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XVII INTERNATIONAL FORUM-CONTEST OF STUDENTS AND YOUNG RESEARCHERS

TOPICAL ISSUES OF RATIONAL USE OF NATURAL RESOURCES

SCIENTIFIC CONFERENCE ABSTRACTS

VOLUME 1

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UNDER THE AUSPICES OF UNESCO

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The Volume contains works of young researchers - participants of the XVII International Forum-Contest of Students and Young Researchers “Topical Issues of Rational Use of Natural Resources”, which was held at St. Petersburg Mining University on 31 May-6 June, 2021. The Volume can be of great interest for a wide range of researchers, scientists, university lecturers, specialists and managers of industrial enterprises and organisations as well as for businesspeople involved in exploration, prospecting, development and processing of minerals.

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Session 1. INNOVATIVE TECHNOLOGIES IN THE FIELD OF DEVELOPMENT AND OPERATION OF HYDROCARBON FIELDS

Session 5. PHYSICAL AND CHEMICAL PRINCIPLES OF MANUFACTURING PROCEDURES AND EQUIPMENT FOR MINERAL PROCESSING AND METALLURGY

Session 6. SOLID MINERALS EXTRACTION TECHNOLOGIES LABOR PROTECTION AND INDUSTRIAL SAFETY

Session 7. GEOMECHANICS AND MINE SURVEYING IN MINING AND UNDERGROUND CONSTRUCTION

Session 8. GEODESY, GEOINFORMATICS, LAND MANAGEMENT AND CADASTER

Session 9. PROSPECTING AND EXPLORATION OF MINERAL DEPOSITS, MINERALOGY, PETROLOGY, GEOCHEMISTRY, HYDROGEOLOGY, GEOLOGICAL ENGINEERING, AND GEOPHYSICAL EXPLORATION TECHNIQUES

ANNA AIRAPETOVA
North-Caucasus federal University
ALEXANDR VERISOKIN
North-Caucasus federal University

DEVELOPMENT OF A DEVICE FOR CLEANING PERFORATION CHANNELS IN A WELL

Introduction. Hydraulic fracturing is currently one of the most effective methods for increasing well productivity. But usually in the process of this method the proppant gel doesn't disperse completely. The suspension settles and clogs the perforation channels of the well. This reduces the effect of hydraulic fracturing.

Aim. After studying this problem, we set out to create a new cost-effective device for flushing perforation channels in the well.

Materials and methods. To solve this problem we have conducted an analysis of analogues and developed more sophisticated device that washes perforation channels. Proposed device is reliable, provides high efficiency of jets action, has a simple construction and has bigger durability in comparison to competitors.

Results. This device is lowered into the well to the required depth. Then the washing liquid is pumped through it. Due to the rotation of the nozzle heads in opposite directions, and due to the action of the jets at an angle to the well wall, it is possible to flush the perforation channels.

As a result, our device has a simple design, which makes it less expensive to manufacture. But at the same time we managed to maintain and increase the efficiency and productivity of the device compared to its analogues.

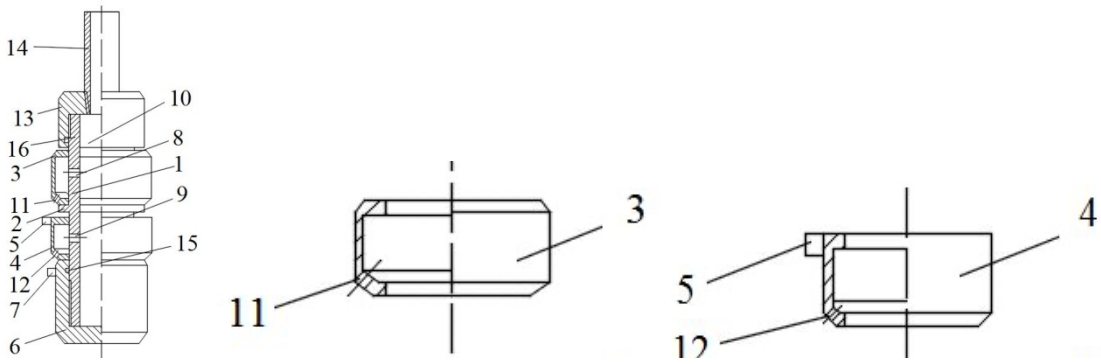

Figure 1 – Drawings of the device: in its initial position, general view and nozzle heads separately

Conclusion. We think that all gas and oil companies around the world may be interested in using this technology after fracturing in order to reduce time for stimulation of wells and save a lot of money.

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[3]. 2014.09.27Parosochenko Sergej Anatol'evich (RU)FLUSHING DEVICE

MAKSIM I. BORISOV
Perm National Research Polytechnic University
IVAN B. STEPANENKO
Perm National Research Polytechnic University

MAGNETIC OIL TREATMENT TO REDUCE THE VISCOSITY AND INTENSITY OF THE FORMATION ASPHALTENE-RESIN-PARAFFIN DEPOSITS

Currently, many oil fields in the Perm Region are in the late stages of development, which dictates the introduction of innovative technologies in order to optimize the oil production process and combat existing complications. These are the formation of asphaltene-resin-paraffin deposits (ARPD) on the walls of pipes and equipment, high-viscosity emulsions, corrosion, salt deposition, which entails large financial costs for repair and cleaning operations. Control technologies are divided into methods of prevention and methods of elimination of already formed complications. The current solution to these issues is the technology of magnetic oil treatment. The effectiveness of the magnetic field effect on oil was studied by a number of authors -Zlobin A. A., Loskutova Yu. V., Ushakov A.V., Phuong-Tung Nguyen, T. Vermeer, Klassen V. I.

At the moment, there is no systematic scientific approach that explains the mechanism of the effect of the magnetic field on oil. A large number of scientific studies and patent applications confirm the relevance of research in this area. According to the works of the above-mentioned authors, a general conclusion can be marked that the object of the magnetic field is iron compounds that are in complex with asphaltene and form an "armor shell" (Fig.1) [1]. When these complexes are destroyed, an increase in the centers of crystallization of deposits is achieved, which leads to a decrease in their accumulation on the walls of pipelines, a decrease in the dispersion of the emulsion, which leads to an improvement in rheological properties, and the polarization of water droplets, which accelerates the process of coagulation [2].

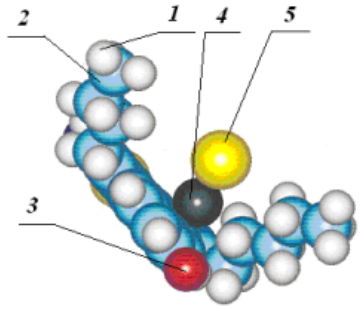

Figure 1 – Model of the complex “asphaltene – iron sulfide”. 1 – a hydrogen atom; 2 – carbon; 3 – oxygen; 4 – iron; 5 – sulfur

The authors of [3], [4] obtained practical results of magnetic oil treatment, associated with a reduction in corrosion of pipelines and equipment by up to 50%, a decrease in liquid viscosity by up to 30%, an increase in the rate of emulsion delamination by up to 50%, and a decrease in the intensity of formation of ARPD and salt deposits. Liquids with a high content of iron compounds, salt ions and a mass percentage of resinous substances are most effectively subjected to magnetic treatment. An important advantage of this type of treatment is the energy efficiency of the process and the absence of harmful effects on the environment, personnel and equipment [5].

The treatment is carried out by devices of a static and alternating magnetic field. The advantages of the first group of devices are simple design and relative durability. The advantages of the second group is the ability to select the treatment mode for each oil. As part of the research, a pulsed electromagnetic installation was developed that reaches a magnetic induction value of up to 1 T and a pulse repetition frequency of up to 50 Hz (Fig.2). The goal of the research is to identify the effectiveness of reducing the viscosity and intensity of the formation of ARPD, depending on the magnitude of the magnetic induction and pulse repetition frequency.

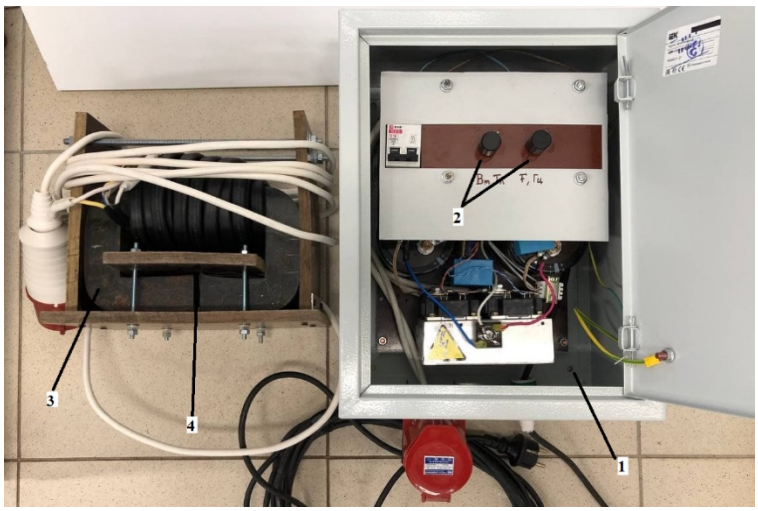

Figure 2 – Pulsed magnetic installation. 1 – control station; 2 – adjustment of magnetic induction and frequency; 3 – electromagnet; 4 – magnetic gap

According to the results of the research conducted by the authors, the following results were obtained:

1) The possibility of reducing the intensity of the formation of ARPD to 80%;
2) Providing a 20-50% reduction in viscosity, depending on the selected treatment mode;
3) The direct dependence of the magnetic induction value and the processing efficiency is obtained;
4) The most effective frequency of treatment is 30 Hz.

The results of this work confirm the effectiveness of magnetic oil treatment. The obtained dependences of the decrease in the intensity of the formation of ARPD and viscosity on the parameters of the impact of the physical field are of scientific novelty. In order to form a general theory of magnetic oil treatment, a number of tests and scientific studies are still to be carried out, in particular, the formation of criteria for selecting an object, clarifying the mechanism of the treatment, and identifying the presence of magnetic fluid memory.

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The academic advisors are Ph.D. Ilyushin P.Y. and Ph.D. Lekomtsev A.V.

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Dr. Prof. LUBOV` A. MAGADOVA
National University of Oil and Gas «Gubkin University»
POLINA K. KRISANOVA
National University of Oil and Gas «Gubkin University»
ANDREY A. FILATOV
National University of Oil and Gas «Gubkin University»

DEVELOPMENT AND RESEARCH OF FRACTURING FLUID BASED ON MODIFIED VISCOELASTIC COMPOSITION

Hydraulic fracturing is one of the most common and effective methods of enhanced oil recovery. Crosslinked guar gels are most commonly used in fracturing processes [1]. Remnants of guar gel are able to clog the pore space of reservoirs and formed hydraulic fractures. Residual conductivity of the proppant pack is 50-60%, even with the use of oxidative breakers, which degrades the quality of the hydraulic fracturing process. Viscoelastic surfactant (VES) fluids are currently a promising alternative to guar gels. VES fracturing fluids are characterized by lower viscosities and high elastic properties. These properties of the composition ensure the transportation of the proppant deep into the treated interval. VES fluids are destroyed and carried along with formation fluids to the surface upon contact with oil and formation water, thereby eliminating the need to introduce breakers into the fracturing fluid [2,3]. However, the use of VES is still limited due to their low thermal stability, high cost, and addiction to leakoff into the formation. Therefore, the issue of modifying these systems is relevant.

In this work, VES systems based on a zwitterionic surfactant were studied. Methylcellulose (MC) was studied as a modifier. This choice was based on the possibility of association between surfactant and polymer molecules [4]. Such associates act as additional centers of engagement in the micellar network, strengthening its structure. In addition, the study was carried out of the effect of a polyvalent metal salt (PMS) on the VES fluids properties. The PMS ions promote the shielding of hydrophilic groups of surfactant molecules. Due to this, the electrostatic repulsion between the head groups of the surfactant decreases, which leads to the strengthening of the micelle structure. Complex compounds can form between the polyvalent metal ion and VES molecules, which can also positively affect the viscoelastic structure of the system.

In this work, rotational and oscillatory studies were carried out on a viscometer HPHT M5600 Grace Instrument Rheometr (figure 1).

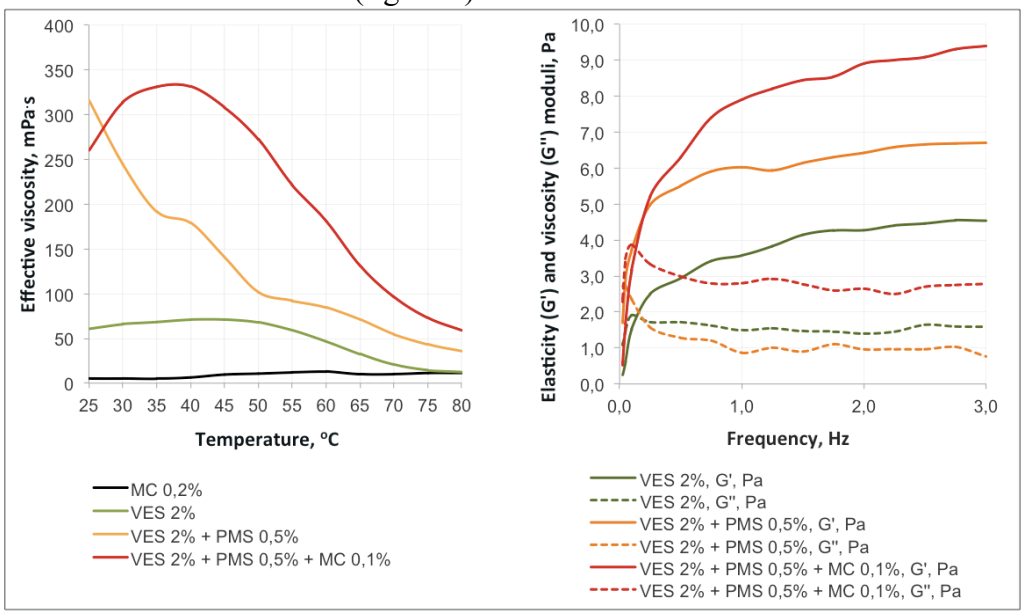

Figure 1 – Rotational studies of systems at shear rate 100 s-1 (left) and oscillatory studies of systems (right)

As can be seen from the data in Figure 1, synergistic effects appear in the VES-PMS-MC system. These effects are manifested in a sharp increase in viscosity, including at high temperatures. At the same time, solutions of VES and MC in individual form have low rheological parameters. The predominance of the elasticity modulus over the viscosity modulus in the studied compositions can be concluded from the data of oscillatory studies. This indicates large structuredness of the polymer-micellar systems.

As part of the work, proppant suspension ability test was carried out. This test determines one of the most important technological properties of the fracturing fluid. It was found the VES fluid has proppant suspension ability comparable to high viscosity crosslinked guar gel. The results are explained by the high values of the elastic properties of VES systems.

From the above, it can be concluded that the use of polymers with salts of polyvalent metals is perspective as modifiers of VES fluids. In further studies, it is planned to evaluate the ability of the polymer additive to influence the leakage of VES fluids. Based on the structure of the surfactant used, it is assumed that these compositions have a hydrophobic effect and a stabilizing effect on clays. Relevant studies will also be carried out.

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DAWID GAJDA
Silesian University of Technology

SEALING EFFICIENCY OF EPOXY LINERSIN UNDERGROUND HYDROGEN STORAGE

Underground large – scale energy storage is necessary to develop the renewable energy sources and increase their share in energy production. Excessive energy needs to be stored in order to reduce the production fluctuations, caused by the uneven atmospheric conditions, influencing directly on the renewable energy sources efficiency. One of the possibility is to produce the hydrogen, using excessive energy in Power-2-Gas technology, and utilize it in peak demand periods. However, hydrogen needs to be stored in efficient and safe way.

Due to the strong diffusion capability of hydrogen, a proper sealing materials need to be used to prevent the hydrogen from leaking. There are a number of operating Lined Rock Caverns (LRC) to store natural gas [1]. Lining responsible for sealing the gas tank is made of stainless steel. This material has a very low diffusion coefficient for hydrogen, which makes it an efficient sealing material. However, stainless steel is expensive and susceptible for hydrogen embrittlement [2].

A number of polymer materials were investigated to establish the substitution for the stainless steel in LRCs for hydrogen [3]. Substitution material should have a satisfying hydrogen permeability coefficient, as well as other properties, like mechanical strength, corrosion and erosion resistance. Material should also be available and economical. As a result of performed research, epoxy resin has a relevant sealing and mechanical properties to successfully substitute the stainless steel in LRC.

This paper deals with the sealing efficiency of the epoxy resin. A number of estimations have been done to investigate the amount of hydrogen leaks in different storage conditions (gas pressure, tank volume, liner thickness and storage time). Some geomechanical and engineering aspects of the Lined Rock Caverns are also discussed.

Laboratory research of hydrogen permeability of investigated samples, as well as leaks estimations through the sealing liner are promising for utilize the epoxy resin as a sealing liner in underground gas storage, in particular for storing hydrogen.

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ABDUMALIK T. GAYUBOV
Gubkin Russian State University of Oil and Gas
Dr. Prof. ANATOLY B. ZOLOTUKHIN
Gubkin Russian State University of Oil and Gas

ANALYSIS OF NON-LINEAR EFFECTS IN POROUS MEDIA USING MACHINE LEARNING METHODS

Fluid flow in a porous medium is an essential component in many areas of the oil and gas industry, such as field development, formation water hydrology, environmental protection and many others. An accurate description of fluid flow behaviour in porous media is necessary for solving the problems of field development system design. This task requires physical and mathematical models that correctly describe fluid flows under various reservoir conditions.

For many years, Darcy's law was considered the fundamental equation governing fluid flow in a porous medium. However, Darcy's law is valid for a certain range of fluxes and some basic assumptions (laminar single-phase flow, an isothermal condition, constant fluid viscosity, and no rock-fluid interaction) for fluid flow in porous media [1-3]. Indeed, when the flow rate increases, the pressure drop is no longer proportional to the seepage velocity. This phenomenon needs to be characterized as it is a decisive factor in reducing well productivity.

This paper examines the nonlinear effects of fluid flow in a porous medium, governed by a new equation from two aspects: equation derivation and experimental verification. The rigorous derivation of the new equation is presented with a semi-analytical approach in which the gas slippage effect and inertial forces are described. The derivation of this equation is based on a combination of the classical approach and modern analysis methods such as dimension analysis, data normalization and machine learning methods. Comparing the experimental results with the proposed model showed good agreement between them over the whole range of basic reservoir and fluid parameters. Studies have also shown a transition zone from linear to a nonlinear flow rule, which is determined by the interval of Forchheimer numbers. The use of the Forchheimer number made it possible to identify a universal law of fluid flow through a porous medium in a simple analytical form valid for any flow geometry.

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GAUHAR A. AKHMETZHANOVA
Satbayev University
ANAR M. ISKENDIROVA
Kazakh-British Technical University

NEW SUBSOIL CODE AND ITS IMPACT TO PETROLEUM EXPLORATION AND DEVELOPMENT OPERATIONS

According to BP Statistical Review of World Energy (2020) proved oil reserves of Kazakhstan listed as 30 thousand million barrels [1], and most of these reserves located in the Pre-Caspian sedimentary basin, both in shallow post-salt and deep pre-Kungurian complexes of sediments [2]. At the same time, geologists have identified 15 Sedimentary Basins with possible resources of about 76 billion tons of equivalent oil.

With the aim to accelerate exploration works, as a part of the execution of the of the National Plan "100 Concrete Steps" (steps 74 & 75), in 2017 was developed a new “Subsoil Code”, which entered into force on June 29, 2018. The main changes stipulated by the “Code” are simplified procedure for granting Subsoil use rights by analogy with the Australian model based on the “first in, first out” principle, transition to the International Standards for Reserves Estimation, provision of open access to geological information and its conversion to digital format, more strict requirements for liquidation of consequences of subsoil use to ensure environmental safety, etc. The New “Subsoil Code”, which is the legal framework that establishes the main principles of subsoil use, entailed changes to the subordinate documents defining the rules, requirements and recommendations in the Oil and Gas Industry.

The Oil field, where some of new provisions of legislation were applied to Subsoil user operating in Mangistau region of Kazakhstan, tectonically confined to the western part of Mangyshlak Basin, Zhetibay-Uzyen Fault Terrace Belt on northern slope of the basin (Figure 1). This area is one of petroliferous basins of Kazakhstan, with area of 75000 km2 and more than 30 discovered Oil and Gas fields. The Basin mainly controlled by NWW-SEE striking faults. Regionally, the faults and tectonic features generally presented as striking uplift-depression pattern including the central uplift zone, the south Mangyshlak sag and the Turkmenia anteclise depression. It also regionally affected by the western large Astrakhan-Atyrau “sinistral” strike-slipping fault, which complicates faults and structures [3, 4]. Three wells were drilled within field, including 1 production, and 2 appraisal wells, which were drilled as part of the exploration work within Contract area. Based on the drilling results, three oil-bearing horizons were identified within Middle Triassic sediments (T2A-II, T2Б, T2B), which were combined into one development Object. It should be noted that the testing of T2A-II horizon’s reservoir was carried out jointly with horizon T2Б. In this regard, the data obtained are ambiguous for a specific horizon, then it was recommended to perform separate testing of layers.

Estimation of hydrocarbon reserves in Kazakhstan based on the Soviet (State Reserves Committee) reserves system. This may result in inconsistencies between the reserves estimation for governmental use purposes and any external Reserves audit, which is usually based on the Petroleum Resource Management System (PRMS). In both cases, for correct and complete assessment of the field's reserves, it is necessary to carry out core and water researches, tests and

other types of works in order to obtain geological/petrophysical information for further efficient development and substantiation of the main technological indicators for the development period.

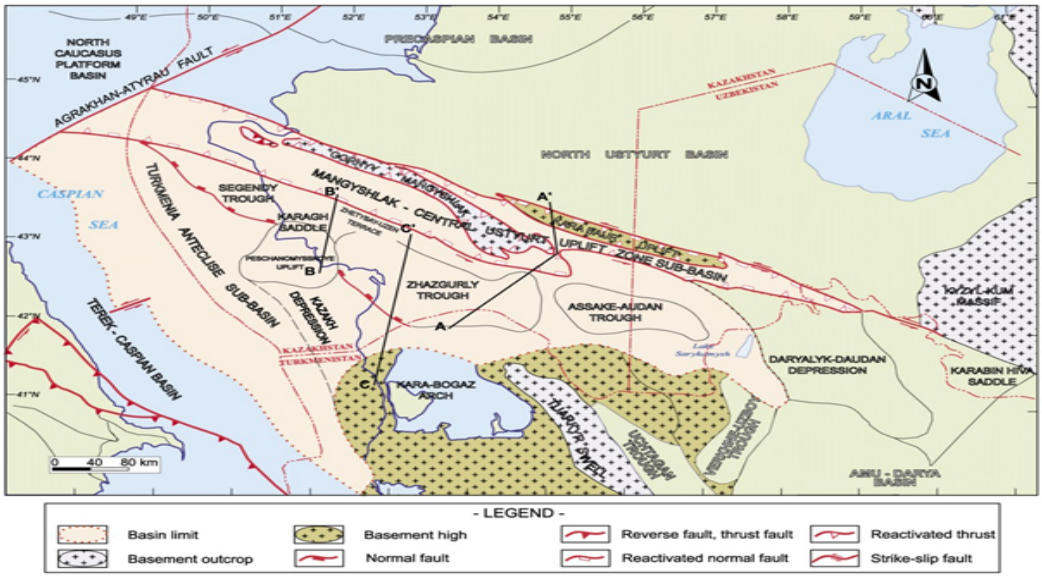

Figure 1 – The structural framework map of Mangyshlak sedimentary Basin

The scope, sequence and necessity for researches determined by the "Uniform Rules for the Rational and Integrated Use of Subsoil" (2018). According to the "Rules ..., paragraphs 333, 335, ...", a set of studies to control the development of operational facilities have been added to the Addendum to the Pilot Production Project, in order to provide systematic and single-time measurements. For the purpose of additional exploration of the Field, it was recommended to carry out monitoring the geological environment, including groundwater, assessments the effectiveness of the environmental protection works carried out by the Subsoil user, to conduct geodynamic monitoring to organize control over the activation of tectonic disturbances, horizontal movements of rock massifs, subsidence of the earth's surface, as well as to identify and prevent possible anomalous geodynamic processes of a natural or natural-man-made nature [5].

Thus, insufficient knowledge of the geological structure and oil content the field as a whole, the conventionality of the accepted OWC, lack of analytical studies, led to necessity for additional works to be done at the field.

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VUSAL KARIMOV
Higher Oil School
Supervisor: Director of BHOS Center for I&R. **Farad Kamyabi**

SCREENING, EVALUATION, AND RANKING OF RESERVOIRS SUITABLE FOR CO_2-FLOOD EOR AND CARBON DIOXIDE SEQUESTRATION

CO2-flood EOR has been implemented since the 1970's, and today CO2-EOR is regarded as a considerably established application in oil and gas industry. CO2-flood EOR is performed by injecting CO2 to the reservoir in which it can change residual oil characteristics, and allow oil to move. With the aid of the miscible CO2-flood, the lifetime of the field can be extended up to 25 years, and additional 20% OIIP can be recovered (Austell and Hustad, 2004). Furthermore, besides improving oil recovery, it makes possible to store considerable amounts of CO2 in the formation.

Due to continuous growth in energy demand, fluctuation in oil price, considerable drops of field productivities and low possibilities to discover new fields, now operator companies tend to focus to improve hydrocarbon recoveries of mature fields. Apart from this trend, the comprehension of sustained excessive CO2 emitted to the atmosphere by combustion of fossil fuels made almost every company realize that there are considerable climatic changes. Up to 2014 more than 36.2 billion tons of CO2 were emitted on account of fossil fuel combustion, and this number was able to increase by 1.3% on average each year (K. Dodds et al, 2014). This has become a big problem which put a huge burden on the oil industry, and made companies find effective methods to decrease CO2 emissions.

One of the main solutions to the abovementioned problem is carbon capture and storage (CCS). CCS operations include firstly capturing anthropogenic CO2, and then directly injecting it to the porous layers. (N. Florin et al, 2011) This distinctive approach is regarded the main factor to achieve the aim - desired mean temperature in Earth regulated by Paris agreement, but unfortunately the government's intervention has important influences on the success of this method, without it, it would be almost impossible for industries and companies to get sufficient economic incentive to maintain the approach (Ramage, 2018). Necessity for the economic incentives gave the notion of carbon capturing, utilizing and storing (CCUS) that allow CO2 to be implied in EOR, prior to its storage in reservoirs. Since using EOR methods provides extraction of hydrocarbons that cannot be recovered by primary and secondary recovery methods, for both abovementioned problems CO2-flood EOR can ensure an advantageous solution. CO2-flood EOR has not been used in Azerbaijan yet, however in Europe, South America, North America and Africa it has been applied successfully (Kotungal, 2011).

CO2-flood EOR was used widely in USA in the last century, and now is becoming popular in some countries. Azerbaijani reservoirs provide ostensibly optimal position for CO2-flood EOR. Relatively deep reservoirs with low API oil in Azerbaijan can be selected for CO2-flood EOR. South Caspian Basin also generates huge volumes of CO2 that is at the present time discharged directly into the atmosphere. Applying CO2-flood EOR can have influences on both CO2 footprint of oil and gas companies in Azerbaijan and oil recovery of South Caspian Basin. In spite of these factors, there is considerable literature shortage regarding with CO2-flood applicability in South Caspian Basin.

The main objective of the study provided is to give information to the public, energy companies especially petroleum industry about importance of CO2-flood EOR in Azerbaijan. A screening investigation was performed on the reservoirs in South Caspian Basin to check feasibility of CO2 injection to the oil producing reservoirs.

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KHAMIDULLIN D.F.
St.Petersburg Mining University

CREATION OF A COMPREHENSIVE ALGORITHM FOR ANALYSIS OF OIL FIELDS TO INCREASE THEIR ECONOMIC ATTRACTIVENESS

The state of oil fields at the final stages of development is characterized by high water cut of the produced products, falling oil production and low efficiency of fluid extraction from the subsurface. According to classical concepts [1], during the final stage, it is necessary to introduce methods of enhanced oil recovery and stimulation of oil flow to the well, to take measures to optimize the operation of the main oil production facilities in order to achieve the approved oil recovery factor, which in turn requires additional investments.

Recently, the situation on the world oil market has been characterized by high volatility in oil prices, which is associated with geological, macroeconomic, political and other factors. There is an acute issue of identifying risky assets in the portfolios of oil companies - the so-called “tail fields”[2] (fields with declining oil production, specific free cash flow below zero in the medium term) and universalizing the approach to finding solutions aimed at increasing the investment attractiveness of these assets.

This implies the current goal of creating a comprehensive analysis of tailing deposits for the selection of a set of possible solutions in order to increase the profitability of these deposits, minimize the risks arising from uncertainty and integrate the developed algorithm into the information systems of design institutes.

At the moment, the topic of developing special algorithms designed for a comprehensive analysis of the development of oil fields has been little studied. There are only ways to assess the individual elements involved in the operation of an oil field.

The proposed algorithm is based on the elements of the theory of fuzzy sets [3]. Due to this, the field can be abstractly represented as one large set, formed in turn from various kinds of subsets that characterize the activity of individual subsystems. This approach makes it possible to manage the complexity of the model, making it possible to form both a complex system consisting of a large number of subsets and rather trivial models in which excessive differentiation is not required. In turn, this allows for the most complete and detailed analysis of the development of the field and all the processes that together form the operation of the oil field.

In one of the works of domestic oil scientists [4], the theory of fuzzy sets was used to formalize the decision-making procedure when carrying out various geological and technical measures. To describe the indicators that influence the decision to carry out geological and technical measures on the well, the criteria were highlighted, expressed as belonging to various fuzzy sets. Using the operations of intersection and union of subsets defined in fuzzy set theory, these criteria were combined into one aggregate fuzzy set membership function, which served as the final indicator by which it is already possible to judge the need for a planned event.

Thus, by dividing a single "field set" into various subsets a certain number of times and introducing into consideration the membership functions of these fuzzy sets, taking values from 0 to 1, it is possible to quantitatively evaluate certain aspects affecting the final oil production. When passing to supersets using the operations of intersection and union of fuzzy sets, it is possible, if necessary, to make a transition to the aggregate membership function of a fuzzy set, by which it already seems possible to judge the state of the entire system.

It is also possible to move from a quantitative assessment of certain oil production processes to a qualitative one, by setting intervals of quantitative values taken by the membership

functions of fuzzy sets and attributing a qualitative characteristic to them. For example, values from 0 to 0.3 correspond to a poor state of the subsystem, values from 0.3 to 0.7 are satisfactory, and values from 0.7 to 1 are good. The advantage of this approach lies in the convenience of data presentation and a more rapid formation of an idea of the state of the system for decision-makers.

Another important point of the proposed approach is the multi-criteria nature of oil field development management. So, an authorized expert should maximize some of the available indicators in the decision-making process, and, on the contrary, minimize the rest. This opens up room for the introduction of game theory and other mathematical tools, which are not in short supply in modern science.

The algorithm proposed in this work is carried out in several stages. At the first stage, it is proposed to choose the most attractive of the existing deposits to increase their economic efficiency.

The second stage of the algorithm is the construction of a fuzzy model for the development of the selected fields and their more detailed analysis for the presence of problem areas. It is supposed to split a complex development system into simpler subsystems - blocks "development-geology", "well operation", "collection and preparation". In this case, these subsystems are formed from membership functions of fuzzy sets, each of which is an indicator of the effectiveness of one of the aspects of the subsystem.

The third stage involves the formation of a set of solutions for individual membership functions of fuzzy sets of subsystems. The values of the functions obtained during the calculations are compared with the critical values, which form the ranges of permissible and optimal values. The proposed solutions for each function are aimed at increasing the numerical values of the functions.

Each selected solution must correspond to the conditions of a particular field, have an assessment of economic efficiency, taking into account risks and total costs of implementation and operation. In addition, the selected solutions should be evaluated from the point of view of mutual influence and economic efficiency of the particular set of solutions.

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VALERII V. KHIMULIA
Ishlinsky Institute for Problems in Mechanics RAS

DEFORMATION AND FILTRATION PROCESSES IN RESERVOIRS OF UNDERGROUND GAS STORAGES WHEN IMPLEMENTING THE DIRECTIONAL UNLOADING METHOD

The Russian Federation occupies the key position among natural gas suppliers in the global market of resources. Russia has a unique Unified Gas Supply System, an integral part of which is the system of underground gas storage facilities. The system of underground gas storages makes it possible to securely supply territories with natural gas regardless of seasons, temperature fluctuations and emergencies. The exceptional importance of underground gas storages (UGS) in Russia stems primarily from climatic peculiarities and vast territories of the country, which complicates gas transmission to ultimate consumers. Today, the largest number of UGS facilities is created either in depleted oil and gas fields or in water-bearing formations. However, with any design of an UGS facility its safe and effective functioning requires constant control, as well as maintenance of the correct mode of operation [1].

Changes in stresses in reservoir rocks during cyclic well operations can directly affect changes in pore space and rock permeability [2]. A decrease in permeability, even in a small vicinity of the well, significantly reduces its productivity [3]. This decrease may be due to well operation - periodic injection of large volumes of gas, which contains solids and oil droplets.

One of the most promising ways to significantly increase the permeability of rocks in the bottomhole zone is the directional unloading method created in IPMech RAS. It is based on the use of huge elastic energy, stored in the rock mass due to the weight of overlying rocks and formation pressure [4]. Methods and parameters of such impact are determined on the basis of geomechanical approach. The use of the directional unloading method at UGS fields has a number of distinctive features in comparison with its application at oil and gas fields. This is due to cyclical changes in reservoir pressure of the field in the course of its operation.

In this work we carried out physical modeling of deformation, filtration and creep of UGS reservoir rocks under conditions of actually occurring stress states on the borehole walls when implementing the directional unloading method. The research was carried out on a true triaxial independent load test system of the Institute for Problems in Mechanics of the Russian Academy of Sciences. This test facility allows to load cubic rock samples according to any program independently on each of the three axes and to measure the permeability change during the experiment [4].

A theoretical analysis of the stress state in the vicinity of horizontal wells, taking into account changes in reservoir pressure, was carried out. The corresponding loading programs were compiled and implemented. The deformation curves were constructed and the time dependences of rock deformations under complex triaxial loading were investigated. The rheological and filtration characteristics of rocks and their dependences on stresses were established. The results of the experiments indicate that there is a real possibility of increasing the permeability of UGS reservoir rocks by the directional unloading method by creating in the bottom-hole zone of the formation the stresses of the required level. Preliminary technological parameters of applying the method on the studied UGS wells were determined, in particular: optimal stages of operation mode and values of necessary drawdowns. If further research confirms the possibility of implementing the method, it will help to significantly simplify and reduce the cost of operation of the investigated underground gas storage facility.

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ARTUR A. KHISAMOV
Bashkir State University

UNSTEADY FLOW THROUGH A POROUS STRATUM WITH HYDRAULIC FRACTURE

At present, the hydraulic fracture technologies are widely used for intensification of oil and gas recovery from reservoirs with hard-to-recover reserves. The simulation of the processes of flow through porous reservoirs with hydraulic fractures is fairly completely developed in the steady-state flow approximation. Unsteady processes of pressure distribution are considered with reference to the theory of hydrodynamic methods of investigations of wells in which asymptotically limited intervals of variations in the coordinates and time, i.e., the distances of the order of the well radius and time much smaller than the characteristic time of the process of flow through the porous medium, are considered [1, 2]. At the same time, in the reservoirs with hard-to-recover reserves (low-permeability reservoirs and high-viscosity oils) the duration of the unsteady processes of pressure redistribution can be of the same order as the characteristic time of flow through the reservoir. Therefore, the investigation of the time-dependent models of flow through a porous medium in the reservoir–fracture system is topical from the point of view of the development of general theory of these processes. The solutions of the problems are constructed using the Laplace transform technique [3-5].

New analytical solutions of the theory of time-dependent fluid flow through a porous reservoir with vertical hydraulic fracture are given. The solutions are obtained on the basis of the implementation of a model which takes into account fluid flow through a porous reservoir and the fracture compressibility. The model proposed is more general as compared with the models available in literature. These solutions and their asymptotic representations are of importance for the theoretical justification of the methods of hydrodynamic investigations of reservoirs and for estimation of the production rate of wells with hydraulic fracture. It is shown that the nature of flow through a reservoir is qualitatively changed in the presence of the hydraulic fracture, namely, the dependences of the pressure on time, fluid viscosity, and the reservoir permeability and elastic capacity are modified. In the case of injection wells the use of the solutions obtained makes it possible to describe dynamics of water flooding of the reservoirs with hydraulic fractures, in particular, to determine the velocity of movement of fluid in the fracture and reservoir when simulating the tracer investigations.

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MAKHMETKHOZHA S. SHAKHMARDAN
Kazakh-British Technical University
Prof. DARKHAN K. KURALKHANOV
Atyrau Oil and Gas Univeristy

CALCULATION OF MAXIMUM ALLOWABLE ANNULUS SURFACE PRESSURE

The goal of the project is to create a MAASP calculator app that improves the performance of supervisors by speeding up the speed of calculations and minimize human error.

Standardize the MAASP calculation to identify repeatability and ensure the quality of calculations, as well as to determine the operating parameters of wells during operation. MAASP occurs when drilling wells - this is the maximum closed (non-circulating) pressure that can be applied to the annular space on the surface before the formation directly under the casing Shoe begins to collapse (leakage). Today on field staff uses "Wait and Weight", "Driller's" methods are used in the kill sheet which are time-consuming to calculate manually, while app can solve this problem and minimize risk of human error. The list of formulas was taken from the official source ""IWCF Well Control Practice"". By the way all data provided based on IWCF as they have international accreditation and standardization.

In order to calculate MAASP value were used «Wait and Weight», «Driller's» methods. These methods used in order to prevent leakage and maintain stability in the well. Wait and weight method is killing well in one circulation. Once the well is shut in and the pressure has stabilized, the pressure in the closed drill pipe is used to calculate the weight of the kill fluid. Sludge of the required mass is prepared in the mud pits. When ready, the kill fluid pumped into the drill pipe. Initially, it is necessary to maintain a pressure in the drill pipe sufficient to circulate the drilling fluid, plus a reserve equivalent to the initial pressure in the drill pipe when closing. This total decreases steadily as the mud descends towards the bit, until, with the blind mud on the bit, the pressure required is simply equal to the pressure required to pump the blind mud around the wellbore.

Driller’s method is borehole impact using existing drilling weight. Then the drilling fluid rises to the required level and circulates through the well. The choke adjusted to reduce the pressure in the drill pipe when the kill fluid pumped into the string. When the muffler is on the bit, the static head of the mud in the drill pipe balances the formation pressure. During the remainder of the circulation, when the inflow pumped to the surface, followed by the contents of the drill pipe and the mud, the pressure in the drill pipe maintained at the final circulation pressure by adjusting the choke. First circulation: Pump the shock out of the well using the existing drill weight. Second circulation: Pump the kill fluid around the well.

My main suggestion for solving this problem is creating an application.

– Java" was chosen as a programming language due to its features such as cross-platform, as well as the ability to work with an unlimited number of variables. In addition, the language "Java" is easy to write and easy to understand.

– The values calculated in the Killsheet app are accurate to the hundredth, which minimizes the risk of errors and inaccuracies.

– Given that supervisors spend about 15 minutes on conventional fields, the application will reduce the time for extraction to 2 minutes.

– Also, for the purpose of detecting errors in production, there is an additional function for writing data in excel sheet..

– Deposits in different countries of the world sometimes use different units of measurement, which proves the need to add a new function, such as unit conversion.

	Function	Description
1.	The accuracy of the computed values	Rounding values to thousands minimizes the risk of error due to inaccurate data output
2.	Time	Allows you to save time spent on calculations up to 2 minutes
3.	Chronology	The application allows you to record all the calculated values in a file format "Excel", which will allow you to react in a timely manner to any inaccuracies in data entry and simulate the previous outcome
4.	Conversion	Convert units to create a common system of input units

Implementation of program simplifies one of the problems in well control by reducing human factor and reducing time to make operations. According to financial calculations, it will also bring economic value to oil companies.

App has some development opportunities such as

– Adding a function for monitoring wells online, which will allow the supervisor to respond to them in a timely manner in case of problems..

– The function of tracking the progress of drilling, namely uploading all the necessary indicators to the cloud and the ability to observe the trends in the development of the field from anywhere in the world

– Ability to predict well capture by entering additional data

– Given the simplicity of programming in the "Java" language, all data received from sensors, such as the SIDPP indicator, which is recorded using the sensor. Data from the sensor will be loaded into the program and, if necessary, the code will be rewritten on the microcontroller for simplicity and convenience.

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ANDREI MALTCEV
St. Petersburg Mining University

MODELLING OF SECONDARY REACTIONS TO IMPROVE SANDSTONE ACID TREATMENT EFFECTIVNESS

Stimulation methods make up a significant part in oil recovery efficiency. And acidization is the most rentable stimulation method mostly because it is cheap. But the statistics of its' effectiveness shows a huge potential in development of acidizing technology and methods especially on sandstone oilfields. This paper describes one of the way to reach the potential by improving the design of acid treatment.

This work is dedicated to understanding of physical and chemical processes in porous media during acid treatments by using mathematical modelling. Sandstone acidizing is one of the most complicated tasks in oil industry. The possibility of negative result is high and depends on well operation quality, design and well selection. Sandstone reservoirs includes huge number of

minerals so for every case we need the right acid composition. During mineral salvation secondary and tertiary precipitation can become the problem. Another problem in good design is accounting non-vertical geometry of high-tech wells and pore filling (formation damage) in near wellbore zone. Using the modelling helps us to decrease the uncertainty caused by the lack of information even with all the possible data from laboratory tests.

The currently existing commercial software for design of acidizing can't model all chemical and hydrodynamic processes that occurs in formation during well operation. Moreover, the opportunities of specialized software are limited in tasks of optimization issues. Optimization tasks usually is the prerogative of operator. The main idea of new simulator [1, 2] is describing all processes in near-wellbore zone that effects on formation properties. This simulator includes mathematical model of unlimited reactions between water components and between rock and acids. Information from other research [3] and information from own laboratory tests was used to tune the model. First step of research was concentrated on simulation of silica-gel precipitation and its' effect on permeability during acidizing of sandstone samples with different mineral composition. The difference between last researches is that Western Siberian sandstones includes bigger part of field spar than Berea sandstone, so the influence is much bigger.

The second step is simulation of special tests with infiltration of drilling mud (kaolinite and smectite). As in near wellbore zone segments the quartz/mud ratio increased it influence on optimal composition and acid pumping ratio.

The result of first and second steps is optimum trends for acid pumping ratio, volume of pre-flush stage and composition ration of most used HF and HCl acids for different miniral compositions.

The third step includes number of simulations to understand meta trends for main mineral compositions. On that stage the methodology of applying laboratory test to full scale well was developed. In this part different standard tests and geological information was used to make fitting to simulator static model of wellbore zone. Also different approaches of adaptation and influence of numerical effect during upscaling the model were researched and improved.

The main results of work show the uncertainties of math models and its influence on results. Meta trends of different acid ration, volume and composition applicable to Western Siberian sandstones were developed. Different methods were improved and bounded to get missing information for acid simulation. And the final result is approach of using simulator to increase the effectivity of acid treatment in sandstones and to decrease the risks of operations.

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NGUYEN VAN THANG
St. Petersburg Mining University
Dr. Prof. MIHAIL K. ROGACHEV
St. Petersburg Mining University
ALEKSANDR NIKOLAEVICH ALEKSANDROV
St. Petersburg Mining University

TECHNOLOGY TO PREVENT THE FORMATION OF WAX DEPOSITS IN GAS-LIFT WELLS ON OFFSHORE OIL AND GAS FIELDS IN VIETNAM

Gas-lift is one of the artificial methods in which gas is injected down the production casing-tubing annulus and enters the production tubing through a number of gas-lift valves [1,2,3]. During the production of a gas lift well, the injected compressed gas might cause changes in pressure, temperature as well as fluid composition. When the temperature of the oil falls below the wax appearance temperature, it leads to the formation of organic wax deposits. Wax precipitation in well tubing and processing equipment might lead to dramatic reduction in production, equipment failures, loss of storage and transport capacity, and loss of efficiency [4].

The gas-lift application can affect flow assurance issues. A principal challenge in many oil industry production situations is paraffin wax. Up to 80% of the world's oil suffers when wax precipitates out and solidifies in formation pores and fluid flow channels, at the wellbore, on the sidewalls of wells, in the tubing, casings, pump strings, and in processing systems. Wax precipitation may change the flow behavior of the crude oil from Newtonian to non-Newtonian which leads to higher liquid viscosity and consequently leads an increase in energy consumption for pumping as well as a decrease in pumping capacity.

This paper presents a detailed study of wax formation in a gas lift well. Taking into account changes in the oil component composition during gas injection, the depth of wax formation has been determined by applying a highly accurate developed algorithm. The optimal operating regime of the gas-lift well has been determined using a compositional multiphase model.

In this work, we used the results of laboratory studies of the physicochemical properties of the high-wax oil in the Dragon field in Vietnam, as well as the results from modeling the movement of the specified high-wax oil along the wellbore of a gas-lift well through the Schlumberger PIPESIM software package.

Using the system analysis function to evaluate the effect of a change in the volumetric flow rate of the produced compressed gas injection on the liquid flow rate of a gas-lift well with an increase in the water cut makes it possible to determine effective well operation regime. A methodology has been developed for determining changes in the component composition of oil in a gas-lift well during the injection of produced petroleum gas. As a result of the analysis of the gas lift well of the Dragon field in Vietnam, it was observed that when the pressure decreases during the lifting of the fluid along the wellbore, the wax appearance temperature decreases and the depth of onset of wax formation in oil is from 300 to 400 m from the well-head.

The method offers potential solutions to cope with wax deposition problems and it is highly recommended for practical application during gas-lift well productions

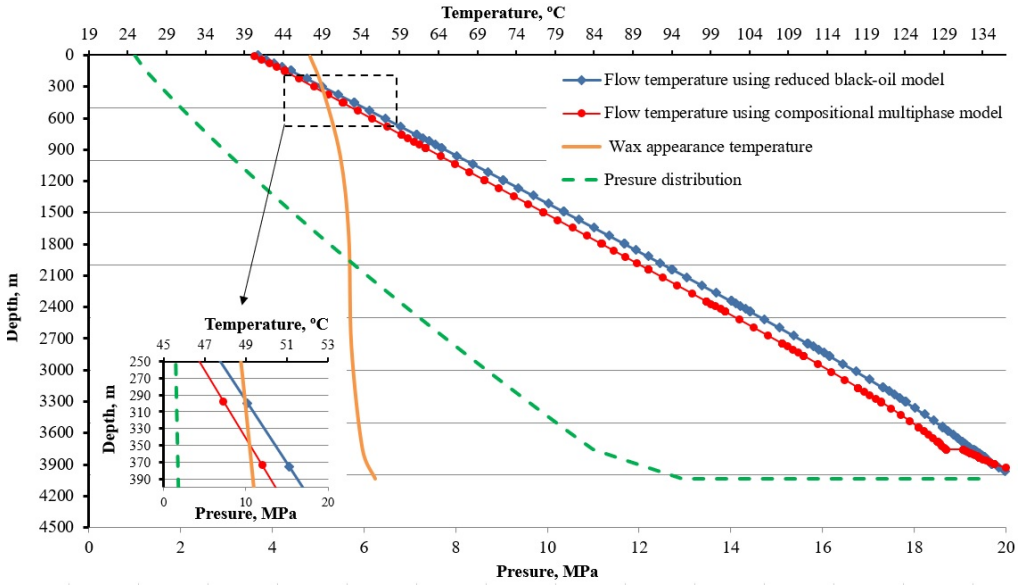

Figure 1 – Determination of wax formation depth in the gas lift well

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VLADISLAV A. OGAI
Industrial University of Tyumen
ANTON V. SHIROKIKH
Industrial University of Tyumen
ANTON Y. YUSHKOV
Industrial University of Tyumen

USING THE METHOD OF GAS-LIQUID FLOW RESEARCH AT DIFFERENT GAS PRESSURES

Liquid loading problem occurs in the process of gas field development when the reservoir pressure declines and the rate of produced gas in the wellbore is reduced. Under these conditions, gas production continues to decline until it is completely stopped. Mostly, the liquid contains condensed water from the gas and free water from the reservoir. Liquid loading is one of the most common problem in natural gas production. Special studies are carried out and various technologies are used for its solution, such as compression, velocity tubing, plunger lift, gas lift, rod pump, electric centrifugal pump, foaming agents [1]. Analysis from various works of literature confirms high level of efficiency by using foaming agents. Deliquification of gas well at the inlet of the foaming agent is due to its interaction with the fluid and the ascending gas flow, which leads to a decrease in the surface tension of the liquid and in the density of the gas-liquid mixture, the forming of a foam. The conditions for cleaning the well and its stable operation are improved [2]. Surfactants can be introduced into the well as solid sticks or as liquid solutions. Prediction of the foam flow performance and pressure gradient calculation in production tubing are important and real issues. On the one hand, gas well operation technology with foaming agent requires selection

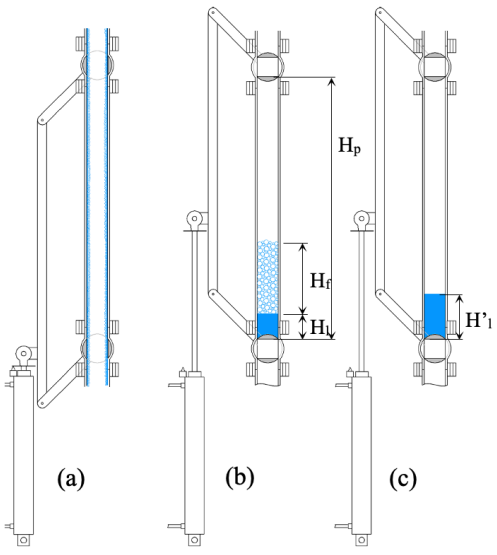
of optimal surfactant concentration for creation of a stable foam and the maintenance of a minimum pressure gradient in wellbore. On the other hand, it is important to correctly assess the effect of the introduction of this technology to the design process.

Some well-known research projects have been implemented to obtain experimental data on the foam flow and to develop calculating models of the pressure gradient. Experimental data on the foam flow were obtained under atmospheric conditions [3]. When operating gas wells, the pressure can reach relatively high values and this certainly affects the behavior of the foam flow. For this reason, there may be errors in the calculation models. For the implementation of studies of the foam flow at different pressures (up to 1,5 MPa), a method of conducting experimental work was developed. Using this method, it is possible to study the vertical foam flow in a pipe with a height of 7 m. The corresponding pressure of the experiment is achieved by pumping air into a closed circulation circuit by the compressor. The required gas flow rate is set by adjusting the power of the centrifugal pump. The injection of the foaming agent solution is carried out due to the pressure difference between the liquid supply system and the pipe. Thus, the gas and liquid separately, but simultaneously enter the pipe. The liquid is dispersed in the gas flow, the foam is formed and rises due to the pressure. After the foam flow is stabilized, the flow data (including the pressure gradient) is recorded using sensors and software. The technical specifications of the facility are shown in Table 1.

