонының стандарт көрсеткіштерін едәуір жақсартатындығы анықталды. Атап айтқанда, битумдағы көмір наноұнтағының мөлшері 2 % болғанда асфальтбетонның сумен қанығуы 18 %-ға азаяды, ығысуға тұрақтылығы 43 %-ға артады, 20 °С температурадағы құрғақ және суға қаныққан күйдегі беріктігі тиісінше 9 % және 17 %-ға өседі, 50 °С температурадағы беріктігі 29 %-ға артады, 0 °С температурадағы беріктігі 44 % (2 есеге жуық) кемиді.

Түйін сөздер: битум, көмірден алынған наноұнтақ, нанокөміртекті ұнтағы бар битум, нанокөміртекті битумы бар асфальтбетон, стандартты көрсеткіштер.

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АСФАЛЬТОБЕТОН С НАНОУГЛЕРОДНЫМ БИТУМОМ

Аннотация. В настоящей статье показана возможность получения дорожного асфальтобетона с улучшенными характеристиками с использованием ранее полученного нами битума с нанокремнеземным порошком по сравнению с традиционно применяемым асфальтобетоном. В ней определены и сравнены стандартные показатели двух видов дорожного асфальтобетона: 1) горячего мелкозернистого асфальтобетона типа Б, приготовленного с использованием битума с нанокремнеземным порошком; 2) традиционного горячего мелкозернистого асфальтобетона типа Б, приготовленного с использованием чистого битума марки БНД 70/100. Чистый битум произведен Павлодарским нефтехимическим заводом, нанопорошок (150-200 нм) получен из угольной породы месторождения «Сарыадыр» (ТОО «Корпорация «ОН-Олжа», Акмолинская область) путем трехстадийного измельчения в механическом диспергаторе (до 2-3 мм), аэродинамической мельнице (до 20 мкм) и реакторе с вращающимся электромагнитным полем (150-200 нм). Модифицирование чистого битума нанокремнеземным порошком в количестве 0,5 % и 2 % осуществлено в Казахском дорожном научно-исследовательском институте путем непрерывного перемешивания чистого битума и нанокремнеземного порошка в течение 30 минут при температуре 160 °С.

Асфальтобетоны были приготовлены по стандарту СТ РК 1225-2013, их объемные характеристики и стандартные показатели были определены по стандарту СТ РК 1218-2003. Для приготовления асфальтобетонов были использованы щебень из Ново-Алексеевского карьера (Алматинская область), песок – из завода «Асфальтбетон-1» (г. Алматы) и активированный минеральный порошок – из ТОО «Жартас» (п. Кордай, Жамбылская область). Установлено, что использование нанокремнеземного битума существенно улучшает стандартные показатели дорожного асфальтобетона. Так, при содержании нанопорошка в битуме 2% водонасыщение уменьшается на 18 %, сдвигоустойчивость увеличивается на 43 %, прочность при температуре – 20 °С в сухом и водонасыщенном состояниях повышается соответственно на 9 % и 17 %, прочность при температуре 50 °С повышается на 29 %, прочность при температуре 0 °С уменьшается на 44 % (почти в 2 раза).

Ключевые слова: битум, нанопорошок из угля, битум с нанокремнеземным порошком, асфальтбетон с нанокремнеземным битумом, стандартные показатели.

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STRENGTH AND CRACKING PROPERTIES OF HLaY-CONTAINING COMPOSITE CATALYST ON Al-PILLARED MONTMORILLONITE IN CaNa-FORM

Abstract. It was shown that additives of montmorillonite in the Na form contribute to a significant increase in the crushing strength of cracking catalyst granules while preserving their activity in gasoline yield. Comparison of the results of vacuum gasoil cracking on catalysts of the same composition, but with and without NaMM binder, showed that the introduction of NaMM increases the strength of the CaNaHMM-based catalyst and does not significantly affect the gasoline yield.

Catalysts based on MM in CaNa and Na-forms showed similar activity in the release of gasoline from vacuum gasoil, regardless of the composition of the exchange cations. It was found that due to the stages of activation and pillaring, Na is completely removed from the finished catalyst. Pillarization and introduction of zeolite provide an increase in specific surface area and total pore volume. Catalysts have a high number of acid sites. The maximum yield of gasoline equal to 44.8% and light gas oil 14.6% was obtained with Al (2.5) CaNaHMM+HLaY+NaMM with the addition of a binder and crushing strength of 60-70 N / sm².

Key words: catalytic cracking, binder, montmorillonite, strength, gasoline, zeolite, vacuum gas oil.

Introduction. One of the promising directions for optimizing the composition of cracking catalysts is the use of layered aluminosilicates and their modified forms as a component of the matrix of cracking catalysts [1,2]. In cracking catalysts developed in Russia, Tagan montmorillonite (natural bentonite) is used as a matrix component, which has binding properties, increasing strength and increasing the bulk density of the catalyst. New highly efficient zeolite-containing vacuum gasoil (VG) cracking catalysts with the production of gasoline were developed using columnar aluminum montmorillonites, which are characterized by an increase in the number of mesopores and an increase in thermal stability. However, the strength of such catalysts does not always meet the requirements of their operation in apparatuses with a moving and fluidized bed in the processes of cracking of crude oil.

The purpose of the work is the synthesis of HLaY zeolite-containing catalysts deposited on aluminum pillared montmorillonite in CaNa- form and to reveal the effect of a binder on the activity of catalysts in the cracking of vacuum gasoil and its acid properties.

Experimental part. To prepare cracking catalysts, montmorillonite in CaNa form was used from the Zapadnyi quarry, 12 horizons, containing the following alkaline cations: Na⁺ > 35 mg / equiv, Ca⁺⁺ ≥ 28 mg / equiv, Mg⁺⁺ = 24 mg / equiv, K⁺ ~ 4,0 mg/equiv. As a raw material for cracking, VG from LLP Pavlodar Oil Chemistry Refinery, trade mark B, type 2 was used with a density of 907.7 kg / m³, with a boiling end of 510⁰C, kinematic viscosity at 50⁰C equal to 27.05 mm² / s, sulfur content of 1.5 mass%, pour point 30⁰C and coking ability of 0.14 wt.%. Montmorillonite activated with a H₂SO₄ solution and pillared Al, as well as the synthesis of zeolite Y modified with lanthanum, were carried out by known methods.

The elemental composition of the catalysts was determined by X-ray fluorescence spectroscopy (INCA - Energy 450 at SEM JSM6610LV, JOEL, Japan). The textural characteristics of the catalysts were determined from isotherms of low-temperature adsorption and desorption of nitrogen on an Accusorb

instrument (BET method). The crush strength of the catalyst granules was determined by the compression method ("Prochnomer of catalysts" PK-21-015). The acidity of the catalysts was determined by the thermal desorption of ammonia. The catalytic activity of the samples was determined on a laboratory flow-through installation, corresponding to the standard, with a fixed catalyst layer with a volume of 40 ml in the temperature range 480-550°C. When the catalysate was distilled, a fraction of gasoline $T_{b. b.} - 205^{\circ}\text{C}$ and light gas oil fraction 205-350°C were taken. Cracking products were analyzed by GLC with a flame ionization detector and a capillary column 100 m long; temperature 250°C; carrier gas - helium (Chromos GC-1000).

Results and discussion. The influence of the exchange form of MM on the activity of the cracking catalyst while maintaining its composition and method of preparation was studied using MM in a CaNa form (a new batch of MM from horizon 12). From table 1 it is seen that the gasoline yield on this catalyst ranges from 44.8-43.6% at cracking temperatures of 480 and 500°C, which almost completely coincides with the gasoline yields on catalysts of the same composition (42.0-39.5%), but based on NaHMM when cracking two different lots of VG, varying in composition.