Table 1 – Technical specifications of the facility

Specification	Unit	Value
Tubing length	m	7
Inner diameter of tubing	mm	42
Pressure in the system (not more than)	MPa	1.5
Temperature in the system (not more than)	°C	50
Max gas velocity at pressure 1.5 MPa	m/s	15
Volume flow of liquid	l/h	300
Substances	Air, solutions (water and foaming agent)	

To measure the phase ratio in the foam flow (gas void factor, liquid layer factor, foam film factor, liquid/gas fraction in the foam), a method of mechanical flow clipping was developed. Obtaining empirical correlations of these parameters as a function of different flow characteristics is an important part of foam flow modelling process. In the developed method, the flow is cut off by the energy of the compressed air in the pneumatic cylinder. The cylinder rod moves the rail that drives the ball valves. This design provides a rigid mechanical connection between the valves and ensures their synchronous operation (Figure 1).



$\alpha_l = \frac{H_l}{H_p}$ – liquid layer factor (1)

$\alpha_f = \frac{H_f}{H_p}$ – foam film factor (2)

$\alpha_g = 1 - \alpha_l - \alpha_f$ – gas void factor (3)

$f_l = \frac{H_l' - H_l}{H_f}$ – liquid fraction in the foam (4)

$f_g = 1 - f_l$ – gas fraction in the foam (5)

H_p – pipe segment height, m;
H_l – initial water height, m;
H_f – initial foam height, m;
H'_l – ultimate water height, m.

Figure 1 – Diagram of the developed method, a – before cutting off the flow, b – after cutting off the flow , c – after the foam destruction

ACKNOWLEDGMENTS

The use of this method will allow us to obtain experimental data on the foam flow at different pressures (up to 1,5 MPa) and to develop a calculated model of the pressure gradient with a low level of error. This work was supported by the Russian Foundation for Basic Research (RFBR), grant № 20-41-720002.

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TIBA A. RABEEAH
University of Karbala

WELLBORE HEAT LOSSES AND CASING TEMPERATURE DURINGSTEAM INJECTION

In the past few years, the price of oil and gas is increasing very fast as the demand for oil and gasis increasing drastically Thus the oil and gas industries are looking for new ways to maximize theirproduction and at the same time maximize their profit [1]. One of the main focuses of all the oil andgas industries are on the technique on how to increase the recovery of oil and gas. Enhance Oil Recovery (EOR) is one of their focus nowadays in worldwide oil and gas industries. There are three main types of EOR, including chemical flooding, gas injection and thermal recovery. Thermal recovery introduces heat to the reservoir to reduce the viscosity of the oil. Many times, steam is applied, there are three main types of EOR, including chemical flooding, gas injection and thermalrecovery. Thermal recovery introduces heat to the reservoir to reduce the viscosity of the oil Many times, steam is applied to the reservoir, thinning the oil, and enhancing its ability to flow. thermal recovery [2,3] now accounts for more than 50% of applied EOR. Chemical injection EOR helps to free trapped oil within the reservoir. This method introduces long-chained molecules called polymers into the reservoir to increase the efficiency of water flooding or to boost the effectivenessof surfactants, which are cleansers that help lower surface tension that inhibits the flow of oil throughthe reservoir [4,5].

A numerical investigation of the effect of using a new insulation of Yttrium oxide with thermalpainting of (5 wt.%) on the heat losses from steam injected in the enhanced oil recovery process. ANSYS Fluent v.16 was used in the simulation. Results were obtained for inlet oil velocity of 5 m/s., temperature of 313 K, and inlet stream velocity of 0.1 m/s, temperature of 373 K. The length of the tube is 0.5 m. Pressure through the oil decreases along the distance, while through the steam seems to be unchanged. The insulation does not affect the pressure distribution. Velocity through the oil decreases along the distance and decreases slightly through the steam. Using the insulation lead to reduce the velocity of oil. Steam temperature decreases before using the insulation and slightly decrease after using the insulation. Using the insulation leads to make the temperature of steam along the distance greater than the temperature before using the insulation.

The following conclusion were obtained from the present work:

1. Pressure through the oil decreases along the distance, while through the steam seems tobe unchanged.
2. The insulation does not affect the pressure distribution.

3 Velocity through the oil decreases along the distance and decreases slightly through the steam.

4. Using the insulation lead to reduce the velocity of oil. Steam temperature decreases through before using the insulation and slightly decrease after using the insulation.

5. Using the insulation leads to make the temperature of steam along the distance greater than the temperature before using the insulation

For the future work, it can be recommending the following:

– using another nanoparticle (No) with the thermal painting to make a new insulation.

– using different weight percent of the nanoparticle used in this work such as 2, 4, and 6 wt.%.

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KIRILL A. RAVELEV
Perm National Research Polytechnic University

DEVELOPMENT OF RECOMMENDATIONS OF THERMOBARIC TRANSPORTATION CONDITIONS OF CARBON DIOXIDE IN A ROAD TANK TO THE OIL PRODUCTION WELL

Currently, the problem of utilization and use of carbon dioxide (CO2) is a serious issue that is being addressed all over the world [1]. The oil industry is also looking for solutions. Among the most promising options for the utilization of carbon dioxide is its disposal in depleted oil-saturated formations, and methods of enhancing oil recovery using CO2 are also being considered. Such methods include areal injection through a reservoir pressure maintenance system and gas-cyclic injection into an oil producing well operating a reservoir with high-viscosity oil. The last cited technology is called "Huff-n-Puff" [2] and is in great demand in foreign countries, since when stimulating the formation with this method, well production increases significantly, and a review of scientific publications established that the average additional oil production from the injection of dioxide carbon is in the range from 1900 to 2000 tons [3].

As part of the study of the use of CO2 in the Perm krai, one of the promising solutions is the use of Huff-n-Puff technology. The possibility of using stripping gases from the hydrogen production unit is being considered as an injected agent. The main component of this mixture is carbon dioxide (88,11%). The rest of the components include methane (7,43%), hydrogen (1,71%) and gases, the percentage by weight of which is less than 1% (ethane, propane, butane, etc.). It should be said that the presence of these components will have a negative impact on the process of gas dissolution in oil. The technology under consideration provides for the transportation of a mixture of gases using a thermoregulated tank truck. This type of transport is the most cost-effective according to foreign experience.

In order to substantiate the technical and economic efficiency of using the Huff-n-Puff technology in the Perm krai, a large number of studies are being carried out. This paper presents the results of studies of the PVT properties of a gas mixture. These studies are intended to assess

the compressibility and phase state of the mixture in order to develop recommendations for creating thermobaric conditions in a thermoregulated truck tanker. The results obtained will make it possible to increase the efficiency of transporting a mixture of gases by increasing the volume of the transported agent and, as a consequence, reducing operating costs.

These experiments were performed using a PVT system. It is represented by a set of equipment for researching the thermodynamic properties of liquids and gases. At the initial stage, the thermobaric conditions of the exit of the considered gas mixture from the hydrogen production unit were modeled. Further studies were carried out at a pressure of 1 to 5 MPa and a temperature of -30 to 0 ˚C. These limits are selected on the basis of the technical characteristics of known models of thermoregulated tank cars, and their further modernization and an increase in the pressure and temperature limits are assumed.

The result of PVT studies is the dynamics of changes in the volume of a mixture of gases when simulating various thermobaric conditions (Fig. 1). The value of these volumes was calculated in relation to the initial volume corresponding to the exit conditions from the block. Thus, the presented values of the ratio of the volumes of the mixture demonstrate the ratio of the decrease in its volume.

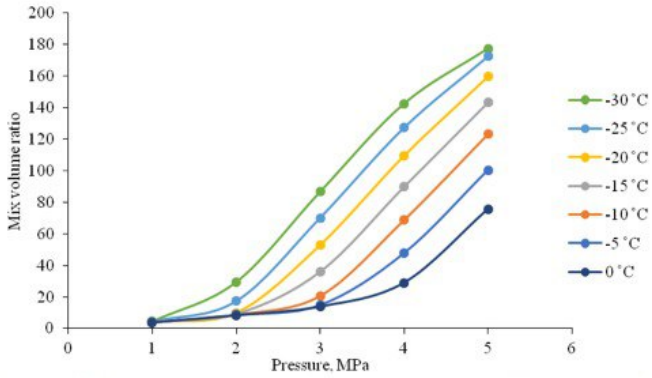

Figure 1 – Dynamics of changes in the volume of a mixture of gases depending on various values of pressure and temperature

On the basis of the above graph, it is possible to distinguish a general tendency towards a decrease in the volume of the studied gas mixture with an increase in pressure and a decrease in temperature.

The maximum decrease in the volume of the mixture is observed when a pressure of 5 MPa and a temperature of -30 ˚C are reached. Under these conditions, the volume of the gas mixture is 177 times less than the initial volume. You can also see in the figure that at a pressure of 1 MPa, the volume of the mixture does not depend on temperature. With a further increase in pressure, the role of thermal characteristics increases, which leads to a significant difference in the numerical values of the mixture volumes at different temperatures.

In conclusion of this work, it is necessary to note the significance of the derived dynamics of the change in the volume of a gas mixture under various thermobaric conditions. These results indicate the fact that it is necessary to modernize the existing thermoregulated tank cars by maintaining higher pressures and lower temperatures. When these conditions are met, an increased profitability of transportation is achieved, since the volume of the transported agent increases. The data obtained should also be used to assess the technical and economic efficiency of the Huff-n-Puff technology application in the Perm krai.

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ZILIA F. SHARAFIEVA
Kazan National Research Technological University
ANNA A. TURUK
Kazan National Research Technological University
Associate Prof. BULAT R. VAGAPOV
Kazan National Research Technological University

RHEOLOGICAL PROPERTIES OF A POLYMER MODIFIED ZWITTERIONIC SURFACTANT

Surfactants are widely used in oil production for its intensification. Viscoelastic compositions are becoming more widespread due to their rheological properties and sensitivity to hydrocarbons. On the one hand, the sensitivity to changes in external conditions is an advantage, since it allows you to manipulate the properties of the system. On the other hand, as a result of the susceptibility, viscoelastic surfactants have insufficiently high values of viscosity and elastic modulus, which also significantly decrease during heating, which limits their use at high temperatures [1].

A zwitterionic surfactant, erucylamidopropylbetaine (EAPB), was chosen as the object of the study, and a hydrophobically modified acrylic polymer (HM polymer) was chosen as the modifier. EAPB was synthesized by the scientific and production association "Research Institute of Surfactants". Hydrophobically modified polyacrylamide was provided by "MUNZING CHEMIE GmbH".

The values of the elastic modulus and the viscosity modulus were obtained both for individual surfactant solutions and for polymer-modified surfactants at a temperature of 25°C. According to the obtained data, it was found that the addition of the polymer does not affect the rheological behavior of aqueous solutions of EAPB. Data on the dependence of the yield strength of the studied compositions on the shear rate at the same temperature showed an increase in this indicator at low shear rates by almost two orders of magnitude. This effect can be explained by the fact that in the presence of the polymer [2], additional topological linkings occur, that is, the cross-linking of the hydrophobic groups of the polymer and the cylindrical micelles of the EAPB occurs.

The dependence of the viscosity on the shear rate at elevated temperatures (60°C) shows a decrease in viscosity in individual surfactant solutions by two orders of magnitude, but no decrease in viscosity is observed with the addition of HM polymer. This is due to the fact that the polymer chains are not subjected to the processes of destruction and reduction for the micellar chains of EAPB [3, 4].

As a result of the study, the occurrence of polymer chains in surfactant solutions modified with GM polymers was detected. As a result, the modified compositions have higher viscosity values, both at room and at elevated temperatures. The presence of such properties makes compositions based on surfactants and HM polymers promising for use as process flu-ids for the intensification of oil production processes.

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MAXIM V. SHARONOV
Samara State Technical University
CSc OLEG A. GRIBENNIKOV
Samara State Technical University
Doc. LYUDMILA N. KHROMYKH
Samara State Technical University

TEMPERATURE OPERATING MODE DETERMINATION OF WELLS EQUIPPED WITH ESPS AND ASSESSMENT OF THE COMPLICATIONS PROBABILITY WHEN THE PUMP UNIT LEAVES THE OPTIMAL TEMPERATURE ZONE

In Russia, more than 70% of production wells are equipped with electric submersible pumps (ESPs) that produce more than 80% of oil [1]. Intensive heat generation and temperature growth accompany operation of ESPs. The pump is cooled by the well production (gas-liquid mixture), which often does not cool the pump efficiently enough. The gas in the well production significantly complicates heat removal and with increased gas content at the pump intake and insufficient flow rate can break the normal temperature regime that will lead to uncontrolled temperature growth of pump unit and power cables, their melting and failure of ESP. It is the cause of downtime of these wells and increased operational costs associated with restoration of their operability.The temperature increase may also intensify scale deposition on the pump moving mechanisms and lead to the reduction of its technical characteristics, which will lead to the drastic reduction of the overhaul period, loss of the pump unit and the costs, indicated earlier in this work.

This work presents a methodology for calculating the temperature regime of the wells operated by ESPs. Based on the known input parameters the method allows determining the optimality of the ESP operation regime by calculating the equilibrium temperature at which the pumping equipment and the power supply cables are operated. Based on the data on the chemical composition of formation water and the calculated temperature at the pump intake, the probability of inorganic salts deposit according to one of the existing methods as well as the risk of cable line melting can be determined. A software was developed in integration with Excel and VBA. The methodology was applied to the producing wells of JSC Samaraneftegaz, which as of 2020-12-01 more than 76% of all its producing wells had operated with ESPs.

Five temperature ranges specific to a certain type of complications were selected for the analysis. Based on the results of the analysis, a histogram of the distribution of producing wells by temperature at the pump intake was formed and a conclusion about the status of producing wells of JSC "Samaraneftegaz" was made.

When selecting wells for the calculation, the following limitations were imposed:

1) The well should be operated by ESP;
2) The well has to be operated continuously;
3) The well is developing a single reservoir;
4) The well has a Russian-made ESP installed (to determine the pump characteristics);
5) There is only one ESP in the well;
6) There is no packer in the well.

For the analysis 5 ranges were selected. All the wells with <90°C are wells not subjected to intensive salting and there are no problems with overheating and melting of the cable line by the pump. Above 90° C, the solubility of inorganic salts such as calcite, barite, anhydrite and gypsum decreases, so that signs of scale in the well and the pump will occur. In addition, at temperatures close to 120°C, there will be signs of overheating of the cable line, if the extension has an operating temperature limit of 120°C. Above 120°C and up to 160°C, there will also be signs of scale in the well and the possibility of either overheating the cable line (if the extension is at the 160°C limit temperature) or melting the cable line (if the extension is at the 120°C limit temperature). Above 160°C, the main problem in operation will be melting of the cable extension

(reducing the cable line insulation to zero), unless a heat-resistant lead extension designed to operate at temperatures up to 230°C is used. [2-5]

According to the results of the study of 558 producing wells of JSC Samaraneftegaz, the vast majority of wells (71%) operate at a temperature near the pump less than 90° C. There are 53 wells, which are exposed only to the risk of scaling. 108 wells are at risk of cable line melting at the pump (not including scale).

Summarizing the material of the results of the study, we can conclude that 29% of production wells, for which the calculation was carried out, tend to show complications caused by scale or melting of the cable line due to insufficient cooling of downhole pumps and overheating. Thus, the presented methodology allows to calculate the temperature regime of wells equipped with ESPs, to assess the state of the pump and well operation, the probability and type of complications typical for a particular well. By taking into account the chemical composition of the formation fluid, it is possible to additionally assess the risk of complications associated with mineral salt deposits. Early identification of wells with pumping units operating in the non-optimal temperature region will allow taking preventive measures to eliminate potential accidents and improve technical and economic performance of the producing wells. The developed software through the producing wells' operating mode is able to test whether a well is operating in non-optimal temperature mode and to take timely measures to optimize their operating mode.

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ELVIRA I. SHMELEVA
Kazan (Volga region) Federal University
Ph.D., associate professor ALEXEY V. VAKHIN
Kazan (Volga region) Federal University

INFLUENCE OF OIL-SOLUBLE PRECURSORS OF THE CATALYST ON THE CONVERSION DEGREE OF SAMARA REGION HEAVY OILS UNDER STEAM STIMULATION PROCESSES

The development of the production of heavy oil requires the use of thermal methods enhanced oil recovery methods, which will allow the full disclosure, stabilization and, as a result, growth of the oil industry. Of particular interest in many oil-producing countries of the world is the use of steam-based methods, which create conditions for the chemical conversion of high-molecular components (resins and asphaltenes) with the formation of light saturated and aromatic hydrocarbons. The relevance of research with the use of catalysts in relation to the in-situ upgrading of heavy oils and natural bitumen is due to the improvement of rheological characteristics and the possibility of their further processing [1-4].

The main purpose of the research is to develop oil-soluble catalyst precursors based on the metals Fe, Co and Ni and the study of their catalytic effect under the conditions of steam stimulation of Samara region heavy oils.

Heavy oils from Mayorovsky and Vozdvizhensky fields of the Samara region (Russia) were taken as objects of this work to evaluate their transformation during the process of the steam stimulation in the presence of catalyst precursors.

Autoclave experiments simulating the conversion process of heavy oils during steam stimulation were carried out in a laboratory reactor at a temperature of 300°C. The choosing of

oil-soluble catalyst precursors based on Fe, Co, and Ni is determined by their efficiency in the processes of destructive hydrogenation of resinous-asphaltene substances, as well as the possibility of their introduction into the heavy oil reservoir with a hydrogen-donor solvent. An oil solvent (nefras-C4-150/200), which is a mixture of aliphatic, alicyclic and aromatic hydrocarbons, was used as a hydrogen-donor solvent. In addition, different techniques were used to study the initial oils and their conversion products in autoclave experiments, including standard methods for determining the physicochemical properties were used such as SARA analysis, dynamic viscosity, IR spectroscopy, GC/MS, MALDI mass spectrometry, elemental analysis and NMR.

As a result, it was found that, along with the generation of monoaromatic hydrocarbons understeam stimulation treatment. In addition, catalyst precursors contribute to the intensive formation of diaromatic compounds, i.e. degradation products of resins and asphaltenes. An abrupt increase in the amount of methane hydrocarbon gases and hydrogen sulfide indicates the depth of conversion of high-molecular oil components (resins and asphaltenes). Hydrogen sulfide is formed as a result of the rupture of carbon-sulfur bonds in the bridging structures of asphaltenes, which ensures not only a decrease in their amount, but also a decrease in molecular weight. Based on the data obtained on the group and elemental composition of oil, individual fractions and viscosity characteristics, the optimal ratio between three catalytically active metals in the composition of a mixed catalyst was determined. As a potential, and for using at the Mayorovskoye oil field, a catalyst is proposed containing Fe/Ni in a ratio of 85/15, which provides an intensification of this process and a significant decrease in viscosity (150 times relative to the initial sample and 24 times relative to the experiment without catalyst at a temperature of 300°C) as a result deep chemical conversion of resins and asphaltenes (more than 2 times at a temperature of 300°C). For the Vozdvizhenskoye oil field, the commercial use of catalyst precursors, for steam stimulation treatment is not suitable, since there are no significant changes in the group composition and viscosity.

The established patterns in the change in the composition of heavy oils under steam stimulation treatment in the presence of catalyst precursors can serve as a scientific basis for a wider application of catalytic technologies for the development of unconventional hydrocarbon resources.

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IVAN B. STEPANENKO
Perm National Research Polytechnic University
MAKSIM I. BORISOV
Perm National Research Polytechnic University
VITALY S. BAKANEEV
Perm National Research Polytechnic University
Cand Sc., Associate Professor ALEXANDER V. LEKOMTSEV
Perm National Research Polytechnic University

DEVELOPMENT AND JUSTIFICATION OF THE COMPLEX TECHNOLOGY BASED ON THE WATERFLOODING SYSTEM ENERGY RECOVERY, AIMED AT INCREASING OIL PRODUCTION EFFICIENCY

Improving the efficiency of oil and gas production is one of the main goals facing oil companies. In the current conditions of reducing the level of hydrocarbon consumption and oil prices for it, the actual task is to find, develop and apply new, more effective methods and technologies for oil and gas production [1-3]. The use of jet pumps in the oil and gas industry has shown high efficiency over the past two decades and, as a result, has become widespread throughout the entire technological processes of hydrocarbon production. The authors of the work have developed a comprehensive technology for the intensification of oil production based on the energy recovery of the waterflooding system. An extensive scientific and technical literature review on the subject of the study is carried out. A complex technology is described and a technological scheme is developed, criteria for selecting the implementation object are formed, laboratory experiments of the process of emulsion formation and delamination are carried out, and also mathematical and software modeling in the Ansys CFX module.

It is assumed that the highest efficiency of the technology is achieved at the values of the initial water content close to the point of phase inversion. This is due to a decrease in the dynamic viscosity of the emulsion at the exit of the jet pump.

By modeling the operation of a surface jet pump in the Ansys CFX software module, the limits of the effectiveness of this technology were determined and the criteria for selecting an object for its implementation were obtained.

The following factors were taken to determining the efficiency limits:

- design of the jet pump (nozzle diameter);
- consumption of active and passive part;
- water content of oil at the jet pump outlet;
- pressure of the active part.

Figure 1 shows the distribution of the oil velocity in the jet pump by the modeling in the Ansys CFX software module.

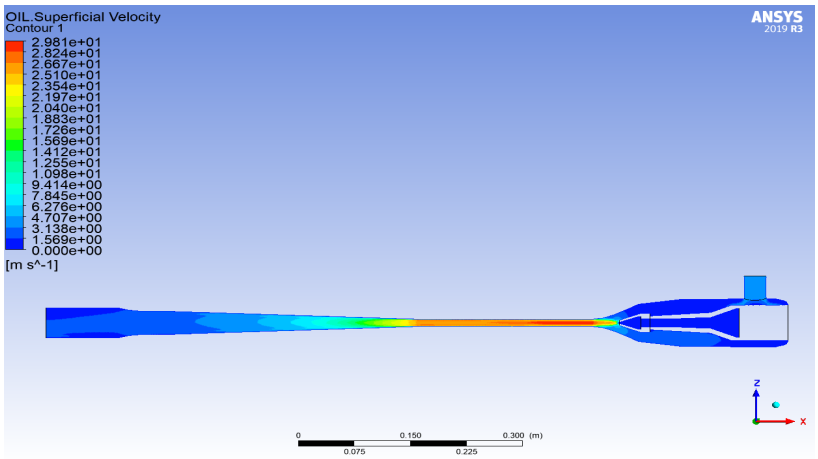

Figure 1 – Distribution of the oil velocity in the jet pump during simulation in the Ansys CFX software module

Thus, complex technology based on the waterflooding system energy recovery, aimed at increasing oil production efficiency will allow optimizing the production of hydrocarbon with minimal impact on oil gathering system.

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POLINA A. TSVETKOVA
Lomonosov Moscow State University
ROMAN S. SAUTKIN
Lomonosov Moscow State University

A NEW VIEW AT THE DEVELOPMENT OF DEPOSITS OF THE VIKULOVSKAYA FORMATION OF THE KRASNOLENINSKII ARCH

Nowadays increased attention in oil and gas geology has been paid to the problem of developing hard-to-recover reserves associated with undersaturated, thin-layered reservoirs. These are the deposits of the Vikulovskaya Formation, tectonically confined to the southern part of the Krasnoleninskii arch of the Frolov oil-gas area on the West Siberian platform.

According to the recent sedimentological studies, new structural features of the productive formations VK1, VK2-3 and VK2-3incised were identified [2]. Deposits of the Vikulovskaya Formation are predominantly silty-sandy with clay interlayers. Sandy and clayey reservoirs are often characterized by a microlayer lenticular structure and are complicated by faults originating from the pre-Jurassic complex. The considered object VK1-3 is bounded from above by clays of the Khanty-Mansiysk Formation. The VK1 layer was formed in the early Albian time, during the beginning of the regional transgression, and is composed of silty fine-grained sandstones, siltstones, silty mudstones, unevenly alternating with each other. Its total thickness is 21.7 m on average. The bottom of the bed is limited by a regional clay member. The reservoir VK2-3, excepting the incised valley deposits, is represented by uneven interlayering of fine-grained clayey and coarse-grained sandy siltstones, in places with carbonate cement of both sedimentary and postsedimentation genesis.

In the process of the development of thin undervalued reservoirs of the Vikulovskaya Formation, many problems have been identified that are associated with both the geological structure of the reservoir, its filtration-capacity properties, saturation, and with the selection of measures to increase oil recovery. In order to solve them, the experience of developing analogous fields with layers similar to the Vikulovskaya Formation was analyzed. For this, the international system for the selection of analogous deposits PRMS (Petroleum Resources Management System) was used. Initially, more than 20 reservoir and fluid parameters were used, but after analyzing the degree of influence, six main ones were left - porosity, permeability, oil saturation, oil viscosity, reservoir pressure and depth [4].

After calculating the synthetic criterion, which is the sum of the residuals of the values of each parameter in relation to the analogous parameters of the studied object, three, out of more than 20 considered, analogous layers with similar properties were determined. These are the Meleikha (the Bakhariya reservoir), the Zhaoyan (the Kong-2) and the Kalol (K-VI, VII reservoirs)

fields. It is assumed that the fundamental approaches to the development of objects of the selected group may be similar.

In the course of the work, it was possible to establish that the most promising methods from the point of view of the development of the Vikulovskaya Formation are the drilling of infill directional and horizontal wells, drilling of multilateral wells, stimulation of the reservoir pressure maintenance system without taking hydrocarbons in injection wells and carrying out multi-stage hydraulic fracturing. Thus, at the Meleikha field, it was possible to increase the oil recovery factor by 10.2%, according to infill drilling, and at the Kalol field, the pilot multilateral well KL-541 made it possible to produce 4 times more oil than from adjacent vertical wells [1, 3].

Particular attention is paid to geological and hydrodynamic modeling of objects, on the basis of which forecasts of changes in the structure of reserves and targeted proposals are made for the modification of development systems, well grid density, waterflooding systems, the use of hydraulic fracturing and drilling multilateral wells.

Also, the great interest is the use of a geomechanical reservoir model in the Zhaoyang field, along with a hydrodynamic one. The use of geomechanical modeling made it possible to substantiate a fundamentally different method of hydraulic fracturing. The change in the stress-strain state (SSS) of the formation over the area and in time and the direction of orientation of the hydraulic fracture was taken into account. As a result, two hydraulic fracturing operations were carried out on the field, the first was aimed at restoring the initial stress-strain state of the formation, the second - to create “filtration channels” in places of residual hydrocarbon reserves.

Taking into account the above, it was concluded that for the effective development of thin-layered undersaturated reservoirs of the Vikulovskaya Formation, it is necessary to pay attention to the construction of a detailed geological model, on its basis to conduct hydrodynamic modeling and take into account the change in geomechanical properties during the production process. Thus, it is necessary to conduct 4D geological and hydrodynamic modeling for a comprehensive analysis of the reservoir and reduce risks during development.

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GERMAN N. ZAOZERSKIJ
Northern (Arctic) Federal University named after M.V. Lomonosov
MARCEL G. GUBAIDULLIN
Northern (Arctic) Federal University named after M.V. Lomonosov

COMPREHENSIVE STUDY OF THE EFFECT OF PARAFFIN DEPOSITS ON THE OIL DISPLACEMENT COEFFICIENT BY WATER OF DIFFERENT TEMPERATURES ON THE EXAMPLE OF A HIGH-PARAFFIN OIL FIELD

Currently the production of hard-to-recover reserves is becoming an increasingly urgent task that requires a detailed study of all issues of hydrocarbon extraction [1]. At the same timeСпас a significant share of hard-to-recover reserves is occupied by fields with highly paraffinic oils. The development of deposits of this type is inextricably linked with the problems and complications of various kinds that developers may face.

It should be noted that the most studied aspect, both in terms of laboratory support and theoretical foundations, is wax deposition in pipelines and equipment, while the processes associated with wax deposition in reservoir conditions are insufficiently studied and require additional research.

Under normal conditions, paraffins are waxy or solid substances that belong to the hydrocarbons of the alkane or naphthenic series [2]. The main factors affecting the temperature, the beginning of the crystallization of paraffins, are changes in temperature, pressure and component composition [3]. In addition, in some cases, the change in the PH of the fluid observed during hydrochloric acid treatments of wells, the impact of electromagnetic and ultrasonic fields can also lead to the process of paraffin deposition. In the process of reducing the temperature, the solvent capacity of oil in relation to paraffins decreases and at a temperature equal to the temperature of oil saturation with paraffin, the process of their crystallization begins. In laboratory practice, it is customary to determine the following parameters that characterize the formation of paraffin deposits: wax appearance temperature, wax cloud point, wax flocculation temperature.

The main laboratory methods for studying phase transitions of paraffins at the moment are:

– spectroscopic: fixing the moment of phase transitions by the drop in the power of transmitted light radiation, depending on the wavelength of light;

– ultrasonic: determining the moment of the phase transition by the drop in the power of the transmitted ultrasound;

– gravimetric: determination of the moment of phase transitions by the drop in the content of paraffins in the fluid;

– filtration: fixing the moment of phase transitions by the drop in the content of paraffins in the fluid;

– visual: study of the dynamics of particle fallout by analyzing a series of images of a fluid sample from a microscope with a high-pressure cell.

This paper presents the results of a comprehensive study of phase transitions of paraffins in reservoir conditions during the injection of water of different temperatures. A phase diagram of paraffins of formation oil for a highly paraffinic field (content over 10%) of the Timan-Pechora province was constructed.

Phase behavior studies in free space were carried out on representative samples of formation fluid using an AWAI-1000 unit using spectroscopic, visual and filtration methods.

To simulate the processes in the pore space, physical and hydrodynamic studies of the core were carried out at the UIK-5 unit (7) to determine the coefficient of oil displacement by water, which made it possible to analyze the processes occurring during the injection of water of various temperatures into the reservoir.

In addition, the rheological parameters of degassed oil have been determined, which complements the information on the viscosity properties of the system under consideration.

As a result of the research, a set of data was obtained that allows one to assess the risks of paraffin precipitation both in reservoir and in surface conditions. A technique that allows to assess the most critical areas during waterflooding has been identified in this research as well.. Understanding the processes of phase transitions of paraffins will allow effective work to remove risks during waterflooding and other works associated with changes in temperature and pressure conditions, which will further ensure the most optimal technological and economic development indicators.

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KSENIIA S. ZHUKOVA
Leoben Montanuniversität

DATA-DRIVEN MODEL FOR HYDRAULIC FRACTURING EFFICIENCY BY UTILIZING THE REAL-TIMETREATMENT DATA

With the increased global demands on oil and gas, operators strive to maximize production by conducting more advanced drilling, completion and production operations. Unconventional gas and oil resources offer significant production growth potential in the comingyears. Hydraulic fracturing is one of the main methods for unconventional reserves which allowsto increases the permeability of the reservoir and drainage area.

One significant component of the modern hydraulic fracturing operation is streaming which is continuously generating and transmitting high-frequency data from the field to remote locations for monitoring, storage, and finally analysis. Accurate and consistent eventidentification, such as stage start and end times, enables real-time reporting of important stage metrics, including pressures, rates, and concentrations. Usually, Frac Engineers do stage identification manually, which is often very time-consuming and prone to inaccuracies due to thelack of uniform selection, interpretation methods across the industry, experts' view. The purpose of this study is to demonstrate the automation process to identify the different steps of a pumpingschedule and generate some statistics based on the hydraulic fracturing time-series data collected in the field using signal processing techniques and machine learning algorithms [1,2].

This study is based on the analysis of fracturing treatment data from wells landed in different formations across America and Europe. The data includes files from different operators and service companies, including treatments pumped with different fluids (slickwater, high concentration friction reducer, linear and crosslinked gels, and hybrid fluids) and completion systems (plug and perf, sliding sleeves, coiled tubing, and hybrid systems).

The row pumping data includes multiple channels, each collecting data points every second. For this study, the main information channels are selected. The dataset consists of two parts: mini-frac treatment data and main frac treatment data, including treating pressures, bottom-hole pressures, slurry rates, proppant rates, additive rates, and concentrations. All data is introduced in a real-time scale, which means data are dynamic and changes with time. This big data analysis's main challenges are associated with the well-timing issues because time series data are interrelated across time, and basic statistical techniques are concerned with independent and identically distributed data and errors; and the raw field data which is very noisy. It makes it difficult for automated techniques to separate real events from false positives. A lot of missing data and duplicated rows also contribute to challenges. Therefore, before data are used for model-building, data is gathered, cleaned, and preprocessed [3].

This study includes a data-driven model taking into account machine learning and other data mining techniques used to process time-data series. The classification algorithms (neural network, decision tree, support vector machine) are used to build the models for hydraulic fracturing stage identification. The results of the different algorithms are compared and have very close starting and ending flags.

Based on the results of this model, optimization for hydraulic fracturing operation can be applied. The automation process for time-series data processing allows to generate real-time reports more accurately and precisely, concentrations and pressures while execution can be controlled and adjusted that leads to higher efficiency of the treatment.

For further analysis and study it is suggested to build prediction model which will give forecast of starting and ending flags of the stages so that the efficiency of the process execution can be increased which lead to the higher productivity index finally [4].

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LIYBOV G. ZHULINA
North-Caucasus Federal University
ALEKSANDR E. VERISOKIN
North-Caucasus Federal University

DEVELOPMENT OF A BOREHOLE SELF-EXPANDING FILTER

The paper considers the design features of the developed borehole self-expanding filter which reduces the removal of sand from the reservoir into the well in oil and gas fields. The scheme of the invention is presented and the principle of operation of the filter is described. The comparative assessment with existing analogs was carried out.

The problem of destruction of the rock in the bottom-hole formation zone and carrying out base sediments into the wellbore together with the extracted products is increasing of interest at this time in oil and gas production. The problem is typical for poorly cemented rocks that are subject to destruction during the extraction of minerals.

The negative consequences are manifested in the intensive wear of pump elements and pump-compressor pipes, threaded connections, fountain fittings, and the formation of sand jams. The perforation ranges are blocked by sand plugs which leads to a violation of the wellbore operation process and a decline in production.

Sand control includes mechanical, physicochemical, and chemical methods. The making use of downhole filters refers to mechanical methods that prevent the flow of sand from the formation into the well. Special attention is given to the selection of the equipment with the view to maximize the period of safe production over the entire life of the well.

The most effective is the use of a self-expanding filter. The changing of the diameter contributes to do easier pulling and running operations onto the desired interval. The filter expands and reaches the diameter of the borehole or the bottom-hole zone. This process suspends the passage of mechanical impurities.

A comparative analysis of filters was carried out to study technological solutions:

– "borehole expanding filter" based on changes in the radial direction of spring-mounted blades with a buckled shape in the radial plane and a straight shape in the axial plane. This filter isn't persistent to corrosion or erosion so it is possible to spawl the blades in the working position which will lead to certain difficulties when removing this filter to the surface;

– "borehole expanding filter" based on a swollen elastomeric shell with open lengthways grooves evenly distributed around the perimeter. Channel's deepenings full of the bodies of the filter rack brushes with radially oriented bundles of bristles. The disadvantage of this filter is the possibility of premature expansion due to early contact with the liquid and the difficulty in removing such a filter to the daytime surface, and re-use.

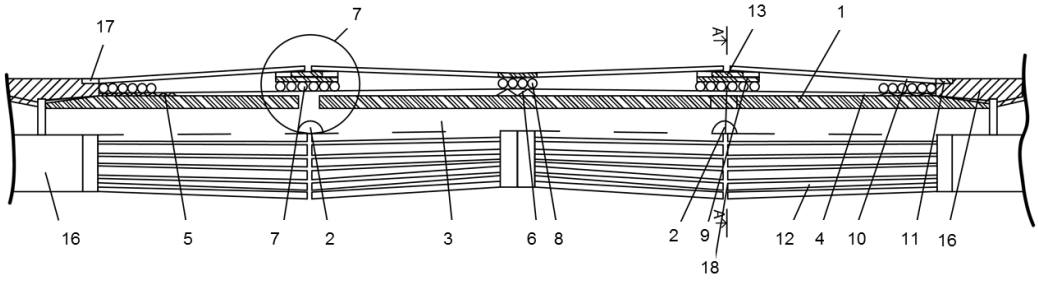
The retrofit design of a self-expanding borehole filter has been developed As a solution to the existing problem. Structural design produced with used innovation material nitinol. The proposed filter is characterized by constructive simplicity in contrast to analogs. The feature filter is the use of a material with a memory of the form.

Nitinol is an alloy of two metals (titanium and nickel) in certain proportions. The material is characterized by high wear resistance which extends the service life of the filter. The main technological quality is shape memory so this material can be used for a variety of purposes.

The technology of expansion: when the filter arrives at the desired interval nitinol springs enlarge. This process leads the filter's diameter to the size of the wellbore or the bottom-hole zone. The temperature of expansion nitinol springs can be regulated (from +60 to +110 degrees Celsius) by introducing various chemical elements into the compound.

Another important design feature is the ease of installing the filter on the downhole and then removing it. The successful fitting of the filter in the planned interval is possible due to the temperature control inside or outside the filter (using ice, circulating fluid, etc.).

The equipment is unique due to the combination of temperature control of the filter shape and the resistance of the material to corrosion and erosion. Filter characterized by efficiency, versatility, and durability.



Fugure 1 – Construction of a borehole filter:
1 –hallow carcass; 2 –perforation holes; 3 –axial canal; 4 –longitudinal slot; 5 –longitudinal stringers in the form of spiral screw springs; 6 –filter shell; 7 –wap of spiral spring; 8 – filter interstices; 9 –thrower rings; 10 –protective shell; 11 –cylinders with a bandage; 12 – shutter; 13 – lock; 14 –lengthway plating; 15 –lengthway sawcut; 16 –conductor joint; 17 –cavities; 18 –ring slot split.

The technological result is achieved by the fact that the downhole filter consists of a hollow body with perforation holes placed on the same level and longitudinal grooves in which self-expanding stringers are placed in the form of coils of a spiral spring.

The filter shell is made in the form of coils of winding from a spiral spring wound on stringers. Thrower rings are installed on the filter cover. The protective shell is made in the form of paired thin-walled cylinders with lobes at the ends.

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HANI AL KHALAF
University of Miskolc, Hungary

DETERMINING THE OPTIMUM CONCENTRATION OF PUMPKIN SEED SHELLS AS FILTRATION CONTROL ADDITIVE TO WATER-BASED MUD SYSTEM

Abstract. Filtrate loss within formations is one of the biggest problems during drilling operations. Therefore, many commercial chemical additives have been used to reduce fluid loss, such as carboxymethylcellulose (CMC) and polyanionic cellulose (PAC), which are expensive and are not environmental friendly substances. This study evaluates the usage of pumpkin seed shells (PSS) as an additive to the drilling fluid to reduce fluid loss which is agricultural waste and at the same time environmental friendly material. Six drilling fluid samples were formulated with adding (PSS) 250 μm in size at different concentrations (1 wt%,2 wt%,3 wt%,4 wt%, and 5 wt%). The effect of adding (PSS) on rheological properties and density were recorded and analysed. Filtration was also studied by using API LT LP press. The results of the study indicated that the addition of (PSS) to the drilling fluid has a clear effect on reducing fluid loss. The optimum concentration of (PSS) was 5 wt%.

Introduction. Oil is one of the most important economic resources for most countries in the world. Drilling operations are one of the most complex and expensive operations. The drilling fluid used in drilling operations carry out many functions which includes the removal of cuttings from the well bottom to the surface, cooling, and lubrication of the drilling bit ..etc. [1]. Drilling fluid is composed of liquid and solid phases, certain additives are added to achieve the desirable properties. The additives affect important properties such as rheology, fluid loss, cake thickness and density. The type and concentration of additives used in the drilling fluid are chosen on the basis of the properties that needs to be modified. Some of the additives when added to the drilling fluid may increase the viscosity while some other might reduce the viscosity depending on the type and concentration of the additives [2]. Hence, the success of drilling process relies on the selection of suitable material used in the drilling fluid with respect to the prevailing conditions. During drilling it is certain that problems like pipe sticking, lost circulation, borehole stability, mud contamination, formation damage and hole cleaning will take place due to different geological conditions. Fluid loss is one of the most common problems that increases the cost and the total drilling time. Significant fluid loss into the formation can result in irreversible changes in the properties of the drilling fluid such as density, viscosity and borehole instability etc [3]. Fluid loss occurs as a result of the pressure difference between the drilling fluid column and the formations, which leads to the penetration of the liquid phase of the drilling fluid into the formations and the solid phase makes a mud cake on the walls of the wellbore. Thus, the properties of the drilling fluid must be modified to reduce the amount of fluid loss as well as to reduce the thickness of the mud cake formed on the wellbore.Water-based drilling fluids are the most common type of drilling fluid used in well drilling due to their lower cost and environment friendly nature. Many materials have been used to control fluid loss and the rheological properties of drilling fluid, such as carboxymethylcellulose (CMC), starch, and xanthan gum (XC). These chemical materials are costly ,harmful to the environment and disintegrates at the high temperatures in the well. Some of the additives are highly toxic and can harm health when used improperly during drilling operations. For these reasons, new additives are being tested which would be safe and affordable comparatively. Researchers focuses on finding the low-cost, environmental friendly materials that reduce fluid loss and enhance the rheological properties of the drilling fluid. In the past environmentally friendly waste has been tested to reduce fluid loss, such as corn cobs, walnut shells, banana peels, rice husks, sawdust, potato husks, etc. Pumpkin seed shells (PSS) are

environmentally friendly waste material, to date, it is noticed that no previous studies were made on the evaluation of pumpkin seed shells (PSS) as an additive in drilling fluid. This Study presents experimental work on pumpkin seed shells (PSS) as an additive to water-based bentonite drilling fluid and a measurement of its impact on many properties of drilling fluid such as rheology, density, fluid loss and cake thickness.

Main part. All experimental measurements were done based on API-RP-13B-1 standards. The measurements included the rheological properties (plastic viscosity, apparent viscosity, production point, gel strength for 10 seconds, 1 minute, and 10 minutes), filtration properties (fluid loss for 30 minutes, and cake thickening), and the density. The density was recorded with different concentrations of pumpkin seed shells powder added to water-based drilling fluid.

In this article, the pumpkin seed shells (PSS) were the main materials used as an additive to water-based drilling fluid. Pumpkin seed shells (PSS) were obtained from Miskolc /Hungary. These dry shells were grinded to the size less than 250 micrometres by an electric grinder. Water-based drilling fluid was prepared with pumpkin seed shells as an additive in different concentrations (1 wt%,2 wt%,3 wt%,4 wt%, and 5 wt%). A single system of water-based drilling fluid consisted of water (base fluid) and bentonite (viscosifier agent) was used. a multi-speed Fann 35 viscometer which was used to perform rheological tests that included measuring plastic viscosity (PV), apparent viscosity (AV), yield point (YP) and gel strength at 10 seconds, 1 minute and 10 minutes respectively. The density of the drilling fluid is measured using a mud balance. API LT-LP press device was used to measure filtration properties. To analyse these properties of the drilling fluid, the samples were prepared by using (PSS). The concentrations which were used here are (1 wt%,2 wt%,3 wt%,4 wt%, and 5 wt%).

3. Conclusion. Successful drilling operation requires minimizing fluid loss inside the formations. For this reason, many commercial materials such as carboxymethylcellulose (CMC) and polyanionic cellulose (PAC) have been used, which are very expensive and negatively affects the total cost of drilling in addition to their harmful environmental effects. In this study, pumpkin seed shells (PSS) were used as an additive to control fluid loss in the water-based drilling fluid. Through experiments, the following conclusions were drawn:

– When using 5% of the pumpkin seed shells (PSS), it will positively affect the reduction of fluid loss, which means that it is the optimum concentration of the (PSS).

– Adding PSS gives a mud cake with acceptable thickness and low permeability.

– It has no significant effect on density and increases the plastic viscosity, apparent viscosity, yield point and gel strength to acceptable values which increases the effectiveness of cleaning the well, reduce many drilling problems such as high torque, and increases the ability of the drilling fluid to carry the cutting during stopping the circulation of the drilling fluid in the well.

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MOHAMMED R. AL-SHEIKH JADEER
University of Mosul, Iraq

DRILLING OF DIRECTIONAL AND HORIZONTAL OIL AND GAS WELLS

Introduction. As it is known and any one works in the oil and gas industry is knows, there are several problems that we will encounter in the oil and gas industry, specially, in the oil and gas reservoirs and all problems which related to decrease the production rate, the overall reserves recovery, amount of reservoir that is exposed to the wellbore and also increase water and gas coning. Also present of geological problems (fault drilling, Salt dome drilling) and inaccessible locations (if reservoir located under river beds, mountains, cities etc.).

Main part. So, to solve these problems it is better use the modern techniques which newly invented with appearance these problems, such as, Directional and Horizontal drilling instead of conventional (vertical) drilling and we got excellent results by increasing production rate and decreasing water and gas coning.

Directional Drilling is the process of drilling which controls the direction and deviation of the boring programmed to the targeted location, through Directional Drilling, we can create multiple wells and drilling locations from any entrance. Began use this technique at 1920s, the first controlled directional well drilled in California in 1930s to tap offshore oil reserves. So, from this method it can exploit several reservoirs at same time, and to solve the problem of the reservoirs that located under cities, river beds, mountains.

To solve other problems which occur through production and development the field, it used the Horizontal Drilling. Horizontal Drilling also use to solve several problems, for example, to avoid gas and water coning, also has several applications, such as, increasing the drainage area, improve sweep efficiencies, and reduce the number of wells needed for water flooding and steam injection for recovering heavy oils, and to improving productivity in fractured reservoirs by intersecting a numbers of vertical fractures.

Conclusion.

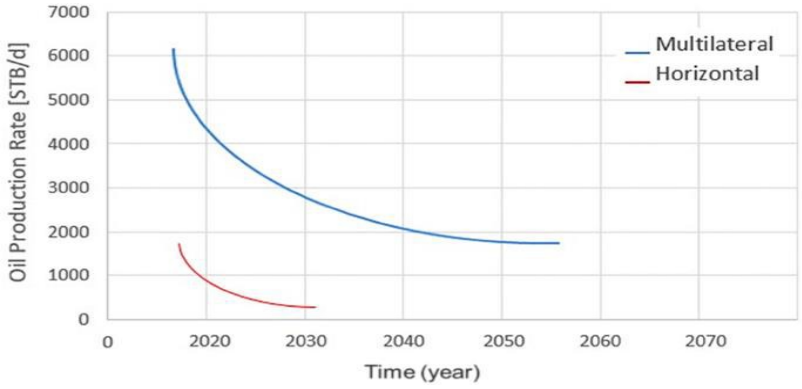

Figure 1 – The Oil production rate of horizontal and multilateral wells based on the simulation outcomes

From above figure is shown the Production rate forecast for single horizontal versus fishbone multilateral well based on reservoir simulation results for single horizontal well. As it is clear in the figure, primary recovery due to nature of the reservoir which is heavy oil and relatively tight reservoir is expected to continue production of oil till 2032. On the other hand, fishbone multilateral well is expected to continue production till 2056.

Thus, it conclusion from several experiments and simulations, the Directional and Horizontal Drilling is very effective and it allows to increase the drainage area, improve sweep efficiencies and thus, increase the production rate and depletion greater amount of oil from the reservoir for long time from the life of the reservoir. Also, from this technique it can exploit the reservoirs which the vertical wells can not to reach it.

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ALIKHANOV N.T.
St. Petersburg Mining University

STUDY AND DEVELOPMENT OF BARITE-FREE DRILLING MUD COMPOSITIONS

One of the most critical problems of modern oil and gas well drilling is an increase in the average depth of reservoirs, and with it the complexity of geological conditions. This trend leads to the demand for using high-density drilling fluids [4]. However, the use of such fluids does not lead to the solving of all problems, and features of operating such fluids create additional factors, which should be considered. To these factors we refer: settling of weighting agents, difficulties in rheology control due to high temperature and pressure, high concentration of solids affects efficiency of polymers, filter-cake, causing plugging of the pay zone, it requires additional investments in reservoir stimulation. All the above led to a technological gap in the development of water-based drilling fluid systems for wells under high pressure and temperature conditions[2,3].

The issue of not using water-based muds has been developed by the widespread practice of applying oil-based muds while drilling production wells. These fluids have been well proven in practice because of their excellent rheological characteristics, good compatibility with reservoir fluids and reduced overall non-production time on the rig [1,3]. On the other hand, the main weighting agent, was barite, due to the maximum mud density it able to set. Despite the huge number of wells that have been successfully drilled by these muds, the current reality highlights several disadvantages that override the entire experience [2].

The main disadvantages of oil-based muds are their high cost, maintenance requirements and environmental impact. In addition, increasing concentrations of barite leads to additional challenges, such as the fact that barite particles cannot be kept suspended in static conditions for long periods of time. The settling of barite leads to the stuck pipe, the potential of fracturing, and solution of these problems results in a rheology with a high equivalent circulation density [4].

Researchers addressed this issue and first decided to find a replacement for barite [1,2,4]. Several options were proposed: hematite and manganese tetroxide - but they could not completely abandon barite, because without it the drilling fluids did not attain the desired densities. Moreover, these weighting agents lead to abrasion of the equipment due to the high hardness of the minerals. Abrasion is observed in the drill string and circulation system places with high flow rates. The solution to the problem has been to grind the iron oxides even more. They have another property that can have an impact during directional drilling - magnetism. The weighting agent will be unevenly distributed along the wellbore, in the filter-cake, which will affect the logging even after drilling, for example, when determining the productivity of the reservoir [5]. So, it became necessary to use new weighting agents with the addition of barite at a ratio of 50-50. However, this did not solve another problem, that when barite is filtered into the pay zone it plugs pores and it is impossible to remove it, because it is insoluble in acid [3].

Therefore, attention was turned to the transition from drilling muds based on oil to the water based. First, it is necessary to understand in what way it is possible to get rid of all disadvantages of water-based muds. Such drawbacks include swelling of clay, dissolving of salt formations, negative interaction with formations, where there is a possibility of formation fluids influx, which catastrophically affects the rheological parameters of the drilling mud. To solve all these issues the authors turned to the possibility of creating drilling fluids not on the water basis,

but on brines saturated with salts. Advantages of such solutions are high density without addition of solid phase, shale inhibition, preservation of wellbore stability in salt formations, safe drilling of formations containing brines, preservation of reservoir properties [1-4].

Based on the studied international and national experience in the development of barite free drilling muds, in the laboratory at the Well Drilling Department of the St. Petersburg Mining University original composition of the drilling mud weighted with inorganic salts were created. Chemical reagents from leading companies in the field of drilling fluid service have been used in developing the high-density, low-solid-phase mud. When selecting the formulation, the main requirement was compliance with current requirements from Russia's leading oil companies, such as Rosneft and Gazprom. The focus was mainly on the idea that the fluid should have a sufficiently high density and not have significant hydraulic resistance. The weighting agent was sodium bromide and potassium chloride, because of its high solubility and the presence of potassium and sodium ions, which have proven to be good clay inhibitors. First of all, when developing the composition, studies were conducted on the possible degree of solubility - pilot tests were carried out at different temperatures from room temperature of 22 degrees to 70 °C. Naturally, the higher the temperature, the higher the degree of solubility, but we, as practicing drillers, try to take into account the real possibilities of preparing this formulation on the rig, so the temperature above 50-60 degrees was not used in further work.

Evidently, the more the percentage of suspended particles in the solution, the more thixotropy it is necessary to provide, and therefore, it is reflected in the whole rheological model of the solution. The standard rheological characteristics of KCL drilling fluid with density up to 1.3 g/cm3 and density of 1.6 g/cm3 with the same content of the solid phase and the best clay inhibition effect have been obtained. The addition of fractional calcium carbonate allowed the filtration value to be within normal limits.

The paper presents the results of the analysis of research works devoted to the possibility of creating such a solution and the results of practical application. Attention was paid to the characteristics of the choice of polymers and their effectiveness, information on possible inorganic compounds for creating brines, experimental samples, and results of performed experiments were provided.

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Scientific advisor: Ph.D. E.L. Leusheva

MOHAMMAD BARKHORDAR
Sahand University of Technology
DR. SEYYED SHAHAB TABATABAEE MORADI
Sahand University of Technology

A REVIEW ON WELL INTEGRITY IN FORMATION-CEMENT-CASING SYSTEM

Well integrity plays an important role in preventing incidents leading to blowout and catastrophic loss of both assets and human life [1]. Wellbore integrity is a general term used to describe the relative safety of a wellbore system after drilling has occurred. Formation-casing-cement system has to protect its integrity during well lifetime (e.g., after well completion, during production, hydraulic fracturing and injection) and it's necessary for the system to resist against the pressures and induced stresses like formation fluid pressure, thermal stresses and vibrations from injection and production fluids. Formation, cement and casing will act as a solid system (Fig. 1), each part of which have different mechanical properties. Therefore, wellbore integrity studies often include complex mechanical interactions between each of the components in the system [2].

Figure 1 – Composite system of rock-cement-casing

At the end of each phase of drilling operation, steel pipes known as casing with specific properties such as thickness, casing connections and diameter are used in order to protects fresh water zones from contamination of drilling fluids or flowing reservoir fluids. To achieve this purpose, casing pipes should be designed considering the formation and well's conditions and also all components of the casing string should be checked to identify the weakest point in the string with regards to available loads. Based on Norsok D-010, well integrity is defined as: “Application of technical, operational and organizational solutions to reduce risk of uncontrolled release of formation fluids throughout the life cycle of a well”. So, the most important role of the casing in the well integrity is the tolerance of applied loads. Due to the presence of downhole stresses (in-situ and induced) in the well, preservation of casing integrity will be a challenging task. Magnitude of in-situ stresses are dependent on the well location, diagenetic processes, reservoir characteristics and regional geo-stress distribution. Induced stresses are mainly results of different drilling and production operations. Buckling, Shear, collapse/burst, fatigue, wear/erosion/corrosion, connection failure and joint seal failure (Fig. 2) are several common types of failure that may occur in the casing as a result of applied stresses. Therefore, it is an essential task to calculate the magnitude and direction of stresses (like burst, collapse and axial load) in all component of the casing string and set the safety factors that can help to achieve well integrity [1-3].

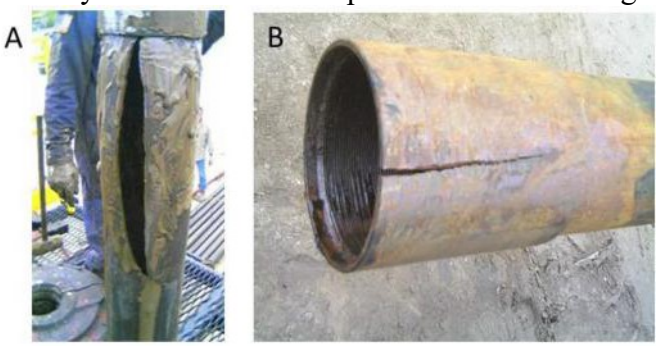

Figure 2 – Typical example of casing connection failure [1]

After setting the casing, the primary cementing must be done to keep the casing in the exact place, to resist pressures from above or below and to protect casings from corrosion. The most important function of the cement sheath is to provide zonal isolation in the wellbore, i.e. to exclude fluids such as water or gas in one zone from oil in another zone. Regarding this issue, a hydraulic seal must exist between the casing and the cement, and between the cement and the formation. This requires a quality bond between casing and cement and between cement and formation. If any of the bonds fail, a pathway for fluid flow may open, which results in disastrous effects in the well. The cement sheath should be impermeable, non-shrinking and ductile – (non-brittle) – to effectively seal the annular space. It, moreover, needs to have long-term integrity to withstand mechanical loads and to be resistant to different chemicals substances (H2S, CO2 and hydrocarbons). Cement sheath should have the ability to resist radial, hoop and axial stresses during hydraulic fracturing and fluid injection. However, in some cases the cement sheath may not tolerate applied stresses, which leads to channeling in the cement. In addition, cement failure could be accelerated if chemical reaction degrades cement barriers as a result of corrosive substances present in the well. Besides, failure of cement could endanger the integrity of casing and its connection [1-3].

Looking at casing, cement and formation as an integrated system, various well integrity issues could manifest themselves. However, mechanical failures of the steel casing and the cement sheath are two primary failures in such a system. Therefore, to have a good well integrity, you must know and calculate all tensions and stresses in the system and identify the weakest point of the system like casing connections and cement debonding between formation and casing [1, 3].

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ADRIAN BUGAJNY
University of Science and Technology
Dr. Prof. TOMASZ ŚLIWA
University of Science and Technology

A COMPARATIVE ANALYSIS OF THE CHANGE IN THERMAL CONDUCTIVITY OF GROUT IN BOREHOLE HEAT EXCHANGERS FOR GEOTHERMAL INSTALLATIONS

The demand for energy in the world is constantly growing. Every year, the consumption ofenergy in the world increases, which results in its increased production. Climate change, one of the most likely causes of which is an increase in energy consumption, has a negative impact on the environment and on human civilization. A gradual increase in the importance of the so-called renewable energy sources, including geothermal energy, which usually do not have a negative impact on the environment.

Geothermal energy is thermal energy obtained from soil, rocks and fluids filling fissures and pores in the rock mass. It accumulates as a result of the heat of the Earth's mantle and core, and at shallow depths under the influence of solar radiation and human activity (e.g. heat from sewage networks). It can be divided into deep geothermal energy and shallow geothermal energy.

Deep geothermal heat is most often found at depths of approx. 3-4 km. It is extracted from geothermal waters accumulated in aquifers or from hot dry rocks with the use of boreholes. Most

often they are made in a geothermal doublet: one borehole is used for water prodution and the other for injection.

Shallow geothermal resources are accumulated at relatively shallow depths in water and soil. They have low temperatures (not exceeding 20°C), at which direct use for energy purposes is impossible. They are operated indirectly, most often with the use of borehole heat exchanger as a source of low-temperature heat for heat pumps.

The design of the borehole heat exchanger affects its efficiency. Design, as well as making boreholes the heat exchanger depends on the type of rocks, their thermal resistance and volumetric heat capacity, the arrangement of layers, as well as hydrogeological conditions. The most common types of structural layouts are single or double U-pipe heat exchanger and coaxial heat exchanger. The U-pipes are usually made of polyethylene, and the remaining space in the borehole is filled with a sealant. It is the most popular type of construction in Europe due to economic reasons and simplicity of execution.

Sealant is one of the most important steps in the execution of BHE and it fills the space between the outer walls of the pipes and the wall of the borehole. The parameters of the mixture are adjusted primarily to the hydrogeological and geological conditions, the type of rocks drilled through, as well as the depth, temperature and pressure in the borehole. The borehole heat exchangers should be filled with a grout of increased thermal conductivity. The goal is to transfer as much heat as possible from the ground into the borehole and further onto the surface to the heat/cold consumer.

The first part of the research carried out was the selection of sealant recipes with increased thermal conductivity. To create them, additives such as copper, iron and magnesium were used, which are characterized by high thermal conductivity, easy availability and a relatively low price. The recipes of individual grout differed from each other in the percentage of the additive and the mass ratio of water to solids. The next step was to test the change in thermal conductivity of the hardened cement slurry samples compared to the sample in which no additives were used.

Based on the results for grout thermal conductivity tests, an analysis was carried out on the impact of changing the conductivity of the borehole filling in terms of increasing the low-temperature energy supplied to the heat consumer via a geothermal heat pump. In the economic part, cost minimization was analyzed by reducing the total depth of the borehole heat exchangers. The tests were carried out with the use of EED 4.1 (Earth Energy Designer) software, which is used to design borehole heat exchangers for data on heat demand, but also cooling for air-conditioning.

In the future, it is planned to test samples in terms of mechanical strength, as well as to test the impact of the use of other additives on the parameters cement for borehole heat exchangers and also energy piles.

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ANTON E. GOLOVCHENKO
Siberian Federal University
Dr. Prof. VYACHESLAV V. NESKOROMNYKH
Siberian Federal University

DEVELOPMENT OF ANALYSIS SYSTEM FOR PHYSICAL AND MECHANICAL PROPERTIES OF ROCKS IN THE DRILLING PROCESS

Modern mining and geological enterprises in the process of developing both new and existing deposits often face serious problems in the field of ore flow management. Rational distribution of ore mass at all stages of the production process directly affects the efficiency of development. However, despite the rather high general level of automation of processes at mining enterprises, the process of identifying rocks in the face to this day has not found a generally accepted method of interactive support. Solving this problem will potentially make a significant leap forward in terms of ensuring better management of ore masses at mining enterprises and will lead to an increase in their efficiency. The development of a system for analyzing the physical and mechanical properties of rocks in the process of drilling is carried out on the basis of the Department of Technology and Exploration Engineering of the Institute of Mining, Geology and Geotechnology of the Siberian Federal University by a team of authors consisting of: V.V. Neskoromnykh, A.E. Golovchenko, D.R. Vyalshin.

Mainly, to date, the advancement of the face at mining enterprises in the development of deposits, both by open and underground methods, is ensured by drilling and blasting operations with drilling blast holes and boreholes in a rotary-percussive way with the use of DTH hammers. The destruction of rocks in the conditions of rotary percussion drilling is mainly provided by axial impacts of high energy, converting the kinetic energy of the rock cutting tool into the energy of deformation of the rock and drill string [1]:

$$U_д = U_п + U_к,$$

where $U_д$ is the kinetic energy of the rock cutting tool, J; $U_п$ – energy of rock deformation, J; $U_к$ is the deformation energy of the drill string, J.

The drill string, perceiving part of the kinetic energy of the rock cutting tool, is elastically deformed. The amount of drill string deformation, according to previous studies, is determined based on the ratio:

$$\Delta l_т = 0{,}5(\delta - \sqrt{\delta^2 + 4\frac{mv_o^2 l}{EF}},$$

where δ is the deformation of the rock, m; m is the mass of the percussion tool, kg; v0 – velocity at the moment of impact of the tool with the rock, m/s; l is the length of a pipe of constant cross-section, m; E is the modulus of elasticity of the drill string material, Pa; F is the cross-sectional area of the drill string, m.

The deformation energy of a rock consists of two components: elastic $\Delta_{уп}$ and plastic deformation $\Delta_{пп}$

$$U_п = \Delta_{уп} + \Delta_{пп}.$$

In the development of a system for the interactive analysis of rocks by their physical and mechanical properties, it is mainly of interest to depend on the components of elastic ($\Delta_{уп}$) and plastic ($\Delta_{пп}$) deformation of rocks both on the elastic-plastic properties of rocks and technical and technological parameters. drilling, such as the magnitude of the shock impulse, the type of cutting tool and the degree of wear of the cutting tool cutting tool [2]. The empirical definition of these dependencies and their theoretical justification will become the basis for the development of an interactive system [3].

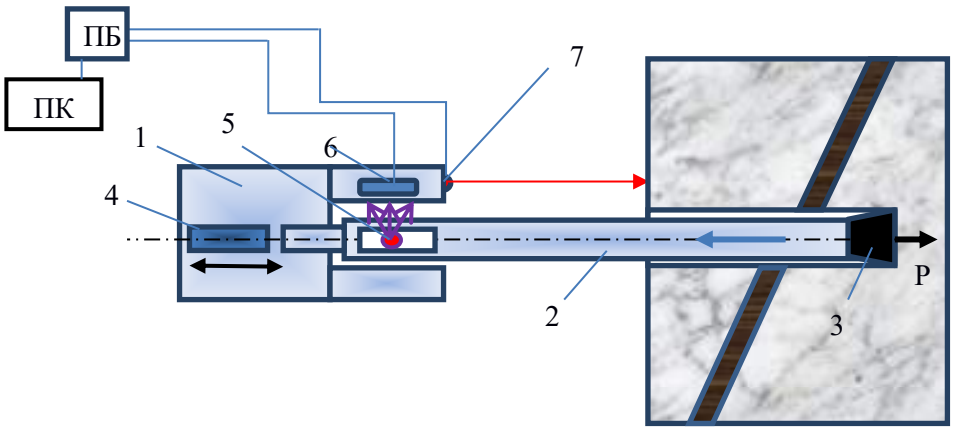

Figure 1 – A drilling rig for drilling boreholes and wells with a system for interactive determination of rock layers and inclusions of various physical and mechanical properties: 1 - drilling unit; 2 - drill pipe; 3 - chisel; 4 - striker of the percussion mechanism; 5 - piezoelectric sensor and transmitting part of the optocoupler; 6 - receiving part of the optotron; 7 - laser rangefinder

Practical implementation of the system for collecting information during drilling is possible using the complex shown in Fig. 1.

The system contains a drilling rig 1, operating in the rotary percussive drilling mode, and fixes the deformation of the drill pipe 2 at the moment of applying the percussion pulse due to the piezoelectric effect. As a piezoelectric sensor, a quartz or other sensor 5 can be used. Compression of a quartz crystal in the piezoelectric sensor 5 is converted into an electrical signal of an optotron, and an electrical signal into an LED of a certain intensity of light flux. The luminous flux perceived by the receiver-converter of the light signal 6 is again converted into an electrical signal by the photothiristor converter, which makes it possible to create the possibility of contactless signal transmission from the pipe rotating during drilling to the body of the drilling machine and then to the receiving electronic device and the computer.

Thus, a signal will be sent to the computer in real time, showing the amount of deformation in the drill string, as a result of the reaction from the rock being destroyed at the moment, depending on the type of rock-destroying tool, its technical condition (wear), the energy of the shock pulse generated DTH hammer.

The effect of the industrial implementation of a system for analyzing the physical and mechanical properties of rocks during drilling is a comprehensive optimization of ore mass flows at enterprises and, as a consequence, an increase in the percentage of ore during rock excavation due to a decrease in dilution, as well as a reduction in the number of unproductive technological operations that today it is necessary to produce to determine the type of drilled rock.

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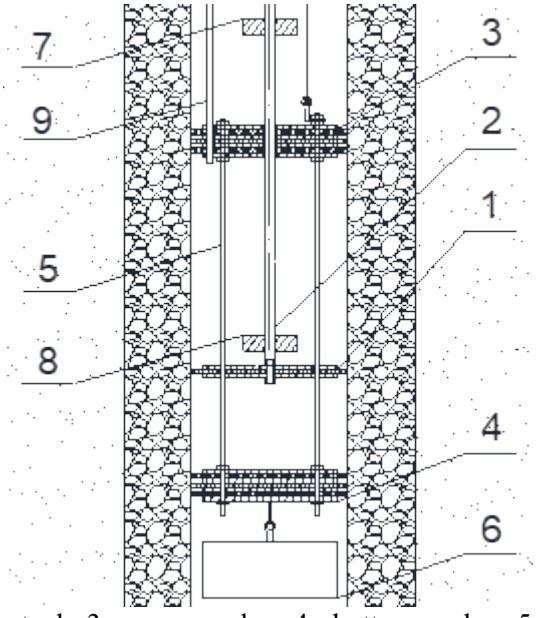
ALEXEY A. HYNKU
Belarusian National Technical University
IRINA E. AMELISHKO
Belarusian National Technical University

INTERVAL REVERSE-REAGENT TREATMENT OF WATER WELLS BY MEANS OF SWABBING

During the operation of water wells, the specific flow rate decreases as a result of colmatage. Operation of a well without carrying out preventive and repair measures leads to a decrease in its flow rate and entails an excessive consumption of electricity for lifting water. Various methods are used to restore the performance of old wells [1]. Each method has its own area of application, advantages and disadvantages. Circulation-reagent methods of well regeneration are the most promising. They can provide the required depth and uniformity of cleaning the filter and the near-filter zone of the wells.

Further improvement of circulating-reagent regeneration technologies that ensure uniform removal of clogging sediment is an urgent scientific and technical task.

In BNTU, it was proposed to carry out a circulation- reagent treatment of filters of water wells by means of swabbing. Regeneration is carried out by intervals in the section of the filter, bounded by two packers and filled with reagent. The proposed downhole device for regeneration by linear swabbing in a closed chamber [2] has a number of complex structural elements. Therefore, we have simplified the design of the device. The scheme of processing a section of a gravel pack with a simplified device for regeneration by the method of linear swabbing is shown in Figure 1.



1 - swab; 2 - stock; 3 - upper packer; 4 - bottom packer; 5 - guide rods;
6 - massive cargo; 7 - top stop; 8 - bottom stop; 9 - hose for reagent supply
Figure 1 – Scheme of filter reagent treatment based on the swabbing method

I lower the device for regeneration into the treated section of the filter. Packers make the selected section of the well closed. A reversible swab in the filter between two packers can create overpressure, which triggers the filtering agent flow, bending around the swab in the filter between the two packers and directed to the reduced pressure zone. The working strokes are repeated until the required degree of regeneration of the filter section is achieved. After the device for regeneration is moved

To calculate the duration of filter processing based on the swabbing method, we will use the procedure for calculating the operating time of the installation for the reverse reagent processing of filters [3]. To describe the process of dissolution of sediments, the system of equations (1) was used: the combined equation of motion and conservation of mass and the generalized equation of kinetics.

$$\begin{cases} -v\dfrac{\partial C}{\partial x} - \rho_{oc}\dfrac{\partial b}{\partial t} = n_0\dfrac{\partial C}{\partial t} \\ \dfrac{\partial b}{\partial t} = -\Phi\cdot(C_m - C) \end{cases}, \quad (1)$$

where *Cm* - the maximum concentration of salts in the reagent (concentration of a saturated solution); *C* - the concentration of salts in the reagent; ν - the speed of movement of the reagent in the gravel packing; *n0* - the initial porosity of the soil, *b* - the specific saturation of the soil with a bridging agent, the density of which is *ρoc*.

$$b(T_0, L) = b_0 - \sum_{m=1}^{k}\left[n_0\cdot\left(1-e^{-\alpha_m T_0}\right)+\alpha_m\cdot e^{-\alpha_m T_0}(1-n_0)\cdot T_0\right]\cdot J_m, \quad (2)$$

Formula (2) allows you to calculate the time after which the specific volume of deposits reaches 0. According to the formulas obtained, a computer program was compiled that allows calculating the number of cycles of device operation, the duration of cleaning and the degree of removal of colmatage at each stage of work.

The program contains the following initial data: the outer diameter of the filter Df = 273 mm; outer diameter of gravel packing Dgr = 450m; the specific volume of colmate agent deposits b0 = 0.1; initial porosity of the medium n0 = 0.3; colmate density ρc = 2250 kg / m3; length of the processed section of the filter L = 1 m; maximum concentration of ferric chloride in a given volume of reagent CmFeCL3 = 529 kg/m3; the speed of movement of the reagent in the closed loading υ = 2 mm/s.

Calculation results: the time for the regent to pass a section 1 m long: T0 = 500 s. Duration of flushing a 1 m long section: Ttot = 25 minutes.

Conclusion: the design of the device for regeneration by the swabbing method in a closed chamber filled with a reagent has been improved and simplified; an example of calculating the duration of the reagent treatment of a filter section when using hydrochloric acid as reagents is considered.

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REZA JALAKANI
Sahand University of Technology
Dr. SEYYED SHAHAB TABATABAEE MORADI
Sahand University of Technology

A REVIEW ON THE EFFECT OF MUD WEIGHT ON RATE OF PENTRATION AND WELLBORE STABILITY

Drilling Fluids play important role in rotary drilling method. Nowadays there are variety of drilling fluid systems in the industry, which serve lots of functions. In general, the major functions are (1) Carry cuttings from the hole and permit their separation at the surface. (2) Cool and clean the bit. (3) Reduce friction between the drill pipe and wellbore or casing. (4) Maintain the stability of the wellbore. (5) Prevent the inflow of fluids from the wellbore. (6) Form a thin, low-permeable filter cake. (7) Be non-damaging to the producing formation. (8) Be non-hazardous to the environment and personnel [1].

Mud weight (MW) is defined as the density of drilling mud (mass divided by volume), expressed in pounds per gallon (ppg or Ib/gal), pounds per cubic feet (lb/ft3), kilograms per cubic meter (kg/m3), or grams per cubic centimeter (g/cm3). MW significantly affects several drilling performance indicators like Rate of Penetration (ROP) and well stability. Objective of this study is to review the effect of mud weight on ROP and wellbore stability [2].

Too fast ROP may result in hole problems and poor hole cleaning that can extend the duration of well delivery and introduce much more complications such as losing part of the bottom hole assembly (BHA) in the hole due to formation instability and collapse. Many factors, which are related to each other, can affect ROP. These factors are divided into five categories including; rig efficiency, formation characteristics, mechanical factors, hydraulic factors and mud properties [2].

There are several published models to predict the rate of penetration; however, most of them focus on drilling parameters such as string revolutions per minute (N), weight on bit (WOB), and pump rate (Q). Only a few of these models include effect of MW and their influence on ROP values [2].

Akpabio et al.showed real field data for several water based and oil based drilling fluids, used to drill in sandstone and shale formations. Based on data, they plotted ROP against the mud weight. For the water-based muds with MWs of 10.5, 11.5 and 8.9 ppg, average ROPs of 25 and 24 and 37 ft/hr were determined respectively. Similarly, ROPs of 28, 35 and 50 ft/hr were obtained by the oil-based muds with MWs of 11.3, 11.1 and 8.6 ppg respectively. Therefore, it can be conclude that ROP was reduced by increase in the MW for both water based and oil based muds [2].

Beside ROP, MW also play a significant role in providing a safe drilling operation with a stable hole. When the borehole is drilled, state of in-situ stresses are disturbed around the borehole. If the induced stresses exceed rock strength, the rock in the borehole wall fails. Figure 1 shows the effect of high and low MW values on wellbore stability [3].

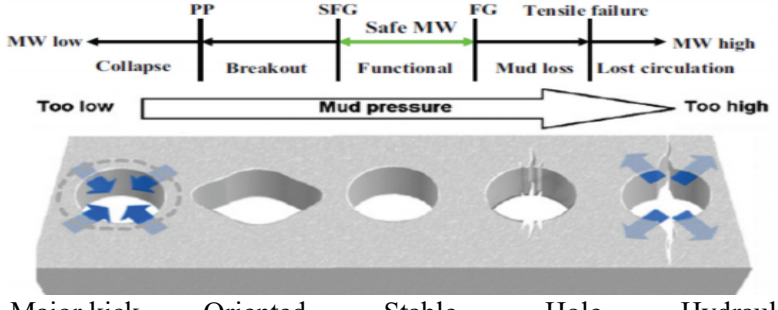

Figure 1– Borehole problems related to MW value [3]

Wellbore stability modeling for drilling operation is to find a proper Mud Weight Window (MWW), which can provide instructions for on-site operators to choose a mud weight that can prevent wellbore collapse and fracturing. The normal way is to firstly calculate the stress distribution around a wellbore, and then derive the mud weight based on proper failure criteria [3].

Therefore, following main conclusions can be made about the effect of MW on ROP an wellbore stability:

– MW is one of the most important factor, which can significantly affectROP and well stability.

– For the weak formations like shale formations, there is an inverse proportionality between the ROP and MW.

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KAMAEV D.R.
Samara State Technical University
Institute of Oil and Gas Technologies
Ph.D., associate professorV.V. ZHIVAEVA
Samara State Technical University

STUDY OF THE EFFECT OF CORROSIVE-ACTIVE AGENTS ON THE PLUGGING MATERIALDESTRUCTION PROCESSES

The most important factors that determine the choice of plugging materials include the temperature, pressure drop and concentration of active fluids of the operated well. Portland cement is a complex physical and chemical structure with a wide range of particle sizes, which is certainly important when modeling the composition and properties of future plugging stone.

The chemical formula of cement is usually expressed as a sum of oxides: tricalcium silicate Ca_3SiO_5 expressed as $3Ca0*SiO_2$ or C_3S (Alite), dicalcium silicate C_2S (Belite). The composition contains an aluminate phase C_3A, a ferrite phase and other components. All oxides are reactive and react with acidic agents - hydrogen sulfide, carbon dioxide.

The physical and mechanical characteristics of the formed plugging stone determine to what extent and for what period under the conditions of an operating well there will be diffusion penetration of a corrosive fluid into it and its destruction will begin.

The main variable quantities that can be determined with a high degree of accuracy at the stage of designing the plugging composition are: absolute and phase permeability, the fraction of the free cross-section of the pores, the free surface per unit volume and the calculated rate of the chemical reaction.

These values are in direct relationship with sedimentation stability and the degree of filtration of cement slurries. When the backfill stone interacts with hydrogen sulfide dissolved in the formation water, the damage to the stone proceeds in layers. Hydrogen sulfide, diffusing deep into the cement stone, enters into a chemical reaction with dissolved calcium hydroxide.

To determine the parameters of the plugging material, after my suggested modification methods, an experimental plan was drawn up to determine the main characteristics of the plugging suspension and stone. These characteristics were determined by me in the laboratory of plugging materials of Samara State Technical University.

As a result of chemical reactions, the pore fluid is depleted in alkali, which leads to a violation of the thermodynamic equilibrium between the solid and liquid phases of the cement stone. The solidification products continue to dissolve and hydrate with the release of free calcium hydroxide. First of all, the solid phase is destroyed, represented by crystalline calcium oxide hydrate, highly basic aluminates, hydrosilicate and calcium hydroferrite. The insoluble part of the cement stone, chemically inert with respect to hydrogen sulfide, forms a buffer zone. It is represented by decomposition products of hydrated phases in the form of SiO_2 and $Al(OH)_3$ gels and corrosion products in solid (CaS, FeS) and liquid phases; The reactive part of the cement stone in the process of hydrolysis and dissolution passed into the solution, and then in the form of highly soluble corrosion products - Ca(HS) - into the environment.

At pH> 11, the main product of the interaction of hydrogen sulfide with calcium hydroxide is poorly soluble calcium sulfide. As Ca(OH)2 decreases from the solution, the balance between the solid and liquid phases is disturbed, which causes the dissolution and hydrolysis of the components of the plugging stone. As a result of hydrolysis, new portions of Ca(OH)2 enter the solution, which are bound by dissolved hydrogen sulfide. Calcium sulfides accumulated in the pores of a cement stone cause internal stresses in it and subsequent destruction. This type of corrosion is typical for plugging material, the stone on the basis of which is represented by free calcium hydroxide, highly basic hydrosilicates and calcium hydroaluminates, the equilibrium pH of which is more than 12.

The reason for the destruction of cement is the formation of the" cement bacillus " of ettringite and the associated volumetric deformations, which are particularly dangerous in already hardened cement stone. Ettringite forms a gypsum with hydrogen sulfide, which has a low suffusion resistance. Diagram of the process of interphase transitions:

$$\text{Ca(OH)2} \xrightarrow{H_2S} \text{ettringite} \xrightarrow{H_2S} \text{gypsum}$$

Volumetric expansion is dangerous when it occurs in already hardened cement stone. The fact is that ettringite can be formed from the products of C3A hydration as a result of sulfate aggression according to the equation

$$3CaO\cdot Al_2O_3\cdot 6H_2O + 3CaSO_4 + 26H_2O \rightarrow \underbrace{3\ CaO\cdot Al_2O_3\cdot 3CaSO_4\cdot 32\ H_2O}_{\text{ettringite}}$$

At the same time, there is a 4-6-fold increase in volume, which in the hardened stone leads to stress, disruption and destruction of the structure. One of the indicators of the destruction of cement stone is also the dispersion of cement particles and formed globules, which leads to an increase in the pore space and mechanical destruction of the structure.

To study the kinetics of structure formation, I used the method of microscopic examination of cement stones.

All microscopic studies were carried out on thin sections made of solidified compounds in transmitted polarized and reflected light at 400 times magnification. In polished thin sections, the distribution and interrelation of components, individual crystals of new formations were observed, it is possible to determine their sizes, assess porosity and fracturing, and the state of the surface.

One of the most important structural parameters of cement stone, which determine its filtration capacity, is the nature of the structure of the pore spaces. Visually, using microphotostructural analysis, it can be noted that in the process of contact with hydrogen sulfide, the body of the cement stone is destroyed, which is confirmed by a change in the size and configuration of pores, an increase in porosity, the presence of dissolution elements in the pores, the formation of cracks and channels. The porosity, size and configuration of pores in the reference samples vary in the range of 2-10%. The values of porosity and pore sizes of reference samples and samples of ten-day and nine-month storage in hydrogen sulfide vary within 5-12%.

The diagrams of changes in porosity and pore size are in the range of 2-15% (for porosity) and 0.25-8 μm (for pore size), respectively. The limits of porosity change for the formed structure of various composition are 2-10%. Capillary spherical pores with a size of 0.01-2 μm prevail against the background of an impermeable matrix. The formed structure of a cement stone under a microscope looks like a fine-grained mass, consisting of crystals ranging in size from 0.005 to 0.1 mm, of an indefinite shape, prone to the formation of clusters and varying in the level of darkness. In reflected light, the preparations characterize the relief and shagreen. All preparations have low relief and shagreen. Cement additives slightly change the structure of the stone, are characterized by the presence of granules with crystallization elements. It can be said that these structures contain a condensed finely dispersed solid phase located in the pore space between the cement grains.

Thus, as a result of the studies carried out, it was found that by the change in the structure of the plugging material during hydration in time or under the influence of a corrosive agent (hydrogen sulfide), one can judge about the one-sided or mutual influence of the reagents used to treat the plugging suspension. Corrosive-active environment, interfering with the process of structure formation, significantly changes its porosity and permeability. The materials in which the treatment reagent (surfactant and stabilizer) participates in the formation of the structure is least susceptible to the effect of a corrosive environment.

The ultimate goal of developing the model is to calculate the operating time of the plugging material when exposed to a corrosive environment, in particular, hydrogen sulfide. The solution of the model will make it possible to select the optimal composition of the plugging material for certain mining and geological conditions. Significant factors for calculating the time of corrosion destruction are the concentration of the corrosive agent, the concentration and chemical nature of the reagent for processing the plugging material, the time of exposure to the corrosive medium under the corresponding temperature and pressure conditions. The computational model should include the rates of longitudinal and transverse diffusion. To obtain these characteristics, additional research is required.

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KAZAKU VITALY
Sergo Ordzhonikidze Russian State University for Geological Prospecting
Dr. Prof. VLADIMIR SOLOVIEV
Sergo Ordzhonikidze Russian State University for Geological Prospecting

DEVELOPMENT OF A SOFTWARE-ALGORITHMIC MODULE THAT CALCULATES PULSED CIRCULATION PARAMETERS IN HORIZONTAL WELLS

In the modern drilling industry, directional drilling is increasingly being used. This type of drilling has a number of advantages over vertical drilling, but at the same time it has its own engineering and technological disadvantages.

One of these drawbacks is the problem of removal of cuttings from the bottom of the well. The reason for this problem is the choice of inefficient methods of circulation ining the well, which in turn suffers huge temporary and financial losses. Therefore, I began to conduct research in this area to understand whether it is possible to somehow optimize this process.

My project is primarily aimed at solving this problem, namely the development of a computer module that will calculate the circulation system using previously unused technology, and will include: the ability to visually monitor the movement of sludge particles along the entire length of the well; a calculation module that takes into account the many hydraulic and rheological parameters of the drilling fluid, properties of drillable rocks and other factors used in modern solutions for hydraulic calculation.

Thus, we get a completely new product that will meet all modern standards and requirements, but at the same time will be more efficient and cheaper than existing analog.

In Figure 1, we simulated the movement of sludge in the “horizontal well” model. It can be seen from the figure that sludge particles are deposited not only in the horizontal section of the well, but also on the bottom wall of the directional well. Moreover, in the places of accumulation of sludge, a “bed” is formed, which interferes with further removal [2,4]. The reason for the violation of the effective washing of the wellbore is not only the hydrodynamic indicators of drilling, but also the geometry of the annulus and the profile of the wellbore.

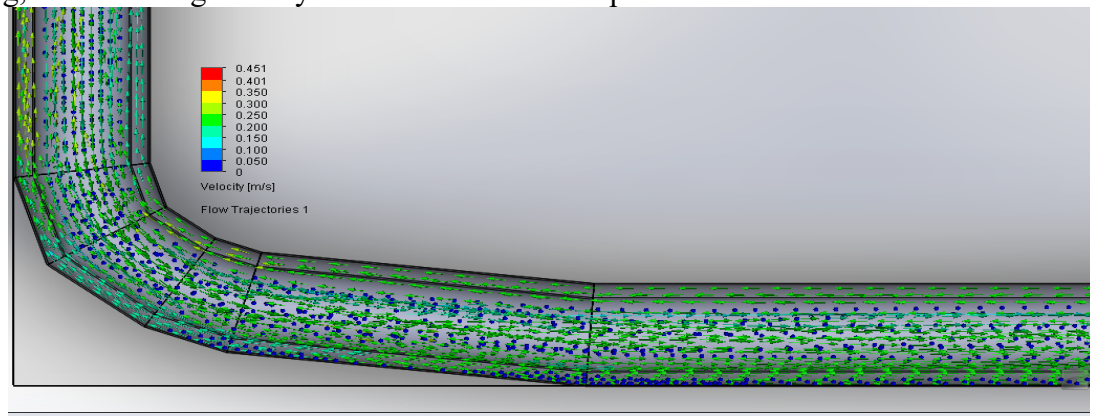

Figure 1 – Velocity distribution vectors and sludge particles in it (well model)

In Figure 2, we simulated the movement of sludge in the “horizontal well” model. It can be seen from the figure that the particles of the sludge move in a pulsating flow, forming moving dunes not only in the horizontal section of the well, but also on the lower wall of the directional shaft. This ensures effective removal of sludge throughout the wellbore.

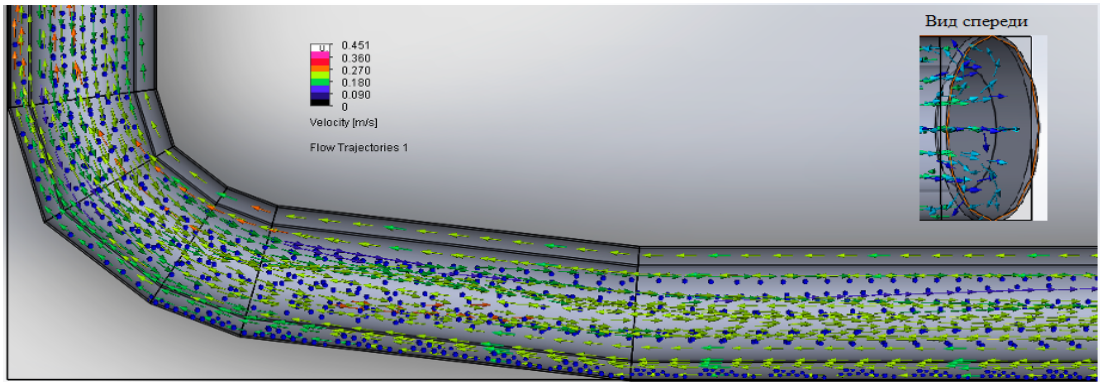

Figure 2 – Velocity vectors with sludge particles in a pulsating flow (well model)

In conclusion, I would like to note that the sludge accumulated in the horizontal section of the well, the section of the well is more effectively washed with a pulsating flow of washing liquid. Also, when using computer simulation, a dune formation model really develops, the behavior of the sludge in the well is completely reflected, i.e. the model works and can be recommended for use.

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KHOSRAVANIAN NABIOLLAH
Sahand University of Technology
DR. SEYYED SHAHAB TABATABAEE MORADI
Sahand University of Technology

A REVIEW ON WELL CONTROL OPERATIONS DURING MANAGED PRESSURE DRILLING

Managed Pressure Drilling is a regarded and adoptive solution for drilling when narrow mud weigh windows are encountered in the wellbore. During MPD, kick, as the unwanted flow of formation fluids into the wellbore, may be detected earlier, which results in reduction of influx volume and non-productive time (NPT) due to easier kick removal. In conventional drilling, fluid circulates through surface equipment and down to drill string and finally returns back to the atmosphere through the annulus. However, in MPD, drilling fluid circulates through a closed loop, which is the main difference between MPD and conventional drilling. When narrow pressure margins are expected, implementation of conventional drilling method to adjust bottom hole pressure in an effort to respond subsurface pressure seems to be a challenging task, as increased mud weight to control influx of formation fluids may exceed formation fracture pressure. [1].

Calculated bottom-hole pressures based on conventional and managed pressure drilling are shown in the Figure 1.

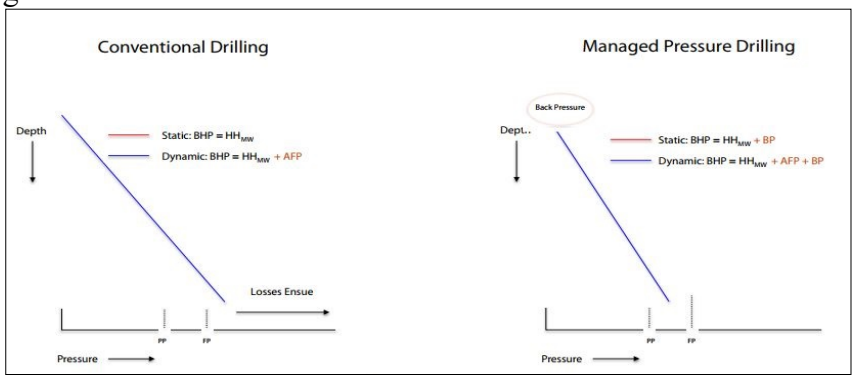

Figure 1 – Bottom hole pressure in conventional drilling and MPD [1]

During connection time in conventional drilling, the driller must stop pumping and pick the string off-bottom, which causes reduction in bottom hole pressure due to lack of Annular Pressure Loss. However, with MPD technique, this is not an issue to be worry about because circulation can be established using Rotating Circulation Device and its Sub, which allows continuous circulation and pumps can be stopped while maintaining constant bottom hole pressure through MPD choke manipulation [2].

Conventionally in suspicion of an influx, the drilling operation must be stopped and driller should position the drill string and perform flow check to confirm the kick. During this time, influx has time to displace the drilling fluid and consequently results in more volume of influx. However, with MPD in the drilling rig, equipped with Coriolis meter, kick is detected earlier and driller can apply pre-defined Surface Back Pressure and circulate out small influx below the planned limit or MPD can terminate influx flow and then handover the well control procedure to conventional method. It has also potential to optimize the handover and in this case it is estimated that secondary barrier is taking over. The relationship between the primary and secondary barrier is critical and MPD operation matrix provides a method to define the interface between two [3].

When it comes to offshore drilling except for riser less mud recovery top-hole technology, the industry has not been capable of developing and utilize dual gradient drilling in a cost effective way. The EC-Drill system is a technology beyond dual gradient system. The primary purpose of this system is to terminate the outcome of ECD and stabilize bottom-hole pressure in the mud window. While the mechanism of dual gradient is based on under balanced drilling system, in EC-Drill technology a submerged mud pump, connected to the conductor pipe or drilling riser, is utilized to keep mud hydrostatic pressure above pore pressure. This in turn leads to reduction of riser effective length and mud level in the riser can be adjusted based on downhole required pressure [4].

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VLADA S. KOVALCHUK
St. Petersburg Mining University
Dr. Assoc. Prof. ELENA Y. TSIGELNYUK
St. Petersburg Mining University

ANALYSIS OF EFFICIENCY OF CARBON MATERIALS INTRODUCTION INTO PLUGGING MIXTURES

This paper discusses the issues of the efficiency increasing of well cementing in difficult conditions. Trends in environmentally friendly and safe production are being introduced into all industries and dictate quality standards for the introduction of new technologies, methods and compositions. The search for an alternative green inorganic binder with increased strength is a key task for modern scientists [1, 2, 3, 4, 5].

The analyzed world studies on the carbon materials use as an additive in concretes, composites and cements have shown the ambiguity of the carbon materials influence on the quality of cement stone for well casing. The use of carbon theoretically and practically should be effective, which focuses on current trends towards waste-free production and improvement of the environmental situation.

The several carbon materials are presented, which are used as additives to cement slurries. The choice of the additive is due to the solution of the problem of utilization of carbon-containing components, for example, obtained as a result of combustion and deposition processes. For experimental studies as the basis for the grouting slurries were chosen ordinary Portland cement PC-I-50 brand, alumina cement AC-40 and high-alumina cement HAC-II, as well as additives in the form of three types of soot and various plasticizers that increase the mobility of the cement mortar. The optimal percentages of the reagents with the mixing water volume and with each other were selected empirically using the theory of experiment planning, taking into account their compatibility and the main parameters of the resulting grouting mixture and cement stone. Experimental studies were carried out in the laboratory of drilling and grouting fluids (Department of Well Drilling, St. Petersburg Mining University). The structural and rheological parameters of the grouting compositions and the physical and mechanical properties of the cement stone were studied in accordance with Russian and international standards: GOST 26798.1-96, GOST 310.2 and ISO 10426-1. The optimal content of carbon materials and plasticizers in the binder has been estimated, which makes it possible to obtain high mechanical properties of cement stone in comparison with a solution without additives. It has been determined that small doses of modifiers are required for optimal effect on the properties of the cement stone. The physical, mechanical and operational properties of the modified grouting mixture are considered. The comparative analysis of the influence of three types of soot is given and the most effective carbon-containing material for use as an additive in grouting mixtures is determined.

The experimental results of the modification of cement slurries with carbon materials showed an increased strength of the cement stone and a reduced permeability of the cement stone relative to samples without additives, along with the compliance of the cement slurries with all technological parameters. The increase in the strength of cement stone for uniaxial compression is associated with the mechanism of interaction of cement with carbon materials and plasticizers, which at the molecular level stick together cement particles and create a dense structure when cement slurry hardens. The most optimal amount of carbon materials was 0.5-2.0% by weight of cement. With an increase in their content, a deterioration in the strength characteristics of the grouting mixture is observed in the first week of hardening. It was determined that the introduction of plasticizers has a positive effect on cement slurries with the addition of carbon materials. So, there is an increase in the mobility of the cement slurry, which leads to an increase in its strength and a decrease in porosity. Thanks to the highly abundant and cheap carbon, micro-reinforcement of the crystal lattice is observed, the amount of pore space in the cement stone is reduced, the surface of metal casing pipes is protected, and the harmful chemical contamination of underground

fluids and rocks is reduced. The use of carbon materials as additives in cement slurries not only solves the problem of high-quality well casing, but also makes it possible to utilize carbon-containing components, for example, obtained as a result of combustion and sedimentation processes. Thus, the addition of carbon-containing materials provides micro-reinforcement of the cement stone and prevents the propagation of cracks in it. These conclusions will allow us to assert the promising use of carbon materials as additives in cement slurries for well construction.

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KSENIIA O. KOVALEVA
Samara State Technical University
OLGA A. NECHAEVA
Samara State Technical University

MECHANISMS OF DESTRUCTION OF MUDSTONES AND METHODS OF THEIR INHIBITION

During the construction of oil and gas wells, there has recently been a tendency for destruction of rocks, composed of fractured mudstones, which results in the loss of stability of the wellbore, complication of the drilling process, as well as a decrease in its technical and economic indicators. Sloughs and landslides occur mainly through the passage of compacted clays, mudstones or shales. To be able to prevent and eliminate mudstone collapse, it is necessary to understand the mechanisms that precede its destruction.

In the rock, shear and normal stresses compensate each other, but as the drilling fluid replaces the cylinder of the drilled formation, these stresses begin to act with different magnitudes on the borehole walls, since the drilling fluid is not able to withstand the shear stress [1]. This leads to a redistribution of stresses around the wellbore, creating stress concentrations. The magnitude of the stress difference is compensated for by the hoop stresses, which are concentrated around the wellbore and keep the rock in a tied state. If these stresses exceed the rock strength, then it begins to collapse. The process of the appearance of microfracturing in rocks composed of mudstones is as follows: under the influence of temperatures above 70 ° C, bound water is released in clay deposits due to the dissociation of molecules, and the open area of the pores increases. As a result, clay particles grow together and form lamellar intergrowths, destroying the stress concentration.

In the course of considering the problems of the stability of clay deposits, in particular mudstone, the question of balancing the stresses necessary to ensure the geomechanical stability of the rock after it was opened by drilling was of paramount importance. In addition, the effect of chemical interaction of the drilling fluid and its filtrate with the rock should not be excluded. Based on this, we decided to find a solution to prevent the formation of fractured mudstones, that is the development of a drilling fluid formulation capable of eliminating or minimizing this complication during the construction of oil and gas wells

The practice of drilling wells has shown that the most promising method to combat the formation of clayey rocks is the use of inhibiting solutions. One of the solutions to prevent talus

and collapse of horizons, composed of mudstones with interlayers of various types of clays, is the use of a water-based flushing system. The essence of the system lies in the mechanism of triple inhibition of the rock, the reagents of which are organic and inorganic inhibitors, as well as a high-molecular-weight encapsulator. An inorganic inhibitor is potassium chloride: this reagent is a coagulant of the colloidal clay phase. An organic inhibitor is polyekol: it achieves a synergistic effect with potassium chloride, suppressing clay hydration, reducing the space between clay plates, minimizing the wedging effect of water. A high molecular weight encapsulator is sodium petroleum sulfonate "PDS" containing various water-, water-oil- and oil-soluble anionic surfactants (sodium salts of aromatic sulfonic acids of various structures, petroleum sulfonates). To increase the surface activity of surfactants, as well as expand the molecular weight distribution of anionic surfactants, the product samples contain surfactants with a dimeric structure, that have a higher surface activity, making it possible to reduce the interfacial tension and the critical concentration of micelle formation [2].

The inhibitory ability of the test solution was assessed by the linear swelling index. During the experiment, four samples of cuttings and four test fluids were used: inhibiting drilling mud with surfactants, gel-solution [3], clay (bentonite) mud, and water. The graph (Figure 1) shows the dependence of the swelling of a rock sample on the swelling time for 120 hours. As a result of the study, it was found that samples of cuttings taken from an interval composed of mudstones are subject to destruction and swelling to varying degrees. It was also recorded that when interacting with a triple inhibition solution, the best results were shown - the absence of swelling dynamics and established stable behavior throughout the entire study period.

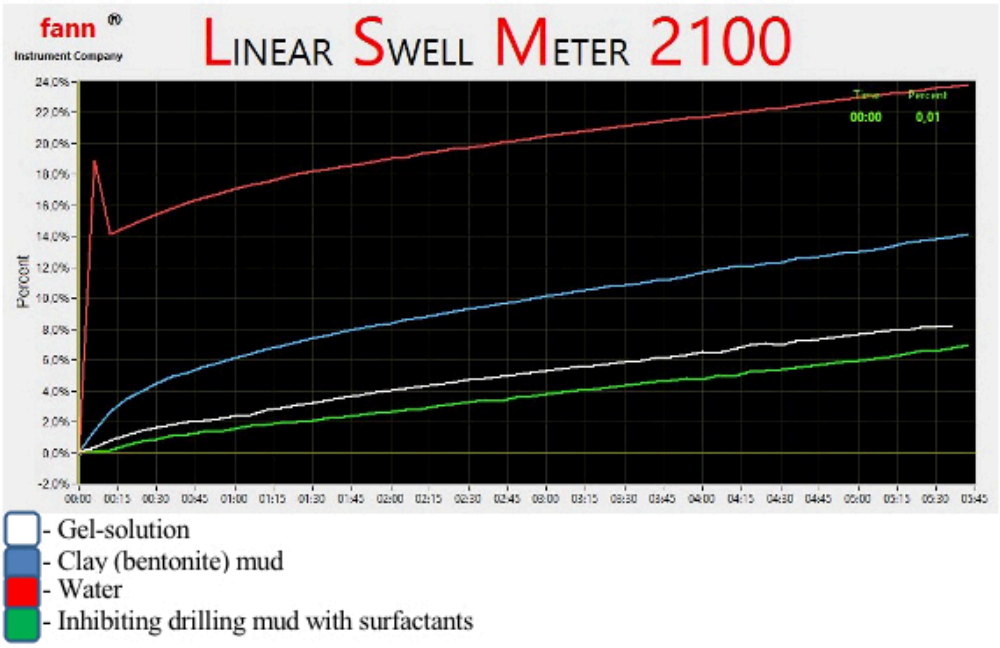

Figure 1 – The dependence of the swelling of a rock sample on the swelling time.

The ability of the proposed flushing system to prevent the processes of moistening, swelling and dispersion of the rock makes it possible to preserve the integrity of the borehole walls. Preventing the ingress of moisture from the drilling fluid and its filtrate into the formation minimizes the destruction of its structure, thereby preventing rock falls and debris. Slowing down the hydration of the mudstone is achieved by encapsulating the cuttings sample.

Further studies of argillite samples will be carried out on a triaxial loading unit, developed at the Department of Oil and Gas Well Drilling, SSTU [4].

According to the results of the first stage of research, it was determined that with linear swelling of the samples, the proposed washing liquid with dimeric surfactants possesses the best inhibiting properties. On this basis, a flushing system with a triple inhibition mechanism can be recommended to prevent collapses and debris of unstable borehole walls when drilling oil and gas wells.

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MEHDI MAZLOOM
Sahand University of Technology, Tabriz, Iran
Dr. SEYYED SHAHAB TABATABAEE MORADI
Sahand University of Technology, Tabriz, Iran

A REVIEW ON EFFECT OF MUD CAKE PROPERTIES IN WELL CONSTRUCTION PROCESS

When drilling operation is performed in over-balance pressure mode, due to the dominance of drilling fluid pressure over the underground formations pressure, a membrane of mud cake is formed on the wall of the formation adjacent to the wellbore. In other words, mud cake formation is a layer of mud emulsion that is formed from the drilling fluids during the drilling operation [1-3].