Table 1 – Material balance of VG cracking on Al (2,5) CaNaHMM + HLaY + NaMM catalyst at various temperatures. The strength of this catalyst is 60-70N/sm²

VG raw materials	The yield of products, mass. %	
	480°C	500°C
Cracking temperature	480°C	500°C
Gas	28,3	28,9
Gasoline (s.b.-205°C)	44,8	43,6
Light gas oil (205-350°C)	14,6	13,5
Heavy gas oil (> 350°C)	7,3	8,4
Coke	2,9	3,3
Losses	2,1	2,3
Product Amount	100	100

Based on the results obtained, it can be concluded that two samples of catalysts of the same composition, but using Al-pillared MM in two different exchange forms, showed similar activity in gasoline yield. In connection with the foregoing, it was of interest to compare the elemental composition, textural and acid properties of the studied catalysts using activated and pillared Tagan MM in various exchange forms in the composition of the finished catalyst. The results of elemental analysis showed, that thanks to the stages of activation and pillaration, Na is completely removed from the initial MM regardless of the exchange form. With the introduction of HLaY, the elemental composition and porous structure of two MM-based catalysts in different exchange forms is practically the same.

A comparison of the acidic properties of optimal catalysts based on montmorillonites of various horizons is given in table 2, from which it can be seen that the total content of acid centers (a.c.), and also in particular the relative and absolute amount of strong a.c. of the NaHMM-based catalyst is 1.7 times superior to the catalyst supported on activated MM in CaNa form.

Table 2 – Acidic properties of optimal cracking catalysts

Sample	Content a.c.	Acid centers			Total acidity
		Weak <200°C	Medium 200-300°C	Strong >300°C	
Al(2,5)CaNaHMM+HLaY	%	43,52	36,48	20	100
	Mkmol NH ₃ /r	161,64	135,50	74,28	371,43
Al(2,5)NaHMM+HLaY	%	36,3	30,1	33,6	100
	Mkmol NH ₃ /r	139,6	115,4	129,2	384,5

From the results obtained, it is seen that the introduction of NaMM as a binder into the zeolite-containing cracking catalyst significantly increases the crush strength of the granules while maintaining the activity of the catalyst in terms of the yield of gasoline during VG cracking. It was shown that zeolite-containing catalysts based on MM pillared with aluminum in the Na and CaNa forms are characterized by a close elemental composition, texture and acid properties, which leads to their close activity in VG cracking with the formation of gasoline. The maximum yield of gasoline equal to 44.8% and light gas oil 14.6% was obtained on Al(2,5)CaNaHMM +HLaY+ NaMM with the addition of a binder and crushing strength is 60-70 N/ sm².

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**CaNa- АУЫСПАЛЫ ФОРМАСЫНДАҒЫ АЛЮМИНИЙМЕН ПИЛЛАИРЛЕНГЕН
HLaY-ҚҰРАМДЫ КОМПОЗИТТІ КАТАЛИЗАТОРДЫҢ
КРЕКИНГТІК ЖӘНЕ БЕРІКТІК ҚАСИЕТТЕРІ**

Аннотация. Na формасындағы монтмориллонит қоспа ретінде крекинг катализатор түйіршіктерінің сыну күшін арттыруға едәуір ықпал ететіні, сонымен қатар, олардың бензин шығымындағы белсенділігін арттыратыны көрсетілген. ВГ крекингінің нәтижелері бірдей құрамдағы катализаторларды салыстырғанда NaMM байланыстырғышсыз және NaMM енгізу катализаторлардың беріктігі арттыратындығын және бензиннің шығымына айтарлықтай әсер етпейтінін көрсетті.

CaNa және Na-формалардағы MM негізіндегі катализаторлар катиондардың құрамына қарамастан, жоғары температуралы газдардан бензин шығаруда ұқсас белсенділік көрсетті. Белсендіру және пиллаирлеу кезеңдеріне байланысты Na дайын катализатордан толығымен шығарылатындығы анықталды. Пиллаирлеу және цеолитті енгізу беткі қабаттың жалпы көлемін және кеуектердің жалпы көлемін арттыруды қамтамасыз етеді. Ұсынылған катализаторлар қышқылдың орталық санының көптігімен ерекшеленеді: Al(2,5)CaNaHMM+NaMM-катализаторында байланыстырғышты қосқанда беріктігі 60-70Н/см², бензиннің ең жоғары шығымы 44,8% және жеңіл газойль шығымы 14,6% құрады.

Түйін сөздер: каталитикалық крекинг, байланыстырғыш, монтмориллонит, беріктік, жанар май, цеолит, вакуумды газойль.

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**ПРОЧНОСТНЫЕ И КРЕКИРУЮЩИЕ СВОЙСТВА
HLaY-СОДЕРЖАЩЕГО КОМПОЗИТНОГО КАТАЛИЗАТОРА
НА Al- ПИЛЛАИРОВАННОМ МОНТМОРИЛЛОНИТЕ В CaNa-ФОРМЕ**

Аннотация. Показано, что добавки монтмориллонита в Na-форме способствуют существенному росту прочности гранул катализаторов крекинга на раздавливание при одновременном сохранении их активности по выходу бензина. Сравнение результатов крекинга ВГ на катализаторах одинакового состава, но со связующим NaMM и без него, показало, что введение NaMM повышает прочность катализатора на основе CaNaHMM и не оказывает существенного влияния на выход бензина.

Катализаторы на основе ММ в CaNa и Na –формах проявили близкую активность по выходу бензина из ВГ независимо от состава обменных катионов. Найдено, что благодаря стадиям активации и пилларирования Na полностью удаляется из готового катализатора. Пилларирование и введение цеолита обеспечивают рост удельной поверхности и общего объема пор. Катализаторы отличаются высоким количеством кислотных центров. Максимальный выход бензина, равный 44,8% и легкого газойля 14,6% получен на Al(2,5)CaNaHMM+HLaY+NaMM с добавкой связующего и прочностью на раздавливание 60-70 Н/см².

Ключевые слова: каталитический крекинг, связующая, монтмориллонит, прочность, бензин, цеолит, вакуумный газойль.

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**FORMATION OF SELENIUM POWDERS
IN CATHODE REDUCTION OF SELENITE IONS
IN COPPER (II) HYDROCHLORIC ACID SOLUTION**

Abstract. The work presents the results of the study of cathode reduction of selenium (IV) ions in hydrochloric acid medium in the presence of Cu (II) ions. The following electrolysis parameters were studied: concentrations of hydrochloric acid and copper (II) ions. In the course of the studies, it has been found that an increase in cathode current density and hydrochloric acid concentration leads to a decrease in the current yield of selenium powder. This exposure to hydrochloric acid is due to the fact that the formed copper monovalent ions are complexed with chlorine ions of type CuCl_n^{n-} , where the number "n" increases with an increase in the concentration of hydrochloric acid and, accordingly, this leads to a decrease in the reducing capacity of cuproions. The effect of copper (II) ion concentration has a positive effect on the current output of the powder formation of the investigated element. This is due to the increase in the concentration of intermediate products - monovalent copper ions.

It should be noted that under all optimal electrolysis conditions, little colloidal selenium powder is observed in the near-cathode space, due to the monovalent ions involved in the reaction. At high cathode current densities, partial formation of copper selenide is also observed. This is because freshly formed selenium and copper powder interact with each other to form metal selenide. Thus, the cathodic reduction of tetravalent selenium in hydrochloric acid solutions in the presence of divalent copper ions to form selenium powders was first investigated. It has been shown that an increase in copper (II) ion concentrations leads to an increase in the current yield of selenium powder and an increase in hydrochloric acid concentration leads to a decrease. The proposed "red-ox" Cu (II) - Cu (I) system allows electrocatalytic reduction of selenite ion to form ultradisperse selenium powders.

Key words: selenium, powder, recovery, selenite ion, copper (II).

Introduction. Selenium is a constant companion of many sulfide ores and concentrates of heavy and non-ferrous metals, isomorphic replacing sulfur, due to its high chemical activity, is present in raw materials, usually as selenides and in some cases as elemental [1]. The main industrial significance are sulfide deposits. The selenium content in sulfides ranges from 7 to 110 g / t. Global selenium reserves are estimated at ~90 thousand tons for copper deposits. Selenium is also found, for example, in coal and crude oil (from 0.5 to 12 ppm), as well as in seawater (4 ppm), which increases its global reserves by 80-90 times, but these resources are not currently involved in industrial turnover. It seems that in order to implement this technology, there must be a significant increase in selenium prices. The main industrial sources of selenium are slurries formed during electrolytic treatment of copper anodes. Copper slurries contain 5-25 % selenium in the form of compounds with noble metals. The main producers of selenium are countries such as Japan, Canada, Europe, the United States, China, Mexico and Russia [2].