Drilling fluid type is also an effective factor on the characterization of the filter cake deposited on the wall of the formation. In general, colloidal drilling fluid consists of a main continuous phase and a solid phase (suspended particle). It is clear that the type of the solid particles suspended in the drilling fluid as well as their sizes the geometric grains shapes significantly affect the thickness and efficiency of the filter cake made during the filtration process . In types of drilling fluids with higher solids content and larger grains, the thickness of the cake filter increases and its fluid loss control performance decreases dramatically. Recent studies on water-based drilling muds which most of them are composed by bentonite clay show that the type and mineralogical composition of the bentonite clay can have different effects on rheology and filtration properties (cake filter deposition) of drilling fluids [4-7].

The continuous phase of the drilling fluid is mainly liquid where provides the main environment for the dispersion and suspension of solid particles. Colloidal stability and good dispersibility are some of the features expected from the desired continuous phase. Usually, the thickness of the filter cake in oil-based muds (drilling fluid with continuous oil or diesel phase) is less thick and have better quality and efficiency compared to water-based drilling muds. Also, mud filtrate in this type of fluids, due to their nature, causes less damage to the production zones and the chemical reactions between them and the formation fluids in the production zones will be minimized. The presence of this mud cake is an advantage for the protection of production zones. Controlling the fluid loss or invasion of the drilling fluid filtrate to the formation is the most important advantage of filter cake. Invasion of the drilling fluid solid particles clogs the pore-throats in production zones and the chemical reactions caused by the interaction between the aggressive liquid filtrate and the formation fluids content will cause severe damage to productive layers. On the other hand, poor quality and thick filter cake can cause many problems during drilling and cementing operations. High torque and drag, possibility of stuck pipes, poor quality of cement bond to the formation and also poor quality of survey data in well drilling operations are such disadvantages. Therefore, it is very important to control and manage the quality of the deposed filter cake [8-9].

This research tries to review the role of filter cake in drilling operations, cement bonding quality, petrophysical survey results. It also focuses on the factors that affect the quality of the filter cake and review their effect on the filtration rate, thickness and depth of liquid invasion. From the previous studies, it can be concluded that filtration velocity and mud cake thickness depend on the formation permeability, overbalance pressure, invasion time and also the mud cake properties such as its permeability, density and porosity. Based on the parametric studies, formation permeability plays the most important role in determining the filtration velocity and invasion depth. Parameters such as overbalanced pressure, formation porosity, cake permeability and also formation permeability have been identified to affect the thickness of mud cake, the velocity of the filtration and also the invasion depth.

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RAMON PERDOMO
Ukhta State Technical University

THE ROLE OF BIG DATA AND DIGITAL ACCELERATION TO OVERCOME CIRCULAR ECONOMY CHALLENGES AND COST-EFFECTIVE USE OF RESOURCES IN OIL AND GAS INDUSTRY

Introduction. This presentation will explore the ways in which big data, data analytics and digital acceleration can address climate change - the Circular Carbon Economy and its 4Rs - reduce, reuse, recycle and remove - as an inclusive and balanced solution to address greenhouse gas emissions.

Throughout this presentation it will be explained how the forces that pressure the oil industry are forcing the industry as a whole to define its new business imperatives where governments and oil and gas (O&G) companies are reimagining business models, business processes, and job descriptions enabled by the transformation drivers to achieve:

- Innovation beyond the barrel – energy outcome providers
- Products and service digitalization
- Ability to compete as an ecosystem
- Digital platform

Main Part. Despite the world's intention to move towards a carbon-neutral future, global fossil fuel demand continues to grow. The oil and gas industry is being challenged to meet the increased need for energy while simultaneously reducing overall emissions. Such scenarios call for practicable and convincing solutions to support the transition towards a low-carbon world. As digital technologies gradually permeate all activities in our societies, they have an ever-stronger impact on patterns of economic growth, social inclusion and environmental sustainability. In this changing landscape, energy efficiency is also changing, with new digital technologies enabling greater control optimization and analytics. New policies and new business models will greatly enhance end-use and systems efficiency to guarantee a reliable and affordable supply of energy.

The oil and gas industry is committed to investing in new technologies to meet energy demand and the challenges of sustainability. The industry is investing heavily in the research and development of new technologies to improve efficiencies in operations. The industry is also at the forefront of creating the next-generation of advanced biofuels and large-scale offshore wind; developing and advancing renewable technologies from pilot project.

First part analyzes how O&G companies can decarbonize and how current technologies can address most of the O&G industry´s emissions. Second part introduce the participants to the world of big data, data analytics and digital acceleration, while explaining why big data is considered the fourth paradigm of science. It will define with facts and data the characteristics of big data and the business models created from data analysis and technologies. The third part of this fact-based research will analyze the applications of circular carbon economy and its 4R in the O&G industry, with applications based on big data and digital acceleration.

Conclusion. This fact-based research is the result of the author's systemic approach to how O&G companies can decarbonize while using big data and taking advantage of digital acceleration in a way that can benefit businesses, society and the environment. In order to overcome the hard facts and data. The author will define along this presentation the priority actions to be implemented by the industry to guarantee the fulfillment of environmental commitments, take advantage of the digital acceleration and guarantee a sustainable continuity of the business development.

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SHAHBOZ SH. QODIROV
South Ural State University (National Research University)
Dr. Prof. ALEXANDER L. SHESTAKOV
South Ural State University (National Research University)

NEURAL NETWORK PREDICTIVE MODEL OF DRILL TOOLS STICKING BY TIME OF WELL DRILLING

The construction of wells is always accompanied by various complications and accidents, the most common and capital-intensive among which is drill pipe sticking. Sticking accounts for 26% to 60% of the total number of accidents [1-4]. Oil and gas companies incur large losses due to stuck drilling tools annually, especially when the technological tools used include a telemetry system and a downhole drilling motor. Drill pipe sticking is a process that occurs due to the instability of the borehole and immobility of the drill string in the borehole. There are three groups of mechanisms which cause sticking: a) differential sticking (under the influence of pressure difference); b) sticking due to geometric changes in the wellbore (while the drilling tool is moving in the well); c) sticking due to the narrowing of the borehole section (due to the settling of sludge, weighting agent, collapses, rock bulging, gland formation, etc.) [1-6]. In practice, the same factors and processes can cause different types of sticking. For example, when stopping pipe columns (when jamming in the narrowed parts of the trunk or gutter workings), the process of sticking begins due to pressure differences, or when circulation stops the deposition of sludge particles, weighting agent, etc. occurs [2-5]. The processes which occur in the well during tool sticking are related and complicate the phenomena, adding on to one another.

Since sticking is an unforeseen (fast-moving) process, its occurrence can be avoided only if the operator (specialist) reacts promptly to the first signs of an upcoming sticking. But, in practice, these signs are not always noticeable, since they depend on numerous factors. Based on the previous signs of sticking and existing influencing factors, it remains urgent for drilling companies to develop models to predict the occurrence of stuck pipe.

After analyzing the existing methods for recognizing and predicting sticking, we found that all physical predictive methods are divided into two groups: I) depth-based predictions, a method which takes into account the parameters at set depth intervals of the well drilling process and then issues predictions (the probability of stuck pipe occurrence), also at set intervals of the drilling process; II) time-based predictions, a method which takes into account changes in the values of parameters and drilling modes by the time the tool has been located in the borehole. This method predicts the probability of stuck pipe occurrence after certain time intervals. In this paper, we consider time-based methods for predicting drill pipe sticking.

The main part of the work deals with the quality of the data set, the formulation of the list of elements of input data, the primary processing (normalization) of data. Also, the paper discusses the method of sliding window with its main parameters (the dimensions of the window matrix). The choice of the neural network model and type, network architecture, network optimization and regularization, and network hyper-parameters are justified. Assessment of the quality of the network is made by the method of k-fold cross-validation. The test of the quality of the developed model is carried out on the real industrial data set of stuck (on the example of oil wells in the Tyumen region of the Russian Federation).

In conclusion, it should be noted that: the paper proposes a method for developing a model of a neural network with a sliding window for predicting drill pipe sticking; conducted experiments

on real data that showed that the quality of the developed model exceeds the quality of previously existing models; the resulting prediction model can be used in the process of drilling wells, which will minimize the risk of stuck pipe; the developed model will allow to predict the occurrence pipe stuck (based on experimental data) with a prediction accuracy of 86%.

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ASAD SAFAROV
Baku Higher Oil School
SAMIRA MUSAYEVA
Baku Higher Oil School

OPTIMIZATION OF HIGH PRESSURE HIGH TEMPERATURE GAS WELL CONTROL

During the drilling and workover operations, the wellbore can be fully or partially filled with formation gas which should be bleed off and replaced with the drilling mud to keep the well under control. During this process, a certain amount of the fluid is injected into the well and after this, some amount of the gas is released. In the research, the optimization algorithm is introduced to carry out this process in a way that, following the outcomes, it is possible to reduce the wellhead pressure to zero while the bottomhole pressure fluctuates within the safety margin. In HPHT wells, the gas properties dramatically change as the gas bubbles mitigate up to the surface which the well control issues in these wells is more challenging than the conventional wells [1]. In this paper, the effects of this phenomena to the well control procedure will be analyzed using both ideal and real gas laws.

There is a well with gas influx up to the depth of h. The expansion of the formation gas in the wellbore creates an additional pressure wellbore pressure which also increases the bottomhole pressure. It is important to place the gas with the drilling fluid in order to keep the well control and to continue for the further activities. Here, the main challenge is a dramatic change of the gas properties in HPHT conditions. This process is undertaken with recycles – first, some amount of the mud is injected to the well and then some amount of the gas is bleed off. During the repeated cycles, should be maintained between the pore pressure and the formation fracture pressure. If too much liquid is injected, the hydrostatic bottomhole pressure will exceed the fracture pressure and

it will lead to the loss of the fluid into the formation. On the other hand, if too much gas is removed from the well during a cycle, can be less than the pore pressure which will cause a new influx. Therefore, the volume of the liquid and gas should be calculated beforehand to keep the well under the control [2].

The optimization algorithm for the well control is encrypted in Python. The bisection method is used to solve the equation numerically with a maximum of 20 iterations. Since it is very complex to find out the derivatives of the equations used in the simulation, the bisection method is preferred rather than Newton Raphson iterations. The algorithm will end up when the minimum volume of the mud is injected which can keep the well balanced without the existence of the gas column.

This research was also once tried to solve by Elgassier in 2015 [3]. To compare the results, his numerical example is used for the well control model, and outcomes are compared. The differences between the figures can be explained with the method of the averaging well parameters, assumptions and numerical calculations. However, the final values are too close to each other and it proves the accuracy of the new method.

In this paper, a new well control model is introduced. It helps to solve the influx issues using optimal volumetric value within optimal time. In this method, some modifications are applied to the original method and therefore it is possible to solve multiple problems. In addition, the results of the new method are compared to the original ones and the differences between them are explained with details.

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ROMAN S. GRISHIN
Samara State Technical University

DEVELOPMENT OF AN AUTOMATED SYSTEM FOR REMOVING SEDIMENTS FROM RESERVOIRS

During the storage of oil in tanks, especially during the transport of high-viscosity oil, the formation and accumulation of bottom sediments occurs, the amount of which sometimes amounts to up to a quarter of the useful volume of the tank per year. The resulting deposits reduce the useful capacity of oil tanks, and also lead to the appearance of foci of increased corrosion rate. Accumulations of bottom sediments in vertical steel tanks with high-viscosity oil complicate the operation process during commodity transport operations, as they lead to an increase in the time spent on carrying out the erosion of bottom sediments and, accordingly, complicate their removal from the tanks. Thus, the accumulation of bottom sediments leads to an increase in material costs and a decrease in the technical and economic performance of tank farms and the transport system as a whole.

Currently, electromechanical screw agitators ("Diogenes" or "Typhoon") are used in vertical steel tanks to prevent the accumulation of bottom sediments. The erosion of deposits is carried out by a mobile directed jet due to the reciprocating angular movement of the propeller. The jet created by the propeller, due to the slow rotation of the shaft in the horizontal plane, leads to the rotation of the entire mass of oil in the tank, due to which the bottom sediments are disrupted. The total mass of oil with the raised bottom sediments is then pumped out of the tank through a receiving and distributing device installed in the tank belt.

The existing method of freeing the tank from bottom sediments during operation is that after washing out, the oil and the mass of bottom sediment suspended with it, consisting of heavy high-viscosity components of aromatic hydrocarbons, asphalt-resin-paraffin substances with a high concentration of metals and sulfur compounds, are pumped through a receiving and distributing device in the direction of the consignee.

The main disadvantage of erosion and removal of bottom sediments by the existing method is that after erosion, the suspended mass must be pumped out in the direction of the consignee. However, recently there has been a trend of requests from processing organizations to exclude the erosion of bottom sediments in tanks, before pumping out the product, in order to preserve the quality characteristics of the transported oil. As a result of these actions, bottom sediments up to a meter high are formed in the tanks of the final points of oil shipment, which, over time, turn into a non-fluid state, which leads to equipment failure and the operation of the reserve is stopped.

To solve the problem of erosion and removal of bottom sediments from the RVS, it is proposed to supplement the existing system of erosion of bottom sediments in reservoirs with a system of accumulation and removal of these sediments. The proposed system structurally consists of bottom sedimentation pits located along the perimeter of the bottom of the tank, performing the functions of accumulating and collecting bottom sediment, connected to a heated drainage pipeline with shut-off valves. The collection device is an oval-shaped recess in the bottom of the tank with geometric dimensions: depth 1000 mm, width 1150 mm, length 4000 mm.

The pipeline located under the tank is wrapped in a fire-proof shell. The bend of the pipe is made of two 45-degree angle bends and a straight insert between them to improve the passage of the bend. The end of the pipeline is connected to the common collector by a collector, in front of which a shut-off valve (gate valve) is installed. Technically, the heating of the pipes is provided by cables attached along the outer surface of the pipe and special auxiliary systems that provide electric heating of the pipes along the entire length, as a result of which the steel pipes cannot cool down below the critical level and lead to clogging of the inner part of the pipeline with oil.

After a certain amount of sediment has accumulated in the sump pit, the sensor will send a signal to the RP operator, who will call a specially equipped tank truck with a pump installed. After connecting the tank to the collector, the operator for collecting asphalt-tar deposits will turn on the heating, open the shut-off valves with an electric drive and remove the bottom sediments from the collection pits.

During the washout, the suspended mass of sediments is separated from the bottom of the tank and rotates together with the oil, due to the centrifugal force, it is shifted to the wall. For the direction of precipitation in the collection pits, it is proposed to install pre-grad guides in the form of involutes. When filling the pit, the sediment is pumped out through a pipeline that is brought to the base of the device and equipped with electric heating with thermal insulation. The heated pipeline is connected to a common collector located behind the tank square and is serviced by a vehicle with a tank.

The proposed technical solution will automate the process of freeing the tank from asphalt-resin-paraffin deposits. This technology has no analogues. Recoverable deposits can be processed, which will allow to return some of the oil back to the tank farm, use the extracted bitumen and various metals in the industry. The use of human manual labor will be reduced, and the likelihood of a negative impact of the oil environment on human health will also be reduced. This solution will lead to increased productivity in tank farms, savings, and increased safety in the operation of tank farms, in addition to increasing the time of uninterrupted operation of tanks.

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OLEG A. IGNATCHENKO
Branch of Gazprom UGS LLC Krasnodarskoye UPHG
Kuban State Technological University

TECHNOLOGIES FOR INCREASING THE EFFICIENCY OF COMPRESSOR STATIONS DUE TO USE OF VENTED GAS

Compressor stations use gas pumping units and gas turbine units, the function of which is to transport gas through main pipelines. These types of units have a common drawback associated with the release of gas into the atmosphere when they are stopped, and the issues of efficiency and environmental friendliness remain relevant today. This problem was considered by the author on the example of the compressor station of the Krasnodar UPHG.

In the compressor station of the Krasnodar UPHG, compressor shops are operated, in the machine rooms of which gas engine compressors of the MK-8 and MK-8M types are installed. During the operation of the units, cases of planned, forced and, in some cases, emergency stops are not excluded. [one]

The volume of gas released into the atmosphere was calculated by the author using the Mendeleev-Clapeyron formula. As a result, 369.9 m3 of gas was obtained from one unit of compressor shop No. 1 and 391.2 m3 of compressor shop No. 2 under the condition of an average

pressure of 80 kgf / cm2 and an average temperature of 30 ° C, and this is for one gas bleeding. [2]

In the Krasnodar UPHG only in 2018, according to the author's calculations, according to the officially entered data, 72 gas bleeds were performed at CC # 1 and 64 CC # 2. That is, gas with a total volume of 26632.8 m3 of CC # 1 and 25039.3 m3 of CC # 2 was vented to atmosphere. According to the order of the Federal Antimonopoly Service of 03.09.18 No. 1087/18 "On Approval of Wholesale Prices for Gas Produced by PJSC Gazprom and its Affiliated Persons, the cost of gas for 1,000 m³ in the Krasnodar Territory sold to consumers in the Russian Federation is RUB 4,792, which in terms of the compressor station of the Krasnodar UPHG is 247,612.71 rubles. [3.4]

The use of unused gas and minimizing the impact on the environment is possible by installing gas gathering points at the GPU of the compressor shops.

The author proposed to introduce piping systems, the task of which would be to select gas from the circuit stopped by the GPU and deliver it to the fuel line of the neighboring GPU, while passing the pressure regulators and sent to the fuel gas reduction point.

The technological process of the proposed technical solution will take place in the following sequence: when the shift dispatcher gives a command to open the control gear to bleed gas from the circuit, the gas movement will pass through the collecting manifold through the pressure regulator under a maximum pressure of 100 kgf / cm2, and after that it is reduced to 4 kgf / cm2 and then through the check valve enters the operating gas separator, after which, mixing with the gas flow taken from the 1st stage suction manifold, it enters the fuel gas collector of the compressor shops and then into the GPU.

As a result, an insignificant part of the process gas remains in the circuit under a pressure of 4 kgf / cm2, the amount of which can be calculated using the same Mendeleev-Clapeyron formula.

In one season, the following indicators were obtained: 1332 m3 of gas at CC # 1 and 1251.84 m3 of gas at CC # 2 under the condition of a pressure of 4 kgf / cm2 and an average temperature of 30 ° C - this is the gas that still remained in the GPU circuits after equalizing the pressure and which subject to further bleeding.

According to the previously mentioned order of the FAS dated 03.09.18 No. 1087/18, the cost of gas per 1,000 m³ in the Krasnodar Territory is 4,792 rubles, which is 12,381.76 rubles in terms of conversion.

As a result, the author calculated the economic efficiency of the proposed technical solution. Savings of 559,704.15 rubles were obtained. by reducing the fine for methane emissions into the atmosphere and for saving gas consumption.

The scientific novelty lies in the analytical and experimental determination of the optimal parameters of the equipment of the gas-gathering points of the compressor shops, the study of gas-dynamic flows and the thermal characteristics of gas.

The practical significance lies in the fact that the implementation of gas collection points in compressor shops does not require significant material costs, while minimizing environmental impacts and reducing fines by upgrading existing equipment.

In conclusion, we can say that the recoupment of this implementation will be approximately 8 years - with the modernization of the existing compressor station and less than 5 years - when designing a new compressor station with the proposed technical solution. After the introduction of this technology, positive qualities should be noted, such as: a reduction in gas emissions into the atmosphere, an increase in environmental safety, a reduction in the cost of paying fines for gas emissions into the atmosphere, a reduction in gas losses when bleeding the GPU circuit, reducing the noise level when bleeding the remaining gas. Another of the advantages of this implementation is that there is no need to make global changes to the original design, since most of the equipment has already been installed at the compressor station at the fuel gas preparation points; all that is required is additional re-piping and installation of pipeline fittings.

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RADMILA R. KHAYRULLINA
Ufa State Petroleum Technological University
Dr. Prof. ANVAR R. VALEEV
Ufa State Petroleum Technological University

STUDY OF THE NEGATIVE IMPACT OF VIBRATION ON THE TECHNOLOGICAL PIPELINES OF COMPRESSOR STATIONS

The intensive development of gas transport and compressor manufacturing aimed at increasing the unit capacities of gas pumping units, creating high-flow centrifugal blowers, increasing the productivity of compressor shops has led to the appearance of fundamentally new problems in the diagnosis of industrial pipelines.

The reasons for premature failure of piping manifold of gas pumping stations can be associated with both high static voltage in the pipelines and a high level of vibration. The main reasons for the increased vibration of the technological pipelines of the centrifugal blower can be: significant disturbing forces of the gas flow, coincidence of the natural frequencies of the pipeline system elements with frequencies of the disturbing forces, low dynamic stiffness of the pipeline-support system or a combination of the above conditions.

The most effective method for studying problems such as low-frequency vibrations is the combination of engineering means for calculating dynamic processes and the results of measurements of the parameters of these processes in real systems and operating modes of the compressor stations.

The hypotheses of the occurrence of low-frequency vibrations in pipelines are considered during the study, the acoustic properties of the process piping, and the resonant vibrations conditions are calculated. A computing model was created in the ANSYS Workbench software in order to consider the loading conditions for process piping.

Based on Gazprom company standard 2-2.3-324-2009, an algorithm is proposed that is of practical importance for engineers of plant diagnostics operating gas transmission equipment. It is proposed to combine the performance of vibroacoustic studies and computing modeling with the determination of trends in the technical condition of the system for the analysis of changes in vibro-parameters.

As a result of the work, direct measurements of the vibrodiagnostic specialists of the operating compressor station were compared with the obtained modeling data (figure 1). Some

methods were proposed to reduce the impact of operating conditions and design of the process piping on unacceptable low-frequency vibrations.

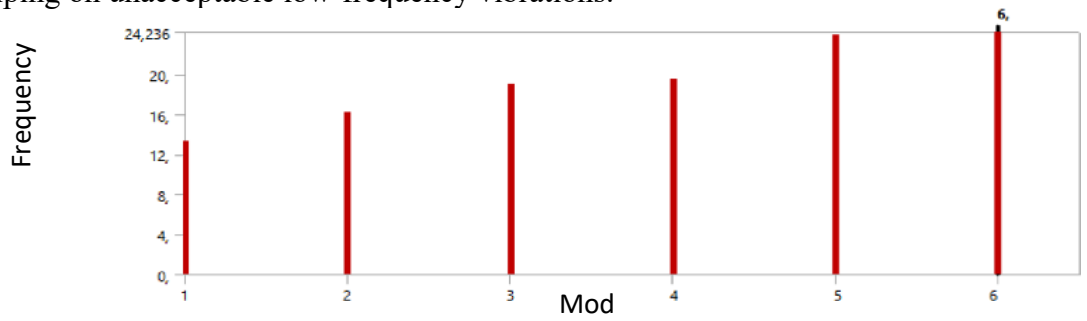

Figure 1 – The obtained values of the natural frequencies of the system depending on the vibration mode

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MIKHAIL V. KLOCHKOV
Siberian Federal University
MAXIM I. PRYAZHNIKOV
Siberian Federal University
PhD of Physico-Mathematical Sciences ANDREY V. MINAKOV
Siberian Federal University

ANALYSIS OF THE EFFECTIVENESS OF METHODS FOR REDUCING THE HYDRAULIC RESISTANCE OF FLUID FLOW IN MAIN PIPELINES

At the present stage of development of the oil-extracting industry, a tendency to increase the volume of oil produced is more and more clearly traced, which, in turn, leads to the emergence of the problem of its uninterrupted transportation to the places of processing and sale. In addition, new fields are being actively developed, often located in remote and inaccessible areas. All this significantly increases the cost of transporting the extracted raw materials, therefore, various ways of solving this problem are proposed [1].

Investigation of the effectiveness of anti-turbulent additives. To carry out the research, a setup was designed, intended primarily for the study of anti-turbulent additives, but also applicable for assessing the effectiveness of other chemical reagents. Setup is a closed-loop hydraulic system based on the principle of a circulating ring. The setup includes a hydraulic tank, a steam bath, a gear pump, a test section, a pressure gauge, and a coriolis flow meter. When testing the installation on water, the maximum deviation between the calculated and experimental values of the pressure change and the Reynolds number was 5.4%. The test sample was oil with a low sulfur content and low density. The object of the study was an anti-turbulent additive, which is an ultra-high molecular weight polymer dispersed in an organic carrier. Before the experiment, an anti-turbulent additive was introduced into the test oil in the amount established by the manufacturer's technical passport. Based on the results of the experiment, we conclude that the maximum effect of the additive is observed when the pumped oil is heated to 60°C. Its value is 35.6%, while at 20°C the decrease in hydraulic resistance is 19.9%, and at 40°C it is 25.9%.

Ultrasonic oil treatment. Under the influence of acoustic fields on a liquid, the effects of a chemical and physicochemical nature are associated with cavitation. As a rule, ultrasonic cavitation is accompanied by the formation of bubble cavities in the ultrasonic field during the stretching phase, which is present in an alternating sound pressure. At the moment of the compression phase, these cavities and bubbles collapse, forming significant local instantaneous pressures, reaching values of 105-110 N/m^2. The ultrasonic vibrations absorbed by the substance are partially converted into thermal energy, partially spent on changing the structure of the substance [2, 3].The research work was carried out with three samples of oil with a viscosity of 26.24mPa·s, 12.95mPa·s and 9,98mPa·s. The irradiation was carried out by an ultrasonic device "Volna", the power of ultrasonic exposure was 50% of the maximum possible power of the installation (400 W). The viscosity change was monitored using a Brookfield DV2T viscometer. During the ultrasonic treatment, it was found that the second and third samples showed a steady increase in viscosity. At the same time, the viscosity of the first sample decreased by 5.5%.

Conclusion. Summing up the results of the work done, it can be concluded that when studying the effectiveness of antiturbulent additive, the theoretical foundations of the flow regime of liquid in the pipeline, the mechanism of action, the composition and properties of antiturbulent additive were studied. A test facility was also developed and tested, which allows evaluating the effectiveness of antiturbulent additive and conducting a comparative analysis of antiturbulent additive from different manufacturers. The effectiveness of the additive is confirmed, its high efficiency is proved. The largest decrease in hydraulic resistance was 35.6%. During the measurement of the dynamic viscosity of various samples, it was revealed that the colloidal particles of the oil dispersed system under the influence of ultrasonic radiation can both decrease and increase. Which may lead to a weakening or strengthening of the links between them. Based on the results of the experiments, it can be concluded that under the influence of ultrasonic radiation, both an increase in viscosity and its decrease are observed. It was found that for oils of different component composition, the time required to achieve the maximum positive effect is determined individually. Thus, based on the analysis of the effectiveness of two different methods, it can be concluded that the most effective is the method based on the use of anti-turbulent additives.

ACKNOWLEDGMENTS

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DMITRII N. PEKHTEREV
Samara State Technical University
PhD in Pedagogy GULSINA M. ORLOVA
Samara State Technical University

MONITORING OF ENGINEERING STATUS OF MAIN PIPELINE LINEAR PORTION

The topicality of the paper is contingent on the existing necessity of improvement of operational reliability and safety, and costs reduction during the operation of main pipelines, as well as on the need to move from a system of scheduled preventive maintenance to a more efficient and cost-effective service system based on the relevant engineering status. Review of literature on the problem of the paper showed that methodological support using the apparatus of neural network technologies and machine learning, which makes it possible to assess the indicators of the engineering status, reliability and safety of objects of the carbon transportation system, in particular, energy-mechanical equipment, has been currently developed [2]. Therefore, the paper substantiates the feasibility and practicability of utilizing the engineering status monitoring system based on self-learning artificial intelligence.

The paper considers the current system of monitoring of engineering status of the linear part of main pipelines, the block diagram of which is shown in Figure 1.

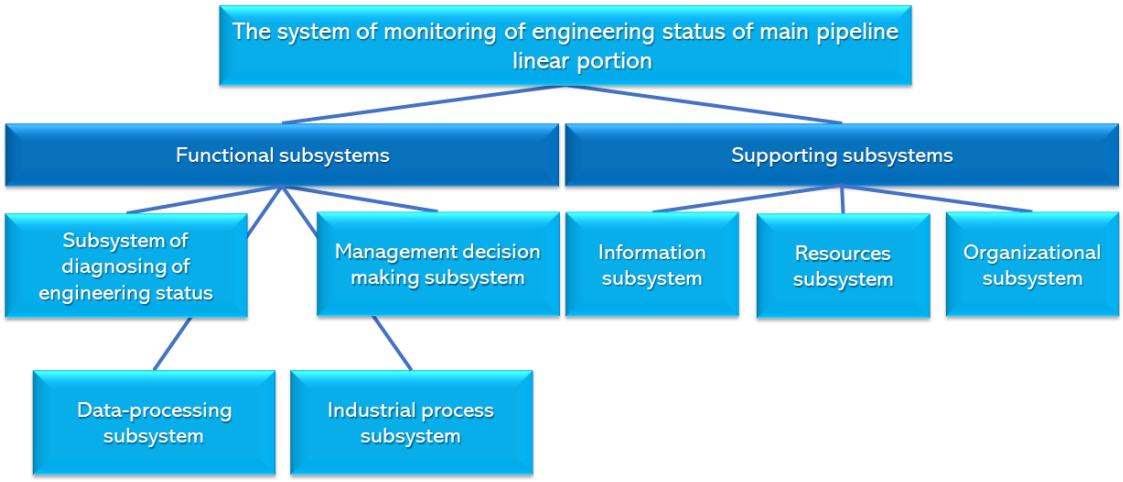

Figure 1 – Block diagram of the system of monitoring of engineering status of main pipeline linear portion

The system consists of functional and supporting subsystems. The functional subsystems implement individual functions of the system: realization of technical diagnostics of the linear part of the main pipelines, processing the accumulated data with the purpose of performing calculations and analyzing them, as well as making management decisions to support the faultless and operational condition of the linear part. The functions of supporting subsystems include harvesting, storage and transmission of engineering status data; these subsystems also comprise of a complex of equipment, materials, energy resources and human resources necessary for the operation of the system and an aggregate of legal norms that govern the operation of this system. Interaction between subsystems is carried out by operational staff, which limits the amount of information processed and reduces its reliability due to the presence of a human factor.

The analysis of the data provided by the enterprise on the results of technical diagnostics run at different periods of time at the “Zimovniki-Ekaterinovka” diagnostics section of the “Kuibyshev-Tikhoretsk" main oil pipeline was carried out. Based on the results of each diagnostics, the following calculations were carried out: the calculation of stress-strain behavior of the pipeline with a defect, which showed the nominal stresses and deformations arising in the section of the pipe with a defect; the calculation of strength and plasticity criterions, which made it possible to determine the conditions of the limit behavior of the pipeline; the calculations of the destructive pressure and destructive depth of the defect, and the remaining life of the pipeline

sections, which made it possible to determine the deadlines for the elimination of defects detected during in-line inspection. As a result of calculations, the following regularity was revealed - carrying out subsequent technical diagnostics allows not only to establish the dynamics of the development of defects, but also to determine the remaining life of the pipeline with greater accuracy.

It is proposed to carry out the presented calculations of the remaining life of the pipeline and determine the deadlines for eliminating defects, as well as their analysis, using artificial intelligence, which at the initial stage analyzes the available data on the diagnostics and inspections of the pipeline, after which it accumulates the data and learns from them. At the next stage, artificial intelligence receives new data on the diagnostics and examinations performed, interprets them, performs calculations, analyzes their results and issues optimal management decisions.

Utilizing of a system of monitoring of the engineering status of main pipeline linear portion based on self-learning artificial intelligence is possible and advisable, since in addition to increasing the level of automation, and, consequently, reliability and safety, the proposed system makes it possible:

– to increase the volume and reliability of the processed information about the engineering status;

– to ascertain the remaining life of the linear part of the main pipelines not only on the basis of the conditions of the pipeline route passage, but also on the basis of the cyclicity of its loading, as well as other parameters;

– to determine the optimal frequency of carrying out diagnostic examinations of sections of the main pipeline;

– to identify the dynamics of the development of defects, to assess the speed of their development and to issue optimal management decisions.

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VAYNER D.B.
Soloviev RSATU
Ph.D. , Associate Professor A.V. Manin
Soloviev RSATU

REDUCING THE VISCOSITY OF THE TRANSPORTED OIL WITH THE USE OF CONTROL MONITORING BY ULTRASONIC IMPACT

Currently the share of produced high-viscosity oil is constantly growing, this causes significant problems with its pumping through main pipelines and, accordingly, the increase in its cost.

Oil and its fractions are capable of changing under the influence of various external factors. According to this, and taking into account the dispersion of the oil system, during the pumping process the following methods can be used: mixing of oil flows, introduction of active additives, physical methods: thermal heating, excitation of elastic vibrations of various natures in the oil medium - magnetic, ultrasonic, mechanical, electrical, microwave radiation.

A few methods for increasing the oil fluidity have long found practical application despite their significant energy and material costs. Methods based on devices that create elastic vibrations have not found mass application, although they have clearly positive effects and are at the stage of research development. This is due to the fact that the above methods for reducing the kinematic viscosity in general have their disadvantages:

– during the heat treatment heat pipes are used, the temperature of the oil on the surface of which is higher than in the rest of the volume , which will lead to deterioration of its characteristics and structural changes;

– the addition of surfactants requires regular correction of surfactants depending on the chemical composition of the oil ;

– mixing with the oil with a lower viscosity is economically unprofitable, since it requires the presence of light oil in the fields;

– the use of ultrasonic installations with focused radiation throughout the entire volume of products is associated with high energy consumption;

– exposure of the high-frequency electromagnetic field in order to improve the rheological properties of the oil with the increased content of resinous-asphalt substances can lead to increase in the oil viscosity because of the formation of large associates.

Based on many publications devoted to reducing the oil viscosity, it can be concluded that there are various directions for creating new methods for reducing it and for improving devices based on known methods of reducing energy consumption and increasing the physical effect.

So, it is necessary to focus on more details about the ultrasonic method of influencing the oil in order to reduce its viscosity. According to the results of experimental studies, the most effective frequency is 19 - 22 kHz, a more significant increase in frequency leads to the opposite effect. When the oil is exposed to ultrasonic vibrations in the vacuum phase, cavitation bubbles or cavities appear in it's structure, which together create cavitation regions. In the compression phase, under the action of increased pressure and surface tension forces, the bubble collapses, creating significant pressure, high temperature and propagating a spherical shock wave. So, cavitation region is a kind of power transformer, in which energy is relatively slowly accumulated and released within a very short time, as a result the instantaneous power is many times higher than the average power introduced by the emitter into the cavitation region. The irreversible decrease in the oil viscosity occurs even under irradiation with ultrasound in the range of 10 W/cm^2 for a certain time. However, the high intensity of radiation may change the physical and chemical composition and even increase the kinematic viscosity [1].

Based on the results of the preliminary analysis it can be concluded that to build the acoustic system for reducing the oil viscosity when pumping through the pipeline, the acoustic system should consist of a number of distributed magnetostrictive transducers with controlled

radiation intensity in order to limit the volumes of cavitation regions. Since there is a constantly moving oil flow in the pipeline, and the radiation intensity of a single generator must be limited, a number of emitters should be installed to irradiate the full volume. For the formation of a cavitation region of the corresponding volume a certain time is required. Therefore, by establishing short periods of switching on, it is possible to ensure that the number of pulsating cavities formed during the switching on was small, and at the same time the maximum transfer of energy for breaking the bonds between molecules was ensured. The effect of creating the necessary average radiation power in the pipeline section during the operation of short-term switching on of the ultrasonic field is created by a number of transducers, the number of which is equal to the duty cycle of their switching on mode. At the same time, so that there is no mutual complement in time of the ultrasonic fields created by separate emitters, they are turned on so that the corresponding zones of pressure antinodes would not coincide [2].

Additionally, the radiation intensity is being corrected according to the results of measuring of the oil viscosity at the entrance to the irradiation zone (the initial viscosity) and at the exit from the zone. Monitoring data from the sensors of viscosity, temperature and velocity enters the information processing unit and the correcting signal is generated according to the known calculated ratios. The use of pulse-width modulation in the ultrasonic generator makes it possible to change the intensity and frequency of radiation of acoustic vibrations for the current processing mode [3].

Conclusion. The method of ultrasonic impact on oil makes it possible to reduce its kinematic viscosity by more than two times, and the relaxation time ranges from several hours to several days. This method is the least expensive in terms of both energy and material components. To break intermolecular bonds in cavitation regions a relatively low intensity of ultrasonic radiation is required. To create a stable viscosity reduction effect during oil pumping it is proposed to include into the oil pipeline a group of radiators distributed along it's length. To create controlled cavitation regions in the oil volume, the emitters must work according to the certain algorithm, alternating the switching on of the emitters. Continuous monitoring of information from viscosity, velocity and temperature sensors additionally allows to change the radiation intensity and control the volumes of cavitation areas. Thus, the use of a distributed ultrasonic unit with monitoring of the rheological parameters of oil will allow to reduce the power of the main pumps at the required flow rate, as well as to minimize the use of traditional methods of reducing the viscosity.

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YIYUAN YANG
Tsinghua University

LONG-DISTANCE OIL AND GAS TRANSPORTATION PIPELINE SAFETY EARLY WARNING SYSTEM BASED ON DEEP LEARNING APPROACH

Oil and gas pipelines are known as the backbone of global energy. Their small size and fast construction make them widely used in the field of energy transportation [1]. Currently, the length of long-distance transportation pipelines worldwide exceeds 3.5 million km and is increasing by approximately 30,000 km per year. However, because buried pipes are not easy to supervise, and the environments along those pipelines are complicated, accidents are unfortunately not rare enough. If an accident occurs, it may cause energy leakage or even an explosion, and cause great economic losses, casualties, environmental pollution, and extremely negative publicity [2]. Automated pipeline safety early warning (PSEW) systems are designed to automatically identify and locate third-party damage events on oil-gas pipelines. They are intended to replace traditional, inefficient manual inspections [3]. However, the following problems with PSEW systems remain: (1) The spatiotemporal features of sensor signals consistently change. (2) Strong noise, weak signals, and signal fluctuations at the scene make an algorithm trained on an ideal condition difficult to fit. (3) A low-frequency signal with higher processing speed and cheaper cost has a higher requirement on the algorithm [4]. To address those problems faced by PSEW systems, we present a novel action recognition method based on a distributed fiber optic sensor (DOFS) network that jointly considers temporal and spatial aggregation. Our experiments show that the results of the proposed method markedly outperform those of other baselines and can effectively alert us to events that could damage the oil and gas pipelines in real time.

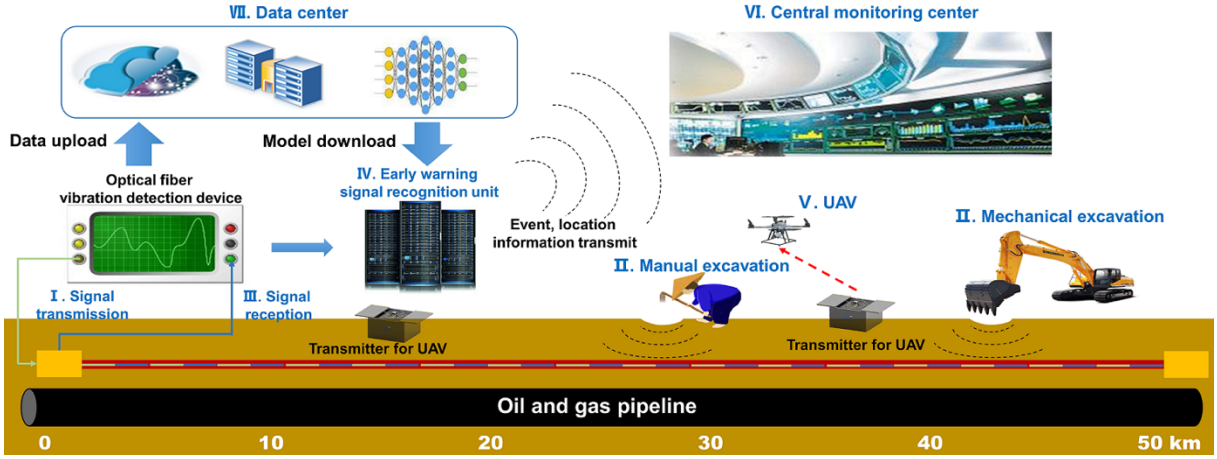

Figure 1 – Structure of a novel oil and gas PSEW system

A novel DOFS-based long-distance oil and gas PSEW system shown in fig.1 is an intelligent system that recognizes and locates dangerous behaviors, issues early warnings, conducts on-site inspections, and records data in real time. Based on that we put forward two complementary features, i.e., peak and energy features, to describe signals of fiber sensors and built a new action recognition deep learning network based on those features. Besides, experiments were carried out at two different real PipeChina pipelines with different deployments, environmental conditions, signal frequencies, and pipeline lengths (48 km and 85 km). The total dataset was 2.17 TB which took us nearly five months to collect with over $100,000. The fig.2 shows the experimental facilities of our PSEW system.

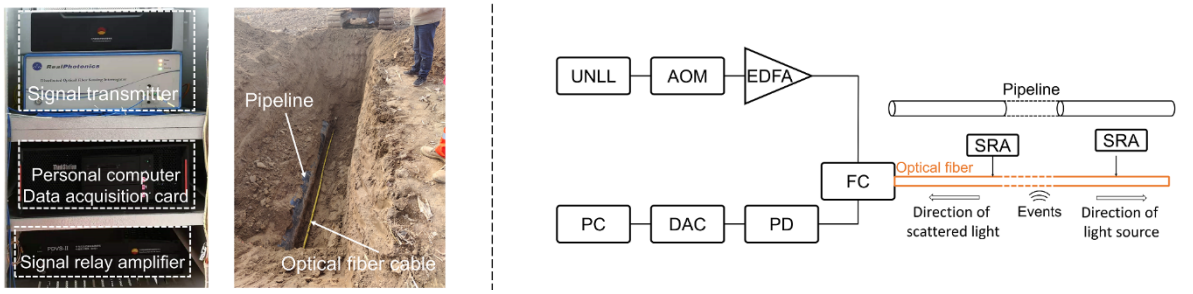

Figure 2 – Real experimental facilities of our PSEW system

Encouraging empirical results from the above tests indicate that the proposed scheme can identify and locate damage events with good robustness. It demonstrates a high average accuracy of 95.86% for 100 Hz signal and 97.53% for 500 Hz data. Besides, the proposed feature generator can effectively extract features in a short period and has a good visualization effect. More importantly, our system fully meets the industry standards of model size, real-time performance, and adaptability to different deployment conditions and environments, and has already been deployed in a real long-distance oil transportation pipeline for half a year. The fig.3 shows the features (upper) and identification results (lower) from this operational PipeChina pipeline.

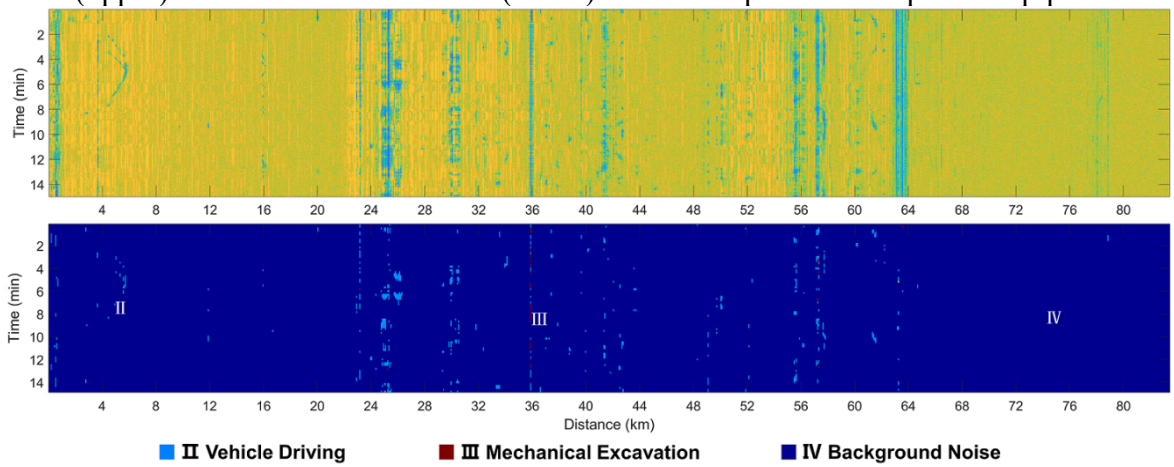

Figure 3 – Feature maps and identification results. It can be seen that mechanical excavation occurred for 15 mins at around 36 km, which was usually accompanied with the vehicle driving; i.e., the excavators' engine was running or the position was adjusted to find a better angle for excavation

Our work provides a new perspective on the practical application of PSEW systems in industrial scenarios and it will be more effective in securing energy pipeline transport. In future, we are interested in exploring higher spatial-temporal resolution and exploring the applications of perimeter security for pipeline stations.

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DARIA A. ALFEROVA
St. Petersburg Mining University
Dr. Prof. OLGA V. CHEREMISINA
St. Petersburg Mining University

INCREASING THE EXTRACTION RATIO OF RARE EARTH ELEMENTS FROM SOLUTIONS WITH TITANIUM ADMIXTURES

According to the European Committee [1], Rare Earth Elements (REEs) are critical for the industry. The main global supplier of REEs is the People's Republic of China, with a global market share of approximately 70%. The Russian Federation has a strategic reserve of a valuable resource contained in the depths of the Kola Peninsula in the form of fluorapatite [2]. Nowadays, this mineral is used in the technology of obtaining phosphorous-containing mineral fertilizers, so it is advisable to consider the extraction of REEs exclusively from the intermediates of this technology – phosphoric acid and phosphogypsum.

The object of this research is the extraction of REEs from phosphoric acid solutions. Its features are high acidity of solutions, low content of target components, and the presence of iron and titanium impurities. The most effective method of metal recovery and separation is solvent extraction using di-(2-Ethylhexyl)phosphoric acid (D2EHPA) as an extractant. The chemical reaction of REEs and extractant is described by Equation 1 [4]. This reaction describes the way the REEs reacts with extractant by cation exchange and donor-acceptor mechanism

$$Ln(H2PO4)^{2+} + (1+0,5s)\ (HR)2 = Ln(H2PO4)R2\cdot(HR)s + 2H^{+} \quad (1)$$

where s – is the number of solvating acid molecules, $Ln(H2PO4)^{2+}$ - complex REEs ions (3+).

As well as the valuable component, impurity elements – iron (Fe) and titanium (Ti) – pass into the organic phase, interact with the extractant and reduce its capacity by the REEs. To get a pure solution, it is required to implement the stage of the purification from Fe and Ti. Previously, a method for isolating an extract of rare earth elements with an iron content of less than 0.1% was obtained [4].

The purpose of this research was to find an effective solution for obtaining a REEs extract that does not contain titanium impurities. To accomplish the task, it was necessary to describe the chemical reaction of titanium re-extraction, select a re-extractant, determine the effective re-extraction parameters, and obtain individual metal compounds.

It was previously studied [3] that at a phosphoric acid concentration of 5-6 M, titanium in the system is in the following forms:

–TiO(HPO4)–TiO(HPO4)–TiO(HPO4)–TiO(HPO4)– and
–TiO(H2PO4)2 –TiO(H2PO4)2 –TiO(H2PO4)2 –TiO(H2PO4)2 - [3].

The chemical interaction of titanium and extractant compounds describes Equation 2:

$$(TiO)n2n+aq + 2n(H2X2)org = (TiO)n(HX2)2n\ org + 2nH^{+}aq \quad (2)$$

Titanyl ions interact with D2EHPA by cation exchange and donor-acceptor mechanisms. Thus, to extract titanium from the complex with the extractant, i.e., to change the direction of the reaction, a substance with acidic properties that forms strong complexes with titanium ions is necessary. These requirements are met by oxalic acid (lgKstability (Ti)=5.7-10.7 in a wide pH range), which is also used to purify the extract from iron impurities [4].

To determine the effective purification parameters, the dependences of the degree of titanium recovery on the concentration of oxalic acid, the time of the process, the mixing rates, the relative content of the aqueous and organic phases and the temperature were studied. The results of the experiments are presented in Table 1.

Table 1 – Effective parameters of purification of REEs extract from titanium impurity

Parameters	Numerical value	Units of measurement
D2EHPA concentration in kerosene	50	%
C2H2O4 concentration	0.25	Mol/l
Vorg/Vaq phase ratio	0.5	

According to the tangent of the slope angle of the logarithm of the degree of approximation to equilibrium as a function of time, it was found that an increase in temperature by 20 °C only increases the speed of the process by 1.5 times, which characterizes the process in the diffusion region, which corresponds to the calculated value of the activation energy equal to 2.8±0.4 kJ.

The enthalpy of the reaction (2), determined based on the obtained metal distribution coefficients between the aqueous and organic phases, is 16.5±0.6 kJ/mol. The reaction is endothermic, i.e., it proceeds with the absorption of heat. Thus, an increase in the temperature in the reaction zone shifts the equilibrium in the direction of obtaining reaction products.

To increase the degree of purification of solutions from titanium, a multistage counter-current contact of the extract and oxalic acid is used. The higher the number of stages of oxalic acid re-extraction, the higher the degree of titanium recovery. The optimum is reached after 14 stages when the mass fraction of titanium (relative to REEs) is less than 0.9%, and its concentration in the organic phase is reduced by more than 10 times with the REM content unchanged. Moreover, the removal of impurity metals makes it possible to increase the capacity of the extractant for REEs by 2-2.5 times.

Based on the obtained data, a scheme for the extraction and separation of REEs was compiled. Its products are individual purified compounds with the content of the target component from 83 to 95% and the content of non-rare earth impurities at the ppm-level.

ACKNOWLEDGMENTS

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DANIIL A. BALANDINSKIJ
St. Petersburg Mining University
Dr. Prof. OLGA V. CHEREMISINA
St. Petersburg Mining University

SYNERGISTIC EFFECT OF D2EHPA ON APATITE FLOTATION WITH FATTY ACID COLLECTOR

Flotation is the only way to enrich apatite nowadays. Hence, improvement of the reagent modes is the actual problem because of constant decreasing quality of the native ore. Both chemical and physical forms of sorption influence the efficiency of the flotation process. Because of that, collecting ability of the traditional fatty acid collectors can be improved by the usage of specific modifiers. In the solution, saponified fatty acids have a great tend to aggregate due to dispersion interactions between long-chain tails. These molecular aggregates have a negative impact on the flotation process because of their large sizes, low mobility, and low spreading on the mineral surface. In recent works [1, 2], it was reported that short-chain surfactants could

significantly change the aggregation ability of the long-chain surfactants. In work [3] was shown that using SDS (sodium dodecyl sulfonate), with shorter chain length, in mixture with oleic acid collector could improve apatite flotation.

In this work, the effect of saponified D2EHPA (Di-(2-ethylhexyl) phosphoric acid) in a mixture of sodium oleate on the foam flotation of apatite was studied. Structures of these reagents are shown in figure 1.

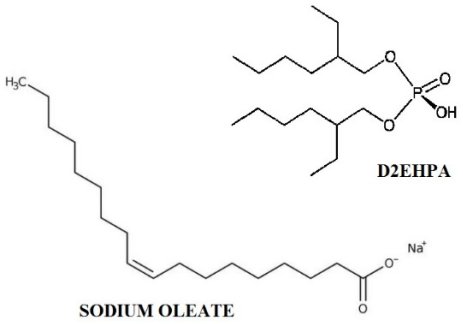

Figure 1 – structures of sodium oleate and D2EHPA

The experimental data are shown in figure 2. The pH value in each case was 9,69 due to the presence of sodium silicate at a concentration of 100 mg/l.. Sodium salt of D2EHPA at a concentration of 67 mg/l practically does not float apatite. However, mixtures with different ratios of D2EHPA and sodium oleate in which the content of D2EHPA does not exceed 55% demonstrate high recovery rates. A futher increase in the proportion of D2EHPA in the mixture has a negative impact on the flotation process. Also, with an increase in the proportion of D2EHPA in the mixture, the quality of the concentrate decreases, which indicates non-selective sorption of the reagent at a mixture concentration of 67 mg/l. However, a mixture consisting of 15% D2EHPA and 85% sodium oleate demonstrates the best quality of the product and an acceptable degree of recovery. At the same time, sodium oleate in its pure form at a concentration of 33 mg/l practically does not float apatite.

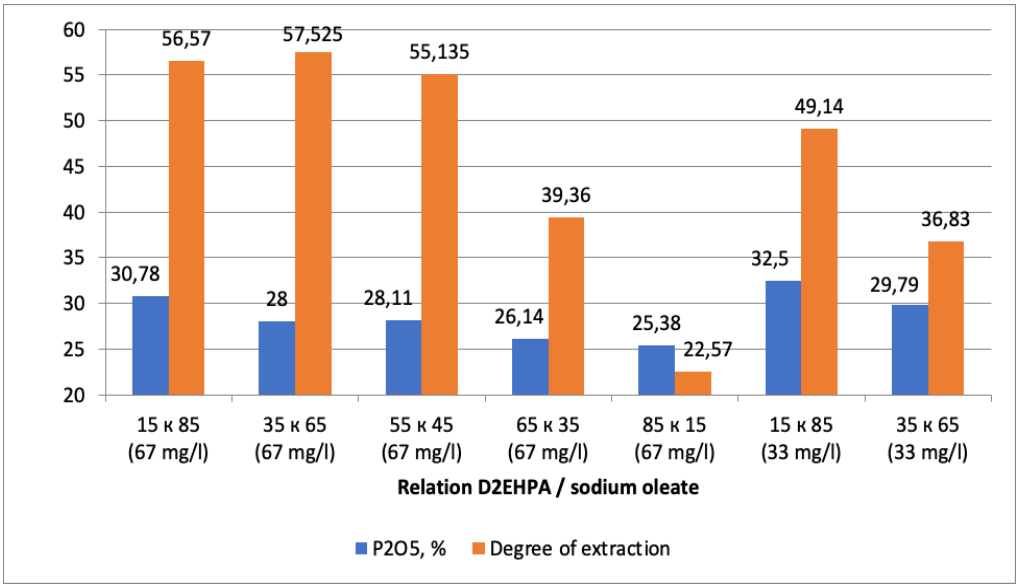

Figure 2 – degree of extraction and quality of the apatite concentrate

Thus, the use of small amounts of D2EHPA as a modifier of the fatty acid collector makes it possible to obtain apatite concentrate at reduced collector costs. Establishing the optimal ratio of reagents is the next step in developing the best technology.

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TAN SANG CAO
Faculty of Applied Sciences, Ton Duc Thang University
KHANH AN VO
Faculty of Applied Sciences, Ton Duc Thang University
ANH KIET NGUYEN
Faculty of Applied Sciences, Ton Duc Thang University
HO ANH HAO NGUYEN
Faculty of Applied Sciences, Ton Duc Thang University
THUY THUY TRANG NGUYEN
Faculty of Applied Sciences, Ton Duc Thang University
NGOC PHUONG NGHI NGUYEN
Faculty of Applied Sciences, Ton Duc Thang University
KIM NGAN NGUYEN
Faculty of Applied Sciences, Ton Duc Thang University
DIEU-HIEN TRUONG
Faculty of Applied Sciences, Ton Duc Thang University

CHANGES IN TOTAL SAPONIN CONTENTS AND ANTI-TRYPSIN ACTIVITY OF *Codonopsis javanica* FRACTIONS DUE TO LIQID-LIQUID EXTRACTION

Introduction. *Codonopsis javanica* is one of the medicinal herbs which is used as a tonic for peat body weakness, anemia, and other symptoms including cough, adrenal gasps, and stomach ulcers [1]. It is noted that trypsin, an enzyme from serine protease class, is involved in the destruction of proteins. Excessive activity of trypsin could strongly implicate in various diseases such as acute pancreatitis, inflammation and tumour and balanced activity of trypsin is necessary for different physiological functions. Thus, it is needed to develop new trypsin inhibitors from natural sources. Although some recent researches have recommended that triterpenoid saponin can be main compounds from *Codonopsis* species [2, 3], the effects of fraction extracts on anti-trypsin activity has not yet indicated.

Studied activity. The antitrypsin activity of extracts obtained from two different fraction extracts of *Codonopsis javanica*, was tested *in vitro* in the present study.

Fractionation by liquid – liquid extraction (LLE): The methanolic crude extract (CE) of *C. javanica* roots was dissolved in distilled water at a 1:20 (v/v) ratio, and the mixture solution was used for liquid-liquid extraction with petroleum ether (PE), dichloromethane (DCM), n-butanol (BuOH) at a ratio of 1:1 (v/v) for 3 hours and evaporated by rotary vacuum to obtain fraction extract, respectively. The fractions collected were tested for their total saponin contents determined through spectrophotometry with oleanolic acid (OA) as standard reagent, as described by Wei et al. [4] and their antitrypsin activity using the microtitration colorimetric assay adapted after Bergmeyer et al. [5] with some minor modifications, in triplicates. Briefly for antitrypsin activity, 25 mM pH 7.4 Tris-HCl buffer, trypsin solution and fractions or methanol (as blank) or Indomethacin (as reference standard) were incubated for 5 min at 37 °C on a microplate shaker [Statfax 2200, USA]. 70% Perchloric acid was added and the reaction was at time 0 and after 10 min. The results are represented as the mean ± standard deviation (± SD). Analysis of variance

(ANOVA) (Minitab 15 software and Tukey's multiple comparison test) were used to compare the variation between assays; *p* values < 0.05 were considered significant.

The results showed that inhibition % values of *Codonopsis* fraction extracts on trypsin were increased with increasing concentration (from 14.71% to 40.72% in 250 to 750 µg/mL of fraction extracts (Table 1) and they varied significantly ($p < 0.05$). Particularly, the antittrypsin activity of all fractions was higher than the methanolic crude extract activity. PE fraction extract showed the highest antitrypsin activity. The total saponin content was also highest from the PE fraction extract (Table 1).

Table 1 – The antitrypsin activity of *C. javanica* fraction extracts

Extract name	**% Trypsin activity**			**Total saponin contents (mg OA/g DW)**
	250 (µg/mL)	500 (µg/mL)	750 (µg/mL)	
Methanolic CE	27.35	30.38	34.28	-
PE fraction	29.96	37.52	40.72	*91.792*
DCM fraction	26.71	28.19	35.39	*28.875*
BuOH fraction	14.71	17.62	19.58	*58.458*
Indomethacin	32.04	38.10	42.10	-

Conclusion. For all fraction extracts (PE, DCM, BuOH), the presence of C. javanica trypsis inhibitors exhibited a significant degress of inhibition from 250 to 750 µg/mL, compared to the methanolic crude extract. In which, PE fraction was highest among the tested extracts. It is related to the total saponin content in these extracts, except for the BuOH fraction. This suggested that possibly the antitrypsin activity of the *Codonopsis* extracts was maybe influenced the saponin components. It is also noted from liquid –liquid extraction, the distribution of the protease inhibitors is somewhat different. It can be suggested that C. javanica fraction extracts which shows high ttrypsin inhibitory activity may be approproate to be applied as trypsis inhibitors and will provide an additional support to drug treatment in the field of health. To obtain more insights in medicine application, protease inhibitors from Codonopsis root fraction extracts should be investigated in further depth.

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RAYANA HELLEN CARNEIRO ARAUJO
Institute of Energy Process Engineering and Chemical Engineering
TU Bergakademie Freiberg
DIPL.-ING. WEI FU
Institute of Energy Process Engineering and Chemical Engineering
TU Bergakademie Freiberg
DIPL.-ING. ANDREAS HERRMANN
Institute of Energy Process Engineering and Chemical Engineering
TU Bergakademie Freiberg
DIPL.-ING. OLAF SCHULZE
DBI-Virtuhcon GmbH

PROCESS ENGINEERING CONCEPT DESIGN AND PLANT ENGINEERNG DEVELOPMENT FOR THE DECENTRALIZED PRODUCTION OF SYNTHETIC FUELS FROM BIOGAS

Since introducing the EEG (German: Erneuerbare-Energien-Gesetz, abbr.: EEG) in 2000, biomass has become an essential component of the German energy system, especially for biogas production. Biogas is the most significant contributor to electricity generation among biomass energies, with approximately 57% share [1]. In 2019, Germany counted around 9,500 biogas plants, meanwhile this number has considerably decreased in recent years. The major problem is the comparatively high electricity production costs, which hardly permit the continued economic operation of biogas power plants in particular. Due to the changes in market conditions, it is assumed that around 1,000 plants could be excluded from the EEG subsidy by 2021, which corresponds to around 10% of the current number of plants [2,3].

In this context, biogas methanisation technology offers a new perspective for this industry. While methanisation plants for SNG production based on synthetic gas have been successfully employed for decades, the use of biogas as a raw material offers the opportunity to include this biogenic fuel in future energy scenarios related to power-to-gas processes [3]. Specifically, synthesizing the hydrogen from electrolysis with the carbon in the biogas through methanisation forms methane or synthetic natural gas, which can then be injected directly into the natural gas infrastructure. Such an arrangement combines the electricity and gas systems by storing surplus and fluctuated renewable electricity from wind, solar or hydro power plants in the form of SNG.

In this way, the methanisation of biogas proposes to solve the problem of long-term and large-scale energy storage, to renew the perspectives of the biogas industry, which already has considerable development and structures, as well as to reduce greenhouse gas emissions. In addition, another factor of substantial economic relevance is the continued use of the national gas pipe network.

The concept of methanation process proposed in this work is that of thermochemical methanation. Thermochemical methanation is defined as the conversion of hydrogen and CO or CO2 into CH4 in the presence of a catalyst. While experience in CO conversion is extensive, methanation facilities for SNG production from H2 and CO2 are not yet available at an industrial scale. Nonetheless, the experience gained from CO methanisation plants provides a solid knowledge base for developing specific methods to utilize biogas in future projects.

The thermodynamic equilibrium of the reactions of CO and CO2 to methane is on the side of methane at low temperatures. However, at low temperatures, the conversion rate for methane formation is low due to kinetic limitations. In order to achieve high conversion rates even at low temperatures, the use of catalysts with a particularly high activity is indispensable. Typical operating conditions for thermochemical methanation are temperatures in the range of 300 to 550 °C and 1 to 100 bar pressures. A promising option could be the application of noble metal catalysts, with which high conversion rates can be achieved at temperatures significantly below 300 °C. Consequently, an almost complete conversion of CO2 into methane can be realized.

Fixed-bed adiabatic methanation is currently state-of-the-art technology and most widely used method, in which reactors are usually connected in series and operated adiabatically or nearly isothermally. The key challenge in fixed-bed methanation is the temperature control in the reactor, resulting from the highly exothermic methanation reaction. The proposed design relies on implementing active and multistage-adjustable cooling system to guarantee high isothermal conditions in the reactor, avoid hot spots, and increase the product yield.

With the aforementioned process engineering design and reactor development in our present research work, a sustainable alternative for biogas industry is introduced, contributing to the configuration of an intelligent energy system by integrating various sectors and infrastructures. The opportunity to utilize existing valuable assets, such as biogas plants and the national gas transport network, requiring little or no retrofitting of the structure represents a significant advantage of this technology and points a viable way forward towards a future of sustainable energy production and consumption.

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NGOC DO THI BICH
FGBO VPO “KNITU”, Kazan, Russia,
EVGENY V. CHEKUNKOV
Arbuzov Institute of Organic and Physical Chemistry
FRC Kazan Scientific Center, Russian Academy of Sciences
SALIMA. T. MINZANOVA
Arbuzov Institute of Organic and Physical Chemistry
FRC Kazan Scientific Center, Russian Academy of Sciences

PROSPECTS FOR PROCESSING BEET PULP FOR OBTAINING PECTIN

Introduction. Beet pulp is a large-tonnage waste of the sugar beet industry. The expediency of involving sugar beet pulp in the economic turnover is due to the fact that it solves the problems of resource conservation and environmental protection. Due to its high nutritional value, beet pulp is widely used for livestock feed in fresh, dried and silage form. A promising direction is the production of a functional product from beet pulp - pectin, which is used in the food industry and pharmacology. Taking into account the current international economic relations, the absence of industrial production of pectin in Russia, the development of modern technologies based on domestic raw materials and secondary material resources, allowing to reduce the cost of a valuable product, remains an urgent task [1, 2].

Research aim - development of a method for obtaining pectin from beet pulp with the intensification of the hydrolysis-extraction process by using microwave, ecological and economic assessment of the beet pulp of processing.

Results. The object of this study is beet pulp (Krasnodar). The technology of obtaining pectin from beet pulp is a multi-stage long-term process, including the following steps: wash the crushed raw materials with water, extraction pectin with a 0.75% oxalic acid solution, filtration, concentration the obtained extract, precipitation pectin and drying. In order to improve the

efficiency of hydrolysis-extraction processes, it is necessary to develop new methods with the help of microwaves [3, 4].

In this study, process for obtaining pectin from beet pulp with the combination technique of hydrolysis-extraction by solution of oxalic acid 0.75% and assistance of the microwave at different powers: 350 W, 500 W and 700 W have been studied. To ensure effective extraction of pectin substances, the hydrolysis-extraction process was carried out at a hydromodule 1:5 (solid / liquid ratio) in 15 minutes of the processing. Next, the obtained extract is filtered through lavsan filter cloth to obtain a solution containing pectin.

On the basis of experimental data, the dependence of the concentration of dry substances and pectin in the extracts was established. For this, samples are taken at regular intervals (5, 10, and 15 minutes), the concentration of pectin in the extracts is determined by the calcium-pectate method, and the concentration of dry matter is determined by the gravimetric method. It is shown at a microwave oven power of 700 W the concentration of dry substances in the extract (15 minutes) is 1.84%, pectin is 1.53% of the mass.

Using a centrifuge (SIGMA 4-15), the obtained beet pectin extracts are centrifuged for 30 minutes at a rotor speed of 4000 rpm, then concentrate on an IR-1LT rotary evaporator at 40 °C. Beet pectin is precipitated from concentrates with a double volume of 96% ethyl alcohol (v/ v). Drying of wet pectin is carried out at a temperature not higher than 60 °C. After grinding in a ball mill received the finished product - amorphous powder gray-beige, odorless, taste slimy.

Identification of the obtained pectin is carried out by IR spectroscopy, and IR spectra were recorded with a resolution of 1 cm-1 in the range of 400-4000 cm-1, KBr tablets. The samples of the studied pectin contain characteristic absorption bands corresponding to the structural fragments of pectin polysaccharides (OH, CH, COOH, COOR, CO, pyranose cycle), which confirms their belonging to pectin substances.

Intensification of hydrolysis-extraction in a microwave oven made it possible to reduce on the process time from 5 hours to 15 minutes, to increase the yield of pectin on the DIA of raw materials from 9.35% to 13.93%, which decrease in the production cost to ~ 25%. The characterize of obtained pectins according to GOST 29186. It was shown that they have good physical and chemical properties: 350 W – DE = 61,15%, M = 16,40 кDa; 500 W – DE = 62,41%, M = 15,66 кDa; 700 W – DE = 61,90% and M = 15,73 кDa. The free carboxyl groups of pectin molecules are 12,15%, 11,45% and 10,80%, respectively.

Conclusion. The possibility of using the microwave to intensify the process of hydrolysis-extraction of pectin from beet pulp has been shown scientifically substantiated and experimentally. The optimal conditions for microwave processing of raw materials with a 0.75% oxalic acid solution has been found: temperature 90 °C, hydromodule 1: 5 in 15 minutes. The yield of pectin to DIA of raw materials reaches 13.93%.

The practical application of this technology module to produce pectin in regions with a developed sugar industry not only effectively solves environmental problems, but also acquires pectin with good physical and chemical properties, which can be viewed as a valuable functional product.

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EKATERINA N. FEDOROVA
National Research Tomsk Polytechnic University
KSENIIA B. KRIVTSOVA
National Research Tomsk Polytechnic University

COMPARATIVE ANALYSIS FOR PORPHYRINS OF VARIOUS FIELDS HEAVY OILS

Nowadays, we have a problem that increases constantly, it is a weighting of oil, which is caused by a large amount of high molecular compounds – resins and asphaltenes [1]. Most of the rare metals are concentrated in asphaltenes due to metal porphyrin inclusions. The most common metals in oils are vanadium and nickel [2]. There are oils of vanadium type (V > Ni) and nickel type (Ni > V). Vanadium in the form of a vanadyl cation (VO^{2+}) and nickel in the form of a cation (Ni^{2+}) form a part of the porphyrin complexes and act as their core. A wide range of studies in oil chemistry and ore material composition has revealed that the vanadium and nickel content in heavy raw materials (300-600 gram per ton) can be comparable to the concentration of these metals in ores, and sometimes can be many times higher. [3].

Possessing the properties of surface-active agents (surfactants), porphyrins reduce the system surface tension, thereby reducing wettability and increasing oil recovery. In this regard, the study of crude oil porphyrins' structure and properties is the most important for marginal wells exploration, and the obtained information will contribute to the development of new innovative ways on improving oil recovery.

The object of the study is the porphyrins of various heavy oil fields (Poselkovoye, Snezhnoye, Yasnoye, Usinskoye). Asphaltenes were isolated by the “cold” Golde method. To isolate porphyrins, we chose the method of acid concentration (treatment of raw materials with concentrated sulfuric acid) followed by extraction with benzene. Porphyrin solutions in organic solvents, exposed to ultraviolet irradiation, emit intense fluorescent luminescence of various colors, which indicates various series of porphyrins in the sample (Illustration 1). The porphyrins obtained during the experiment are a mixture of homologs from several homologous series.

The extracts obtained after chromatographic separation were analyzed on an infrared Fourier spectrometer Cary 600 Series FTIR Spectrometer

«Agilent Technologies» in the range 4000-500 cm^{-1} (Illustration 2). Each spectrum has bands characteristic of porphyrins, corresponding to the vibrations of the pyrrole rings C–N at 1458 cm^{-1} and N–H at3315, 940 cm^{-1}.

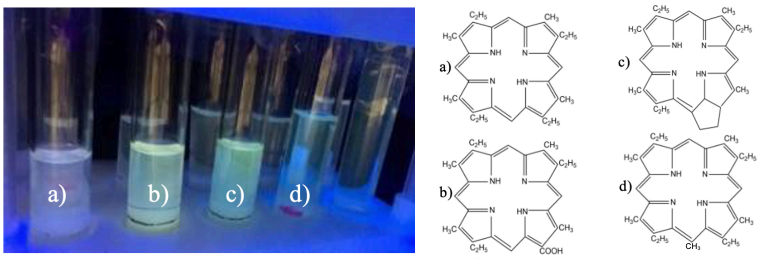

Figure 1 - Extracts of isolated free porphyrins of various series (on the left – view under UV irradiation, on the right – molecular structure): a) etio- series; b) rhodo- series; c) deoxophylloerythroethio- series; d) phyllo- series

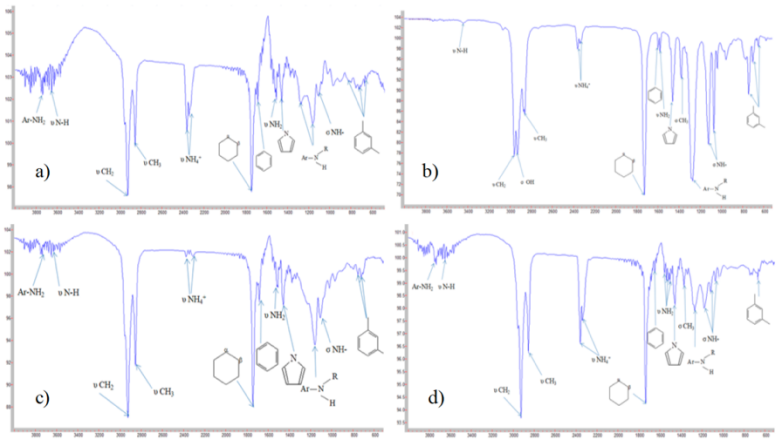

Figure 2 – IR-spectra of isolated free porphyrins extracts:
a) oil of the Poselkovoye field. Etio- series porphyrins;
b) of the Snezhnoye field. Rhodo- series porphyrins;
c) of Yasnoe field. Deoxophylloerythroethio- series porphyrins;
d) of Usinskoye field. Phyllo- series porphyrins

Porphyrins of various series predominate in each oil extract (Illustration 2). The bands of 1743 cm^{-1} and 1655 cm^{-1} correspond to unsaturated C=H bonds inside the porphyrin molecule. Thus, the rhodo- series is characterized by OH-group deformation vibrations (in acid residues). The spectra of the etio- series porphyrins and the deoxophylloerythroethio- series porphyrins differ in the intensity of the bands in the range 900 – 1500 cm^{-1}: in the case of the deoxophylloerythroethio- series, they are more intense. The spectra of the phyllo- series porphyrins have intense bands in the range of 2800 – 3000 cm^{-1} (CH_3-groups stretching vibrations).

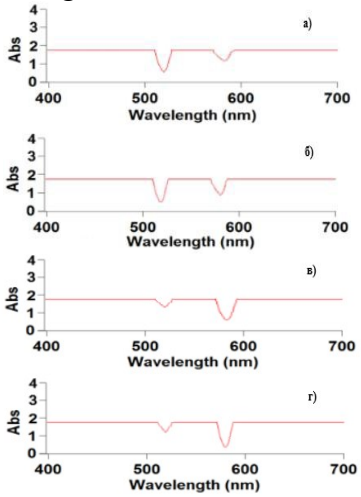

Illustration 3 - Porphyrins UV spectra:
a) of Poselkovoye field; b) of Snezhnoye field; c) of Yasnoye field;
d) of Usinskoye field

We recorded two absorption bands' presence with different intensities at 530 and 570 nm for each oil extract, and it confirms the presence of V and Ni in excess concentration (Illustration 3).

The properties and influence of different series of porphyrins on the oil dispersed system is different. The study of the crude oil porphyrins structure and properties is a priority task, and it's solution will make a big step towards the development of new innovative ways for improving oil recovery.

Also, because metal porphyrins have rare metals (V, Ni) in high concentrations, it is necessary to develop the process of rare metals extraction from heavy oils and oil residues. The process of separating metal porphyrins from heavy oil feedstock will optimize oil refining processes, as well as obtain metal porphyrin concentrates, which makes this stage not only efficient but also economically profitable.

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ANDREA M. GALLARDO
Yachay Tech University
Dr. Prof. EDWARD E. ÁVILA
Yachay Tech University
Dr. Prof. ALFREDO VILORIA
Yachay Tech University

STUDY OF REGENERATION OF H_2S ADSORPTION PELLETS BASED ON CHEMICAL AND MAGNETIC PROPERTIES

It is known that the industrial sector continuously seeks to optimize its efficiency both at an operational and economic level. In the natural gas industry, the implementation of acid gas removers has made it possible to optimize the gas processing steps. Among the technologies used to eliminate these pollutants, there are the solid beds [1]. These adsorbent agents must have certain characteristics to comply with their designated use, and among them, an important one is regeneration [2]. This capacity is a vital property as it represents an attractiveness from an economic and environmental point of view. This research studies the potential of an H2S adsorption pellet, made from Ecuadorian natural resources, to be regenerated by analyzing important properties that allow it to be competitive with conventional technologies. Ecuador has great natural resources for the development of adsorbent pellets. In fact, metal oxides, that could be found in Ecuadorian sands, have been extensively used as adsorbents for hydrogen sulfide capture.

In this study, two pellets labeled as C/15%SS and C/25%SS formed from Ecuadorian clay (CZY-304) and Ecuadorian sieved sand (SS104) were evaluated. A solid conformation for H2S adsorption of the natural gas that is going to be subjected to regeneration must have high mechanical resistance to withstand the conditions to which it will be exposed. For this reason, after the pellets had been manufactured and calcined, the resistance to compression and to fall was evaluated as a selection criterion. With this technique, it was identified the conformation that shows the greatest resistance. The adsorption capacity of the pellet was evaluated recreating an H2S environment. The regenerability of the sample that has already been in the H2S environment and therefore has consumed its adsorption capacity was tested by the Fenton reaction. This reaction is based on the interaction of iron ions and hydrogen peroxide, forming hydroxyl radicals that oxidized the sulfur compounds [3].

The samples were characterized with X-Ray Diffraction (XRD) and Scanning Electron Microscopy - X-Ray Energy Dispersion Spectroscopy (SEM-EDS). To facilitate the identification of the iron oxides that compose the sand, it was magnetically separated and analyzed by XRD. Using these characterization techniques, the adsorption and regeneration reactions in the composite pellet were verified. In addition, magnetic susceptibility measurements were taken to the samples to create a quantifiable indicator of conversion through a magnetization – demagnetization analysis. With comparative measurements, the loss of magnetic properties

associated with the reactivity of the pellet and the regeneration capacity of the sample under study were quantified.

The regeneration of pollutant adsorbents for natural gas is a property of them to be highlighted since this capacity represents an alternative industrially and environmentally viable. With the objective of evaluate this property, a lot of experimentation was implemented. In a first instance, it was determined that the composition with the best mechanical properties is C/15%SS. After the reaction with Hydrogen Sulfide took place, it was determined, by means of physical and phase analysis, the adsorption capacity of the pellet. Additionally, by the analysis of the core-shell structure formed after the reaction, it was found that the model that describes the reaction process is the Shrinking Core Model (SCM). For the regeneration reaction, with the phase and atomic composition analysis, it was constated the regeneration of Hematite. Regeneration was found to be the result of a complex interaction. The mechanism involved in this process is complicated, and important aspects of intermediate species formation are not completely elucidated. That is why further studies into the detailed mechanism of the sulfidation-regeneration process on this iron oxide-based adsorbent need to be implemented. Nevertheless, taking advantage of the magnetic properties of the conformation, it was identified that the sulfidation reaction was done in 30%, and the regeneration was about 19%.

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LIVAN GARCÍA OBREGÓN
University of Moa
LUIS A. PÉREZ GARCÍA
University of Moa

EVALUATION OF THE MANIFESTATIONS OF KAOLINITIC CLAYS FROM FARALLONES, MOA, FOR THE PRODUCTION OF LOW CARBON CEMENT

At a time when cement ranks as the second most used material on the planet and its production one of the most widespread and harmful to the environment, a formula developed by Cuban and Swiss specialists seeks to transform this dichotomy.

According to international data, global cement manufacturing exceeds four thousand 400 million tons and is responsible for between five and eight percent of carbon emissions into the atmosphere, a reality that could change with the introduction of LC3. Limestone Calcined Clay Cement, a novel mixture that has the novelty of the synergy between calcined clay and limestone, which influences the reduction of clinker volumes, the most polluting element in common compositions1.

Previously, clays of high purity and metakaolin were used for the production of this type of cement, however, its use on a large scale is limited by the low availability of deposits and competition as a source of raw materials in industries such as ceramics and paper. Alternatively, recent research2–4 has shown the possibility of obtaining from clays with only 40% kaolinite a reactive material with a behavior similar to commercial metakaolin, which allows substitutions of

up to 30% by weight of Portland Cement in the binder. This type of clay deposits, with moderate kaolinitic clay content, are very abundant in tropical and subtropical areas where the demand for cementing materials is concentrated and where their resources must exceed billions of tons. That is why it is generally considered that calcined clays constitute the group of Supplementary Cementing Materials (MCS) with the greatest potential in the coming years2.

In this work, the influence of the chemical and mineralogical characteristics of the kaolinitic clay in Farallones was made, for the production of low carbon cement. The samples were characterized chemically and mineralogically using XRD, Thermogravimetric Analysis, and XRF. Pozzolanic activity analyzes were carried out by isothermal calorimetry. Losses on ignition (LOI) and kaolin equivalent correlation with compressive strength were calculated. The results of chemical analysis showed low values of sodium, magnesium, calcium, manganese, and phosphorus, and a high concentration of silica and alumina. In addition, high iron and carbon values were determined. General paragenesis was defined as that composed of quartz, muscovite, vermiculite, albite, illite, kaolinite, and montmorillonite. As the main result, the pozzolanic reactivity analysis showed that the optimum temperature for the thermal activation of the clays studied is 750 ºC. According to the correlation between the equivalent kaolin content and the compressive strength, it was determined that in all cases, the latter exceeds the values established by the Cuban Norm 2013.

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ILIA S. GRISHIN
Ivanovo State University of Chemistry and Technology
Dr. Prof. NIKOLAI N. SMIRNOV
Ivanovo State University of Chemistry and Technology

STRUCTURAL FEATURES OF SILICON OXYCARBIDE COMPOSITES OBTAINED BY MECHANOCHEMICAL ROUTE

Silicon oxycarbide composites are usually considered as materials based on silicon oxycarbides (SiOC), which formally can be described as products of carbon incorporation into the network structure of silicates. The structure of silicon oxycarbides is mixed network of silicon atoms tetrahedrally bonded to oxygen and carbon atoms. However, this network structure is different from nanosized silicon carbide and silicon dioxide, because it has the entire spectrum of structural units, which correspond to the general formula SiO_xC_{4-x}. According to that formula, there could be SiO_4, SiO_3C, SiO_2C_2, $SiOC_3$, and SiC_4 [1]. In addition to the structural units mentioned above, there is also a phase of segregated sp^2-hybridized carbon in silicon oxycarbides. This carbon is highly disordered, and turbostratic. Thus, there are two types of carbon in the SiOC structure: carbide carbon, which is a part of the sp^3 hybridization network, and sp^2-hybridized carbon. At present, the exact microstructure of SiOC has not been established yet. Unique structure of silicon oxycarbides determines all their properties, for example high strength, chemical and

thermal stability. Silicon oxycarbide composites are used to produce a large number of different types of materials, in particular coatings, tubes, fibers, etc. [2]. The most interesting are porous structures. Such composites are well suited as carriers of Ni, Co and Pt [3]. High catalytic activity of the Pt/SiOC composite in the process of conversion of CO to CO_2 was noted, which was achieved by improved distribution of Pt particles. Another potential application of silicon oxycarbide composites is production of effective adsorbents [4]. Despite all the advantages of silicon oxycarbides and composites based on them, the key disadvantage is high cost of their production. Currently, silicon oxycarbides are prepared from organosilicon polymers as raw materials, polyorganosiloxanes in particular. The raw materials are subjected to pyrolysis at 1200°C and higher. A new approach was proposed to the synthesis of silicon oxycarbide composites based on intensive mechanical treatment of activated carbon and silica. The deformation processes changes the structure of materials significantly, and mechanical energy supplied accelerates reactions due to local overheating.

Mechanochemical synthesis of silicon oxycarbide composites was carried out as follows. Several mixtures of activated carbon and silica with various mass ratios of the components were subjected to mechanical treatment for 15 min in a roller-ring vibratory mill. Samples obtained were analyzed using various experimental methods including powder X-ray diffraction, IR Fourier spectroscopy, low-temperature nitrogen adsorption/desorption, potentiometric titration, scanning electron microscopy, and synchronous thermal analysis.

It was established that mechanochemical synthesis of SiOC composites proceeds together with the oxidation of activated carbon, which increases the concentration of various functional groups, in particular phenolic and carboxylic ones. The significant increase in the concentration of oxygen-containing groups was also caused by the appearance of various types of silanols. Probably, the formation of Si-O-C bonds occurs due to these groups. The structure of the composites obtained varied depending on the initial mixture composition. In fact, the larger the proportion of silica, the more Si-O-C bonds could form. This trend was observed in absolute terms. However, the degree of binding of AC and S decreases, since silica excess overlaps the network structure of silicon oxycarbides by crosslinking of Si-OH bonds to form Si-O-Si. The data on low-temperature nitrogen adsorption/desorption showed that specific surface area and pore volume of silicon oxycarbide composites decreased as more silica was added. This is because partial destruction of the porous structure due to intensive mechanical impact. Another possible reason for the decrease in the specific surface area may be the blocking of access to some pores as a result of the silica particles sticking onto the surface of the activated carbon ones.

The thermal behavior of silicon oxycarbide composites was investigated. Heat treatment can become an effective tool for controlling the structure of silicon oxycarbide composites. For example, heating of the composites to comparatively low temperature (400-450°C) leads to their restructuring. More complex network architecture is then formed, and nanostructures appear as well. Nevertheless, even at such temperature, partial decomposition of activated carbon occurs that results in the removal of functional groups in the form of CO and CO_2. Concentration of silanols decreases too, as crosslinking process of them takes place. At 900°C significant structural changes were observed. They were expressed in the crystallization of silicon dioxide, and its sintering. This negatively affects the adsorption properties, since the porous structure is destroyed, and in addition, a large number of functional groups are removed.

Based on the obtained experimental data and information from literature, an attempt was made to model the structure of silicon oxycarbide composites. The main ways of binding of activated carbon and silica are shown on the example of their model fragments. Changes in the structure occur as a result of deformation processes leading to bonds break and consequent formation of active sites on the surface of activated carbon and silica. Radicals and broken bonds become centers of attachment. Together with the presence of an oxidizing environment, this also leads to the oxidation of activated carbon. For that reason, direct connection of activated carbon and silica with the formation of Si-C bonds is impossible during intensive mechanical treatment of the two. Using model fragments as an example, it was also shown how the structure of

composites changes with an increase in the proportion of silica in the initial mixture subjected to mechanical treatment.

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MIN HAO
China University of Mining and Technology (Beijing)

SWELLING RESPONSE OF ANTHRACITE COAL DURING CH_4-CO_2 COMPETITIVE ADSORPTION BY MOLECULAR SIMULATION

Introduction. In the energy sector, the enhanced coalbed methane (CBM) recovery by injecting CO_2 into the geological reservoir to reduce emissions is a promising method, which can achieve a double effect of the extraction of unconventional gas and the sequestration of CO_2. Due to the preferential adsorption of CO_2 on coal with respect to CH_4, the injected CO_2 can drive and replace CH_4 in the coal seam, significantly improving the CH_4 recovery. In this process, the competitive adsorption of CH_4-CO_2 on coal would occur and its swelling response is essential for CBM recovery because the volumetric strain directly determines the permeability of the coal seam.

Main part. In this work, adsorption isotherms of pure CH_4, pure CO_2 and their binary mixture on anthracite coal were quantitatively compared through molecular simulation. Moreover, the volumetric strain of anthracite coal during CH_4-CO_2 competitive adsorption was investigated based on an extended model. Finally, the influence of geological conditions on the adsorption capacity and volumetric strain was discussed.

Adsorption-induced swelling is a major concern for gas injection to promote recovery in coal reservoir. Especially in the CH_4-CO_2 competitive adsorption process, its further understanding is crucial because it directly determines the permeability of the reservoir. In this work, adsorption isotherms and the swelling response of anthracite coal during CH_4-CO_2 competitive adsorption were investigated through molecular simulation and an extended model. The results show that the adsorption capacity of CH_4 would be suppressed due to the preferential adsorption of CO_2 on anthracite coal. The increase in the mole fraction of CO_2 would increase the total adsorption capacity of the binary mixture. Moreover, as the fugacity increases from 0.1 MPa to 10.1 MPa, the volumetric strain dominated by adsorption-induced swelling gradually increases. Also, the increase in the mole fraction of CO_2 would increase the volumetric strain of the binary mixture. Taking into account the geological reservoir conditions, the combined effect of temperature and pressure affects the adsorption capacity and volumetric strain during CO_2 injection to promote CH_4 recovery. The results can provide a reference for on-site engineering.

Conclusion. In this work, adsorption isotherms and the swelling response of anthracite coal during CH_4-CO_2 competitive adsorption were investigated through molecular simulation and an extended model. The main results of the present research work can be summarized as follows:

(1) Specifically, the adsorption capacity of CO_2 is about twice that of CH_4 on anthracite coal. The adsorption capacity of CH_4 would be suppressed due to the preferential adsorption of CO_2 on anthracite coal. With the increase in the mole fraction of CO_2, the total adsorption capacity of the binary mixture would increase. Comparatively, the adsorption capacity of CO_2 gradually increases whereas that of CH_4 tends to decrease.

(2) The volumetric strain depends on CO_2 mole fraction, fugacity and temperature. In the range of fugacity given, the volumetric strain is dominated by adsorption-induced swelling, and the increase in fugacity leads to a gradual increase in volumetric strain. Also, the increase in the mole fraction of CO_2 would increase the volumetric strain of the binary mixture.

(3) In the geological reservoir conditions, the combined effect of temperature and pressure affects the adsorption capacity and volumetric strain during CO_2 injection to promote CH_4 recovery. The results can provide a reference for on-site engineering.

This work can indeed provide technical support for the extraction of coalbed methane and shale gas, as well as the capture and storage of CO_2 in geological formations. However, some conclusions of this work are only based on the molecular model of anthracite coal in China. Meanwhile, the calculation of volumetric strain is slightly simplified. Therefore, the molecular models of different coal ranks and the state of the mixture gas will be considered in later research.

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LIJINHONG HUANG
Jiangxi University of Science and Technology, China &
Curtin University, Australian
Dr. Prof. LIHONG LIU
Curtin University, Australia

RECOVERY OF LANTHANUM CATIONS BY FUNCTIONALIZED MAGNETIC MULTI-WALLED CARBON NANOTUBE BUNDLES

Rare-earth elements (REE), including La, are critical raw materials in many technological advancements. Collection of physically adsorbed REEs on clay minerals can be realized first by ion-exchange leaching, followed by adsorption enrichment. Ever increasing demand and limited resources of REEs have fueled the development of nanostructured adsorbents. In this paper, multi-walled carbon nanotubes (MWCNTs) were purified by concentrated H2SO4 and HNO3, then coupled with magnetic Fe3O4 nanoparticles to make it retrievable for low concentration La ion extraction from water. The MWCNT@Fe3O4 composites were further crosslinked with 0.1 wt% epichlorohydrin and functionalized with 0.5 wt% carbon disulfide to achieve La3+ adsorption capacity of 23.23 mg/g. We fully probed the morphology, crystallinity, chemical composition, and magnetic properties of the as-prepared adsorbent by scanning/transmission electron microscopy, X-ray diffractometer, X-ray photoelectron spectroscopy, vibrating-sample magnetometer, and thermal gravimeter. These results indicated that MMWCNT@Fe3O4 nanohybrid may be a promising candidate for recovering La ions from aqueous solutions.

The rare earth elements (REE) comprise a group of fifteen lanthanides on the periodic table (IIIB metals) plus scandium and yttrium. The unique chemical, electrical, magnetic, optic, and luminescent properties of REE render them essential components to high-tech and green-energy products, such as nuclear medicines, lasers, electronic displays, high strength alloys, radar, and vehicle catalytic converters [1]. The extraction of REE from commercially significant bastnäsite ores involves large up-front capital investments, high energy costs and environmental risks [2]. An alternative source to obtain REE is from weathered crust elution-deposited rare earth ores, also known as ion-adsorption clays [3]. The clay deposits contain 0.05 to 0.2 wt% rare earths, out of which 60-90% occur as physically adsorbed species recoverable by simple ion-exchange leaching with concentrated monovalent cations [4]. The free rare earth ions (RE3+) are then precipitated with oxalic acid and converted to RE oxides via 900 °C calcination. However, when RE3+ concentrations are low, the use of adsorbents for ion pre-concentrating is necessary [5]. Indeed, adsorption is the most explored method due to its simplicity and wide-ranging availability for low concentration REE recovery from electronics waste, brines, and various industrial wastes.

Biosorption based on a variety of biomaterials such as algae, fungi, bacteria, etc., have been proposed for the recovery of RE3+, but more efforts are needed to solve the problematic nature of biomass regeneration. Recently, bulky zeolite, clay, active carbon, and nanomaterials (NMs) have received increasing attention. Numerous non-magnetic SiO2, TiO2 and carbon based NMs have been reported for this type of application [6]. In particular, the large surface areas, high porosity, hollow and layered structures have made multi-walled carbon nanotubes (MWCNTs) an ideal adsorption material. On the one hand, the high adsorption capacity of MWCNTs stems from the large specific surface area, hence having more active or binding sites. On the other hand, the sorption of RE3+ is primarily controlled by electrostatic forces, which are associated with negatively charged surface function groups [7]. Oxidized MWCNTs and graphene oxides have emerged as excellent metal ion adsorbents due to possessing many oxygen donor groups (e.g. hydroxyl, carbonyl and carboxyl) on their surfaces [8,9].

The sorption performance of MWCNTs relies on their homogeneous dispersion. It is a challenge to remove the suspended MWCNTs from the aquatic phase. Experiments have been conducted to explore the use of magnetism as an effective means of separating the spent adsorbents. Magnetite (Fe_3O_4) and maghemite (γ-Fe_2O_3) are commonly incorporated with

MWCNTs for adsorption removal of Cr^{6+}, Pb^{2+}, Mn^{2+}, Cu^{2+} and organic cationic dyes [10-13]. However, few studies on the interaction between RE^{3+} and magnetic MWCNTs has been reported which serves as the primary motivation of this work.

The overall objective of this research is to modify MWCNT to become a magnetically retrievable adsorbent that can efficiently recover REEs. Firstly, an attempt has been made to purify and oxidize MWCNT to overcome the hydrophobicity issue by the introduction of hydroxyl and carboxyl groups. Polyvinyl alcohol was employed to assemble MWCNT@Fe_3O_4. Upon the surface treatment, epichlorohydrin (ECH) was used to cross-link the CNTs through reaction with –OH. There are sparse studies regarding the use of magnetic MWCNTs-ECH hybrids for the removal of La^{3+}. It was expected that the 3D structure formation can enhance the mechanical strength of the adsorbent in harsh acid solution. Functionalized CNTs-based nanomaterials have exhibited an enhanced performance for energy-related oxygen evolution reaction and water oxidation[14-16]. In this study, MWCNT@ Fe_3O_4 with CS_2 was conducted based on the innate affinity of S^{2-} for metal ions[17]. The ability of the as-prepared adsorbent to recover La^{3+} was evaluated under a range of ECH and CS_2 weight ratios. Effective La^{3+} sorption was accomplished with 0.1 wt% ECH and 0.5 wt% carbon disulfide.

In this study, uniform Fe3O4 nanoparticles were embedded into multi-wall carbon nanotube (MWCNT) bundles via a facile epichlorohydrin (ECH) cross-linking process. The nanocomposites were further functionalized by CS_2 as a reusable magnetic adsorbent for enhanced rare earth La^{3+} adsorption in aqueous media. The maximum adsorption capacity was found to vary with ECH and CS_2 concentrations. The best concentration combination for favourable La^{3+} adsorption was determined by orthogonal array analysis and experimental results. Different characteristics of the final absorbent are explored through FESEM, XRD, TGA, BET, FTIR, XPS, and VSM methods. This retrievable nano adsorbent has exhibited suitable efficiency in La^{3+} recovery and made the process highly valuable from environmental perspective.

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ALEKSEI S. ILMENSKII
Kazan National Research Technological University
CES, Associate Prof. SERGEI M. PETROV
Kazan National Research Technological University

STUDY OF THE CATALYTIC ACTIVITY OF THE ZEOLITE-CONTAINING SILICEOUS ROCK DURING CRACKING OF A C_{12}-C_{22} ALKANES MODEL MIXTURE

Nowadays, depletion of light oil sources with increase in the demand for light fuels, utilization of alternative sources like heavy and inferior oil for gasoline and diesel production has become inevitable [1]. The existing technologies at the majority of Russian refineries are not adapted for the heavy oil processing. In this regard, there is a need for a cost-effective technology for the heavy oil primary treatment without the use of expensive catalysts and hydrogenation processes. It can be realized, in particular, by visbreaking using a natural cheap expendable catalyst - zeolite-containing siliceous rock. The destructive reactions mechanism of the of oil compounds is well understood. It is known that heteroatomic organic compounds and high molecular weight

paraffinic hydrocarbons are thermally unstable, while alkanes with a lower molecular weight are quite stable at temperatures below 400 °C [2]. Therefore, it is advisable to study the catalytic activity of natural aluminosilicates in the cracking of just such stable alkanes. The paper considers the catalytic activity of the zeolite-containing siliceous rock during cracking of a C_{12}-C_{22} alkanes model mixture. The object of the study is a zeolite-containing siliceous rock of the Tatar-Shatrashan zeolite deposit.

To analyze the structure and composition of a rock sample, the XRD, XRF and porosimetry methods were used. According to the results of X-ray structural analysis, it was found that the content of zeolite in the rock is equal to 9%. Based on the XRF data, a significant amount of Al (28%) and Si (61%) was found in the composition of the amorphous phase of the rock sample, which indicates the presence of amorphous aluminosilicates in the sample. The amorphous aluminosilicates can also exhibit catalytic activity in the hydrocarbons cracking process. According to the porosimetry data, the specific surface area of the rock pores is 67 m^2/g, and their average diameter is 10 nm, which is sufficient for the hydrocarbons diffusion into the catalyst pores [3].

The experiments with a model mixture of hydrocarbons were carried out in a fixed-bed reactor at a pressure of 0.25 MPa and temperatures of 400 and 450 °C. The light liquid hydrocarbons yield was 3.3% and 5.8% for 400°C and 450°C, respectively. Alkenes (81%wt.) dominate in the catalyzate composition, the content of isoalkanes 4%wt., cycloalkanes 8%wt., and aromatic hydrocarbons 7% wt. With an increase in the process temperature to 480 °C, the formation of gaseous products increases. In the composition of gaseous products, there are more propane (17.3%), then, in descending order, propene, ethane, ethylene, etc.

Based on the data obtained, it can be concluded that the zeolite-containing siliceous rock in its pure form exhibits catalytic activity in the process of cracking the C_{12}-C_{22} alkanes model mixture. It seems promising to continue the work in the direction of studying the optimal ways of activating the zeolite-containing siliceous rock with the aim of increasing the specific surface area and pore diameter and, as a consequence, increasing the catalytic activity.

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S. KHUSNUTDINOV
Montanuniversität Leoben
Dr. Prof. JOHANNES SCHENK
Montanuniversität Leoben
Dr. Prof OLEG DUBOVIKOV
St. Petersburg Mining University
Dr. Prof ISMAGIL KHUSNUTDINOV
Kazan National Research Technological University

DEVELOPMENT OF TECHNOLOGIES FOR PROCESSING OIL-CONTAINING WASTES OF THE METALLURGICAL INDUSTRY

The production and consumption of petroleum products, solvents, lubricating oils, greases, flushing fluids and other refined products at petrochemical enterprises, metallurgical enterprises, railway transport and other industries leads to the formation of a large amount of hydrocarbon-containing waste. Warehousing and accumulation of which bears direct and indirect damage to the region and the enterprise.

Recycling waste from the metallurgical, oil refining, petrochemical, and transport industries is a key issue in improving the environmental well-being of the regions where production is located and the economic stability of enterprises.

Considering that at present, all over the world, increased attention is paid to the recycling of raw materials and the environmental aspects of production and consumption, it is necessary to consider this waste as a man-made raw material, the rational processing of which will lead to the production of new marketable products and an improvement in the environmental situation.

The accumulation of these wastes and irrational recycling methods are associated with the lack of technological solutions that allow to efficiently process of such a variety of oily-oily waste with an unstable and complex composition.

Among these wastes, a special place is occupied by sludge from cleaning and decomposition of cutting fluids (coolant sludge) and oily scale. This is because cutting fluids are artificial emulsions with highly effective emulsifiers and various additives that increase their stability. During the decomposition of such emulsions, especially stable sludges (coolant sludge) are formed, which are complicated by mechanical impurities, products of bacterial decomposition. The oiled scale is one of the types of waste, the processing of which using existing technologies leads to a significant impact on the environment.

The complexity of processing these wastes lies in their large volume of formation, which leads to their accumulation on the territory of metallurgical enterprises, which are large industrial centres with a high population density and limits the options for the disposal of oily scale, cutting fluid sludge and other oily waste. The processing of these raw materials is a separate, particularly acute task.

In this dissertation work, several scientific and technical solutions for the recycling of difficult process an oily waste of metallurgical enterprises are proposed.

For the recycling of this waste, a complex scheme has been proposed, the main processes of which are:

1. The process of thermomechanical dewatering for the processing of highly stable emulsions, oil-oil sludge
2. The process of introducing oily scale, pasty and solid oily waste into metallurgical processing together with pulverized coal.

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NIKOLAI V. KONDRATEV
St. Petersburg Mining University
Ph. D. NATALIA A. ROMANOVA
St. Petersburg Mining University
Ph. D. VLADIMIR S. LEONTIEV
St. Petersburg Mining University

USE OF STRUCTURED PACKING WITH LOW HYDRAULIC RESISTANCE WHEN COMBINING DISTILLATION COLUMNS IN ENERGETIC RECTIFICATION UNITS

In general modernization of the distillation plants can be divided into two ways: upgrades, that require mechanical intervention (for instance replacement of the standard distillation column plates with structured packing) and formation of the energetic rectification units, which requires redirection material flows of the heat carriers, raw material and product flows. In this work on the example of the diethylbenzene producing plant the formation of the energetic rectification unit was occurred, combining together two methods mentioned above.

The technological scheme of producing diethylbenzene fraction is given below.