The presence of a wide range of related metals and chemical elements in selenium-containing industrial products implies a variety of processing methods.

To date, the main amount of selenium (up to 90 %) is extracted from the electrolyte slurries of copper and Nickel production, which has led to the emergence of a large number of technological studies in this direction.

Under the guidance of Professor A. Bayeshov, numerous works were carried out and the electrochemical properties of selenium were studied in more detail [3-4]. It is shown that it is possible to

obtain selenium powder from tetravalent selenium ions when polarized by a cathode pulse current, and that it is possible to restore selenium (VI) anions in the presence of "red-ox" systems Ti (III)-Ti (IV), Cr (II)-Cr (III) and Fe (II)-Fe (III).

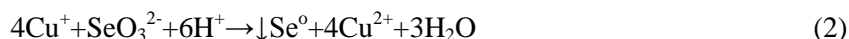
The standard potential (E^0) of the Cu (I) - Cu (II) system in hydrochloric acid solution is -0.54 V, and the potential of the Se-Se (IV) system is 0.77 V. This indicates that monovalent copper ions chemically reduce tetravalent selenium ions to an elementary state, while copper (I) ions are oxidized to a divalent state.

The divalent copper ions present in the solution at low cathode current densities are also reduced stepwise and mainly to the monovalent state by reaction:



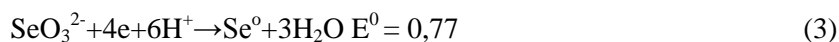
which can participate in the reaction of reducing selenite ions to elemental powdered selenium by reaction (2).

The monovalent copper ions formed by the reaction (1) according to the potentials of the above-mentioned redox systems Cu (I) - Cu (II) and Se-Se (IV), in the cathode space as well as in the volume of the solution, will enter into the chemical reaction of reducing selenium ions (IV):



at the same time, dispersed selenium powders of red-brown color are formed.

There is also a direct cathode reduction of Selenite ions at the cathode:



Experimental part. In this paper, the experiments were performed in an electrolyzer with a volume of 50 ml, the electrode spaces are not separated. A titanium plate was used as the cathode. The current yield of selenium powder was calculated by the weight of the resulting powder.

As can be seen from figure 1, increasing the concentration of hydrochloric acid leads to a decrease in the current output of the formation of selenium powder. This effect of hydrochloric acid is due to the fact that the formed ions of monovalent copper bind in a complex with chlorine ions of the CuCl_n^{n-} -type, where the number "n" increases with increasing concentration of hydrochloric acid and, accordingly, this leads to a decrease in the reducing ability of cuproions by reaction (2). All this in total leads to a decrease in the current output of the formation of selenium powder.

As can be seen from figure 2, with an increase in the concentration of divalent copper ions in the solution, the cathode yield of the selenium powder formation current increases. This is due to an increase in the concentration of intermediate products - monovalent copper ions.

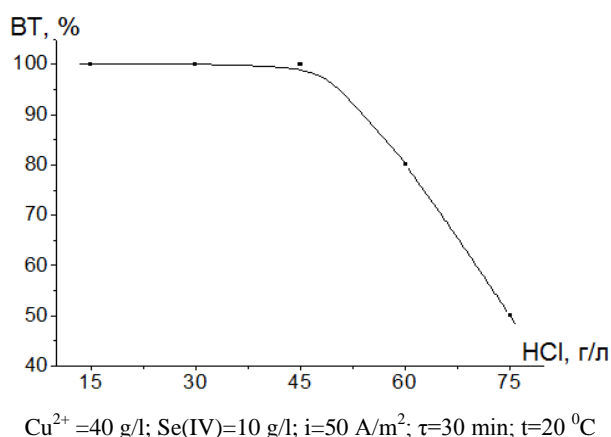


Figure 1 – Effect of hydrochloric acid concentration on the current output of selenium powders formation

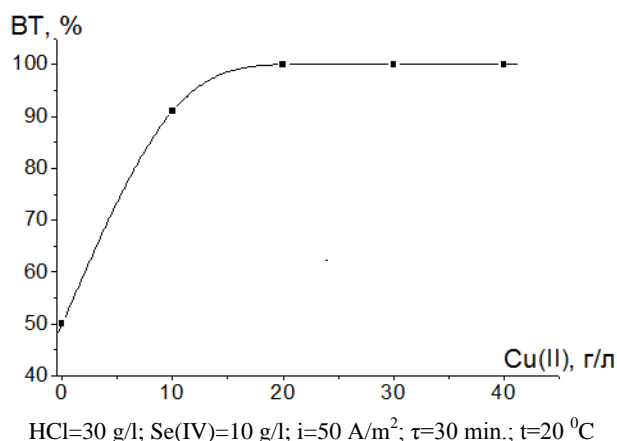


Figure 2 – Dependence of the current output of selenium powders formation on the concentration of copper (II) chloride

Results and discussion. When the solution temperature increases from 20 to 60 $^\circ\text{C}$, the current output of selenium powder formation has a maximum current output of 100 %.

It should be noted that in all optimal conditions of electrolysis in the cathode space, a small amount of colloidal selenium powder is observed, this is due to the participation in the reaction of monovalent ions formed by the chemical reaction (1) and (2). At high cathode current densities, partial formation of copper selenide is also observed.

This is due to the fact that freshly formed selenium and copper powders interact with each other to form metal selenide:



Thus, for the first time, the cathode reduction of tetravalent selenium in hydrochloric acid solutions in the presence of divalent copper ions with the formation of selenium powders was studied. It is shown that an increase in the concentration of copper (II) ions leads to an increase in the current yield of selenium powder formation, and an increase in the concentration of hydrochloric acid leads to a decrease. The proposed "red-ox" Cu (II) - Cu (I) system allows electrocatalytically restoring selenite ions to form ultrafine selenium powders.

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**МЫСТЫҢ (II) ТҰЗ ҚЫШҚЫЛДЫ ЕРІТІНДІСІНДЕ
СЕЛЕНИТ-ИОНДАРДЫ КАТОДТЫ ҚАЛПЫНА КЕЛТІРУДЕ
СЕЛЕН ҰНТАҚТАРЫН ҚАЛЫПТАСТЫРУ**

Аннотация. Жұмыста Cu (II) иондарының қатысуы негізінде тұзды қышқылды ортада селен иондарын катодтық қалпына келтіруді зерттеу нәтижелері ұсынылған. Электролиздің мынадай параметрлері зерттелді: ерітіндінің температурасы, тұз қышқылы мен мыс (II) иондарының концентрациясы. Зерттеу барысында тұз қышқылының концентрациясы артатындықтан, селен ұнтағының пайда болу тогының шығымы төмендейтіні айқындалды. Тұз қышқылының мұндай әсері бірвалентті мыстың түзілетін иондары CuCl_n^{n-} типті хлор-иондармен кешенге байланыстырылуына қатысты, мұнда «n» саны тұз қышқылының концентрациясының ұлғаюы негізінде өседі және тиісінше, бұл купроиондардың қалпына келтіру қабілетінің төмендеуіне әкеледі. Мыс (II) иондары концентрациясының әсері зерттелетін элемент ұнтағының пайда болу тогына оң әсер етеді. Бұл аралық өнімдер, яғни, мыстың бір валентті иондарының концентрациясының ұлғаюына байланысты.

Айта кететін болсақ, электролиздің барлық оңтайлы жағдайларында катодтық кеңістікте селен коллоидты ұнтағының шамалы мөлшері байқалады, бұл бір валентті иондар реакциясына қатысуға байланысты. Токтың жоғары катодты тығыздығы кезінде мыс селенидінің жартылай түзілуі байқалады. Бұл жағдай селен мен мыс ұнтағы бір-бірімен өзара әрекеттесіп, металл селенидінің пайда болуына әкеледі.

Түйін сөздер: селен, ұнтақ, қалпына келтіру, селенит-ион, мыс (II).