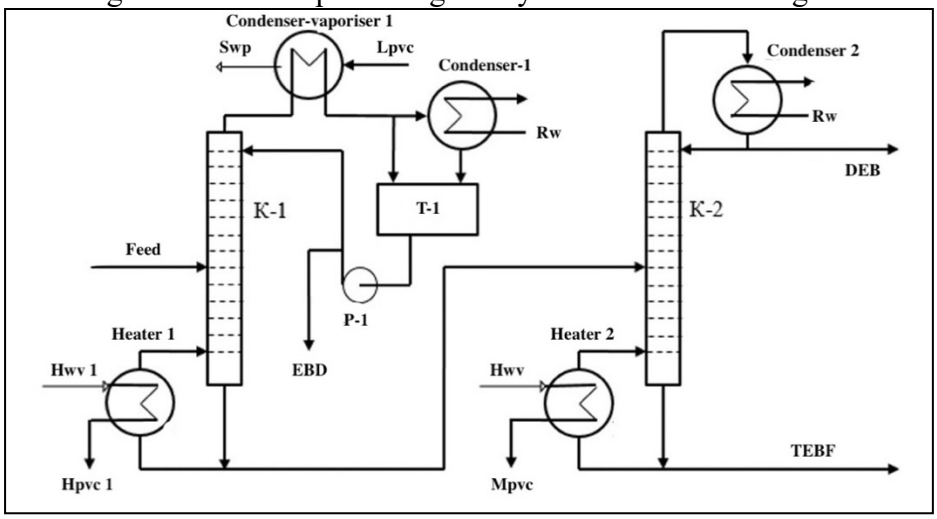

Figure 1 – Technological scheme of producing diethylbenzene fraction before modernization.

Modeling of the initial technological scheme was made with the help of AspenTech Hysys software package. The main condition, that should be taken into account while formation of the energetic rectification unit is the equality of the heat flow, that is supplied to the K-2 column bottom and the amount of heat that is being removed from the upper part of the K-1 column while condensing the ethylbenzol distillate. Second important condition that should be fulfilled is temperature pressure between upper part of the K-1 column and K-2 column bottom. These two conditions form ideal environment to form the energetic rectification unit.

Replacement of the column's contact plates with structured packing with lower hydraulic pressure will inevitably lead to changes in column temperature profile. Thermodynamic modeling showed, that in our case replacement of the K-2 column's contact plates with structured packing with lower hydraulic pressure will lead to K-2 bottom's temperature drop from $\sim 150\ C^{\circ}$ to $\sim 100\ C^{\circ}$. Analysis of the temperature profiles showed, that partial redirection of the ethylbenzol distillate from the K-1 column with $\sim 150\ C^{\circ}$ temperature to the K-2 column bottom with $\sim 100\ C^{\circ}$ will form temperature pressure of $\sim 50\ C^{\circ}$ which is enough to form the energetic rectification unit. These changes will lead to K-2 column's bottom heater power consumption reduction which economically viable.

Replacement of the K-2 column's contact plates with structured packing, characteristics of which are shown in the table below will eventually lead to lowering the K-2 bottom's pressure without changing any of the technological parameters such as distillate rate, bottom's flow rate or reflux ratio.

Table 1 – Shevron 14-4 structured packing characteristics.

Packing type	Efficiency, n t.p./m	$F = w \cdot \sqrt{\rho_n}$, $kg^{0,5}/(c*m^{0,5})$	$I = F \cdot \sqrt{\rho_n} \cdot n$ kg/m^3*c	I_i/I_1
Shevron 14-4*	6	2,5	18	0,99
*- Regular packing produced by «ИнТАРекС», Russia				

Technological scheme of the diethylbenzene producing plant after modernization is given below.

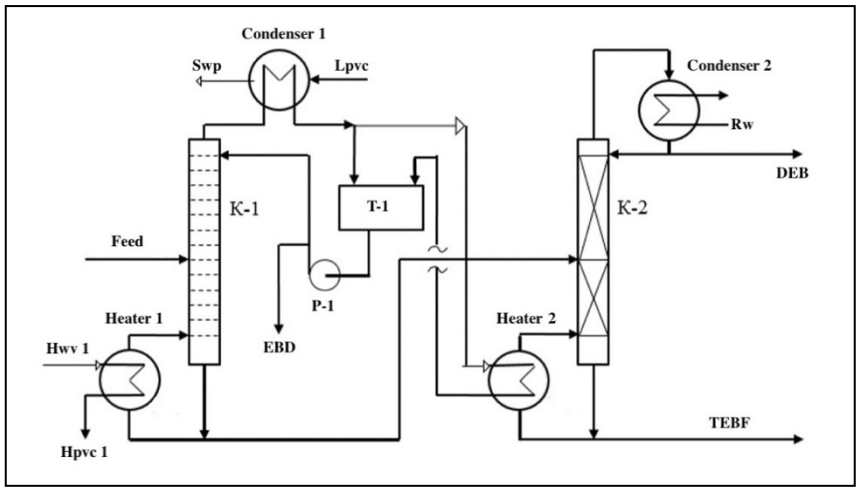

Figure 2 – Technological scheme of the diethylbenzene producing plant after modernization.

Conclusion. Formation of the energetic rectification units combining with replacement of the standard contact plates with structured packing with low hydraulic pressure in some cases gives opportunity to lower the bottom's heater power consumption on the upgraded column. Economical effect of such type of modernization in our case is obviously beneficial due to the fact, that bottoms heat flow of the K-2 column is completely saved.

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Scientific director: Ph. D. Natalia A. Romanova

AKZHAN A. KORDASHEVA
Karaganda Technical University
DIANA A. ISSAGULOVA
MADINA M. ABDILDINA

INVESTIGATION OF THE MANUFACTURING PROCESS OF COMPOSITE MATERIALS WITH VIBRATION-SOUND-ABSORBING PROPERTIES

In the conditions of modern mechanical engineering, to increase the efficiency of production, the task is to reduce time and material costs when developing new products and ensure high quality of products, their competitiveness with high labor productivity, which is directly related to the improvement of mechanical processing technology, the geometric accuracy of the products. The increase in the speed and capacity of machines and equipment has led to a significant increase in harmful noises and vibrations, which reduce the reliability of mechanisms, the quality of processing products, and significantly worsen working conditions in production.

The solution to this problem is seen in the development and application of composite materials with high vibration and sound-absorbing properties in structures exposed to dynamic loads.Many years of experience in combating noise and harmful vibrations have shown that the most effective vibration-sound-absorbing materials are polymer composite materials (PCM).

PCM has a complex of physical and mechanical properties that favorably differ from traditional structural materials (metals, alloys, concrete, wood) and together open up wide opportunities for improving existing dissipative materials and products for various purposes, as well as for developing new structural elements and technological processes.Periodic vibrations and noises that occur during mechanical metal cutting have an undesirable effect on the quality of the resulting parts and products and working conditions in production (noise level of more than 70 dBA). In this regard, the task of developing effective vibration-sound-absorbing polymer materials is very relevant and promising.

The problem of reducing the sound level in the construction industry is effectively solved by using parts or gasket materials with open porosity (hydro concrete, Anti-vibration paste). But due to the lack of high sound-absorbing, vibration-damping and deformation-strength properties in the complex at the same time, such materials are not widely used in mechanical engineering as structural materials and products. However, by varying the wide range of selection of thermosetting resins, modifying components, fillers, and optimizing the design of the composite system, it is possible to obtain such unique composites.

The solution of this problem is associated with the development of new methods for calculating and predicting the sound-absorbing, vibration-damping and elastic properties of polymer composite materials, as well as optimizing the compositions when creating them.

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KOSOLAPOVA S.M.
St. Petersburg Mining University
KONDRASHEVA N.K.
St. Petersburg Mining University

COMPARATIVE EVALUATION OF ALKALINE AND ACID CATALYSIS METHODS FOR OBTAINING BIODIESELFUELS FROM VEGETABLE RAW MATERIALS

Abstract. In this work, a comparative study of acid and alkaline catalysis for the production of biodiesel was carried out. To establish the efficiency of the catalyst was conducted synthesis of ethyl esters of fatty acids based on vegetable oil. The study used an oil that was low in free fatty acids. An efficient catalyst was selected based on the chromatographic analysis of the representative results of the internal standard analysis method.

Since its inception in the 1990s, the technology for obtaining transport biodiesel fuel has grown from a local idea of stimulating the agro-industrial complex to the global level that has become part of the implementation of systemic state policy in more than 60 countries [1]. The relevance of the development of a technology for obtaining transport biodiesel fuel is due to the search for energy sources alternative to fossil hydrocarbons with the growing desire of the world community to switch to "green energy". However, today in Russia, due to the rich resource hydrocarbon base, this technology remains poorly studied. In literary sources, there are contradictions regarding the conditions of the technological process.

One of these contradictions is the selection of the optimal catalyst for the transesterification reaction of triglycerides of vegetable oil. The structural formula of triglycerides is shown in Figure 1.

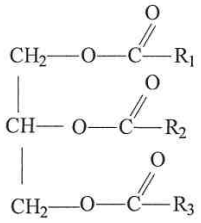

Figure 1 – Structural formula of triglyceride, where R1, R2, R3 are alkyl radicals of the corresponding fatty acid residues

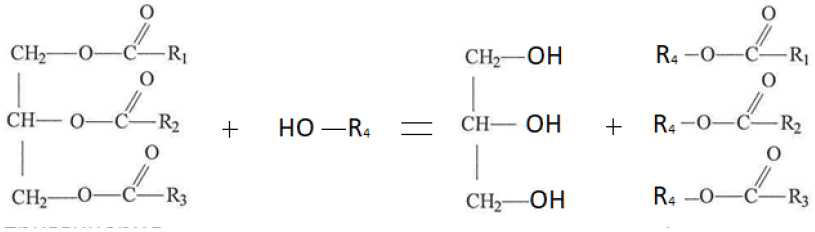

Figure 2 – The reaction of transesterification of vegetable oil

The transesterification reaction of glycerides is reversible and proceeds in three stages. At each stage, one of the fatty acid residues is replaced by the hydroxyl group of a monohydric alcohol (Fig. 2). In this case, both strong acids (acid catalysis) and alkalis (alkaline catalysis) can act as catalysts for the process [2,5]. Methylates and ethylates of sodium or potassium are also actively

used as a reaction catalyst. In addition, it is also known to use heterogeneous catalysts based on calcium and magnesium oxides [4].

Each of these catalysts has its own advantages and disadvantages. For example, the efficiency of alkaline catalysis depends on the water content of the reaction system. In the presence of water and alkali, oils are irreversibly saponified, forming sodium or potassium salts of fatty acids. As a result, at the stage of preparation for the process, additional drying of alcohol is required. Acid catalysis does not produce side saponification reactions. However, sulfuric acid is less effective in accelerating transesterification reactions than potassium or sodium hydroxide. In addition, acid catalysis forms effluents of sulfur compounds that require purification.

In the research part of the work, two series of tests were carried out with acid (sulfuric acid) and alkaline (potassium hydroxide) catalysts.

The synthesis of ethyl esters of fatty acids was carried out in a system of parallel reactors with a reflux condenser and a magnetic stirrer at a ratio of alcohol to oil by weight of 1: 1, 2: 1, and 3: 1, respectively. The reaction mixture was heated to 70 ° C and stirred at a speed of 200-250 rpm. within 4 hours. Upon completion of the synthesis, the mixture was defended until complete separation into two layers - ether and glycerol fractions.

The target product was determined by gas chromatography-mass spectrometry. The internal standard method was used to determine the yield of the target product. 10 mcl were taken from the ether fraction and dissolved in 1 ml of hexane. Then, a known amount of internal standard was added to the sample. Dodecane ($C_{12}H_{26}$) was chosen as the internal standard. The concentration of the target product was calculated by the formula:

$$C_{eth} = \frac{S_{eth}}{S_{in}} \cdot C_{in},$$

where C_{eth} and C_{in} – are the concentration of ether and internal standard, respectively; $\frac{S_{eth}}{S_{in}}$ – ratio of the ether peak area to the internal standard peak area.

In the first series of tests, 1% concentrated H2SO4 (99%) was added to the reaction mixture, and in the second, 1% by weight of KOH (after having dissolved it in reaction ethanol). Refined sunflower oil with an acid number of 0.4 mg KOH / g was used as plant material.

According to the results of chromatographic analysis, the target product was absent in all three samples of reaction mixtures after acid catalysis. In contrast, in the samples of ether fractions after alkaline transesterification, a significant content of the target product was determined (Table 1). Hence, we can conclude about the effectiveness of alkaline catalysis (KOH) in comparison with sulfuric acid in relation to plant materials with a minimum amount of free fatty acids.

With an increase in the ratio of alcohol to oil in the mass range of 1: 1, 1: 2, and 1: 3, the yield of the target products increased. The results of the experiment are presented in table 1.

Table 1 – Yield of target products when synthesized with KOH

Ratio oil: alcohol (ml: ml)	Target products yield,% mass
10:10	52,28
10:20	63,17
10:30	72,78

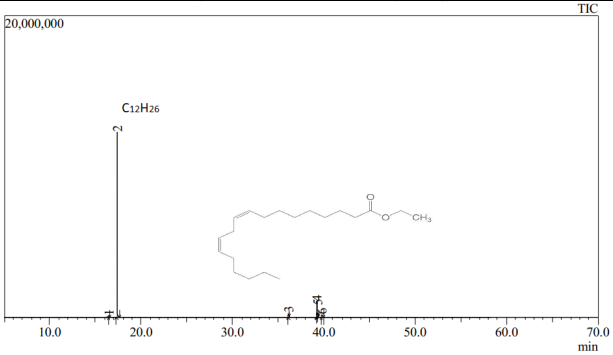

Figure 3 – Chromatogram of the ester fraction after synthesis with an acid catalyst

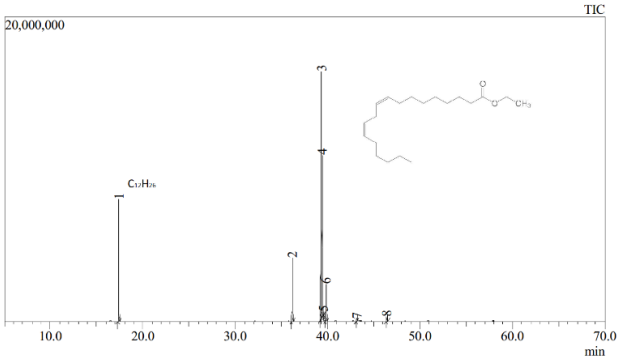

Figure 4 – Chromatogram of the ether fraction after synthesis with an alkaline catalyst

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EMMA LAASONEN
Lappeenranta-Lahti University of Technology
D.Sc VESA RUUSKANEN
Lappeenranta-Lahti University of Technology
D.Sc MARKKU NIEMELÄ
Lappeenranta-Lahti University of Technology
D.Sc Prof. TUOMAS KOIRANEN
Lappeenranta-Lahti University of Technology
D.Sc Prof. JERO AHOLA
Lappeenranta-Lahti University of Technology

INSIGHTS INTO CARBON PRODUCTION BY CO_2 REDUCTION IN MOLTEN SALT ELECTROLYSIS

The amount of greenhouse gases in the atmosphere is increasing. As greenhouse gases are a major cause of climate change, it is crucial to take actions against this phenomenon. With carbon capture and utilization (CCU) technologies, it is possible to take CO_2 from air and transform it into valuable carbon products, such as graphene and nanotubes. Molten salt electrolysis used for CO_2 reduction to solid carbon has been known since the 1960s, though most of the studies have been conducted since 2010. It is known that via highly accurate process parameter controlling, e.g. temperature and current control, chosen carbon allotrope can be produced with high purity. So far

carbon nanotubes (CNTs) [1], nanofibers (CNFs) [2], nano-onions (CNOs) [3], and platelets [4] have been produced by this type of synthesis.

In this study, CO_2 was reduced to solid carbon by molten lithium carbonate salt electrolysis. The reactor used for the electrolysis was a coaxial-type unit, where a cylindrical nickel cathode was placed inside a cylindrical stainless-steel vessel. Such a coaxial-type reactor has not been used before molten salt electrochemical reduction of CO_2. With this type of configuration, current density distribution throughout the electrolyte is expected to be even, which is a benefit when considering the structural consistency of the product.

From the synthesis presented here, carbon nano-onions were obtained as a main product. Nano-onions are multi-layered fullerenes with various possible applications. This allotrope of carbon has only been known since 1990s. Product identification was carried out based on Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM) and X-Ray Diffraction (XRD) analyses. Results also showed that iron, chromium and nickel metals are released during electrolysis. Iron and chromium can only be released from the stainless-steel anode, as nickel can come from anode or cathode. Metal release from the materials can be prevented by choosing inert materials for electrodes.

Data monitoring revealed a high accuracy of temporal temperature control. On the other hand, spatial temperature variations were observed. By adding insulation or making structural changes, heat loss at the top of the reactor could be prevented, which would lead to decrease of temperature difference. Thermoneutral voltage for the process was theoretically determined to be 1.02 V. Experimental results confirmed that the thermoneutral voltage is indeed around 1 V.

By using this type of coaxial electrolyser system the main product from the synthesis was CNOs. Similar spherical structures were observed in all the experiments as a main product, and based on SEM analysis, the particle sizes seemed to be similar. Still, the system is not considered fully stable, as some differences concerning the product were seen in XRD patterns. Major differences were observed especially in the heights of nickel oxide peaks. This issue with metal release can be corrected by changing electrode materials. After the stability of the system is secured, studies can be expanded to the investigation of process conditions, such as temperature and current density to determine the effect of process conditions to the carbon allotrope produced.

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WORARUETHAI LAKANTHA
Freiberg University of Mining and Technology
Prof. Dr. JAN C. BONGAERTS
Freiberg University of Mining and Technology

LIFE CYCLE ASSESSMENT OF DRILLING AND BLASTING TECHNOLOGIES: CASE STUDY ON AN OPENCAST COAL MINE IN THAILAND

Nowadays, there are many natural disasters happening frequently around the world; therefore, the environmental problems are the serious issues needed to be concerned from people across the world. There are various organizations drawing great attention to solve these problems with the development of strategies for environmental preservation. Many tools have been applied to evaluate the environmental impacts and Life Cycle Assessment (LCA) is one of them. However, there are still the limited LCA application in mining as well as in the domestic mining industry in Thailand. According to the statement of problem, this study is specifically aimed to assess the environmental and health impacts of drilling and blasting technologies and to identify the environmental and health impacts by process stages of the technologies applied to an opencast coal mine in Thailand using the LCA method.

The scope of the study is cradle-to-grave LCA of the drilling and blasting technologies at the study site for the lifetime of the operation of the technologies with a functional unit of 51,591,350 bulk cubic meters of removed overburden calculated as 7,185,425 metric tons of coal equivalent. The inventory is obtained from both primary and secondary sources. The impact assessment is performed with Umberto LCA+ software based on ecoinvent database v3.7 using the ReCiPe method at midpoint and endpoint levels on three cultural perspectives without long-term effects.

At midpoint level, it is found that disposal/recycling is the stage with the highest impact for all three cultural perspectives through the majority of the midpoint environmental and health impact categories. The stages of raw material preparation and use of consumables come in second and third places, respectively. However, there are exceptions for the midpoint impact categories of particulate matter formation and metal depletion. For particulate matter formation, the stage of use of consumables causes the largest impact, followed by the stage of disposal/recycling in a distant place. For metal depletion, the stages of disposal/recycling and raw material preparation account for similar shares of the impact. In terms of the midpoint impact categories, the impact of climate change is getting higher when the cultural perspective is longer while it is vice versa for the midpoint impact categories of human toxicity and terrestrial ecotoxicity. The impacts of resource depletion (fossil resources, metal and water), natural land transformation, ozone depletion and particulate matter formation are the same in magnitude for all three cultural perspectives.

At endpoint level, disposal/recycling is the stage with the highest impact for all three cultural perspectives. Raw material preparation and use of consumables come in very distant second places. The endpoint area of protection “damage to human health” account for the highest total impact in all three cultural perspectives. The endpoint areas of protection “damage to resource availability” and “damage to ecosystem quality” come in second and third places, respectively. In terms of the midpoint environmental and health impact categories for all three cultural perspectives, all stages taken together have the largest impact through climate change, followed by fossil depletion and particulate matter formation. In addition, for the cultural perspective of egalitarian, all stages taken together also have the large impact through human toxicity.

In conclusion, the objectives of the study have been achieved since climate change, fossil depletion and particulate matter formation are the three dominant midpoint environmental and health impacts in all three cultural perspectives. In addition, the endpoint area of protection “damage to human health” accounts for the largest impact in all three cultural perspectives. It is also found that disposal/recycling is the stage with the highest impact for most of the midpoint environmental and health impact categories. The stages of raw material preparation and use of

consumables come in very distant second places while the remaining stages have very small impacts. According to the results, it is suggested that strategies for environmental and health protection should be properly prepared by all relevant sectors and consumption of alternative resources as well as use of green technology should be applied to reduce these impacts. For suggestions, more LCA of mining product/process is recommended in order to increase database and set a rigid framework for the application of this method in the mining sector. The goals and the scope of the study should be clearly defined in the first place and the inventory data should be mainly or firstly collected from primary sources and later filled by secondary sources to account for missing information. For further study of similar topics, a comparative analysis among alternative technologies, for example between drilling-and-blast technology and cutting technology, is suggested to determine low damage-causing alternatives. In addition, the LCA of the case study with a different functional unit is also possible.

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ELENA S. LUKYANTSEVA
St. Petersburg Mining University
VASILIY V. SERGEEV
St. Petersburg Mining University

KINETICS OF YTTRIUM EXTRACTION FROM APATITE PROCESSING SOLUTIONS IN THE PRESENCE OF IRON (3+)

Rare-earth elements (REE) are a crucial raw material for most knowledge-intensive industries due to their specific magnetic, optical, and electrical properties. In ores containing lanthanides and yttrium, REE are found in low concentrations in the presence of numerous impurity compounds. When processing such ores, complex multi-component solutions with extremely low pH values are formed. Extraction is widely used as the main method for obtaining REE from these solutions since it allows their concentration and separation [1, 2]. In Russia that ranks fourth worldwide in terms of rare-earth elements reserves [3], REEs' main source is apatite, which has been systematically introduced in the production of mineral fertilizers.

Solutions of phosphoric acid obtained after the sulfuric acid leaching of apatite contain up to 0.1% REE and were chosen as the object of research. Solvent extraction using di-2-ethylhexyl phosphoric acid (D2EHPA) as the extractant was studied as well as solid-phase extraction using Levextrel resin impregnated with D2EHPA. D2EHPA, being a cation-exchange extractant, is able to interact and form organic complexes not only with REE but also with impurity compounds of iron (3+), the content of which in the phosphoric acid solutions is several times higher than the content of REE. Thus, in addition to the kinetic aspects of REE extraction on the example of yttrium, the research considered also the kinetics of iron (3+) extraction.

To identify the limiting stage of the extraction process, the influence of the extraction conditions was studied using the logarithm of the degree of approaching equilibrium as a function of

the phase contact time at different stirring rates and temperatures. Experimental data have shown that during the solvent extraction of yttrium, the stirring rate has a greater effect on the equilibrium ratio than the temperature, which indicates that the extraction process is limited by diffusion.

According to the experimental data, the limiting stage of the iron (3+) extraction changes with increasing temperature: at a temperature of up to 300 K, the limiting stage is the chemical reaction; at a temperature of 305 K to 333 K, the extraction rate is limited by diffusion (Figure 1). For better separation of yttrium and iron, it is feasible to conduct extraction at a temperature of up to 300 K, when the limiting stages are different.

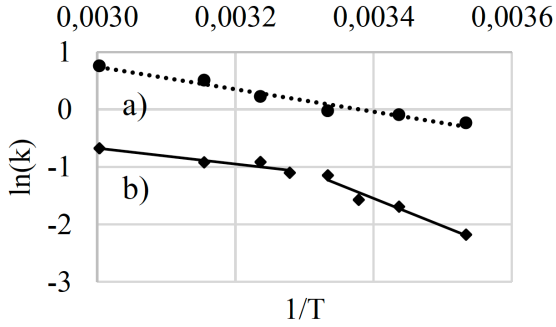

Figure 1. The dependence of ln(k) on the reciprocal temperature for a) yttrium, b) iron

The calculated activation energies of yttrium and iron (3+) solvent extraction are shown in Table 1.

Table 1 – Activation energies for solvent extraction

	Ea	Limiting stage
Yttrium extraction	16.2 ± 1.3 kJ/mol	Diffusion
Iron extraction	11.4 ± 1.2 kJ/mol (T > 305 K)	Diffusion
	40.0 ± 1.4 kJ/mol (T < 300 K)	Chemical reaction

The extraction time should not exceed two minutes since the equilibrium of yttrium extraction is achieved faster than the equilibrium of iron (3+). Such decision makes it possible to increase the separation coefficient for Y/Fe to 23.2.

It takes much longer to establish the equilibrium in the case of solid-phase extraction. To reduce the required time from 2 to 1 hour, it is necessary to increase the temperature to 330 K. The extraction rate is not significantly affected by the temperature and intensity of stirring. The experiment was carried out at the ratio of the sorbent mass and the volume of the solution of 1:10 to ensure the extraction degree of yttrium of at least 80%.

In contrast to solvent, during solid-phase extraction, it is impossible to create non-equilibrium conditions for reducing the degree of iron (3+) extraction into the sorbent. Nevertheless, it is significantly lower and does not exceed 9%, while in solvent extraction it is up to 20%, which is explained by the different configurations of the extractant in the matrix.

The calculated activation energy of solid-phase extraction, which is 18.5 ± 2.0 kJ/mol, is distinctive for gel kinetics. In other words, the process is limited by diffusion in the grain.

By and large, solid extractant has an undoubted technological advantage since it reduces the dependence of the extraction degree on both temperature factor and the stirring ratio. However, the equilibrium in the system is established within 1-2 hours.

ACKNOWLEDGMENTS

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YURI MIKHAILOV
Mendeleev University of Chemical Technology of Russia
Dr. Prof. VLADIMIR S. NIKOLAEVICH
Mendeleev University of Chemical Technology of Russia

CHEMICAL POST-TREATMENT OF NANOPOROUS GLASS TO MINIMIZE RESIDUAL BORON CONTENT

In work influence of chemical post-treatment (acid washing) of nanoporous glass received from liquidated glass in system Na20-B203-Si02, on the maintenance of boron is investigated. The method of laser-spark emission spectroscopy shows that the use of hydrochloric acid solution for glass washing allows to reduce the boron content significantly.

Nanoporous glasses (NPS) are products of chemical treatment of phase-separated alkali borosilicate glasses: under the action of inorganic acids a selective etching of chemically unstable sodium-borate phase occurs, which leads to formation of through nanochannels filled with secondary silica globules. The diameter of such channels may reach 7-10 nm, and with further treatment with alkaline solutions the diameter may increase to 100-400 nm. An important feature of NPS is the possibility of obtaining pores with a narrow size distribution [1]. Due to the presence of through open porosity and the possibility of fine tuning of pore sizes NPS are of great interest for applications in biotechnological research, chromatography, catalysis, creation of sensor devices and biomaterials [2, 3].

The need to create new luminescent and laser environments, as well as environments for laser recording, creates a new demand for NPS. Impregnation of NPS with solutions containing rare-earth or transition metals makes it possible to create nanocomposites containing a given concentration of metal ions. Subsequent consolidation of these composites at the NPS pore collapse temperature (over 1000°C) results in a transparent monolithic glass containing the required number of activator ions homogeneously distributed in the volume of the material. Laser formation of birefringent micro-objects in NPS can significantly increase the rate of data recording, opening the way for the creation of new information carriers [4, 5].

However, if the chemical etching process is incomplete, boron and sodium compounds remain in the formed nanochannels in appreciable amounts. For most classical NPS applications, the presence of these components does not play a noticeable role, but during consolidation of monolithic NPS plates, as well as during laser irradiation, boron and sodium impurities, exposed to high temperature, prevent uniform collapse of pores, formation of microobjects and lead to material deformation.

As noted above, this problem is important for monolithic transparent NPS plates with a small pore size (in the range of 5-10 nm), while the industrial production of NPS is currently carried out only for powder materials. Production of monolithic transparent NPS products was until recently carried out by Coming (USA), the products were produced under the brand name "Vycor 7930", but their production has been stopped. According to Coming company data, porous glass consisted up to 3 mol.% B203 and up to 0.4 mol.%Na20 [6]. Thus, the growing demand for monolithic products from NPS with a minimum content of impurity compounds of boron and sodium, puts a material science problem of optimization of modes of their production.

This work is devoted to determining the possibility of reducing the content of boron compounds in monolithic NPS plates in comparison with the NPS brand "Vycor 7930". NPS samples in the form of plates were obtained according to the standard technique from glass of the composition mol% 4Na20; 27B203; 69Si02 by phase separation at 530°C for 24 h and subsequent chemical etching in H2S04 solution for 12 h at constant pressure and temperature. Chemical post-treatment (washing) of samples in different solutions for 4 h was used as approaches to reduce the residual content of boron compounds in NPS. In this work for washing were used: distilled water, 1M HN03 solution, aqua regia (aqueous solution of HN03 + HC1), 1M HC1 solution.

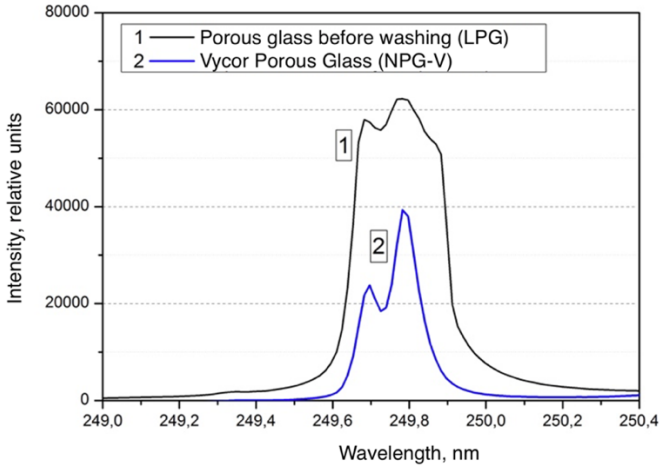

Figure 1 – Atomic emission spectra of NPS samples 1) before post-treatment, 2) Vycor 7930 (comparison sample)

The control of the elemental content of boron in this work was carried out by laser-spark emission spectroscopy using a laser analyzer of elemental composition LEA-S500 (SOL Instruments). Spectra were excited by Nd:YAG laser radiation focused on the sample surface and were recorded by a spectrograph with a built-in digital camera in the spectral range of 230-260 nm. Ten spectra were recorded for each sample, after which the results were averaged. The boron content in the samples under study was analyzed by comparing the average intensities of the atomic lines B-249.68 and B-249.77.

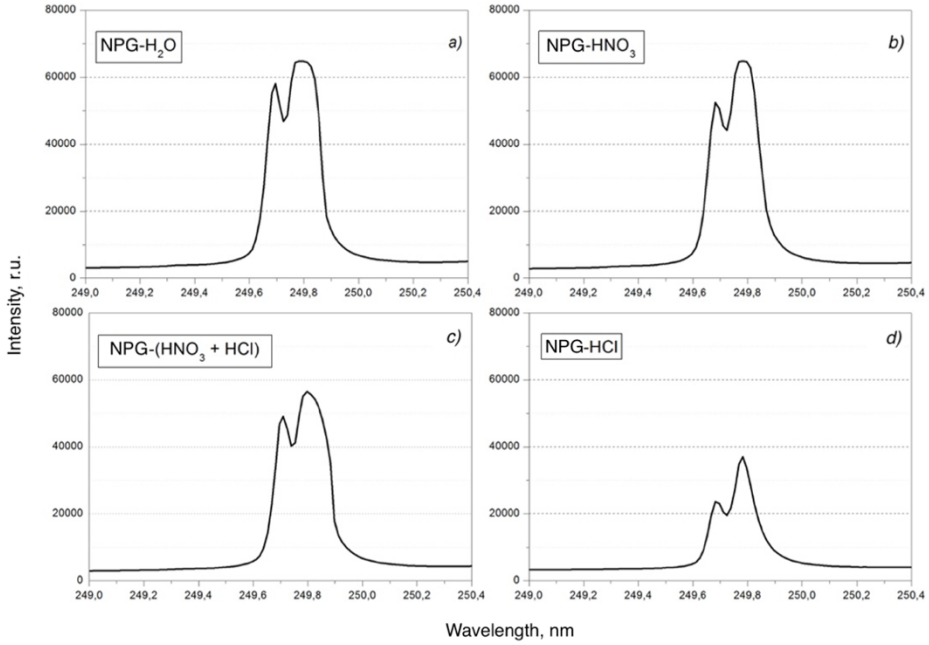

Figure 2 – Atomic emission spectra of NPS samples during post-treatment with the use of (a) H20, (b) HN03, (c) mixture (HN03+HC1), (d) HC1

Figure 1 shows the atomic-emission spectra of the NPS sample "Vycor 7930", hereinafter referred to as NPS-V, and the synthesized NPS sample without additional chemical treatment. The average intensity of boron lines for the NPS sample is more than 2 times higher than the intensity of lines of the NPS-V sample. This fact indicates that the NPS samples can contain more than 6 mol %B203 without additional washing.

At the same time, post-treatment of samples in various media leads to changes in the intensities of boron lines and, as a consequence, the content of boron compounds in glass. Fig. 2 shows the atomic-emission spectra of NPS samples after washing in water and acid solutions. The spectra show that in the series "water - nitric acid - aqua regia - hydrochloric acid" the shape of the spectrum and the intensity of analytical lines change. When washed in water and HN03, lines B-249.68 and B-249.77 become more resolved, but their average intensity decreases insignificantly.

Washing the NPS sample in aqua regia leads to a 15% decrease in the average line intensity, and washing in HC1 solution leads to a decrease in line intensity to values corresponding to the NPS-V sample. The spectral curves of these samples also become similar.

Quantitative comparison of the values of the average intensity of the atomic boron lines for the studied samples of NPS is shown in Fig. 3. It can be seen that when the NPS sample is washed in HC1 solution, the average values of intensities are slightly lower than those for the NPS-V sample. This suggests that post-treatment in HC1 solution reduces the B203 content in the NPS to values less than 3 mol %. The greater efficiency of HC1 to remove boron compounds compared to HN03 appears to be related to the lower value of the acidity constant of HC1, which characterizes it as a stronger acid.

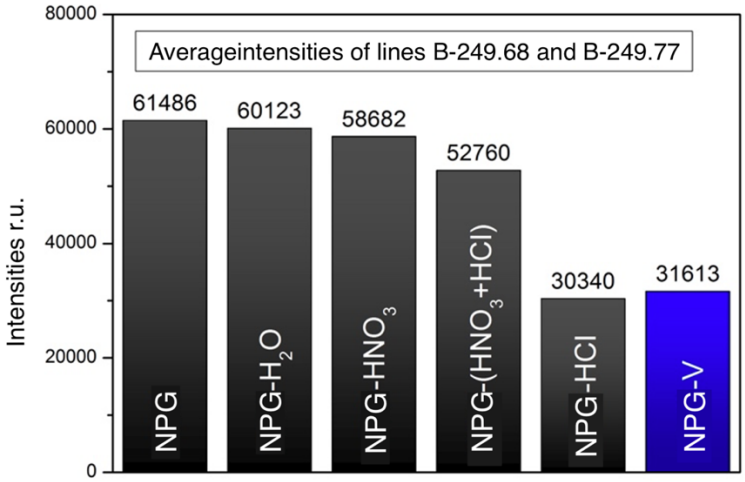

Figure 3 – Average values of the intensities of boron atomic lines for different NFS samples

Thus, the work shows that the use of 1M HC1 solution for 4 h for chemical posttreatment of NPS samples allows to reduce the content of residual boron compounds to the level corresponding to the industrial NPS samples. Further work in this area will be devoted to the optimization of chemical post-treatment of NPS both for the purpose of complete removal of boron compounds, and for the maximum reduction of the content of sodium compounds from NPS.

ACKNOWLEDGMENTS

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ALINA Y. MORKINA
Ufa State Aviation Technical University

ANALYSIS OF THE INFLUENCE OF AMBIENT GAS MOLECULES ON THE GEOMETRIC PARAMETERS OF THE STRUCTURE AND STABILITY OF BISMUTHENE USING AB INITIO MODELING

Recent activity in the study of new materials with reduced dimension has led to interest in two-dimensional mono-element structures such as monolayer phosphorus, arsenic, antimony and bismuth, known as two-dimensional pnictogens. In some cases, these materials can surpass and / or complement graphene and materials based on it. As the last group of the VA group, bismuth has generated considerable interest due to its unique electronic and mechanical properties and increased stability. However, the large surface area of bismuthene due to its corrugated 2D structure dictates the importance of its resistance to environmental molecules. Current work presents an investigation of chemical activity and fine structure features of bismuthene when interacting with a number of common environment molecules.

First-principles calculations are carried out based on density functional theory (DFT) implemented via the Vienna ab initio simulation package (VASP). All structures were subjected to full relaxation until reaching of atomic forces and total energy level smaller than 0.01 eV/Å and 10 −6 eV, respectively.

The band structure calculation of pristine bismuthene the hybrid functional (HSE06) was used to modify the band gap value, commonly underestimated for the semiconductors by the generalized gradient approximation (GGA) calculations. The model including a single molecule on the 5×5×1 bismuthene supercell sheet was used for gas molecules adsorption dynamics. In order to avoid the replicate unit cells interaction we have introduced a 20 Å vacuum space.

The adsorption energy (Ea) of a molecule on bismuthene was calculated as

$$Ea = EBi+mol – EBi − Emol, (1)$$

where EBi+mol, EBi, and Emol are the energies of the molecule-adsorbed bismuthene, the isolated bismuthene, and the molecule, respectively. First-principles calculations are carried out based on density functional theory (DFT) implemented via the Vienna ab initio simulation package (VASP). All structures were subjected to full relaxation until reaching of atomic forces and total energy level smaller than 0.01 eV/Å and 10 −6 eV, respectively.

We found that as a result of the adsorption of the NO2 molecule, the most significant redistribution of charges is observed, which is also reflected in the evolution of the bond length and angles of their misorientation. It was found that the main mechanism of electronic accommodation is deformation, the structure with the adsorption of molecules, the reversal of valence bonds, due to the lower energy consumption with stretching of the combined shells.

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DANIEL PATZKE
TU Bergakademie Freiberg
DR. RONNY SCHIMPKE
TU Bergakademie Freiberg
PROF. BERND MEYER
TU Bergakademie Freiberg

INVESTIGATIONS ON THE PYROLYSIS OF METHANE FOR CO_2-FREE HYDROGEN PRODUCTION

Natural gas is currently one of the main energy sources in the global economy. However, in order to achieve the CO_2 emission reduction targets, fossil natural gas will have to be increasingly substituted by climate-neutral gases in the medium and long term. One of the pathways favored in Germany and Europe is the use of green hydrogen produced by water electrolysis with renewable electricity. In addition to this option, natural gas itself can also be used to generate climate-neutral hydrogen, e.g., via steam reforming or pyrolysis. In order to achieve a positive effect in terms of greenhouse gas emissions, the carbon contained in methane and other natural gas components must be permanently removed from the global carbon cycle. If carbon sequestration is sought, solid carbon from methane pyrolysis is advantegeous over gaseous CO_2 from steam reforming, as the solid carbon could be easier deposited, e.g. in former opencast mines. Production of hydrogen by natural gas pyrolysis has thus gained strong interest in recent years. But while hydrogen production by steam reforming of natural gas is state of the art since many decades, especially in the chemical and petrochemical industry [1], pyrolysis of natural gas has not yet been commercialized for the hydrogen production in large scale due to a number of technical and economic challenges [2].

This study is a part of systematic investigations of the pyrolysis of natural gas at the Institute of Energy Process Enginering and Chemical Engineering, TU Bergakademie Freiberg addressing the development of a market-ready technology for the large-scale hydrogen production. In order to achieve a better understanding of factors governing the thermal decomposition of methane as main component of natural gas, experiments in a lab-scale apparatus were performed involving the structural characterization of produced carbon granules using Raman spectroscopy, scanning electron microscopy, hardness measurements and the characterization of the released gaseous and condensed products using GC and GC-MS analysis.

The thermal decomposition process was investigated at temperatures up to 1150°C using a moving-bed reactor filled with petcoke granules. Cold methane flow was fed at the bottom of the reactor. Carbon granules were moved in counterflow to the gas flowing upwards. In the hot reaction zone methane decomposes to hydrogen and carbon. The required reaction heat was supplied by means of resistance heating. It turned out that the pyrolysis reaction takes place mainly at the surface of the granules. This conclusion is supported by the observed growth of carbon granules passing through the reactor. Product gas and solid carbon leaving the reactor were cooled and submitted to qualitative and quantitative analysis.

In the experiments, the influence of the relevant process parameters, like temperature, partial pressure and residence time, on the methane conversion, the reaction selectivity (formation of gaseous by-products) as well as the morphology, mechanical properties and oxidation stability of the solid carbon product were examined. In addition, the possible catalytic influence of the petcoke support material on the thermal decomposition of methane was considered based on the comparison with experiments in an empty tubular reactor.

Obtained findings allow general conclusions to be drawn about the kinetics and mechanism of the thermal decomposition of methane and the influence of the process temperature on the mechanical and chemical properties of the solid product that are relevant for its deposition for infinite periods.

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ARSENIY S. POLYANSKIY
St. Petersburg Mining University
OLGA S. ZUBKOVA
St. Petersburg Mining University
Dr. Prof. ALEKSEY I. ALEXEEV
St. Petersburg Mining University

ADVANCEMENT IN PURIFICATION TECHNOLOGY OF CIRCULATING WATER CONTAINING SAPONITE SUSPENSION WITH ALKALINE METAL SULPHATES AND OBTAINMENT OF SECONDARY PRODUCT

Diamond mining enterprise PJSC «Severalmaz» at deposit named after M. V. Lomonosov has a major problem of accumulation of saponite fine particles in circular water which form a stable colloid system. Without proper treatment these particles create a significant threat to ecological situation in the region and also reduce efficiency of diamond mining process [1].

Commonly used coagulants and flocculants show small efficiency in saponite coagulation and often require additional conditions for reaction [2], also after use of these compounds obtained sediment is much less usable as a secondary product. Also water processed by all reactives do not satisfy ecological requirements in any case [2]. Developed by SPMI at department of chemical engineering and energy sources processing calcium-aluminosilicate reagent showed higher efficiency and prospects in obtaining sediment with required secondary product properties [3], however the deteriorating situation on the enterprise oblige to search more efficient coagulants which do less adverse effect to the environment.

Treatment of all technological waters of the mining enterprise with sulphates of alkaline metals can solve this problem. Those substances do not rise pH level. Application of alkaline metal sulphates impacts the main reason of suspension stabilization. Neutralization of DEL around saponite particles free absorbed with clay mineral water, making it up to 100% more efficient than common coagulants and forms a long-lasting sediment.

Obtained sediment forms large agglomerates, with higher density (1.1 g/sm3). Weighting materials application based on calcium silicates also allow to strongly enhance process of purification and increase output of water. Sediment obtained with potassium sulphate saturate sediment with K which makes sediment a great raw material for fertilizer production.

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FLORIAN SCHRENK
Technische Universität Wien
LORENZ LINDENTHAL
Technische Universität Wien
HEDDA DREXLER
Technische Universität Wien
AFFAEL RAMESHAN
Technische Universität Wien
Prof. CHRISTOPH RAMESHAN
Technische Universität Wien

LESS COKING AND HIGHER ACTIVITY: *IN-SITU* STUDIES OF DOPED PEROVSKITES DURING METHANE DRY REFORMING

Methane Dry Reforming (MDR) is a reaction with great potential to combat climate change and the rising concentrations of greenhouse gases in the atmosphere, as it is converting two major greenhouse gases into useful synthesis gas. Concretely, methane and carbon dioxide are converted into a mixture of hydrogen and carbon monoxide, which can then be further used in reactions such as Fischer Tropsch or methanol production [1]. However, despite yielding a favourable CO rich synthesis gas, MDR is still not a mature industrial process, such as steam reforming of methane, using water, or partial autothermal oxidation. The biggest hindrances being the need for high temperatures leading to deactivation by sintering as well as coke formation on the surface. Especially Ni based catalysts, that are promising due to their high catalytic activity, suffer from severe carbon deposition and carbon nanotube formation [2]. A material class that can produce nanoparticles resistant to sintering and coking are perovskite oxides [3]. Perovskite-type oxides have the general formula ABO_3, with the two involved cationic places, A and B, being able to consist of more than one element each. These doping strategies lead to a vastly diverse material class that can be tuned very specifically. Under reducing conditions these perovskite catalysts can exsolve nanoparticles on their surface. In this process elements from the perovskite bulk are migrating to the surface and are reduced there, forming nanoparticles. These nanoparticles are socketed in the surface leading to an increased sintering and coking resistance [4]. This opens up new possibilities for the design of coking resistant catalysts for methane dry reforming.

After a screening of several perovskite-type oxide materials with the general formula $La_xCa_{1-x}FeO_3$ and $Nd_xCa_{1-x}FeO_3$, as well as versions doped with Co and Ni on the B-site, with catalytic tests, the most promising catalysts were investigated in more detail. Therefore, the three catalysts $Nd_{0.6}Ca_{0.4}FeO_3$, $Nd_{0.6}Ca_{0.4}Fe_{0.9}Co_{0.1}O_3$ and $Nd_{0.6}Ca_{0.4}Fe_{0.97}Ni_{0.03}O_3$ were investigated with operando X-ray diffraction (XRD) and in-situ near ambient pressure X-ray photoelectron spectroscopy (NAP XPS) during the reaction in MDR atmosphere. Additionally, the catalysts were characterized with scanning electron microscopy (SEM) after the reaction to get insight into the shape and size of the formed nanoparticles.

To exsolve the catalytically active nanoparticles two techniques were employed. On one hand, the catalysts were pre-treated in H_2/H_2O atmosphere before the reaction guaranteeing the exsolution of the particles but adding an extra step. On the other hand, the possibility of in-situ exsolution in MDR atmosphere was investigated. Therefore, only an oxidative pretreatment was performed before the reaction. To investigate the effect of the nanoparticles exsolved in this way, two consecutive catalytic assessments with the same catalyst were performed.

It was found that the exsolution of the catalytical active B-site dopant was indeed possible with both ways as the NAP-XPS as well as the XRD experiments showed. This exsolution is increasing the catalytic activity of the perovskites significantly. However, there was a difference found in the effect of the reduction methods employed. The reduction in wet hydrogen led to a more active catalyst and to the formation of bigger nanoparticles as seen in the SEM images. For

the B-site undoped version of the catalysts no visible exsolution could be found but the catalytic activity is still increasing with prereduction. As for the formation of carbon deposition, nearly no carbon was observed in the XPS spectra and the catalytic stability tests showed only a slight deactivation over time. However, the XRD diffractograms showed a slight formation of graphite which may be due to the higher reaction rates on the surface in comparison to the XPS measurements.

To summarize, it could be proven that the B-site doped catalysts can exsolve catalytically highly active nanoparticles during the methane dry reforming. These particles exhibit sintering resistance, and no carbon nanotube formation could be observed. This shows the general applicability of doped perovskite-type oxides for methane dry reforming, even though further tuning is still necessary to achieve outstanding catalytic activity.

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FANNIE N. SHAPAKA
Rossing Uranium Limited Mine
MELVIN M. MASHINGAIDZE
University of Namibia
G. DOMBO
University of Namibia

DESIGN OF A DENSE MEDIUM SEPARATION CYCLONE FOR RECOVERY OF ION EXCHANGE RESIN BEADS ENTRAINED IN PROCESS SLIMES

The cyclone was designed for a process plant at a Namibian mine producing about 4.1% of the world's uranium from a low grade uranium deposit [1]. This uranium is hosted in Alaskite and consists of 55% uraninite, 40% uranophane, and 5% betafite which is refractory or unextractable by leaching. Ore mining is accomplished by blasting, followed by loading onto 180 ton haul trucks to primary crushers, which reduce rock size to 160 mm. Further size reduction to 850µm occurs through secondary, tertiary and quaternary crushers, and grinding. Through atmospheric pressure sulphuric acid leaching, 89% leaching efficiency is achieved, followed by solid/liquid separation of the pulp using rotoscoops and hydrocyclones, with the coarser particles pumped to tailings while slimes solids, are further clarified at the counter current decantation (CCD) plant. This produces clarified pregnant leach solution liquor with about 100 ppm total suspended solids [2,3]. The uranium pregnant leach solution (PLS) is purified via two enrichment stages; continuous ion exchange (CIX) and solvent extraction (SX) in that order. Four pumps discharge the PLS into four parallel trains of CIX contactors, with six contactors/train, for a total of 24 contactors. During CIX, NCP Duolite A101-Du ion exchange resin in six Porter contactors, upgrades uranium concentration in the PLS from ~140ppm to 3-5 g/l, by counter-current flow PLS, and resin airlifting. The loaded resin is transferred to elution columns, where the uranium is eluted

from resins by a 100gpl (10%) sulphuric acid aqueous solution, and extracted as concentrated eluate, which is fed to SX [2]. There are three elution columns per train, adding up to a total of 12 rubber lined, mild steel pressure vessels [3].

The clarified PLS solution from the CCD plant contains ~100 ppm total suspended solids (TSS) resulting in the accumulation of slimes in the ion exchange contactors and the barren storage tank. In the contactors, NCP Duolite A101-Du ion exchange resin beads are trapped by the slimes reducing the CIX uranium extraction efficiency, as resin transfers between contactors get reduced. Cleaning of the contactors to remove accumulated slimes results in approximately 30m^3 of NCP Duolite A101-Du ion exchange resin loss annually. Although ion exchange resin loss prevention systems such as scavenging contactor six and Derrick screens are installed; NCP Duolite A101-Du ion exchange resin losses to the barren storage tank amount to more than 100m^3/year, and these resin beads are also found entrained in slimes [2]. Thus, this study aimed at designing a hydrocyclone for separation of NCP Duolite A101-Du ion exchange resin beads from slimes for resin re-introduction into the CIX circuit to offset replacement costs and increase overall uranium adsorption efficiency.

The most important parameter in dense medium separation (DMS) cyclone design is the nature or characteristics of the feed slurry. This includes the feed flow rate, slurry specific gravity as well as medium particle size. The slurry solids weight percent was found to be 45 wt.%, with three solids, namely: resins, ore solids, and magnetite medium, of specific gravities 1.12, 2.65, and 5.17 respectively and considered against an average feed of 60% resins and 40% solids yielded a separation density or SG50 of 1.73. DMS cyclone diameter was found to be 30 cm with a 40 m^3/h capacity and for 32m^3/h slurry flow rate, one DMS cyclone is required (Figure 1). Considering the size of the IX resins and solids, the medium particle size has to be fine enough to behave like a fluid, thus magnetite losses of 1.0 kg/ton were selected. Hence total magnetite needed accounting for dense medium loss is 13498.5 tph.

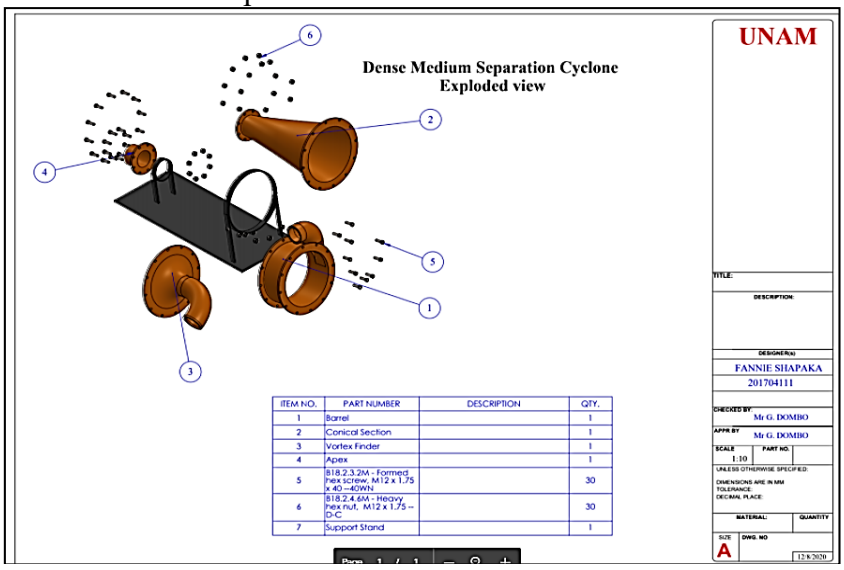

Figure 2 – Exploded view of DMS cyclone CAD drawing

The cyclone housing will be made of 1 cm thick mild steel, with rubber inner lining while a 110.65 mm diameter steel pipe and a Warman 6/4 D-AH heavy line duty pump powered by a 10 kW, 850 rpm motor will feed the cyclone. Computer simulation of this DMS cyclone design is needed to determine the separation efficiency and optimization opportunities. Installation and commissioning of this DMS cyclone will reduce NCP Duolite A101-Du ion exchange resin replacement costs and mean less disposal of resin to the environment via the tailings dam. This will also reduce uranium release to the environment as the entrained IX resin beads contain adsorbed uranium.

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FANNIE N. SHAPAKA
Rossing Uranium Limited Mine
MELVIN M. MASHINGAIDZE
University of Namibia
JASON NGHITOTOVALI
Rossing Uranium Limited Mine
G. DOMBO
University of Namibia

PROCESS VARIABLES AFFECTING ALAMINE 336 DEGRADATION IN A URANIUM SOLVENT EXTRACTION CIRCUIT

Introduction. When leaching uranium, ferric ions (Fe^{3+}) are deliberately added to the system to enhance the leaching reaction by acting as oxidizing agents. However, this intervention creates problems when the pregnant leach solution (PLS) gets to the solvent extraction (SX) circuit for purification. Fe^{3+} ions are detrimental to the organic solvent Alamine 336, which is used as an extractant in the SX circuit which is the second stage PLS purification process after ion exchange (IX) [1].

According to Munyungano [2], an Fe^{3+}/Fe^{2+} ions ratio of 4:1 increases redox potential to above 550mV, which catalyzes the oxidative breakdown of tertiary amines (R_3NH) in the Alamine 336 organic solvent, to secondary amines (R_2NH) (equation 1). At high acid concentration, nitrates in concentrated eluate are converted to the nitronium ion which then reacts with the amine producing an imine which is hydrolyzed to aldehydes and secondary amines.

$$(R_3\ NH)_2SO_4 + NO_3^- \Leftrightarrow ((R_3\ NH)_2NO_2)^+ + SO_4^{2-} \quad (1)$$

The secondary amines also react with nitrous acid-producing nitrosamines

$$R_2NH + HNO_2 \Leftrightarrow R_2N.NO + H_2\ O \quad (2)$$

Secondary amines are not selective in the uranium exchange reactions, and therefore they reduce the extraction efficiency of uranium species [3]. The aimed at establishing the actual relationship between loading efficiency of nitrates and uranium onto Alamine 336, at varying pH/acidity and organic/aqueous phase ratio, at redox potentials of 450 to 750mV.

Methods. The organic solvent consisting of 7% (v/v) Alamine 336 and 3.5% (v/v) isodecanol in a fluid diluent was synthesized in the laboratory. The Alamine 336 initially contained 6.73 % tertiary amines. Materials obtained from continuous process streams included ammonium sulphate and the concentrated eluate from the IX circuit containing 4.54 g/L U_3O_8. After solvent extraction, the raffinate was analysed for nitrates, uranium, and ferric and ferrous ions, while the organic solution was analysed for uranium.

Results. Nitrates loading onto solvent was directly proportional to redox potential, see table 1. The lowest level of nitrates loading onto the solvent was observed at pH 0.1 and O/A of 0.8, while the highest came at pH 0.7 and O/A 1.2. The highest uranium and nitrates loading was achieved at redox potential of 650 mV, pH 0.7, and O/A of 1.2 at 98%, and 89% extraction efficiency, respectively. Lowest uranium and nitrates loading was obtained at a redox potential of 450mV, pH 0.1, and O/A of 0.8 at 58% and 76% extraction efficiency, respectively.

Table 1 – Summary of multivariable regression equations.

Process variables	Regression model	P-values
E_h, pH	$Nitrates\ (\%) = 70.44 + 00236(E_h) - 1.4792(pH)$	0.0271
E_h, O/A	$Nitrates\ (\%) = 54.58 + 0.024(E_h) + 15.27(O/A)$	0.0003
E_h, pH	$Uranium\ (\%) = 36.60 + 0.028(E_h) + 24.58(pH)$	0.0059
pH, O/A	$Nitrates\ (\%) = 69.34 - 1.48(pH) + 15.27(O/A)$	0.0422
pH, O/A	$Uranium\ (\%) = 49.57 + 9.10(pH) + 24.58(O/A)$	0.01

Conclusions. Alamine 336 degradation (measured in by nitrates extraction onto solvent) and uranium loading increase with redox potential until 650 mV. Increasing the O/A ratio also increases uranium extraction efficiency and solvent degradation. Optimum solvent loading conditions were achieved at a high O/A ratio of 1.2 and low redox potential of 450mV, yielding 77% uranium extraction efficiency and 87% nitrates extraction efficiency; and at a low O/A ratio of 0.8 and high redox potential of 650mV, yielding 76 % uranium extraction efficiency and 89% nitrates extraction efficiency. Redox potential from leaching must be controlled to increase uranium recovery and preserve solvent health, thus saving on production cost. Thus the current addition of ferrous wire, to maintain redox potential at 450 mV should be maintained.

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MATEUSZ SKALNY
AGH University of Science and Technology
Dr. Prof. TOMASZ BAJDA
AGH University of Science and Technology

AG MODIFIED FLY ASH DERIVED CARBON-P1-ZEOLITE COMPOSITE AS MATERIAL FOR LIQUID FUEL ADSORPTIVE DESULFURIZATION

Availability to energy resources is a key to technological and social development of mankind. One of the most crucial energy sources are fossil fuels like coal, petroleum and natural gas. Even in 2021 year, when renewable sources of energy are taking over the market, hydrocarbons and coal play significant role in energy mix. One of the undesirable consequences of fossil fuels combustion is SOx emission. Sulfur oxides may cause significant harm not only to human health, but also to the environment. For example, release of considerable amounts of SOx into an atmosphere was a reason, why acid rains appeared and devastated forests in many parts of the globe [1]. Sulfur compounds are also known for its corrosive behavior in relations to engines, steel parts of refining installations and they act as poison to catalysts beds [2]. That is why many countries have undertaken actions to reduce sulfur content in the fuels.

Ordinary way of liquid fuel desulfurization is process called hydro-desulfurization (HDS). HDS is based on catalytic treatment of fuel by hydrogen under 20-100 atm and ~300oC. Due to high pressure, high temperature and usage of costly hydrogen, this way of desulfurization is very expensive. Moreover, HDS is having difficulties with removing refractory sulfur compounds, like benzothiophene (BT), dibenzothiophene (DBT) and their methyl derivatives. An alternative way of desulfurization of liquid fuels is adsorptive desulfurization. Wide variety of materials can be applied as sorbents, which capture sulfur compounds and purify the fuel. The examples of efficient

sorbents for refractory sulfur compounds and general desulfurization are zeolites, active carbons, metal-organic frameworks, mesoporous silica and metal oxides [3]. Due to high surface area, porosity and presence of active sides, an industrial application of these materials may be technologically and economically justified solution.

This study presents an application of fly ash derived carbon-zeolite composites with gismondite structure (NaP1-C) as adsorbent for BT and DBT from model liquid fuel. NaP1-C sorbent was synthesized by hydrothermal method from High Carbon Fly-ash derived from the combustion of coal. Subsequently material was modified with silver nanoparticles (SNP) and silver ions (SI). To obtain SNP sodium tricitrate solution was added dropwise to a AgNO3 solution and mixed for 30 min in 85-95oC. For formation of nanoparticles on surface of composite material, a defined amount of NaP1-C was added to mixture and stirred for 1 h, then material was dried in 105oC for 1 h. SI were deposited on the surface of composite material by ion exchange method. 1 g of material was mixed witch adequate volume of AgNO3 solution for 3 h, dried 105oC for 1 h and calcinated in 350 oC for 3 h. Carbon-zeolite composite modified witch SNP will be noted as NaP1-C-AgN, and ion exchanged carbon-zeolite composite will be noted as NaP1-C-Ag+.

Sorption capacity of NaP1-C, NaP1-C-AgN, NaP1-C-Ag+ was tested by static experiment, where 50 mg of sorbent was mixed with 5 ml of BT and DBT solution at concentration 240 mg/l and 250 mg/l respectively for 4 hours. Isooctane was used as solvent for sorbates to simulate fuel matrix. After experiment test tubes with suspension were centrifuged and 1 ml of solution was taken to vial and introduced into gas chromatography mass spectrometry (GC-MS) apparatus to measure concentration of BT and DBT.

The adsorption experiments allowed to define sorption efficiency of NaP1-C, NaP1-C-AgN, NaP1-C-Ag+ in relation to thiophene compounds. As it is show at figure 1, unmodified NaP1-C has similar removal efficiency for both BT and DBT which reaches level of 10-11%. After modification with silver nanoparticles sorption efficiency increases significantly up to 34% for DBT, but for BT increases only to 16%. Whereas ion exchanged material indicates the best sorption capacity for both BT and DBT, respectively 36% and

27%. Great improvement in removal efficiency of thiophene compounds by Ag modified materials is an outcome of silver ions and nanoparticles ability to complex lone pairs of electrons of sulfur atoms and π electrons of aromatics rings [3]. DBT occurs to be more likely adsorbed on the surface of modified materials, especially in case of SNP modified material. That could indicate that SNP form stronger bonds with π electrons of two aromatics rings of DBT, than with π electrons of one aromatics ring in BT molecule. Ag+ ions also adsorbs DBT better than BT, but the difference is smaller than in SNP modified material. To examine sorption mechanism fully, Fourier transformation infrared spectroscopy (FTIR) or electron spectroscopy (XPS) studies may be carried out. FTIR may provide information about types of bonds formed between thiophenes and Ag nanoparticles or ions, and XPS method may help recognize oxidation state and surroundings of Ag.

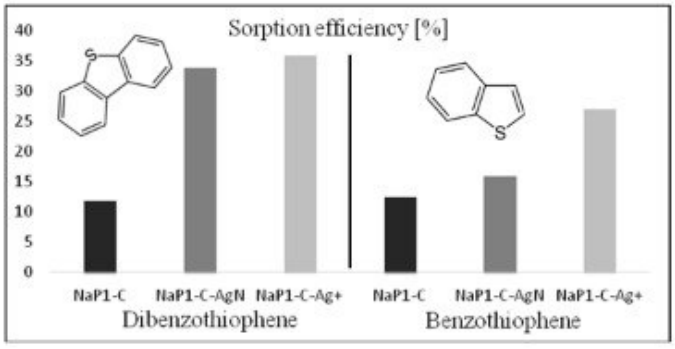

Figure 1 – Sorption efficiency of unmodified and modified with SNP or SI zeolite carbon composite.

The carbon-zeolite composite NaP1-C is characterized by medium sorption abilities towards benzothiophene and dibenzothiophene, but it's silver nano particles and silver ions derivatives show almost three times higher efficiency. Moreover, sorption ability depends on the

type of modification, the ion exchange by Ag^+ turned out to form more efficient sorbent material than reduced silver nanoparticles. Sorption capacity highly depends also on structure of sorbate molecule, DBT is more likely adsorbed in every case. Modification by SNP and SI makes NaP1-C material competitive in relation to other novel sorbents in liquid fuel desulfurization field.

ACKNOWLEDGMENTS

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DZMITRY V. STALMAKH
Polotsk State University
YULIYA A. BULAUKA
Polotsk State University

THE WAY OF NEUTRALIZATION OF OIL CHEMISTRY AND THERMAL POWER WASTE BY UTILIZATION THEM IN PRODUCTION OF BITUMINOUS MATERIALS

Introduction. There are a lot of technological processes in oil chemistry, which give hard-recycling sulfuric waste products. These waste products are heterogeneous systems. One of the most common sulfuric waste products is acid tar, which are form in the processes of sulfonation of oil distillates (production of sulfonate additives), sulfonation of individual hydrocarbons and petroleum fractions in production of detergens, alkylation (when sulfuric acid is used as catalyst) [1]. Despite the reduction of using sulfuric acid for cleaning oils and paraffins, the amount of sulfuric acid waste in the dumps is very significant. Acid tar, being a waste of the second hazard class, is a serious environmental problem. Acid tar accumulates in dumps, where over time the acid is washing out by the rainfall and sulfur oxides are release, which is results water and air pollution.

During preliminary water purification at the CHP huge amount of waste accumulates. This waste consists mainly of calcium and magnesium carbonates, doesn't contain highly toxic substances [2]. However, with their long storage in dumps, there is a threat of increase the mineralization of groundwater in near area and deterioration of the hydrochemical environment of waters. Moreover, large areas of agricultural land are alienated for the creation of landfills [3, 4].

At the same time, both acid tar and waste from chemical water treatment of thermal power plants are a valuable secondary material resource for producing marketable products. The constant need for such petroleum products as bituminous materials with a relatively high cost makes it necessary to search for new ways of obtaining them, including using production waste, which will significantly reduce the cost of the final product while maintaining its quality characteristics at the level of modern analogues, which determines the relevance research in this direction.

Materials and methods. Treatment of acid tar was made as follows: acid tar was heated to temperatures 80, 90, 100, 110 °C and mixed with a neutralizing agent – water treatment waste

of CHP. The neutralizing agent was added at concentrations of 10, 15 and 20 % mass. for acid tar. After keeping the samples for 24 hours, the acid number, total acidity and softening temperature were determined. At the second stage of the research, the task was to get roofing bitumen mastics based on the products of neutralization of acid star with waste of chemical water treatment from a CHP. For the obtained bituminous mastics with 15% mass. product of neutralization according to GOST 2889 are determined: heat resistance for 5 hours; softening temperature according to the "Ring and ball" method; flexibility on the rod at a temperature of (18±2) °C; water content and fragility temperature.

Results. In the course of the research, the following was established: the optimum temperature for the process of neutralizing acid tar from the production of sulfonate additives with waste is 110 °C; chemical water treatment waste is an effective neutralizing agent; at concentrations of the neutralizing agent more than 15% of the mass. the heat resistance of the neutralization product increases by 10 ... 15 °C. It has been experimentally confirmed that an expedient direction for the neutralization and recycling of acid tar and waste of chemical water treatment from a CHP is to obtain hot bituminous roofing mastics on the basis of neutralization products, the quality indicators of bituminous materials are not inferior in terms of operational properties to industrial analogs.

Conclusion. The proposed method for utilization of oil chemistry and thermal power waste will reduce adverse impact on the environment, expand the base of raw materials for the production of bituminous materials through the use of production waste and reduce the cost of the process of obtaining marketable products.

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TROSHINA O. S.
Samara State Technical University

MODIFICATION OF THE STRUCTURE OF SAND AND CEMENT MORTARS BY THE ENERGY OF ELECTROMAGNETIC RADIATION OF THE MICROWAVE RANGE TO IMPROVE THE RELIABILITY OF OPERATION OF OIL AND GAS INDUSTRY FACILITIES

The durability of the cement-based construction materials used can be increased by modifying them with electromagnetic radiation. In particular, the modification of the structure of aqueous solutions and building mixtures used at various facilities in the oil and gas industry, in particular, for cementing wells, can be performed by exposure to magnetic and microwave electromagnetic radiation (UHF EMP). At the same time, an improvement in their physical and mechanical properties is noted.

Thus, an increase in the number of crystallization centers is noted during the structure formation of compositions in industrial water (as well as in a mixed solution mixture), which has

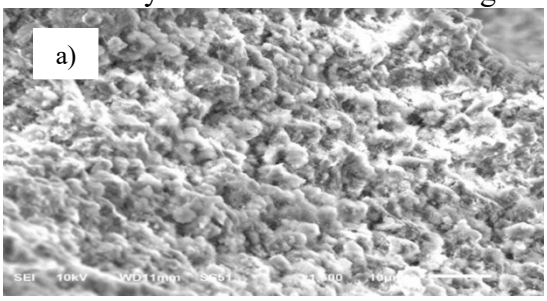
passed through the action of a directed magnetic field. The processes of dissolution and hydration of cement at an earlier time are intensified by magnetic action, which leads to the formation of fine-crystalline structures, and, consequently, to a decrease in porosity, an increase in density, strength, frost resistance and durability in general. However, during the modification process, it is necessary to observe safe irradiation regimes for concrete and cement-sand mortars, because powerful microwave pulses are capable of destroying the structure of the cement matrix.

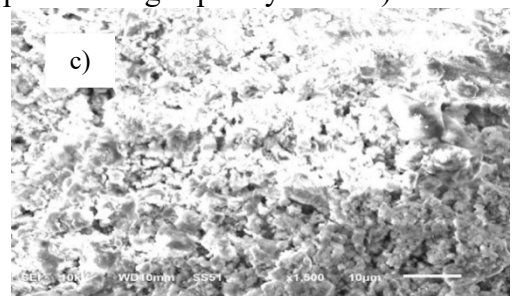
In order to trace changes in the properties of cement-sand mortars (CPR) after exposure to microwave EMR, their physical and mechanical tests were carried out and the results were analyzed in comparison with non-irradiated ones. At the same time, the studies were carried out on two samples of low-grade CPR from dry mixtures (grade for strength at the age of 28 days no more than M150) and two samples of CPR used for repairing concrete and reinforced concrete structures (grade for strength at the age of 28 days more than M300 ... M400) - for clarity of the results. The compositions of four domestic manufacturers were randomly selected, the characteristics obtained were also compared with the indicators regulated by manufacturers at the age of 28 days[1].

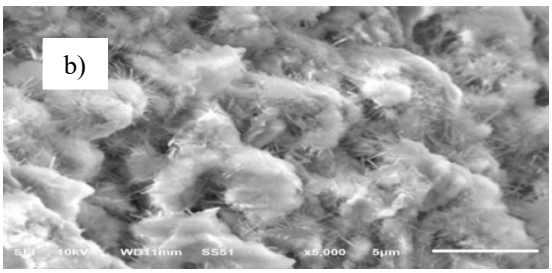
An experimental setup for studying the interaction of cement-sand mortars with microwave EMP consisted of a microwave generator with a variable output power of up to 1 kW with a radiation frequency of 2.45 GHz, an emitting system, a working chamber, a matching load, and equipment for measuring the humidity and temperature of the samples. ... By changing the mass of the sample, the exposure time and the radiation power, it was possible to change the specific dose of absorbed radiation. The irradiation time varied on different samples from 30 seconds to 2 minutes. For these conditions, the optimal mode was chosen with an exposure duration of 1 minute, with a minimum power of 60 W. The samples were irradiated at the age of 0 (immediately after mixing), 1, 2, 3, and 4 days after mixing the dry mixture with water. The determination of individual characteristic physical and mechanical indicators was carried out according to: the compressive strength and tensile strength in bending, as well as water absorption during capillary suction were determined. Investigations of the structure of 7 days old samples were carried out on a JSM 6610 LV scanning electron microscope with an Oxford Inca Energy energy dispersive spectrometer.

For ease of perception, the dash-dotted line on the graphs marks the boundaries of the indices of non-irradiated compositions at the age of 28 days. In addition, not all the characteristics obtained correspond to the indicators regulated by the manufacturers at the age of 28 days. Electron microscopic images of the structure of CPR samples without and after exposure to microwave EMR are shown in Fig. 1, 2 and, in general, confirm the results of physical and mechanical tests.

So, at the age of 7 days (after 4 days from the moment of irradiation), there are obvious differences in the structure of the samples (more dense and regular packing of the crystal structure - in the sample after exposure to microwave EMR). In addition, when studying the structure at fractures of samples in several sections, a decrease in porosity is visually observed (which is confirmed by the results of determining water absorption during capillary suction).







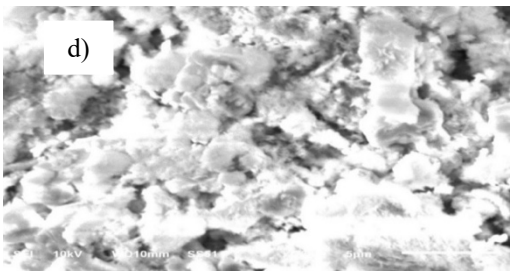


Figure 1 – Electron microscopic images of the structure of CPR samples without exposure:
a) magnification × 5000, segment scale 5 μm,
b) magnification × 1500, segment scale 10 μm

Figure 2 – Electron microscopic images of the structure of the CPR images after exposure to microwave EMR for 2 minutes:
c) magnification × 5000, segment scale 5 μm,
d) × 1500 magnification, segment scale 10 μm

Based on the results of physical and mechanical tests of irradiated samples and comparison of data with non-irradiated microwave EMP samples of CPR, it can be concluded that the most effective irradiation time is, in general, 2 days after mixing both low- and high-quality compositions. At the same time, an increase in the main physical and mechanical indicators was noted in comparison with non-irradiated samples:

- compressive strength - up to 32 ... 35% (for low-quality compositions) and up to 12 ... 14% (for high-quality ones);
- tensile strength in bending - up to 22 ... 25% (for low-quality compositions) and up to 11 ... 20% (for high-quality);
- and also a decrease in water absorption during capillary suction - up to 4 ... 15% (for low-quality compositions) and up to 4 ... 7% (for high-quality ones).

Consequently, in the irradiated compositions, the hydration process proceeds more intensively, which leads to an accelerated gain in strength in the early stages, as well as an increase in strength and density at the age of 28 days in comparison with the control samples, which is also confirmed by the work.

Scientific advisor: Doctor of technical sciences, Professor E.M. Abutalipova

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Dr. Prof. ASTRA M. MAKASHEVA
Karaganda Technical University
Dr. Prof. SERGEI V. MAMYACHENKOV
UrFU named after the First President of Russia B. N. Yeltsin
LAZZAT A. BEKBAYEVA
Karaganda Technical University

CLUSTER-ASSOCIATED MODEL OF THE VISCOSITY OF THE LEAD-TIN ALLOY

The authors of the monograph [1] developed a model for identifying the regularity of viscosity by temperature based on the concept of chaotic particles, which does not contradict the classical theory of viscosity, on the contrary, is its complement. The authors of this concept assume the virtual presence of liquid and gaseous phases in the solid state of the substance.

The cluster-associate model of fluid viscosity allows estimating the degree of cluster association or the number of clusters based on the temperature dependence of the viscosity. The mathematical model of viscosity, the above-mentioned concept, has the form:

$$\eta = \eta_1 (T_1/T)^{a_2 (T_2/T)^b}, \quad (1)$$

where η_1 – is the reference experimental (reference) point of dynamic viscosity at temperature T_1 (K); a – is the degree of cluster association; b – is the degree of aggregation of cluster associations.

We will check the adequacy of the cluster-associated viscosity model on the example of the lead-tin alloy.

A summary of the data on the dynamic viscosity of the lead-tin alloy is given in the reference book [2], from which the reference points are selected: T_m = 456 K [4], T_1 = 510 K, η_1 = 2 mPa·s, T_2 = 600 K, η_2 = 1,6 mPa·s,, T_3 = 660 K, η_3 = 1,5 mPa·s (for Pb with a molar fraction of 0); T_1 = 480 K, η_1 = 3 mPa·s, T_2 = 575 K, η_2 = 2,1 mPa·s, T_3 = 725 K, η_3 = 1,8 mPa·s (for Pb – 0.3); T_1 = 612.5 K, η_1 = 2,8 mPa·s, T_2 = 675 K, η_2 = 2,2 mPa·s, T_3 = 775 K, η_3 = 1,9 mPa·s (for Pb – 1). Substituting the values in the formula (1), the calculated dependencies will take the following form:

$$\eta = 2(510/T)^{1,3730\,(600/T)^{2,1767}}, \text{ mPa·s.} \quad (2)$$

$$\eta = 3(480/T)^{1,975\,(575/T)^{2,0128}}, \text{ mPa·s.} \quad (3)$$

$$\eta = 2,8(612,5/T)^{2,4820\,(675/T)^{2,9648}}, \text{ mPa·s.} \quad (4)$$

A comparison of all the data is shown in Table 1.

Nonlinear multiple correlation coefficient: R = 0.979734 and t_R = 59.814 >> 2 according to reference data [2] and equation (2), R = 0.758241 and t_R = 5.641 >> 2 according to reference data [2] and equation (3), R = 0.992189 and t_R = 180.339 >> 2 according to reference data [2] and equation (4), which indicates the accuracy and functionality of the new viscosity models.

Thus, a viscosity model for the lead-tin alloy is constructed on the basis of the cluster-associated model of viscous fluid flow. The high adequacy of the proposed cluster-associated model of the dynamic viscosity of the lead-tin alloy is established according to the available reference data.

Table 1 – Dynamic viscosity of lead-tin alloys by [2] and by dependencies (2), (3), (4)

T, K	Molar fraction of Pb

	0			0,3			1		
	η [2], mPa·s	η (2), mPa·s	a	η [2], mPa·s	η (3), mPa·s	a	η [2], mPa·s	η (4), mPa·s	a
T_m = 456	–	2,644	2,495	–	3,526	3,150	–	29,149	7,940
460	–	2,575	2,448	–	3,422	3,095	–	25,661	7,737
470	–	2,420	2,336	5	3,193	2,964	–	19,144	7,259
475	–	2,352	2,283	–	3,093	2,901	–	16,746	7,035
480	–	2,290	2,232	3	3,000	2,841	–	14,762	6,820
500	–	2,083	2,042	2,5	2,696	2,617	–	9,544	6,043
505	2,6	2,040	1,998	–	2,634	2,565	–	8,687	5,867
510	2	2,000	1,956	–	2,576	2,515	–	7,950	5,698
520	–	1,928	1,875	–	2,472	2,418	–	6,755	5,379
525	–	1,896	1,836	2,2	2,426	2,372	–	6,269	5,229
540	1,8	1,812	1,727	–	2,304	2,241	–	5,132	4,810
550	–	1,764	1,659	2,2	2,236	2,160	–	4,572	4,555
560	1,7	1,723	1,596	–	2,176	2,083	–	4,123	4,318
575	–	1,669	1,506	2,1	2,100	1,975	–	3,603	3,993
580	1,6	1,654	1,478	–	2,078	1,941	–	3,462	3,891
600	1,6	1,600	1,373	2	2,002	1,813	3	3,011	3,519
612,5	–	1,573	1,313	–	1,963	1,739	2,8	2,800	3,311
620	1,5	1,558	1,278	–	1,943	1,697	–	2,693	3,193
625	–	1,549	1,256	2	1,931	1,670	2,6	2,629	3,118
637,5	–	1,529	1,203	–	1,903	1,605	2,5	2,489	2,940
640	1,5	1,525	1,193	–	1,898	1,592	–	2,464	2,906
650	–	1,512	1,153	2	1,879	1,543	2,4	2,374	2,776
660	1,5	1,500	1,116	–	1,863	1,497	–	2,297	2,653
675	–	1,485	1,063	1,9	1,842	1,430	2,2	2,200	2,482
700	–	1,466	0,982	1,8	1,817	1,329	2,2	2,079	2,228
725	–	1,452	0,909	1,8	1,800	1,239	2	1,996	2,008
750	–	1,444	0,845	–	1,790	1,157	1,9	1,938	1,816
775	–	1,439	0,787	–	1,786	1,083	1,9	1,900	1,648

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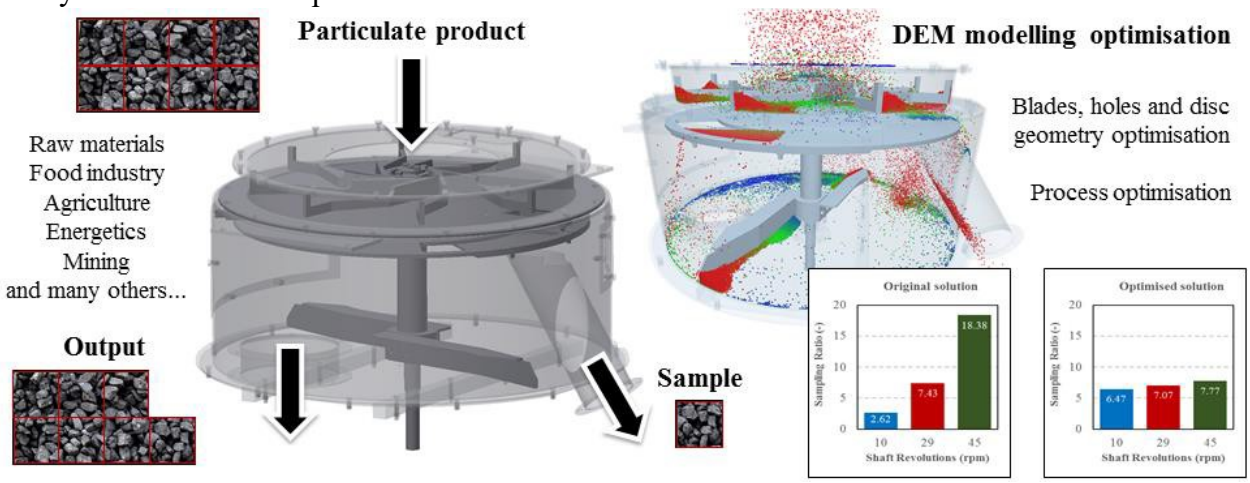
JAN DIVIŠ
VSB – Technical University of Ostrava
Prof. JIŘÍ ZEGZULKA
VSB – Technical University of Ostrava

INNOVATIVE DEVELOPMENT OF BULK SOLIDS ROTARY SAMPLER

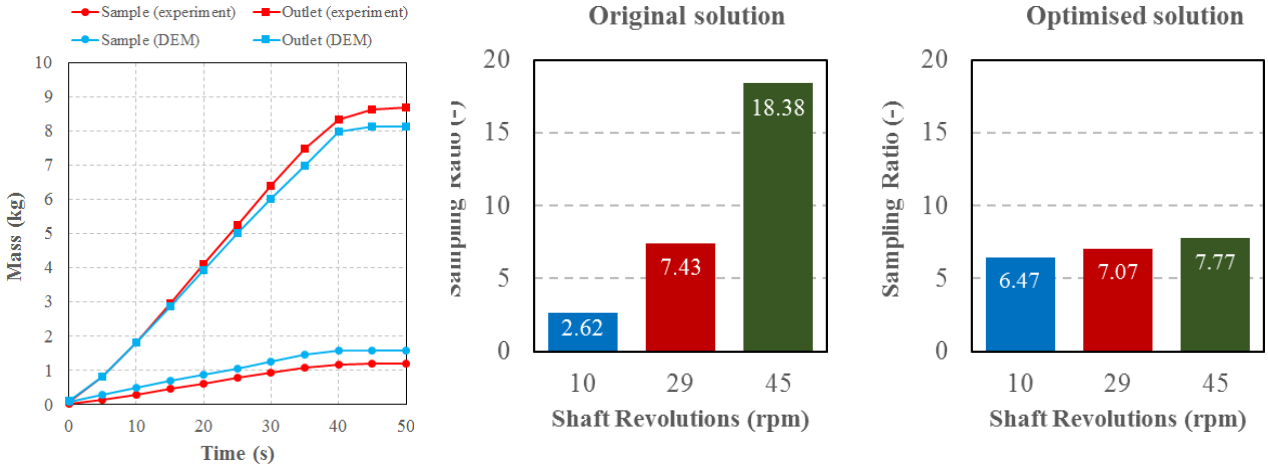
It is necessary to keep track and to record coal quality in a coal mines and incinerators [1]. Therefore, sampling equipment and systems have important role. Innovation in the field of sampling equipment aims for operation automatization including process and operation variations. In the age of modern computer technologies, innovative procedures cannot be done without using of numerical simulation methods. For the process engineering issues in the field of particulate matters, there is the possibility of using the Discrete Element Method (DEM) [2], which simulates virtual models of bulk material dynamic flow in transport, handling, storage, and process systems. DEM is a kind of a progressive approach to design, enabling geometric, material and process optimization of new and existing engineering works. DEM can be used for analysis and study of processes running inside the process equipment, where it cannot be obtained otherwise, for instance with an optical device for imaging and data collection [3]. However, the DEM model calibration of the process equipment is important for the validation of the simulation quality and accuracy, and it is not objective without measurements on real equipment [4]. In this paper, the measurement of the material mass gain over time on a real equipment is used to validate the DEM simulation. Further the simulation is used for research, optimization, and innovative solution of a rotary bulk material sampler.



Experiments were running on a real model of sampling dividing device. There were three main function parts. Particulate product enters the sampler in an upper part of the sampler falling on an impeller. From this space, material enters the middle part through static hole. There is a rotating disc with another holes, which is joined with the impeller by a shaft. Material falls through rotating disc holes into sample output, or into a bottom part of the sampler. In a lower part, there is an impeller scrapping material back to transportation route. This lower impeller is driven by the same shaft as the upper one. Sample output is placed directly under static hole in the middle part. However, in between static hole and sample output, there is a rotating disc with holes. Sampling is done by correct positioning during rotation of the rotary disk hole, when material falls through into sample output. Firstly, tests on a real sampler with parameters used during normal operations of the sampler were done. Ten experiments of the sampler filling and emptying were done, during which resulting mass of the sample output material and the waste were recorded. Optimal dividing ratio defined like waste versus output sample was determined to 7 to 1. Material and interaction properties were defined for Hertz-Mindlin contact model as input data of DEM simulation. Virtual material calibration was done by conventional calibration experiments, such as angle of repose, density, and friction properties. Further, 3D CAD model of sample was created for use in a virtual

environment. Three scanning areas were defined in a virtual environment (input – output – sample). Mass flow data were exported from these scanning areas. Sampling process simulation was validated to various real experiments, so the testing of design and operational modifications would be possible in virtual environment via DEM.

Original design of the sampler showed relatively high instability of the dividing ratio for various shaft rotational speeds, amount of input material, and material properties. Digital twin made by DEM enabled to innovate sampler with design and operational modifications to stabilize sampler functionality. The main modifications were adding distribution cone to the centre of the impeller, the static hole shape and position adjustment, the shape and position of the rotating disc holes adjustment, the shape of the hopper which considers dynamics and trajectory of the falling sample, and design solution of adjustable hole size in the rotating disc. The modifications lead to the stabilization of the dividing ratio with the shaft speed in a range from 10 to 45 rpm. Innovated product can be included into Industry 4.0 as the sampling automatization for the industrial line, such as the black coal operations in mines, power plants, and heating plants. Further advantage is possibility to reuse validated DEM model of black coal in other industrial applications, conveyors, handling and storage equipment, and design knowledge.



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VIKTORIIA A. GRIGOREVA
St. Petersburg Mining University
PhD in engineering, ANNA YA. BODUEN
St. Petersburg Mining University

TWO-STAGE TECHNOLOGY OF PREPARATION OF HIGH-SULFUR GOLD-CONTAINING CONCENTRATES FOR CYANIDATION

To date, cyanidation is the most common method recovery gold from ores and concentrates. However, direct cyanidation is not effective for processing refractory raw materials [1]. This method results in insufficient gold recovery and overspending of the NaCN. The decline and loss quality of the mineral resource base leads to the involvement in the production of poorer and difficult-to-process raw materials, including refractory gold ores. To involve such raw materials in the technological process, it becomes necessary to use additional oxidizing operations before the cyanidation stage. This is done to break down the sulfide matrix of minerals and "freeing" small gold particles, and allows the leaching solution to penetrate to previously inaccessible particles.

Despite the high capital and operating costs, the most promising method is pressure oxidation (POx), which allows to achieve high opening rates of gold-containing raw materials in less than 1-1.5 hours. But the share of ores and concentrates involved in processing with a sulfur content exceeding the autogenicity level (>6%) increases annually. When loading high-sulfur materials, the required pulp dilution index and the amount of heat generated increases, which makes it difficult and inefficient to use this type of equipment[2].

The purpose of this research was to find the most successful combination of operations used for pretreatment of persistent gold-containing concentrate with a high sulfur content before the traditional method of extracting precious metals into solution. The technology is being tested on a flotation concentrate provided by JSC MMC Kazakhaltyn (Bestobe mine, average Ss content=19.8 %). Based on existing global trends, as well as previous studies, the most promising methods for preparing persistent high-sulfur raw materials are a combination of atmospheric oxidation of the ultrafine grinding material (P80=20 microns, Albion process) or biological dissection followed by autoclave re-oxidation of sulfur. This combination will reduce the dilution of the pulp and increase the productivity of the autoclave process.

The aim of this research was to find the most successful combination of operations used for pretreatment of refractory gold-containing concentrate with a high sulfur content before the traditional method of extracting precious metals into solution. The technology is being tested on a flotation concentrate provided by KZAL (Bestobe mine, average Ss content=19.8 %). Based on existing global trends, as well as previous studies, the most promising methods for preparing persistent high-sulfur raw materials are a combination of atmospheric oxidation of the ultrafine grinding material (P80=20 microns, Albion process) or biological dissection followed by autoclave re-oxidation of sulfur. This combination will reduce the dilution of the pulp and increase the productivity of the autoclave process.

Today, a combined two-stage technology has been studied, consisting of preliminary bacterial oxidation (at 40°C) [3] of a persistent high-sulfur gold-containing concentrate, followed by autoclave opening (200°C, oxygen pressure 0.7 Mpa) and cyanidation of the cake. The combined technology "bio-oxidation-POx" has an obvious advantage: with an increase in extraction from 88 to 97 %, the specific consumption of sodium cyanide is significantly reduced from 25 to 4 kg/t. In comparison with autoclave oxidation, it is possible to achieve a reduction in capital and operating costs by reducing the content of sulfide sulfur (oxidation degree of 99%) to the values most acceptable for autoclave oxidation, which leads to a decrease in the volume of the liquid phase of the pulp (W:T from 6.2 to 4) and the required size of the equipment, as well as, as in the previous case, a higher extraction of the precious metal. The consumption of sodium cyanide was lower compared to both single-stage technologies.

The main disadvantage of using bio-oxidation technologies is the long duration of the process. In this regard, it was decided to test the "Albion-POx process" combination. At the initial stages of the research, a significant reduction in both the oxygen consumption and the duration of the autoclaving process of Albion cakes was observed in comparison with the direct autoclave oxidation of flotation concentrate, which does not involve the preliminary removal of sulfur. Based on the results of autoclave oxidation of the flotation concentrate and the solid residue of the Albion process, it can be concluded that research in this area is relevant and that it is necessary to select the optimal parameters of the process in order to achieve a reduction in the specific consumption of cyanide from 4.44 kg/t to 1.69 kg / t. Owing to the inclusion of the "Albion" process in the preparation operation, it is possible to achieve the oxidation of part of the sulfur to the desired value for subsequent autoclave leaching [4], while eliminating the need to remove excess heat from the autoclave or significantly dilute the pulp.

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IVANOV E.A.
St. Petersburg Mining University

DEVELOPMENT OF A METHODOLOGICAL APPROACH TO DETERMINING THE PARAMETERS OF THE FROTH LAYER DURING FLOTATION USING MACHINE VISION

Today there is a great need for the development of various IT solutions in the field of mineral processing. One of these developments is related to image and video processing. The need for this is based on the fact that most of the processes, in particular flotation, can be recorded on a camera, and the data from them can be used to obtain a number of parameters characterizing the process.

Structure of flotation froth is a fundamental factor that determines the quality of the flotation product. Definition of parameters of the froth will deliver the data for optimization of the flotation process. For determination of froth parameters recording system has been created, including cameras combined with a Raspberry Pi microcomputer for recording the surface of the froth and froth layer. Examples of received video frames are shown in Figure 1.

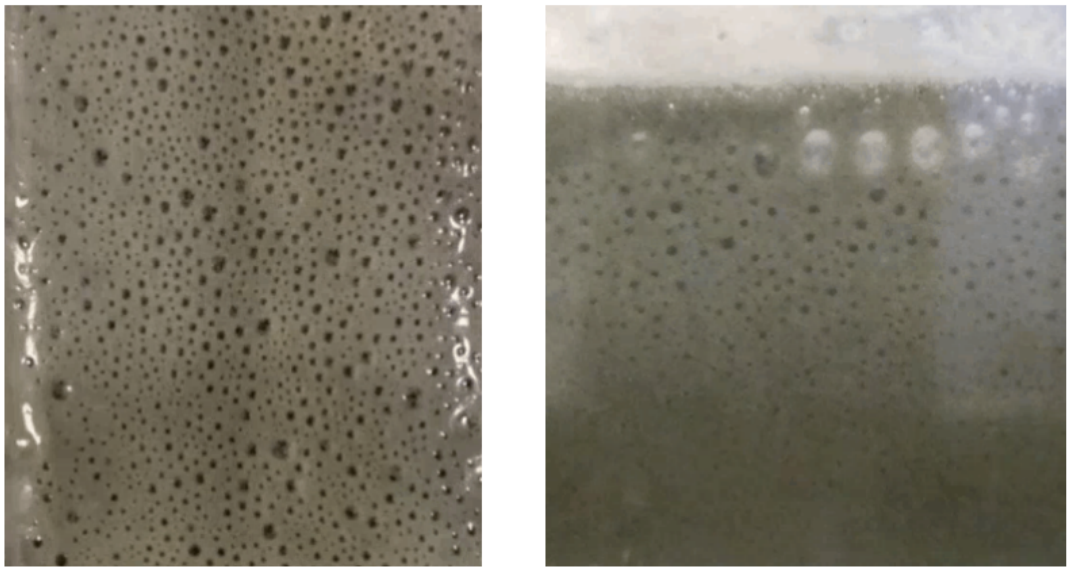

Figure 1 – View from cameras recording flotation froth

To determine the diameter and number of bubbles during flotation computer vision library OpenCV was used. Algorithm of video processing includes threshold binarization for preparing the image for further processing and Hough transformation for detection of circumferences. An example of a processed image fragment acquired during flotation is shown in figure 2.

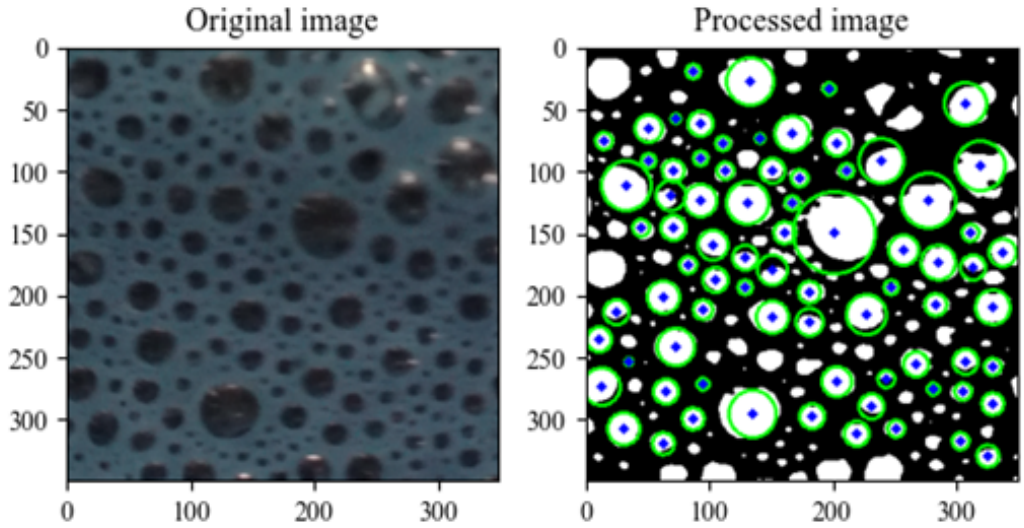

Figure 2 – Example of detection of flotation froth bubbles on an image

The resulting dataset contains radii of the detected circumferences. In general, application of the considered method seems reasonable, however, for a better detection, further improvements should be made to the fitting algorithm for bubble detection in dependence on the type of ore and lighting.

Scientific advisor: Prof. Dr. T.N. Alexandrova

AHMED A. KHALIFA
St. Petersburg Mining University
Dr.Prof. VLADIMIR Yu. Bazhin
St. Petersburg Mining University

MICROWAVE HEATING APPLICATIONS IN CARBOTHERMIC REDUCTION OF RED MUD

Abstract. In recent years, the global alumina production is rising continuously owing to the rapid economic development. The development of alumina industry also leads to a series of environmental and safety problems, especially red mud (RM), the solid waste generated in the alumina production process. The global red mud (RM) stock in 2020 was approximately 5 billion tones, with an increase of 150 million tons per year which are being disposed into a landfill polluting the surrounding environment. Generally, depending on the alumina production process and the bauxite grade used, there will be 0.5-2.0 tons of red mud produced for each ton of alumina. Many environmental risks are incurred in the process of stockpiling. For example, in 2010, a tragic industrial accident occurred at the Ajka Alumina Plant in Hungary, where one corner of the bauxite residue disposal area was collapsed, releasing approximately one million cubic meters of RM waste in its slurry form. On 9th April 2019, HINDALCO Plant at Muri, Jharkhand, India, experienced a failure of one of the dikes of bauxite residue disposal area, leading to spillage of RM slurry spreading across more than 35 acres of land. Another such dike failure incident occurred at Xiangjiang Wanji Aluminium Plant in Luoyang, Henan Province of China (August 2016). Approximately, 2 million m^3 of slurry waste was released, which causes evacuation of an entire village with over 300 people and killing many domestic and farm animals in the en route. Therefore, its management represents a global environmental issue that needs awareness of recycling in an effective way [1][2].

In the context of the potentially serious environmental consequences of RM, as well as the need to save and conserve precious natural resources, it is imperative to investigate its efficient utilization. The recovery of critical raw materials from red mud involves many benefits including environmental, social, financial, economic, and technological benefits. Over the last few decades, intensive work and efforts have been made by many researchers to develop various economic ways and compatible solutions for red mud utilization such as such as building materials, pigments, catalysts, adsorbent, and the recovery of valuable metals such as iron, titanium dioxide, scandium and alumina [3].

The chemical composition of red mud is relatively complex; the physical and chemical properties vary from each other depending on the mining areas and production process. However, there are some common characteristics of red mud from different factories, such as small particle size, complex phase composition and high alkalinity; it means one type of solution will not work.

As a heating method, microwave heating plays an important role in foods, materials and minerals processing because it has properties like selective heating, volumetric heating and rapid heating, which also attracts more attention for researchers to apply microwave to metallurgical processes and metallurgical waste treatment processes [4].

The application of microwaves in the iron industry may be characterized by a high potential for an essential reduction of carbon dioxide emission moreover, can reduce the carbon consumption. In particular, the decline in iron ore quality is a serious problem; low-grade ore is the ore with less iron concentration and poorer sintering performance [2]. RM is considered to be an interesting substance due to its high iron content, which can be used to produce salable pig iron.

Mechanism of heat generation of RM using charcoal under microwave heating is complex because of their different efficiency to absorb microwave energy, and what sort of reaction proceed in the sample. Many theories attempt to understand the specific microwave heating effects [5]. The current paper illustrates the mechanism model of interaction of microwave with different materials in red mud with charcoal during the reduction and heat transfer and explanation significant

phenomena of the cause of superheat during microwave energy absorption in materials. The brief purpose of this contribution is to evaluate the viability of microwave energy in the recycling red mud waste, efficiency of mineral extraction in order to optimize the whole process.

We have conducted a series of experiments to prove the effectiveness of rapid recovery of iron form this solid red mud waste under different temperature and oxygen-containing environment using microwave radiation, and achieved very positive results.

We have found that the microwave treatment provides an edge over conventional reductive technique by providing a significant improvement in iron grade and iron recovery % with higher reduction reaction rate at much lower energy.

Although a great improvement of microwave application, it is still in lab-scale, while how to apply these processes or technologies to industry scale still needs a further research.

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ANATOLY A. KOBYLYANSKI
St. Petersburg Mining University
Dr. Prof. GEORGIY V. PETROV
St. Petersburg Mining University

ALKALINE SULFIDE LEACHING OF COPPER CONCENTRATES AND MIDDLINGS WITH HIGH ARSENIC CONTENT

The current status of processing copper ores containing high concentration of arsenic and antimony was considered. Mining and metallurgical complexes operate under challenging conditions that were identified by the key figures. Based on the current technological processes and industrial experience, problematic factors and their influence on the finished product were determined. Chemical and mineralogical content of off-grade copper concentrates and middlings with high impurities content were investigated. The samples of those materials were received from mining and processing plant of the South Ural region. Arsenic (As) and antimony (Sb) were recognized as the main impurities, since these elements were present in sulfosalts minerals.

Processing of copper ores that contain arsenic is challenging. Arsenic is considered a carcinogen with high mobility in aqueous streams, which in time may lead to increased arsenic concentrations in rivers [1] and drinking water. Moreover due to environmental and plant ecological concerns, pyrometallurgical operations will penalize concentrates that contain arsenic over 0.5 % by weight (sometimes less). The presence of arsenic can also increase concentrates shipping costs, since concentrates are commonly imported/exported overseas [2].

Amongst current technologies, the alkaline sulfide hydrometallurgical process has been found to demonstrate successful results in selective dissolution of arsenic and antimony in certain technologies of the noble-metals industry. Currently, the main efforts of the researches in this subject are focused on the identification of an effective reagent regime and the influence of the mechanical activation on the process [3].

The process of upgrading copper concentrates and middlings undertakes an alkaline sulfide leaching of the samples to transform the arsenic sulfides into soluble compounds. The samples containing approximately 3.2 % As and 19.2 % Cu were treated in alkaline sulfide solutions containing sodium hydroxide and sodium sulfide. Kinetic parameters studied included temperature, concentration NaHS-NaOH, fineness, and mixing rate, over-time. The influence of these parameters was studied in connection with the dissolution of arsenic, antimony, copper and iron.

The analysis of the experimental results showed that the chemical composition of processed (upgraded) products meets the requirements of the national quality standard. The selective leaching of arsenic and antimony using sodium sulfide sulfides in alkaline solutions could be an effective way of upgrading copper concentrates in order to make them suitable for smelters.