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**ФОРМИРОВАНИЕ ПОРОШКОВ СЕЛЕНА ПРИ КАТОДНОМ ВОССТАНОВЛЕНИИ
СЕЛЕНИТ-ИОНОВ В СОЛЯНОКИСЛОМ РАСТВОРЕ МЕДИ (II)**

Аннотация. В работе представлены результаты исследования катодного восстановления ионов селена (IV) в солянокислой среде в присутствии ионов Cu (II). Изучены следующие параметры электролиза: температура раствора, концентрации соляной кислоты и ионов меди (II). В процессе проведения исследований установлено, что увеличение концентрации соляной кислоты приводит к снижению выхода по току образования порошка селена. Такое воздействие соляной кислоты обусловлено тем, что образующиеся ионы одновалентной меди связываются в комплекс с хлор-ионами типа CuCl_n^{n-} , где число «n» возрастает с

увеличением концентрации соляной кислоты и, соответственно, это приводит к снижению восстановительной способности купроионов. Влияние же концентрации ионов меди (II) положительно сказывается на выходе по току формирования порошка исследуемого элемента. Это связано с увеличением концентрации промежуточных продуктов – одновалентных ионов меди.

Следует отметить, что во всех оптимальных условиях электролиза в прикатодном пространстве наблюдается незначительное количество коллоидного порошка селена, это связано с участием в реакции одновалентных ионов. При высоких катодных плотностях тока также наблюдается частичное образование селенида меди. Это связано с тем, что свежесформованный порошок селена и меди взаимодействуют друг с другом с образованием селенида металла.

Ключевые слова: селен, порошок, восстановление, селенит-ион, медь (II).

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**OXIDATION OF CYCLOHEXANE ON COPPER AND COBALT
CATALYSTS SUPPORTED ON PECTIN-MODIFIED OXIDES
AND TAGANSKY MONTMORILLONITE**

Abstract. Supported copper and cobalt catalysts based on pectin (PC) have been synthesized for the process of cyclohexane oxidation with hydrogen peroxide under mild conditions. Synthetic oxides (MgO, Al₂O₃, ZnO) and natural montmorillonite of the Tagansky deposit (TS) were used as supports. Cyclohexane oxidation was carried out in acetonitrile at 40°C and atmospheric pressure in a thermostated reactor with constant stirring. The most effective were copper catalysts. The optimal support for fixing the active phase (Cu²⁺) was found the monmorillonite of the Tagansky deposit. Among the copper catalysts, the most active was a pectin-containing catalyst supported on TS, on which the conversion of cyclohexane was 11.2%.

Key words: Cyclohexane, oxidation, montmorillonite, pectin, copper catalysts, cobalt catalysts.

Clays are widespread, easily available and low-cost chemicals. Both in their native state and in numerous modified forms, clays are versatile materials. In recent years, clays are attracted chemist attention as a potential supports for heterogeneous catalysts due to their abundance, inertness, ability for simple methods of modification of textural properties. Clays structure can be varied by different methods to suit requirements for specific catalytic targets. The textural properties may be improved by intercalation. The formation such materials increases the thermal stability of the obtained material with respect to the natural clay and also generates microporosity in the final material [1]. Clays can be intercalated with a variety of inorganic and organic ions, metal complexes, and organic compounds. Polymer-clay composites at present time are consider as promising materials for both industrial and fundamental purposes [2]. Among them, a montmorillonite is one of the most intensively explored catalytic materials in heterogeneous catalysis due to its low cost and eco-friendliness [3]. The montmorillonite of Tagansky deposit (TS) is a promising material for development new types of catalysts supported on polymer-clay matrix. The use of renewable plant polymers as polysaccharides for the synthesis of such composites and their application in the catalysis meets the requirements of the twelve principles of green chemistry.

The partial catalytic oxidation of paraffins is of particular interest to industry, as it allows the production of valuable oxygen-containing products from crude hydrocarbons. The proper developed catalysts is critical to produce target products based on these processes. A promising approach is to create heterogeneous polymer-metal catalysts that demonstrate significant activity and selectivity in various oxidation reactions at low temperatures and pressures.

In this work, we present the results of a study of the catalytic activity of supported copper and cobalt catalysts in cyclohexane oxidation with hydrogen peroxide under mild conditions. Synthetic oxides

(MgO, Al₂O₃, ZnO) and natural montmorillonite (TS) were used as supports. Pectin (PC), obtained from sugar beet pulp, was applied to produce polymer-modified supports. The catalysts were prepared by the previously developed method of consequent adsorption of polymer and then metal salts on support [4]. According to transmission electron microscopy data, the introduction of pectin into the supported catalysts promotes the formation of metal (Cu or Co) nanoparticle on the surface of the support [5]. The metal content in the catalyst was 1wt.%.

Cyclohexane oxidation was carried out in acetonitrile, as solvent, at 40°C and atmospheric pressure in a thermostated reactor with constant stirring. The reaction time was 4 hours. Hydrogen peroxide was used as oxidising agent. In the first runs, the catalysts tested in hydrogen peroxide decomposition under mild conditions. The activity of the copper catalysts in this reaction decreased, depending on the nature of the supports, as follows: Cu-PC/ZnO > Cu-PC/Al₂O₃ > Cu-PC/ TS > 1% Cu-PC/MgO. The rate of O₂ evolution on pectin-containing cobalt catalysts decreased in the following sequence: Co-PC/Al₂O₃ > > Co-PC/TS > Co-PC/ZnO > Co-PC/MgO.

Oxidation of cyclohexane with hydrogen peroxide is accompanied with lower volume of oxygen release. This indicates participation of the oxygen in the cyclohexane oxidation. Chromatographic analysis detected formation only two products: cyclohexanone (C-none) and cyclohexanol (C-ol), which are call as KA-oil (ketone and alcohol). It should be noted that more amount of ketone to compare with alcohol was formed on all of the catalysts studied. The C-none:C-ol ratio, depending on the nature of the catalyst, ranged from 1.1 to 1.6 (table). Among the copper catalysts, the most active was a pectin-containing catalyst supported on TS, on which the conversion of cyclohexane was 11.2% (table). The yield of KA-oil decreased on the following row: TS > Al₂O₃ > MgO > ZnO.

In the case of cobalt catalysts, the highest conversion was achieved on 1%Co-PC/Al₂O₃ (5.8%). The following regularity was found. The activity of catalysts characterized by an acidic properties and a high specific surface area of supports (TS = 100.7 m²/g and alumina = 96.0 m²/g) was higher than on basic oxides (ZnO = 7.5 m²/g and MgO = 6.8 m²/g) [6].

Oxidation of cyclohexane on 1% pectin-containing copper, cobalt catalysts deposited on the various supports

Catalyst	Reaction products		Conversion, %	Ratio of C-none: C-ol
	Cyclohexanone, %	Cyclohexanol, %		
Cu-PC/TS	6.4	4.8	11.2	1.3
Cu-PC/Al ₂ O ₃	5.9	4.0	9.9	1.5
Cu-PC/ZnO	3.0	2.0	5.0	1.5
Cu-PC/MgO	2.5	1.7	4.2	1.1
Co-PC/TS	2.9	1.8	4.7	1.6
Co-PC/Al ₂ O ₃	3.3	2.5	5.8	1.3
Co-PC/ZnO	2.4	1.7	4.1	~1.4
Co-PC/MgO	–	–	–	–

Thus, the copper and cobalt catalysts based on pectin-modified oxides and TS were synthesized and studied in the reactions of decomposition of hydrogen peroxide and oxidation of cyclohexane. The most effective were copper catalysts. The optimal support for fixing the active phase (Cu²⁺) was found the monmorillonite of the Tagansky deposit.

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ПЕКТИН-МОДИФИЦИРЛЕНГЕН ОКСИДТЕРГЕ ЖӘНЕ «ТАГАН» КЕН ОРНЫНЫҢ МОНТМОРИЛЛОНИТІНЕ БЕКІТІЛГЕН МЫС ЖӘНЕ КОБАЛЫТ КАТАЛИЗАТОРЛАРДЫҢ ҚАТЫСУЫ АРҚЫЛЫ ЦИКЛОГЕКСАНДЫ ТОТЫҚТЫРУ

Аннотация. Жұмсартылған жағдайда сутегі асқын тотығымен циклогександы тотығу үдерісі үшін пектин (ПК) негізінде мыс және кобальтты катализаторлар синтезделді. Тасымалдағыштар ретінде синтетикалық оксидтер (MgO, Al₂O₃, ZnO) және табиғи Таған кен орнының монтмориллониті (ТС) пайдаланылды. Циклогексанның тотығуы ацетонитрилде 40°C температурада, атмосфералық қысымда және термостагирленген реакторда тұрақты араластыру арқылы жүргізілді. Мыс катализаторларының тиімділігі анықталды. Белсенді фазаны (Cu²⁺) бекіту үшін оңтайлы тасымалдаушы Таған кен орнының монтмориллониті табылды. Мыс катализаторларының арасында ТС негізіндегі құрамында пектин кездесетін катализатордың белсенді екені анықталды, ондағы циклогексан конверсиясы 11,2% құрады.

Түйін сөздер: Циклогексан, тотығу, монтмориллонит, пектин, мыс катализаторлары, кобальтті катализаторлар.

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ОКИСЛЕНИЕ ЦИКЛОГЕКСАНА НА МЕДНЫХ И КОБАЛЬТОВЫХ КАТАЛИЗАТОРАХ, НАНЕСЕННЫХ НА ПЕКТИН-МОДИФИЦИРОВАННЫЕ ОКСИДЫ И МОНТМОРИЛЛОНИТ ТАГАНСКОГО МЕСТОРОЖДЕНИЯ

Аннотация. Были синтезированы нанесенные медные и кобальтовые катализаторы на основе пектина (ПК) для процесса окисления циклогексана пероксидом водорода в мягких условиях. В качестве носителей были использованы синтетические оксиды (MgO, Al₂O₃, ZnO) и природный монтмориллонит Таганского месторождения (ТС). Окисление циклогексана проводили в ацетонитриле при температуре 40°C и атмосферном давлении в термостатированном реакторе с постоянным перемешиванием. Наиболее эффективными оказались медные катализаторы. Оптимальным носителем для фиксации активной фазы (Cu²⁺) является монтмориллонит Таганского месторождения. Среди медных катализаторов наиболее активным является пектинодержащий катализатор на основе ТС, на котором конверсия циклогексана составила 11,2%.

Ключевые слова: циклогексан, окисление, монтмориллонит, пектин, медные катализаторы, кобальтовые катализаторы.

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**IMPORT SUBSTITUTION OF SOFTWARE FOR DIGITALIZATION
OF INDUSTRY IN THE REPUBLIC OF KAZAKHSTAN**

Abstract. The state program "Digital Kazakhstan" aims to digitalize all spheres of life and economy of Kazakhstan, leading the country to the fourth industrial revolution. In order to increase digital competitiveness on the world stage, domestic developers should pay attention to international experience, study the experience of leading companies and create their own product aimed at the economy and infrastructure of the Republic of Kazakhstan. The paper reviews foreign and domestic developments in the field of mathematical modeling of chemical and technological processes. Authors describe software complexes "SPK-01-20" and "PVC" created for mathematical modeling of nanostructured sorbents, and determining the optimal configuration of catalytic converters.

Key words: software, airgel, nanomaterials, catalytic converter, mathematical modeling, digitization.

Against the background of the situation in the world, the government of our republic pays great attention to the program "Digital Kazakhstan". The main objective of the program is digitization of all the spheres of Kazakhstan life and economy in order to take the opportunity to occupy the frontline on the world scene, as well as to enhance the quality of the public life and to establish favorable conditions for entrepreneurial development [1-2]. In the coming years it is planned to widely introduce digital technologies into business and industry, attract investments in domestic IT start-ups, commercialize scientific developments, work on import substitution of software. In order to increase digital competitiveness on the world stage, domestic developers should pay attention to international experience, study the experience of leading companies and create their own product aimed at the economy and industry of Kazakhstan.

Today such companies as Unisim, Predict, Ansys, MSC occupy the leading place in digitalization of a wide range of physical and chemical processes both in the world and in Kazakhstan.

Honeywell Predict is a real-time corrosion control system used in refining, transportation, gas refineries and refineries, in exploration and oil and gas production. More than 20 years of experience in modeling and developing solutions to problems has allowed the company to build up an extensive database, allowing for the most accurate forecasts. The value of these technologies for corrosion protection lies primarily in the financial effect. Another product by Honeywell, UniSim Design Suite provides an accurate and intuitive process modeling solution that enables engineers to create steady-state and dynamic models for plant and control design, safety studies, performance monitoring, troubleshooting, operational improvement, digital twins, business planning and asset management [3]. The software enables users to create models quickly to evaluate many scenarios. The interactive environment allows for easy 'what-if' studies and sensitivity analysis. The top candidates can be used to create high fidelity models in which additional equipment and process details are included.

ANSYS and MSC are universal multidisciplinary integrated environments for virtual product development and engineering calculations, existing, solving problems in various fields of engineering (structural strength, thermodynamics, fluid and gas mechanics, electromagnetism and many others). ANSYS exists and develop over the past 30 years currently having 200,000 business and university jobs

worldwide. With the help of MSC, the most advanced samples of aviation, automobile, space technology, high-tech devices and structures in other fields of technology are being developed.

Starting in 2015, «D.V. Sokolsky Institute of Fuel, Catalysis and Electrochemistry» JSC began its way to study the process of creating digital twins and engaged in mathematical modeling of chemical and technological processes. In 2017, within the framework of the scientific project “High-precision modeling for structure prediction and properties of functional and composite nanomaterials using parallel computing”, the first software-computing complex “PVC” was developed. The complex allows to predict the process of adsorption of solid model substances in nanopores of inorganic aerogels.

“PVC” consists of two sections: "Structure Generator" and "Chromatography and Adsorption." Due to the fact that the process of chromatography and, in particular, adsorption is an extremely long process (can take up to 48 hours per sample), these processes are modeled in “PVC” so that research could be carried out without using of reagents, expensive instruments and extra time. Through the comparative analysis of modeling methods using parallelisms of different types (coarse and fine grain), 3 models of generation of chaotic structures were selected: weakly overlapping spheres model (OSM), diffusion limited aggregation with multiple crystallization centers model (MultiRLA), diffusion limited cluster aggregation model (DLCA). Monte Carlo techniques used in these cell-automatic models effectively produce important parameters such as pore size distribution, cluster structure dimensions, and local particle concentrations in the system. In order to bring the simulation results closer to the conditions of real tests and increase the accuracy of calculations, such environmental parameters as temperature, properties of adsorbed solid substance, pressure are taken into account. The software allows to perform calculations on supercomputers using OpenMP and MPI cluster computing technologies, as well as using CUDA fine grain parallelism technology. The software module is implemented in the C# programming language and has the first edition. “PVC” can be used in higher education institutions, specialized research institutes, scientific centers of Kazakhstan, which deal with the problems of creating a new generation of sorbents, as well as the development of new porous materials with a chaotic structure for the chemical, pharmaceutical, medical, space, construction fields.

Software "SPK-01-20" was developed in 2020 within the framework of the scientific project "Modeling of processes in neutralizers of toxic gases for determining their optimal composition and design using parallel computing". It is intended for users for users who do not have special knowledge in the fields of chemistry, mathematical modeling and programming, based on the initial data (composition, temperature and gas flow rate), to quickly obtain the optimal catalyst parameters necessary for the most effective purification of toxic exhaust gases of motor vehicles, diesel generators and industrial facilities by simulating processes taking place in the catalytic converter using parallel calculations. The software complex is a modular hierarchical structure, this allows a gradual deepening in the details of the process being studied by complicating the number and hierarchy of mathematical models as the program develops, thereby gradually creating a full digital twin. The basis of numerical modeling of processes in the neutralizer is the approach based on the theory of cell automata on Boltzmann lattices. This method has proven itself in the simulation of dynamic processes, it is easily to parallelize. Modeling the dynamics of the gas flow passing through the catalytic converters allows to obtain the resistance of the catalytic units and choose the correct geometry to avoid pipe rupture. Data processing module of experimental research results is a constantly replenishing virtual MySQL database storing data on results of aerodynamic as well as physical and chemical tests of catalytic converters. The reference to the experimental database accelerates the modeling process, allows to carry out comparative analysis of calculated and experimental data, thus guaranteeing adequacy of the mathematical model used in the “SPK-01-20”. The software complex is implemented in the programming language C#, the results visualization module is built in the Unity development environment. In the perspective of further development of the software complex it is planned to create a chemistry module. This module will allow to investigate the process of neutralizing gases of various compositions, as well as determine the degree of purification for a particular catalyst configuration. Rapid and automatic selection of the catalyst composition will allow to establish the production of catalytic converters for many types of toxic exhaust gas sources. Currently, "SPK-01-20" is successfully used in the catalytic converter manufacturing workshop at the institute.

Created software is oriented for a wide range of scientific problems, it is based on adequate mathematical models, has high performance, provides high accuracy and representativeness of the

estimated parameters and meets the basic requirements for such products in order to be competitive in the domestic software market.

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ҚАЗАҚСТАН РЕСПУБЛИКАСЫНДА ӨНЕРКӘСІПТІ ЦИФРЛАНДЫРУ ҮШІН БАҒДАРЛАМАЛЫҚ ҚАМТАМАСЫЗ ЕТЕТІН ИМПОРТ АЛМАСТЫРУ

Аннотация. Қазіргі әлем төртінші өнеркәсіптік революцияның – алдыңғы қатарлы технологиялар экономиканың тұтас саласын түбегейлі өзгертетін инновациялар дәуірінің табалдырығында тұр және барлығы жылдам қарқынмен жүріп жатыр. Кәсіпорынның цифрлық трансформациясы нәтижесінде болашақ бұйымның, өндірістік желінің немесе жалпы кәсіпорынның цифрлық қосындыларын – виртуалды модельдерін қолдана бастайды. «Цифрлық Қазақстан» мемлекеттік бағдарламасы елімізді төртінші өнеркәсіптік революцияға жетелей отырып, Қазақстан өмірі мен экономикасының барлық салаларын цифрландыруды мақсат етеді. Әлемдік аренадағы цифрлық бәсекеге қабілеттілікті арттыру мақсатында отандық әзірлеушілердің халықаралық тәжірибеге назар аударуы, жетекші компаниялардың тәжірибесін зерделеуі және Қазақстан Республикасының экономикасы мен инфрақұрылымына бағытталған өнімін жасауы тиіс. Жұмыста химия-технологиялық үдерістерді математикалық модельдеу саласындағы шетелдік және отандық әзірлемелерге шолу жүргізіледі. «ПВК» бағдарламалық-есептеу кешені бейорганикалық аэрогельдер нанопорында қатты модельді заттардың адсорбция үдерісін болжауға мүмкіндік береді. «СПК-01-20» мамандандырылған бағдарламалық кешені бастапқы деректердің негізінде (газ ағынының құрамы, температурасы және жылдамдығы) автокөлік құралдарының, дизель генераторлардың және өнеркәсіптік объектілердің ұйғтты пайдаланылған газдарын параллель есептеуді қолдана отырып, бейтараптандырғышта өтетін үдерістерді модельдеу жолымен тиімді тазарту үшін қажетті бейтараптандырғыштың онтайлы параметрлерін жедел алуға мүмкіндік береді.

Түйін сөздер: бағдарламалық қамтамасыз ету, аэрогель, наноматериалдар, каталитикалық бейтараптандырғыш, математикалық модельдеу, цифрландыру.

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ИМПОРТОЗАМЕЩЕНИЕ ПРОГРАММНОГО ОБЕСПЕЧЕНИЯ ДЛЯ ЦИФРОВИЗАЦИИ ПРОМЫШЛЕННОСТИ В РЕСПУБЛИКЕ КАЗАХСТАН

Аннотация. Современный мир находится на пороге четвертой промышленной революции – эпохи инноваций, когда передовые технологии радикально меняют целые отрасли экономики, и все происходит довольно быстрыми темпами. В результате цифровой трансформации предприятия начинают применять цифровые двойники – виртуальные модели будущего изделия, производственной линии или предприятия в целом. Государственная программа «Цифровой Казахстан» ставит своей целью цифровизацию всех сфер жизни и экономики Казахстана, ведя страну к четвертой промышленной революции. С целью повышения цифровой конкурентоспособности на мировой арене отечественным разработчикам следует обращать внимание на международный опыт, изучать опыт лидирующих компаний и создавать собственный продукт, нацеленный на экономику и инфраструктуру Республики Казахстан. В работе проводится обзор зарубежных и отечественных разработок в области математического моделирования химико-технологических процессов. Программно-вычислительный комплекс «ПВК» позволяет предсказывать процесс адсорбции твердых модельных веществ в нанопорах неорганических аэрогелей. Специализированный программный комплекс «СПК-01-20» на основе из исходных данных (состав, температура и скорость потока газа) позволяет оперативно получать оптимальные параметры нейтрализатора, необходимые для наиболее эффективной очистки токсичных выхлопных газов автотранспортных средств, дизель генераторов и промышленных

объектов путем моделирования процессов, проходящих в нейтрализаторе с применением параллельных вычислений.

Ключевые слова: программное обеспечение, аэрогель, наноматериалы, каталитический нейтрализатор, математическое моделирование, цифровизация.

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**MECHANOCHEMICAL TRANSFORMATIONS
OF HEAVY OIL STOCK IN THE PROCESS
OF HYDRODYNAMIC EFFECT**

Abstract. At the current time the general trend of oil industry is the decrease of proven light oil reserves (the depletion has accelerated), virtually all of the increase of reserves occurs through the oil. At the same time, according to expert data, global reserves of heavy oil constitute over 810 billion tons. Selection of technology for refining the heavy oil stock, during the conversion of which the thermally sensitive high-molecular components of the destruction of organic compounds, resins and asphaltenes are formed in reaction zone, remains a major constraint. In this regard the research of non-traditional technique of refining the high-viscosity oils and their stocks is very valuable and important. The priority is being given to the study of chemical conversion of heavy oil stock high molecular components under the mechano-wave and other types of action. The use of wave technologies is a promising method for reagentless size change of oil system disperse particles. The main directions of application of the effects of mechanical activation of substances on the change in the composition and properties of hydrocarbon substances are reviewed. The possibilities of application of mechanical activation of oil as an effective way for accelerating the mechanochemical processes occurring in a hydrocarbon substance due to intense mechanical loads are considered. The research results indicate the prospects of using the hydrodynamic effect in the technologies for treatment of heavy oil stock for refining and for the disposal of waste of oil and gas complex, which can be considered as secondary industrial raw materials.

Key words: High viscosity oils, heavy oil residues, mechano-wave action, fluid hydrodynamic activator.

Relevance. Recently in many of the world’s oil-producing countries including Kazakhstan, production of so-called “light” oils continues to decline, which necessitates the involvement of heavy hydrocarbon stock (such as high-viscosity oil, native bitumen, shale coal and so on) in stock turnover.

Basic catalytic and thermal technologies do not allow reaching the depth of refining of heavy stocks, since the presence of heteroatoms and metals contained in resinous-asphaltene substances is the main reason for the deactivation of catalysts; demanding on the quality of stocks, large volumes of stillage residues are formed finally. In addition, these processes require the refining of heavy oil with preliminary treatment.

Phase transitions in the reactions of existing oil refining technologies [1-5] are accompanied by a change in the ratio of particle sizes constituting the oil disperse system. To manage phase transitions it is necessary to know the behavior of the components of oil systems during their interaction and physical and chemical transformations.

As we known, under wave effects, mild cracking reactions of high molecular weight oil compounds occur under milder conditions than thermal cracking or visbreaking processes [3,5].

Studies with the original oil sample and its mixture with bitumen. In order to establish the nature of the influence of mechanical activation on the physical and chemical properties of the components of heavy oil stocks, the mixture of high-viscosity oil and bitumen of the Karazhanbas deposit was studied. The nature of the influence of hydrodynamic effects on the properties of oils provides the processing of

samples separately and in combination with each other with the selection of the optimal ratio and with preliminary heating of the mixtures to 100 ° C.

The activation of various types of oil and oil residues was carried out on the hydrodynamic effects unit, which is described in [6].

The analysis of the results of laboratory studies showed that after hydrodynamic processing, the following changes are observed: increase in the number of light fractions; reduction in dynamic viscosity of oil depending on the type of oil; with an increase in the activation time of oil a gradual increase in temperature in the reaction zone to 80-85 ° C is observed.

The decrease of oil viscosity is directly related to the mechanochemical processes in oil as a result of hydrodynamic effects.

The obtained results indicate the ongoing transformations of the components of both oil and bitumen, i.e. during the processing of a mixture consisting of oil phases, both aggregation of the dispersed medium and chemical decomposition of high molecular weight compounds of both phases occur. These transformations lead to a change in the composition of both saturated C₃₆ – C₃₉, C₄₀ – C₄₄, and aromatic C₂₁ – C₂₅ hydrocarbons. For heavy oil of Karazhanbas deposit + bitumen there is an increase in the fraction content C₂₁ - C₂₅ from 6.34% to 17.80% after activation. And at the same time, there is a decrease in the fraction content C₃₆ - C₃₉ from 18.0% to 3.6%.

Thus, the hydrodynamic processing of oil in a mixture with heavy residues leads to the destruction of high molecular compounds with the simultaneous formation of light hydrocarbon fractions and this is also leads to the decrease in the viscosity of oil.

Conclusion The prospects of mechanical activation should benefit from the possibility of regulating the physical and chemical properties of substances. At present, various mechanical devices for mechanical activation have been developed based on various principles of wave action on a substance, which greatly expands the possibilities of using this method on an industrial scale. In addition, most of them are small-sized and at the same time highly efficient.

The development of technologies will increase the depth of hydrocarbon treatment and allow to use non-traditional types of man-made fuel resources. Technologies based on the use of the effects of mechanical activation of substances are environmentally friendly.

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ГИДРОДИНАМИКАЛЫҚ ЫҚПАЛ ЕТУ ҮДЕРІСІНДЕ АУЫР МҰНАЙ ШИКІЗАТЫНЫҢ МЕХАНИКАЛЫҚ-ХИМИЯЛЫҚ ӨЗГЕРІСІ

Аннотация. Қазіргі уақытта мұнай саласының жалпы үрдісі жеңіл мұнайдың (үдемелі қарқында саркылуда) араласқан қорының азайғанын білдіреді, тәжірибе жүзінде қордың барлық өсімі мұнай есебінен болады. Сонымен бірге, сарапшылардың деректері бойынша ауыр мұнайдың әлемдік қоры 810 миллиард тоннадан асатын шаманы құрайды. Ауыр мұнай шикізатын қайта өңдеу үшін технология таңдау күрделі мәселе күйінде қалуда, себебі оның конверсиясы кезінде реакциялық аумақта органикалық зат, шайыр және асфальтендердің термиялық тұрақсыз жоғары молекулалық бұзылу көріністері түзіледі. Осыған орай жоғары тұтқырлығы бар мұнайды және ауыр қалдықтарын өңдеудің дәстүрлі емес зерттеулері өте құнды және маңызды. Механикалық-толқынды және өзге әсер ету амалдар жағдайында мұнай шикізатының түрлі типінің жоғары молекулалық құрамдас бөлшектерінің химиялық өзгеру механизмдерін зерттеу басым болып саналады. Толқынды технологияларды қолдану – мұнай жүйелерінің диспертті бөлшек өлшемдерінің реагентсіз өзгеруі болашағы мол әдіс. Көмірсутекті заттардың құрамы мен қасиетінің өзгеруіне механикалық күшейту әсерін пайдаланудың негізгі бағыттары талданған. Қарқынды механикалық жүктеме салдарынан көмірсутекті зат арқылы өтетін механохимиялық үдерістерді үдетудің тиімді бағыты ретінде мұнайдың механикалық белсенділігін пайдалану мүмкіндіктері қарастырылған. Зерттеу нәтижелері екінші реттік техногенді шикізат ретінде қарастыруға болатын мұнайгаз кешені қалдықтарын пайдаға асыруға арналған және қайта өңдеудегі ауыр мұнай шикізатын дайындау технологияларында гидродинамикалық әсерді пайдаланудың болашағының бар екендігін дәлелдейді.

Түйін сөздер: Жоғары тұтқырлығы бар мұнай, ауыр мұнай қалдықтары, механикалық-толқынды әсер ету, сұйықтықты гидродинамикалық бесендіргіш.

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МЕХАНО-ХИМИЧЕСКИЕ ПРЕВРАЩЕНИЯ ТЯЖЕЛОГО НЕФТЯНОГО СЫРЬЯ В ПРОЦЕССЕ ГИДРОДИНАМИЧЕСКОГО ВОЗДЕЙСТВИЯ

Аннотация. В настоящее время общей тенденцией нефтяной отрасли является уменьшение разведанных запасов легкой нефти (их истощение идет ускоренными темпами), практически весь прирост запасов происходит за счет тяжелой высоковязкой высокосернистой нефти. В то же время, по экспертным данным, мировые запасы тяжелой нефти составляют более 810 миллиардов тонн. Выбор технологии для переработки тяжелого нефтяного сырья, при конверсии которого в реакционной зоне образуются термически неустойчивые высокомолекулярные фрагменты деструкции органических веществ, смол и асфальтенов остается сложной проблемой. В этой связи весьма ценны и важны исследования нетрадиционных методов обработки высоковязких нефтей и их тяжелых остатков. Приоритетным является изучение механизма химических превращений высокомолекулярных компонентов различного типа нефтяного сырья в условиях механо-волновых и других способов воздействия. Применение волновых технологий – перспективный способ безреагентного метода изменения размеров дисперсных частиц, в частности нефтяных систем. Проанализированы основные направления использования эффектов механической активации веществ на изменение состава и свойств углеводородных веществ. Рассмотрены возможности использования метода механоактивации нефти как эффективного направления ускорения механохимических процессов, протекающих в углеводородном веществе вследствие интенсивных механических нагрузок. Результаты исследований свидетельствуют о перспективности использования гидродинамического эффекта в технологиях подготовки тяжелого нефтяного сырья к переработке и для утилизации отходов нефтегазового комплекса, которые можно рассматривать как вторичное техногенное сырье.

Ключевые слова: высоковязкие нефти, тяжелые нефтяные остатки, механо-волновое воздействие, гидродинамический активатор жидкости.

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NEWS

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FULL CYCLE TECHNOLOGY OF LITHIUM ELECTRODE MATERIALS FOR LIB FROM DOMESTIC RAW MATERIALS

Abstract. In recent years, there has been a steady increase in lithium consumption in high technology. Therefore, new methods for the extraction of lithium are becoming increasingly important. The distribution of lithium stocks in the world is uneven, access to its stocks plays a significant role and affects technological development. Rare-metal pegmatites and lithium-bearing brine are used as the main industrial sources of lithium.

This paper discusses the development trends of lithium production from spodumene ore to produce high purity lithium carbonate. The geological characteristics of the main lithium deposits of East Kazakhstan, as well as the possibility of their industrial development, are analyzed. A technology has been developed to produce battery grade lithium carbonate from Kazakhstan spodumene concentrate. Based on high purity lithium carbonate (99.5%), the efficient cathode material LiFePO_4 for lithium-ion batteries was synthesized. The technology of a full cycle of processing domestic lithium-containing mineral and industrial raw materials into lithium carbonate for the production of high-tech products: anode and cathode materials for modern LIB is presented. An efficient technology of lithium electrode materials based on high-purity lithium carbonate from domestic spodumene raw materials has been developed. The fundamental possibility of creating a lithium cluster in Kazakhstan for the production of products with a high degree of readiness for the final consumer is shown according to the scheme: Spodumene ores → Lithium concentrate → Lithium carbonate → Lithium cathode materials → Batteries.

Key words: lithium, extraction, ore, spodumene, technology, lithium carbonate, lithium iron phosphate, lithium-ion battery.

Today, lithium is becoming increasingly popular in high-tech industries such as aircraft manufacturing, space industry, automotive, nuclear, energy, as well as in energy storage systems. In connection with the sharp increase in the production of electric vehicles in the world, lithium has come to be called “future gasoline” and “white oil”. Lithium-ion batteries (LIB) are the market leaders among all available battery technologies. Due to their high energy density, stability and duration of charge-discharge circulation, LIBs are the most promising sources for the needs of alternative energy. The trend towards green energy due to the exhaustibility of hydrocarbons in recent decades has given a great impetus to the development and use of lithium-ion batteries (LIBs). The rapid development of the market for battery devices, especially electric and hybrid cars and renewable energy, over the past 10 years has led to a sharp demand for higher-capacity materials for LIB. All this, as well as the development of technologies in portable electronics (phones and laptops / tablets) and electric vehicles, has led to the fact that lithium is becoming a new strategic material that can influence the sustainable development of the global economy. The market has an urgent task to produce lithium salts, in particular lithium carbonate as the main precursor of lithium electrode materials. The main lithium minerals suitable for producing lithium concentrates, as a rule, are part of rare-metal granite pegmatites. Pegmatite mineral concentrates account for > 60% of lithium production; of these, spodumene is the main raw material for producing lithium carbonate. High purity lithium carbonate of battery quality is the main precursor of lithium electrode materials [1].

The analysis shows that the current global lithium consumption environment is favorable for the emergence of a new producer of lithium compounds, such as Kazakhstan, which has investment-attractive proven large reserves of lithium-containing ores in the Eastern region. Kazakhstan has large reserves of various rare-earth metals and their accompanying lithium. According to the degree of readiness for development and development costs, lithium deposits of the East Kazakhstan region can be divided into two groups. The first group includes mineral deposits of lithium, in which more than 23 thousand tons of lithium oxide and other useful components are concentrated. Given the forecast for the intensive development of the lithium economy, these lithium reserves are of practical interest for their development.

A promising lithium-containing technogenic object is dumps after ore beneficiation of the deposit, formed as a result of their processing at the Belogorsk mining and processing plant. Over the period of his work, more than 32 thousand tons of lithium are in the dumps of processing plants.

All this sets the task of creating a new lithium industry in Kazakhstan in order to become an important player in the world market of storage systems and energy sources, renewable energy, and electronics.

The objective of the proposed technology is the development of a method for obtaining high-grade lithium carbonate directly from spodumene, by passing the stage of obtaining a technical grade product, simplifying the process of cleaning a lithium-containing solution from impurities.

The technical result is to obtain high-grade lithium carbonate in a single technological process of processing spodumene, reducing the number of technological operations of cleaning from impurities, eliminating the expensive operation of concentrating a solution of lithium sulfate by the method of evaporation [2].

The technical result is achieved by a method of obtaining high-grade lithium carbonate from spodumene concentrate, including spodumene calcining, sulfation, water leaching, purification of lithium sulfate from impurities, lithium concentration in solution, reagent lithium carbonate precipitation, washing of lithium carbonate, characterized in that lithium concentration is carried out by a membrane method reverse osmosis, cleaning of metal and anions from impurities is carried out by caustification of lithium sulfate, lithium carbonate is deposited by ammonium carbonate salt at a temperature not more than 40 °C, followed by heating to 90 °C. An essential feature of the method is the use of reverse osmosis membranes for the concentration of a solution of lithium sulfate, which makes it possible to exclude from the technology a very laborious and expensive method of evaporation of a solution of lithium sulfate [3].

Further purification, including caustification of lithium carbonate, ultrafiltration and ion-exchange sorption of a lithium hydroxide solution followed by precipitation with ammonium carbonate salt, bicarbonization and decarbonization of lithium carbonate, made it possible to obtain high purity lithium carbonate 99.5% [4].

Innovative electrode materials for LIB were obtained from high purity lithium carbonate on the basis of domestic spodumene raw materials by synthesis using method of aerosol pyrolysis (MAP) and sol-gel method (ZGM). Thus obtained lithium- iron- phosphate showed quite satisfactory electrochemical properties [5].

The end result is a new generation of innovative cathode and anode materials for modern LIBs with significantly increased capacity and stability, obtained from lithium precursors - battery grade lithium carbonate based on domestic spodumene raw materials.

Thus, technologies have been developed for producing innovative electrode materials for modern lithium batteries with the creation of a full cycle of the production line from lithium extraction from domestic mineral raw materials to high-tech products - cathode and anode materials of modern lithium-ion batteries.

Scientific and technological foundations have been created for the development in Kazakhstan of a high-tech lithium cluster for the production of products with a high degree of readiness for the final consumer according to the scheme: Spodumene ores → Lithium concentrate → Lithium carbonate → Lithium cathode materials → Batteries. Developed a business plan for the creation of cluster-oriented lithium production.

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ОТАНДЫҚ ШИКІЗАТТАН АЛЫНҒАН ЛИБ-КЕ АРНАЛҒАН ЛИТИЙЛІ ЭЛЕКТРОДТЫ МАТЕРИАЛДАР ТЕХНОЛОГИЯСЫНЫҢ ТОЛЫҚ ЦИКЛІ

Аннотация. Соңғы жылдары жоғары технологияда литийді тұтынудың тұрақты өсу қарқыны байқалады. Сондықтан литий алудың жаңа әдістері барған сайын маңызды бола түсуде. Әлемде литий қорларының таралуы біркелкі емес, оның қорларына қол жеткізу маңызды болып саналады және технологиялық дамуға әсер етеді.

Бұл жұмыста жоғары таза литий карбонатын алу үшін сподумен кендерінен литийді өндірудің даму тенденциялары қарастырылды. Шығыс Қазақстанның негізгі литий кен орындарының геологиялық сипаттамалары, сондай-ақ олардың өнеркәсіптік даму мүмкіндігі талданды. Қазақстандық сподумен концентратынан батарея сапасындағы литий карбонатын алу технологиясы әзірленді. Жоғары таза литий карбонатынан (99,5%) литий-ионды аккумуляторлар үшін тиімді LiFePO_4 катодты материалы синтезделді. Жоғары технологиялық өнім: заманауи литий-ионды батареяларға (ЛИБ) арналған анод және катод материалдарын алу үшін отандық литий құрамды минералды және техногенді шикізатты литий карбонатына өндеудің технологиясының толық циклі ұсынылды. Отандық сподумен шикізатынан литий карбонат негізіндегі литий электродты материалдарын алудың тиімді технологиясы әзірленді. Соңғы тұтынушыға жоғары дәрежедегі дайын өнім шығаруға арналған Қазақстанда литий кластерін құрудың негізгі мүмкіндігі келесі схемаға сәйкес көрсетілген: Сподуменді кендер → Литийді концентрат → литий карбонаты → Литийді катодтық материалдар → Аккумуляторлар.

Түйін сөздер: литий, экстракция, кен, сподумен, технология, литий карбонаты, литий темір фосфаты, литий-ионды аккумулятор.

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ТЕХНОЛОГИЯ ПОЛНОГО ЦИКЛА ЛИТИЕВЫХ ЭЛЕКТРОДНЫХ МАТЕРИАЛОВ ДЛЯ ЛИБ ИЗ ОТЕЧЕСТВЕННОГО СЫРЬЯ

Аннотация. В последние годы наблюдается устойчивый рост потребления лития в области высоких технологий. Поэтому все большее значение имеют новые методы извлечения лития. Распределение запасов лития в мире неравномерно, доступ к его запасам играет значительную роль и влияет на технологическое развитие. В качестве основных промышленных источников лития используют редкометалльные пегматиты и литиеносную рапу.

В настоящей работе рассмотрены тенденции развития производства лития из сподуменовой руды для получения карбоната лития высокой чистоты. Проанализированы геологические характеристики основных литиевых месторождений Восточного Казахстана, а также возможности их промышленного освоения. Разработана технология получения карбоната лития аккумуляторного сорта из казахстанского сподуменового концентрата. На основе карбоната лития высокой чистоты (99,5%) синтезирован эффективный катодный материал LiFePO_4 для литий-ионных батарей (ЛИБ). Представлена технология полного цикла переработки отечественного литийсодержащего минерального и техногенного сырья в карбонат лития для производства высокотехнологичной продукции: анодных и катодных материалов для современных ЛИБ. Разработана эффективная технология литиевых электродных материалов на основе высокочистого карбоната лития из отечественного сподуменового сырья. Показана принципиальная

возможность создания в Казахстане литиевого кластера для производства продуктов с высокой степенью готовности для конечного потребителя по схеме: сподуменные руды → литиевый концентрат → литиевый карбонат → литиевые катодные материалы → аккумуляторы.

Ключевые слова: литий, извлечение, руда, сподумен, технология, карбонат лития, литий-железо-фосфат, литий-ионный аккумулятор.

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