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VILENA V. KOSHEVA
Ulyanovsk State University
Dr. Prof. VIKTOR N. GOLOVANOV
Ulyanovsk State University

FEATURES OF TECHNOLOGICAL PURIFICATION OF DIATOMITE FROM IMPURITIES

The explored reserves of diatomite in the modern world are: Russia — 350 million tons, the United States-250 million tons, China-110 million tons. In the USSR, by 1983, 27 diatomite deposits with balance reserves of 139.8 million m^3 were explored. Diatomite deposits are known in Transcaucasia, the Kola Peninsula, the Far East, the eastern slope of the Urals, and the Middle Volga region. Almost half of the reserves are located in the Ulyanovsk region, where the Inzenskoye field is most actively developed. Diatomite, as a natural modification of silica, finds extensive practical application in metallurgy, water treatment, petrochemistry and construction. One of the most appropriate solutions to the problem of cleaning natural and industrial waters from pollution released into the environment as a result of man — made accidents is the use of diatomite as a natural sorbent. Its use in construction is explained by its exceptional heat and sound insulation properties at a sufficiently low density. However, the problem of increasing the mechanical strength of diatomaceous building materials (bricks, slabs, etc.) remains unsolved, which is to some extent due to the high porosity, as well as the presence of undesirable impurities (CaO, MgO, Fe_2O_3, Na_2O, TiO_2 and K_2O), which prevent sintering into a solid structure. In the scientific literature, the following methods of purification of diatomite from iron oxide are known. Methods of purification of diatomaceous rock, presented in the patent of the Russian Federation No.

2314858, IPC B01D 39/06, 2006. and the author's certificate of the USSR No. 1599055 IPC B01D39, 1990, allowed to achieve a reduction in the content of iron oxide to 0.2 % and 0.06%, respectively. It can be noted that the technological cycles of diatomite purification are complex and multi-stage, which complicates the production process and increases the cost price. On the other hand, the developed surface of the structural components of diatomite, as well as its complex chemical composition, open up the prospect of its use as a sorbent, for example, in the treatment of wastewater from soluble organic compounds, including petroleum products [1], radioactive contamination [2], etc. In addition, diatomaceous brick surpasses in many characteristics the materials known to us. For example, its thermal conductivity is much lower than that of aerated concrete. It is also very strong and has excellent acid resistance, hydroscopic properties and fire-resistant properties.

Considering the method presented in the patent of the Russian Federation No. 2314858, IPC B01D 39/06, 2006, which includes grinding of diatomaceous rock, obtaining a suspension in an aqueous solution with stirring, fractionation in an aqueous medium, roasting and dehydration, characterized in that a dispersing agent sodium pyrophosphate is introduced into the aqueous solution, and roasting is carried out after dehydration, it is possible to detect a decrease in the content of iron oxide to 0.2 %. A similar method was considered by the authors of the USSR copyright certificate No. 1599055 IPC B01D39, 1990, which includes the treatment of diatomite with hydrochloric acid, washing, mixing with caustic soda, filtration, drying and calcination. As a result, the authors succeeded in reducing the iron oxide content from 1.8% to 0.06%, in contrast to the method considered in RF Patent No. 2314858, IPC B01D 39/06, 2006. However, the high viscosity of the solution after treatment with hydrochloric acid makes it difficult to wash to remove the acid residue. The analysis of these methods allowed us to draw up a plan for conducting the study.

To study the technological features of the purification of diatomite from impurities, kieselgur from the Inzensky deposit was used (chemical composition of SiO2-81.08%, Al2O3-5.63%, Fe2O3-2.67% and other oxides not exceeding 1%) [3]. The samples were pre-crushed and diluted with water. The treatment of diatomite in an aqueous solution of sulfuric acid under various modes of ultrasound and magnetic separation was studied. Sample No. 1 was processed using an ultrasonic generator UZG13-0,1 / 22 for 15 minutes. Magnetic separation of the second sample was carried out after washing it with water. Sample No. 3 was washed with a 15% hydrochloric acid solution, after which the iron was removed from the sample using an electromagnetic separator. In sample No. 5, the diatomite was washed with bubbling air, after which a magnetic separation stage was performed. In sample No. 6, the diatomite was moistened to 70 %, and ultrasonic treatment was performed in the mode of structure destruction. Samples No. 1-3, 5-6 were subsequently dried at a temperature of 3000C and the fractions were eliminated. Sample No. 4 after magnetic separation was dried, fired at a temperature of 800 ° C, and then the fractions were screened out. The influence of various technological treatments of diatomite on its elemental composition was analyzed using an ICAP-6500 Duo inductively coupled plasma emission spectrometer. To detect the phase composition, diatomite samples were pressed into tablets Ø 20 mm, 5 mm high and subjected to X-ray diffraction analysis on a D2 PHASER diffractometer. At the first stage, the structure of the diatomite was studied after various processing operations using a desktop scanning electron microscope PHENOM PRO-X. It can be seen that there are no obvious morphological differences in the structure of the samples. Mainly solid diatomaceous shells are observed, the size of which reaches ~30 microns, however, smaller structures are also visible, the size of which does not exceed 10 microns.

When washing the diatomite with a solution of hydrochloric acid, the following reaction may occur: $6HCl + Fe_2O_3 = 2FeCl_3 + 3H_2O$. Given that water and iron oxide are low-dissociating compounds, the following ionic equations can be written: $6H+ + 6Cl^- + Fe_2O_3 = 2Fe_3+ + 6Cl^- + 3H_2O$ and $6H^+ + Fe_2O_3 = 2Fe_3^+ + 3H_2O$

As a result, the formation of free or hydrated iron ions facilitates the magnetic separation process. Similarly, the process proceeds in the case of using a solution of sulfuric acid. However,

the effectiveness of this cleaning method was low in comparison with the use of only humidification and ultrasonic treatment. The reason for this may be due to re-oxidation in a humid atmosphere with the formation of higher iron oxides, which are not stable. The work is not finished, but it follows from the research results that the purification of diatomite without reducing its useful properties is possible.

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VALENTIN V. KUZNETSOV
St. Petersburg Mining University
Dr. Prof. TATYANA N. ALEKSANDROVA
St. Petersburg Mining University

DEVELOPMENT OF MINERAL FLOATABILITY DETERMINATION METHODS FOR EFFECTIVE FLOTATION TECHNOLOGY DESIGNS

Nowadays the most urgent problem for the mineral processing is the widespread depletion of high grade ore deposits. That leads to efficiency decreasing of the traditional processing technologies, and significant price increasing over the whole spectrum of the mineral processing production. This is due to the complexity of the material composition of ores and the close relationship of the valuable component with the minerals of the host rock. In that situation it has become imperative to develop and implement new technologies that will allow to efficiently process this type of ores. At the same time, the introduction of brand new technologies is associated with high economic risks for production, which creates the need to forecast the technical solutions effectiveness at the design stage. Justification of profitability is possible by using digital technologies to create models of the proposed processes based on preliminary studies of material's physical and chemical properties.

A highly promising object for implementation of such technologies is copper-nickel ores. These ores are complex raw materials because in addition to the main valuable components: copper and nickel, they also contain gold, silver, cobalt and elements of the platinum group as impurities. Flotation remains the basic beneficiation process for copper-nickel ores. One of the main factors reducing the enrichment efficiency is overgrinding of copper minerals during regrinding operations, which leads to their loss with tailings.

The application of a new reagent regime at the stage of the main flotation will allow to increase the copper recovery in the concentrate during coarse grinding, which will result in reducing losses and improving the quality of the final concentrate. Preliminary evaluation of such technological solution efficiency is possible by copper mineral floatability analysis. The essence of the analysis is in dividing of all material in few classes with close values of flotation rate constant. That will allow to create more accurate model of the process due to more correct recovery values.

The purpose of this work is to justify the choice of a complex of collecting reagents for enrichment of copper-nickel ores based on the evaluation of its effect on the surface properties of sulfide minerals and their floatability.

In order to predict the efficiency of the selected collector in combined action with potassium butyl xanthate, a set of studies of physical and chemical properties of the ore is proposed in this work. The research algorithm is shown in figure 1. The first stage was the study of grinding kinetics of copper-nickel ore, in which the rate of redistribution of the valuable component in the crushed product depending on grinding time was estimated. The second step was to measure the contact angle on the surface of the test sulfide mineral to estimate the hydrophobizing effect of the selected collecting reagent. The boundary angle was measured for water and diiodomethane before and after the treatment of the sample surface with the selected collector. The last step was conducting series of test experiments in copper-nickel ore flotation.

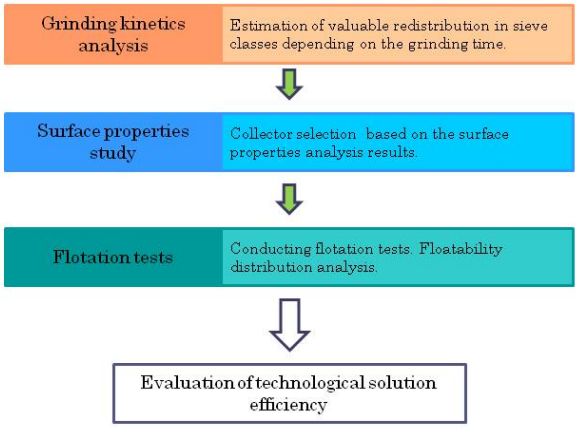
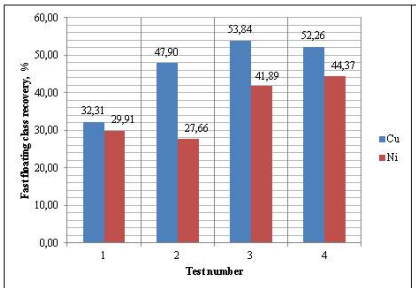
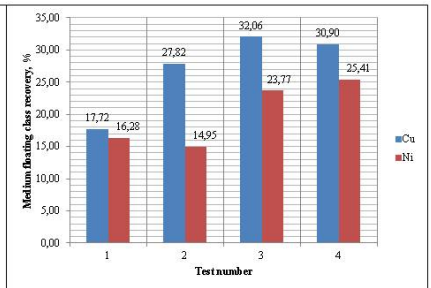
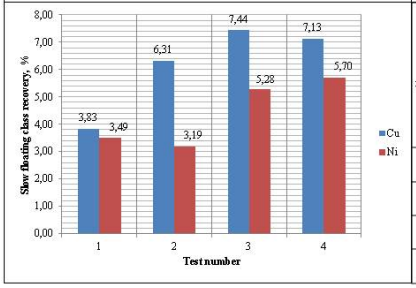


Figure 1 – Research algorithm

In the course of studies it was found that the mixture of potassium butyl xanthate and sodium dibutyl dithiophosphate has the greatest hydrophobic ability in relation to copper minerals. This fact is confirmed both by results of surface properties research and by the results of test flotations series. At identical dosage of dialkyldithiophosphates in the mixture the greatest extraction of copper was reached at application of a mix of potassium butyl xanthate and sodium dibutyl dithiophosphate.







Test number	Floatability classes recovery, %					
	Fast floating class, P=0,01		Medium floating class, P=0,005		Slow floating class, P=0,001	
	Cu	Ni	Cu	Ni	Cu	Ni
1	32,31	29,91	17,72	16,28	3,83	3,49
2	47,90	27,66	27,82	14,95	6,31	3,19
3	53,84	41,89	32,06	23,77	7,44	5,28
4	52,26	44,37	30,90	25,41	7,13	5,70

Figure 2 – Results of floatability distribution analysis.

Flotation conditions: 1,2- yield of a size class -71 micrometer = 52,1 %; 3,4 yield of a size class -71 micrometer = 87,3 %; 1,3 - potassium butyl xanthate – 160 g/t, sodium dibutyl dithiophosphate – 40 g/t; 2,4 - potassium butyl xanthate – 40 g/t, sodium dibutyl dithiophosphate – 160 g/t

The analysis of material distribution by flotability classes for flotation at two different values of grinding time and the dosages of potassium butyl xanthate and sodium dibutyl dithiophosphate in the collection mixture was conducted (fig.2). By results of the analysis it is established that the copper recovery into a concentrate equal to 82,03 % is reached at a yield of a size class -71 micrometer equal to 52,1 % and at the dosages of potassium butyl xanthate and sodium dibutyl dithiophosphate equal to 40 and 160 g/t accordingly. This is presumably due to the synergistic effect of the reagents in the mixture.

Though the maximum recovery of fast floating copper fractions is aligned with higher values of fine classes, the copper recovery in the second case is still high. Thus, if sodium dibutyl dithophosphate prevails in a collecting mixture, flotation extraction of the disclosed fraction of copper minerals in a coarse concentrate is possible with less grinding time that will reduce losses of copper with tailings.

ELLI T. N. NANGOLO
University of Namibia
CLEMENCIA S. GAROES
Swakop Uranium
MELVIN M. MASHINGAIDZE
University of Namibia

LABORATORY EVALUATION OF THE FLOTATION RESPONSE OF CHALCOPYRITE CONCENTRATOR TAILINGS TO RINKALORE RX1 OXIDE COLLECTOR

Introduction. Flotation of copper oxides ores remains a challenge despite many studies [1-4] being conducted. This study investigated the flotation response of chalcopyrite flotation tailings assaying 0.10 % copper (Table 1) to Rinkalore RX1, a secondary copper oxide collector. The results were compared with those obtained when the tailings were floated using the standard suite of chalcopyrite flotation reagents. Rinkalore RX1 dosages tested were 50, 150 and 250 gpt.

Methods. The flotation testwork was conducted using a laboratory scale Denver D12 flotation machine. The impeller speed was set at 1200 rpm and the airflow was controlled manually to maintain the froth level. The flotation was carried out at 30 % solids and pH 9.5 in a 1L cell at 1200 rpm for 6 minutes. The slurry was prepared using 500 g of the tailings sample and 1166.67 mL of water. After adding lime to adjust the pH of this slurry, predetermined volumes of rougher reagents such as Senkol 294, LSB and beta frother (Table 2) were added and conditioned for 3 minutes before floating for 3 minutes. At 3 minutes of floating the sulphurdiser was added and at 4 minutes of floating PAX was added, after which conditioning was done for 3 minutes. Flotation was done for the last 2 minutes and scrapping was done every 35 seconds. The same procedure was followed for flotation tests involving Rinkalore RX1. The Rinkalore RX1 was added at three different dosages of 50 gpt, 150 gpt and 250 gpt.

Results. The 250 gpt dosage of Rinkalore RX1 gave the highest recovery of 86.66% (Fig. 1). However, the mass pull was also highest at this dosage which indicates that the separation process was inefficient. The highest copper grade of 0.37% was obtained at 50 gpt of the Rinkalore RX1 which was the lowest dosage of the RX1 collector (Fig. 1).

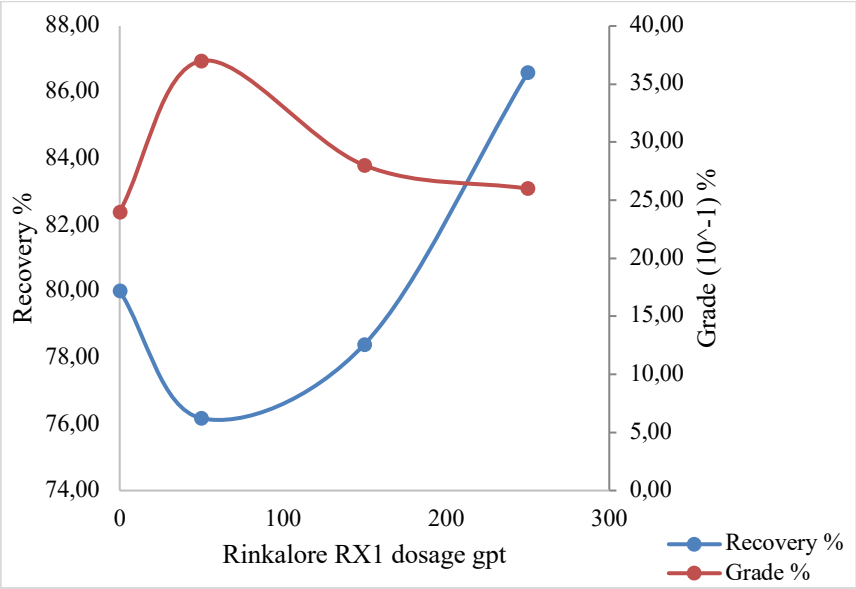


Figure 1 – Grades and recoveries at different dosages of Rinkalore RX1

Conclusion. The flotation tailings contained a very low amount of copper. The highest copper grade of 0.37% was obtained at 50 gpt of Rinkalore RX1. However, the corresponding mass pull of 21.97% is too high for efficient copper concentration. Therefore the best recovery vs. grade combination is 76.18% vs. 0.37%. Future studies should focus on reducing the mass pull obtained from the flotation using Rinkalore RX1 since the mass pull exceeded 15 % in all the trials that were conducted.

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JINHE PAN
China University of Mining & Technology

RECOVERY OF RARE EARTH ELEMENTS FROM COAL FLY ASH USING AN INTEGRATED ROASTING, WATER LEACHING AND ACID LEACHING PROCESS

Background. Economic and environmental issues, as well as permitting and trade restrictions have raised concerns regarding mining and availability of rare earth elements (REE)[1]. Coal fly ash (CFA) has been considered as a viable secondary source of REE[2]. However, the majority of REE in CFA is associated with the aluminosilicate glassy phase, hindering their solubility in the acid leaching process[3].

Research Aim. The main objective of the proposed work is to develop a novel integrated bench-scale circuitry for efficient, low-cost and environmentally benign REE extraction from CFA.

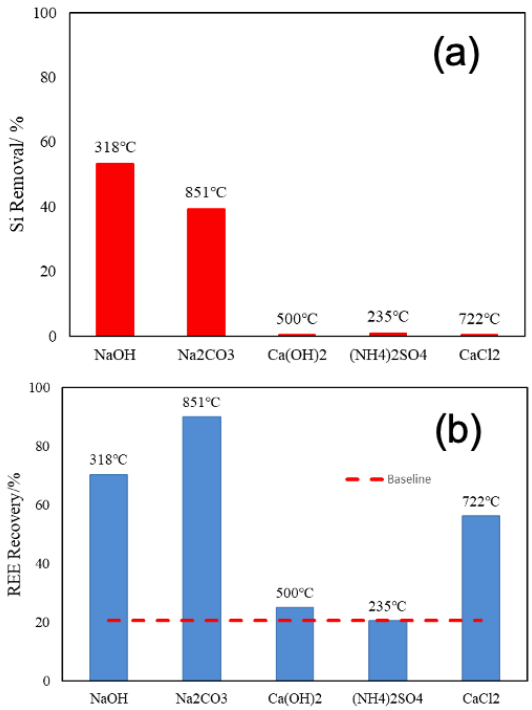

Figure 1 – (a), Si removal in water leaching
(b) REE recovery in acid leaching

Material and Method. Representative F-type CFA sample was collected from a US coal power plant. The effect of several roasting additives on the transformation of CFA phases into water or acid soluble phases was first studied. Water and acid leaching was used to remove the water-soluble fractions, and acid leaching was utilized for recovery of REE. The results were compared with that of baseline acid leaching. The products of each step were also fully characterized. The characterization results were used to formulate the chemical reactions occurred during the process. Finally, the reactions were studied in detail using thermodynamic analysis.

Results. High Si removal using water leaching (i.e., up to 60% and 40%, respectively, for NaOH and Na_2CO_3) suggests that NaOH and Na_2CO_3 are the most effective roasting additives in the transformation of the CFA glassy phases (Fig. 1(a) and 2). Such pretreatment resulted in significant REE recovery improvement from CFA through acid leaching (Fig. 1(b)).

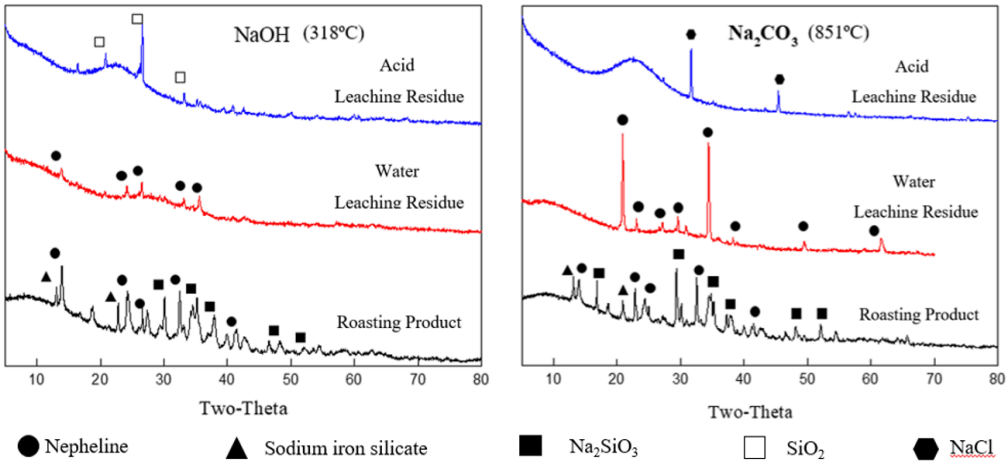

Figure 2 – XRD analysis of CFA products of the proposed process using (a) NaOH, and (b) Na_2CO_3

Conclusion. The proposed sequential roasting, water leaching and acid leaching found to be very effective in recovery of REE from CFA. This process enhanced the REE recovery to 79% and 89% using NaOH and Na_2CO_3 roasting, respectively, compared to 20% REEs recovery in baseline acid leaching.

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LUIS A. PÉREZ GARCÍA
University of Moa

EVALUATION OF THE INFLUENCE OF CALCINATION AT HIGH TEMPERATURES FOR OBTAINING SUPPLEMENTARY CEMENTITIOUS MATERIALS USING KAOLINITIC CLAYS FROM CAYO GUAM DEPOSIT, CUBA

Among Supplementary Cementitious Materials (SCMs), calcined clays are a promising route to increase average levels of clinker substitution. The global supplies of fly ash and slag are limited compared to the amount of clinker produced and a very high proportion of suitable slag and fly ash is already used in blended cements. Kaolinitic clays show the highest pozzolanic reactivity[1–3] However, supplies of the most common SCMs, which are slag and fly ash, are quite limited compared to the worldwide production of cement. Calcined clays are the most promising source of additional SCMs which can make a substantial contribution to lowering further the environmental impact of cement and concrete[4].

In other hand, with the addition of calcined clays, the mechanical strength and durability of the cement matrix is maintained or increased[5,6], and at the same time, the reduction of energy consumption and greenhouse gas emissions by amount of binder is favoured[7].

The investigations on the subject, have been directed towards different sectors, being the temperatures of activation and the content of kaolin perhaps, the most important and the best studied.

In this work, the influence of calcination at high temperatures is evaluated, for the obtaining SCM from kaolinite clays from the Cayo Guam deposit. The chemical and mineralogical characterization of the clay was carried out using XRD, XRF and thermal analysis. The pozzolanic reactivity was evaluated by the alkaline solubility method in combination with test of mechanical strength. The presence of kaolinite, goethite and muscovite was corroborated with hematite as principal companion phase. In the analysis of the results of the equivalent kaolin calculation, it was obtained that the kaolinitic clays of the Cayo Guam deposit present favourable kaolin contents equivalent for the use as SCM, reporting some of the highest values compared to other kaolinitic clays identified in the country. The standardized mortars make with a 30% substitution of OPC by calcinated products from the clays of the Cayo Guam deposit, at temperatures of 800, 900 and 1000 C were analyzed at 1, 3, 7 and 28 days. The results achieved according to the evaluation of the specific surface of the calcined clay were jointly studied. It was possible to determine that 800 ºC is the optimum temperature for thermal activation, with resistance values to mechanical compression of 16.89 MPa above that established by the norm at 28 days. An evident decrease in the specific surface was observed from 900 ºC, which produces a drop in the values of compressive strength. The remarkable filler effect of the calcined clay allowed similar resistances to the control series to be reached after 28 days.

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VALERIA ESTHEFANIA QUIROZ CABASCANGO
St. Petersburg Mining University
Dr. Prof. VLADIMIR YU. BAZHIN
St. Petersburg Mining University

THERMAL EFFICIENCY CALCULATIONS OF A REVERBERATORY FURNACE DURING THE NICKEL ALLOYS MELTING

The calculation of the thermal efficiency of a reverberatory furnace with medium pressure burners is very important to evaluate its performance in the nickel refining industry. Process engineers determined the value of furnace efficiency calculations; because it is very complex process. Focusing on the basics, furnace thermal efficiency calculations offer insight into technology operations. In this work we will show how to calculate thermal efficiency using combustion gas analysis [1].

The method considers the analysis of the flue gas and the temperature of the chimney. To calculate the thermal efficiency, the following are taken into account: the chemical reactions occur inside the furnace during the nickel smelting process, the inlet and outlet temperatures of the gases, smelting temperature and heat losses of the walls sides and roof of the furnace as shown in Figure 1 [2].

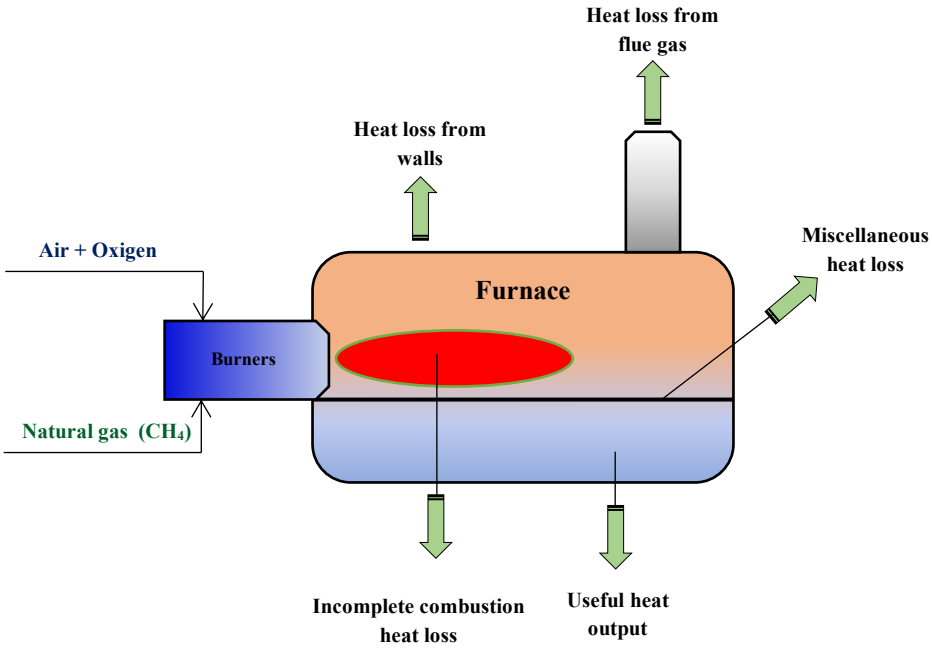

Figure 1 – Schematic representation of energy balance in an nickel reverberatory furnace

Standard graphs used to understand the procedure for the excess air and enthalpies of the flue gas components, and to simplify calculations. The difference between the simplified and the correct calculation is small, and its impact on the final calculation is negligible. The described method is intended only for furnaces that use natural gas [3]. To understand the procedure described, we will calculate: the Lower Calorific Power or heat of combustion of the fuel, the combustion air and flow rate of the combusted gases, the composition of the combusted gases (both dry and wet basis) and finally the thermal efficiency of the furnace [4].

Based on the results, it is found that the variable having the greatest influence on the thermal efficiency is the low calorific value, since it depends on the composition of the natural gas. The proposed methods for calculating the thermal efficiency using a computer program are effective if an operator wants to evaluate the furnace operation efficiency on site.

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BAKYT SULEIMEN
South Ural State University
Dr. Prof. VASILIY E. ROSHCHIN
South Ural State University

PYROMETALLURGICAL PROCESSING OF HIGH-PHOSPHORIC OLITE IRON ORES

Deposits of oolitic iron ores with a high content of phosphorus are widespread all over the world [1]. The main obstacle associated with the development of these deposits is the high phosphorus content, which affects the cost of the pig iron production process due to the high energy consumption and low quality of the resulting "brittle" steel. Phosphorus in oolite ores is mostly evenly distributed and does not occur as individual minerals.

Many attempts have been made to reduce the phosphorus content to an acceptable level by traditional methods: hydrometallurgical (chemical leaching) [2], pyrometallurgical (reducing roasting - magnetic separation) [3], microbiological (bio-leaching) [4].

Some of these methods achieve the goal of removing phosphorus, but they still have disadvantages, such as: low dephosphorization efficiency, environmental pollution, relatively high cost, excessive time consumption, and low iron recovery.

Hydrometallurgical methods (acid leaching or alkaline leaching) produce liquid waste and have a negative impact on the environment and are economically unprofitable.

Pyrometallurgical methods are more attractive in terms of processing scale and cost. However, due to the complex structure of the oolite and the fine inclusions of phosphorus, during the reduction firing, the phosphorus passes into the metal phase, and during the subsequent magnetic separation it enters the magnetic fraction. In this regard, the removal of phosphorus from the concentrate by these methods of enrichment is not possible.

Biological methods require a long processing time. Leaching bacteria require collection, separation, cultivation, and domestication, which affect production efficiency.

Thus, the development of a new method of phosphorus removal is a key factor for the rational use of iron ore resources with a high phosphorus content, which is very important for the development of ferrous metallurgy.

The aim of this work is to study the possibility of pyrometallurgical processing of oolite iron ore with a high phosphorus content.

To solve this problem, high-phosphorous oolitic iron ore from the Ayat deposit was used as the starting material. At the initial stage, it was advisable to conduct a comprehensive study of the source material: a map of the distribution of elements, the sequence of ore transformations during heating, X-ray spectral and X-ray phase analysis of the initial and burned samples. Oxidative roasting was carried out in a muffle furnace at a temperature of 1200 °C.

The map of the distribution of elements showed that some elements, such as Fe, Ca, Si, Al, are distributed unevenly over the volume of the source material, some particles have a high content of Fe, others – Si and Al. At the same time, S and P are distributed much more evenly.

According to the results of the calcination experiment, it can be assumed that in the first section, after reaching 250 °C, the release of hydrate moisture, during the decomposition of goethite, is completely completed, as evidenced by the change in the rate of mass change. In the remaining temperature range of 300-450 °C, therefore, the dissociation of iron carbonates continues. With a further increase in temperature to 1200 °C, the process of sulfur oxidation, and partially its removal in the form of SO_2, has a significant effect on the weight reduction. The total mass change was 23.8 %.

The results of X-ray spectral analysis showed that the initial and fired ore contains the elements Fe, Si, Mg, Al, P, S, and Ca.

X-ray phase analysis showed that the main phases of the initial ore are goethite FeO(OH), quartz SiO_2, $AlPO_4$, and Al_2O_3. The intensity of the peaks of other oxide phases of the obtained

X-ray image was quite low, which did not allow us to determine with sufficient accuracy the phases with a content below <10 wt. % (based on Ca, Mg, S, etc.). According to X-ray phase analysis, goethite decomposes into hematite Fe_2O_3, phosphorus is still present as $AlPO_4$ in the firing product. No other significant changes were observed as a result of oxidative firing.

At the next stage, reduction roasting was performed with solid carbon and gaseous carbon monoxide. The recovery was carried out in a resistance furnace with a graphite heater at a temperature of 850, 900, 950, 1000 °C. The use of a graphite heater guaranteed in all experiments the presence of a reducing atmosphere of CO in the volume of the working space of the furnace. In parallel, under the same conditions, they were also reduced with solid carbon.

The results of the experiments showed that the reduction in the atmosphere of CO, in the metal it is possible to obtain a low phosphorus content (in the order of 0.1%), while the reduction of solid carbon phosphorus content was at the level of 1%.

To further study the distribution of phosphorus between the molten metal and the slag, separation melting should be carried out and the composition of the already molten metal and slag should be analyzed.

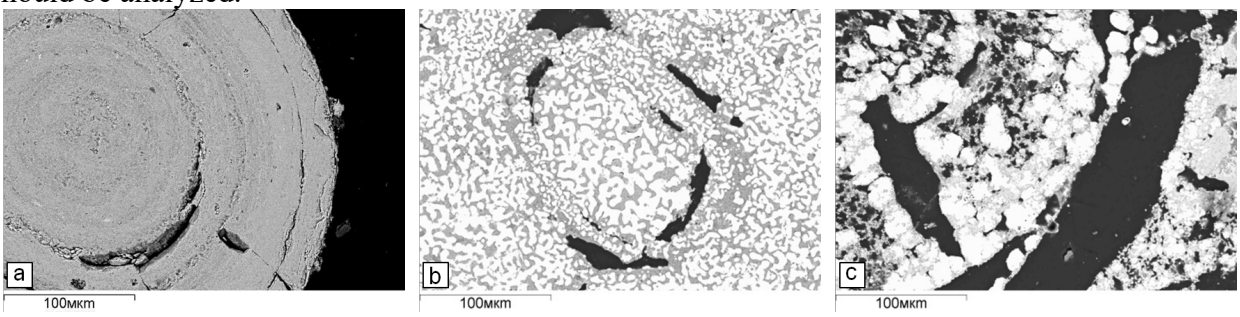

Figure 1 – Type of initial particles (a) results of reduction firing in contact with solid carbon (b) and in the atmosphere of CO (c)

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NINA R. TIMIRBAYEVA
Karaganda Technical University
Cand. Sc. (Technology), Assoc. Prof. ALIBEK S. BAISANOV
Zh. Abishev Chemical-Metallurgical Institute
D.Sc. (Technology), OLEG V. ZAYAKIN
Ural Branch of Russian Academy of Sciences
D.Sc. (Technology) ARISTOTEL Z. ISSAGULOV
Karaganda Technical University

STUDY OF PROPERTIES OF CHARGE MATERIALS FOR TITANIUM-CONTAINING FERROALLOYS MELTING

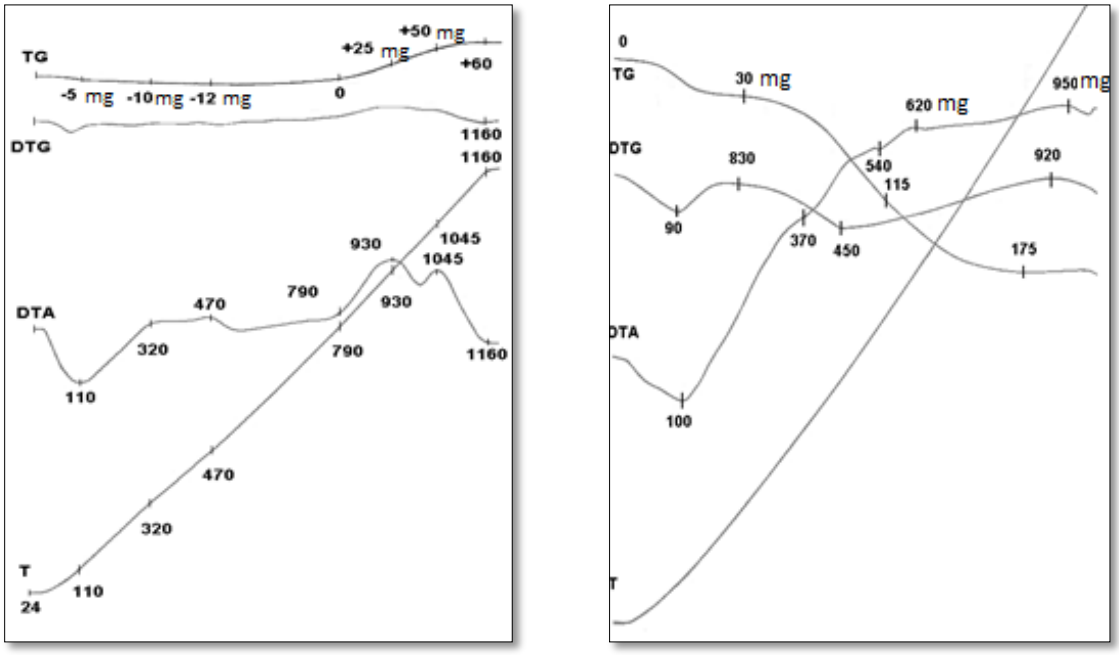
Today the main material used for alloying and deoxidation of steel with titanium is ferrotitanium. Traditionally, ferrotitanium is smelted from ilmenite concentrates by the aluminothermal method [1-2]. However, the practice of using the compositions of charge materials used to obtain ferrotitanium according to known technologies indicates a number of disadvantages. One of them is scarce raw materials using, which require significant material and energy costs, for batching. In this connection, it is interesting to conduct research on the production of titanium-containing ferroalloy by carbothermal methods.

Obtaining new types of complex ferroalloys with high technical and economic parameters of the process depend primarily on the properties of charge materials. During melting, the components of the charge are exposed to high temperatures, which lead to a number of physicochemical transformations that significantly change their initial properties. Such transformations can be recorded on the derivatogram using differential thermal analysis.

In this work, in order to study the behavior of the batch for titanium containing ferroalloys melting during heating, thermographic analysis was carried out using the F. Paulik, J. Paulik, L. Erdei Q-1000 system derivatograph in the temperature range 25-1000 °C at a heating rate 10 °C/min, in neutral and inert atmospheres. The system allows to record the change in mass (TG) and the rate of change in mass (DTG) of the sample, as well as the temperature difference (DTA) between the test and inert samples with continuous heating at a given rate [3]. The charge for thermographic studies was prepared from ilmenite concentrate and carbon-containing reducing agent (fraction 0-0.15 mm).

Physicochemical processes occurring in the concentrate at temperatures of 100-120 °C (Figure 1 a) are accompanied by the removal of hygroscopic moisture with a small 0.22% loss in sample mass. As the temperature rises to 550 °C, hydration moisture and volatiles are released with a decrease in the sample weight up to 0,4%. The DTA curve shows weak exothermic effects of oxidation of lower iron oxides in the temperature range of 320-470 °C. At 800-1000 °C, intense oxidation occurs, the heat content of the sample increases and its weight increases by 1,55%. At higher temperatures Fe_2O_3 is released from the ilmenite composition.

Figure 1 b shows a derivatogram of the mixture of ilmenite concentrate with coal (14 % of the mass of the concentrate). In the temperature range of 100-540 °C, a significant 6,2 % loss in the mass of the mixture is observed, this is due to the removal of hygroscopic, hydrated moisture and volatile substances from the concentrate and coal, as well as the dissociation of complex compounds in the concentrate. At 450 °C, an increase in the rate of weight loss is observed in the sample, which is accompanied by weak exothermic effects, and corresponds to the onset of intense oxidation of coal carbon. At higher temperatures, ilmenite dissociates in the mixture and the oxide Fe_2O_3 is released, which reacts with the carbon of the coal.



ilmenite concentrate; b) concentrate + coal;

Figure 1 – Thermographic analysis data

Thus, under laboratory conditions, the reduction of ilmenite with carbon develops noticeably at temperatures above 1000 °C. This is confirmed by the conducted thermographic studies of the ilmenite-coal charge, taken in neutral and inert atmospheres. Under the conditions of a high-temperature reduction process, such an indicator has a positive effect on the distribution of the reaction gas and its uniform yield, which will have a beneficial effect on the smelting of a titanium-containing ferroalloy. Consequently, when smelting titanium-containing ferroalloys by the coal-thermal method, coals can be used.

ACKNOWLEDGMENTS

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VADIM E. ZINUROV
Kazan State Power Engineering University
Prof. ANDREY A. DMITRIEV
Kazan State Power Engineering University

DEVELOPMENT OF A CLASSIFIER WITH COAXIALLY ARRANGED PIPES FOR FRACTIONATION OF FINE BULK MATERIAL

The classification of bulk material into fractions after grinding is crucial for most industrial enterprises [1]. Air classifiers can be used for this purpose [2], providing quick and energy-efficient fractionation of a large volume of mixed bulk material with various physical properties [3].

At the moment, the classification of fine particles is of particular interest due to the intensive development of the chemical and petrochemical industries, including new chemical components, catalysts, and adsorbents.

At the moment, there are various types of powder classifiers: centrifugal, dynamic, gravitational, sieve, etc. The centrifugal classifier separates the finely dispersed bulk material of fractional composition within the range from 5 to 80 microns by means of centrifugal force and air flow. The range of obtained particles directly depends on the rotor rotation speed and a change in the amount of air flow. The centrifugal classifiers are divided into static ones, when the air flow is created by the movement of blades, and dynamic ones, when the movement of air flow is provided by a rotating rotor. The advantages of centrifugal classifier are the ability to control the range of material separa-tion fineness and provide the greatest accuracy for the particle classification. A significant disad-vantage of this type of classifier is that large powder particles fall into the fine fraction, and small particles fall into the large separation product, therefore, there is a decrease in the efficiency of parti-cle separation and a small efficiency of device. The gravitational classifiers carry out the material separation by means of interaction of resistance and gravity forces. The separation of raw material occurs as a result of different rates of sedimentation of solid particles in a liquid medium under the influence of gravitational forces. The large particles settle down faster, and the small particles settle down slower. The main advantage of gravity method is the simplicity of device design due to the absence of moving parts in it. The disadvantage of gravity classifier is that it is impossible to classify the finely dispersed particles. At the industrial enterprises, the most common method is the sieve method of classifying the powders, which is directly carried out by the material spilling through a set of different sieves, ensuring separation as per the required parameters by fractional composition. This type of device has simple design and is suitable for classifying the particles larger than 40 microns. Despite the positive aspects of this method, it also has certain disadvantages, such as low efficiency of sieving classifiers for the finely dispersed powders and significantly low opera-tional life of sieves due to rapid clogging caused by sticking of particles to their surface.

In order to solve this problem, the authors developed the design of classifier with coaxially arranged pipes [4], shown in figure 1. The classifier with coaxially arranged pipes is a simple structure, con-sisting of cylindrical body 6, inside of which there is an internal cylindrical pipe; in the lower part of this pipe there is an even number of rectangular holes 3 with a certain step, and the bottom part of pipe has a cone-shaped hole *4*. In the middle part of inner cylindrical pipe, there is a screen with co-axially arranged pipes *2*. There is an inlet nozzle in the upper central part of device *1*. The device also has an outlet nozzle *5*. The bunker is located in the lower part of device *7*. When assembling the device, the inner cylindrical pipe is placed in the cylindrical body through the lower hole and insert-ed into the central hole in its upper part, forming an inlet nozzle *1*. The strength of structure is pro-vided by fixing the inner cylindrical pipe to the cylindrical body *6* by means of screen with coaxially arranged pipes *2* and by welding the outer part of inner cylindrical pipe, forming an inlet nozzle *1*, to the device body *6* (figure 1).

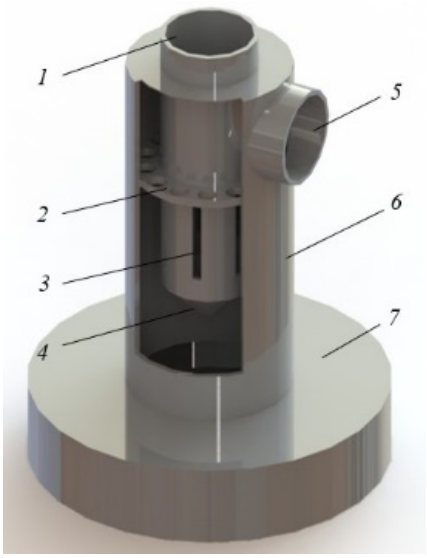

Figure 1 - The classifier with coaxially ar-ranged pipes: 1 – inlet nozzle, 2 – screen with coaxially arranged pipes, 3 – rectangular holes, 4 – additional hole, 5 – outlet nozzle, 6 – device bode (case), 7 – bunker

In the course of study, it was found that the most correctly chosen turbulence model, combined with the optimal number of cells in the calculation geometry, contributes to the acceleration of nu-merical simulation of gas-dynamic processes in the developed device. Among the considered models i.e. laminar, Spalart-Allmaras, k-ω, RSM and Transition SST, the most adequate one is Transition SST model. When changing the number of cells in the calculation grid from 1241551 to 3159388 for this model, the deviation of pressure loss in the classifier was 0.43%.

The advantages of developed classifier with coaxially arranged pipes are the following: design simplicity, ease of operation and high efficiency.

ACKNOWLEDGMENTS

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ELINA M. ABDRASHITOVA
Ufa State Aviation Technical University
Ph.D., Associate Prof. ELINA S. NASYROVA
Ufa State Aviation Technical University

LABOUR PROTECTION AND SAFETY DURING FIRE FIGHTING IN THE TANK FARM

The total number of accidents on tanks among other types of technological equipment is 3,8%. However, the dynamics of accidents at oil industry facilities is not decreasing. Analysis of data over the past 30 years has shown that the most common tank failures are brittle failure, explosions and fires. For storaging petroleum products vertical steel tanks are the most common, both in Russia and abroad. Since the oil industry is the leading branch of the Russian industry, fire safety plays a significant role in its functioning. Special attention is paid to the safety of firefighters. The issue of ensuring the firefighters safety when extinguishing fires in tank farms is considered by both Russian and foreign researchers [1-3]. The most common products stored in tanks are jet fuel, gasoline, fuel oil, and crude oil. Each of these substances is characterized by its own characteristics of the emergency situations occurrence. In this work a hazard matrix of petroleum products combustion is presented.

For example, spontaneous combustion of pyrophoric deposits is typical for crude oil. In this case, a directed graph of spontaneous combustion of pyrophoric deposits is created. It takes into account the factors affective the process of spontaneous combustion of pyrophoric deposits, and also reflects the relationship between the factors. In the article the rate of pyrophoric deposits formation for tanks made of various materials is calculated. If a fire occurs on the tank, there is a possibility of a "domino effect", which is the greatest danger for firefighters involved in extinguishing. For example, according to regulatory documents, it is forbidden to approach a burning tank closer than 100 m, and it is strictly forbidden to climb on adjacent tanks. For monitoring the situation, it is necessary to organize observation posts at a safe distance. At the same time, both extinguishing and monitoring should be carried out from the leeward side.

The explosion hazard of the tank depends on the meteorological parameters. In the work explosion hazard for a tank with aviation kerosene in March 2019 on the territory of Ufa is estimated. Also, the probability of a neighboring tank ignition in the event of a gasoline spill fire is determined. The condition is checked: the maximum wall temperature must be greater than 0.8 of the auto-ignition temperature. It is established that under the selected conditions of fire development, the tank remains stable.

For crude oil tanks boiling and ejection are likely. In this regard, the calculation of the boiling time of crude oil in tanks of various volumes was carried out. The time from the fire start to the boiling point mainly depends of the raw water level in the tank. With an increase of the tank volume, there is an increase in the time from fire start to boiling. The occurrence of fire is possible if three conditions are met simultaneously: fuel, oxidizer and ignition source. In tank farms, a burning tank is a potential source of ignition. The possibility of gasoline ignition from a nearby burning tank when a flying spark of fire enters to tank through the breathing valve is calculated. According to the obtained results, the energy of the flying spark exceeds the gasoline minimum ignition energy, which means that ignition is possible.

According to the Russian Law «Technical Regulations on fire safety requirements» (№123 22.07.2008), 6 fire hazards are identified, while their critical values are regulated only for indoor fires. Given that firefighters have personal respiratory protection equipment and suits protect against heat flow, from 6 factors the first place – reduced visibility in the smoke zone. According

to the calculations, the visibility in the smoke zone is 103 meters, which corresponds to the established 100 meters of safety during extinguishing. On the example of the vertical steel tank – 5000 with gasoline, the thermal impact of a fire is estimated. The safe distance for a person is 60 meters. However, do not lose sight of the fact that according to the regulatory requirements, a safe distance of 100 meters is accepted. For ensuring the safety of firefighters when extinguishing tank farms, specialized combat clothing with an increased level of protection against the thermal effects of flames and fire, the penetration of toxic combustion products, smoke through leaks in the helmet is necessary. Improved models of mittens should protect the hands of fighters, special protective shoes should be used when extinguishing. Thus, in the work the emerging hazards for firefighters when extinguishing a fire in a tank farm are analyzed. Application graph theoretic methodology for identified hazards will improve firefighting.

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KIRILL ANISIMOV
St. Petersburg Mining University
Dr. Prof. VLADIMIR P. ZUBOV
St. Petersburg Mining University

SPECIFIC FEATURES OF MINING PIT RESERVES IN THE CONDITIONS OF THE UDACHNY MINE

At the moment, mining operations at the Udachnaya kimberlite pipe have passed a transitional period.

When conducting underground mining operations using mining methods with caving, there is a possibility of dangerous destruction of the rock mass surrounding the pipe. [1,2]. This collapse can provoke dangerous deformations of underground mine workings and can lead to an emergency at the mine. The kimberlite pipe splits into two closely spaced steeply dipping ore bodies that are simultaneously mined. The rock mass, located between the ore bodies, consists of disturbed sedimentary rocks, with a well-developed network of cracks and zones of unstable stability. During mining operations, the destroyed open pit bottom will move downward, exposing the inter-ore massif [3]. The total height of this outcrop may be 700 meters. The collapse of rock blocks of the inter-ore massif from a specified height can cause catastrophically strong shock dynamic loads on the underlying mine workings. Under these conditions, the lack of a solution to the above-described problem can lead to the entire loss of geological reserves of the Udachnaya pipe.

In scientific work, based on data from open sources of information, the authors reviewed the materials of research and observations of the mining and geological situation during the development of the Udachnaya kimberlite pipe since the commissioning of the underground mine. The paper analyzes the main parameters of the applied high-performance mining method with storey forced caving with one-stage mining and areal ore production. In the work, the functionality and operability of the movable safety ore-rock massif was studied. Also in the scientific work, a

complex of various mining and geomechanical factors was formed and described, potentially complicating the conduct of underground mining operations.

Based on the analysis, recommendations were made on the further direction of research activities and a complex of scientific and technical work to eliminate hazardous mining and geomechanical manifestations caused by a constant increase in the depth of mining, taking into account the mining, geological and infrastructural situation at the Udachny mine. The authors recommend a complex of technical measures aimed at the preventive collapse of a hazardous rock mass. Conducting these preventive drilling and blasting operations will ensure the safe mining of the kimberlite pipe.

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R. L. ATOYAN
National Polytechnic University of Armenia

DETERMINATION OF THE APPLICATION AREAS OF SELECTIVE AND GROSS ORE EXTRACTION IN OPEN PIT MINING

Introduction. The Agarak copper-molybdenum deposit is represented by a single ore body-stockwork [1], which in plan has an ellipsoid shape with a length of 1.5 km along the strike and a horizontal thickness of 300 m.

The ore strength is 70...100 MPa, and the overburden strength is 30...40 MPa. The bulk mass of the ore is 2.56 t/m^3. A characteristic feature of the host rocks is strong fracturing. The ore content coefficient varies in the range of 0.37...1.0.

The problem statement and the method justification. The Agarak copper-molybdenum deposit is exploited by open-pit mining, and the distribution of useful components is very uneven, which leads to the fragmentation of individual blocks of minerals that are separated from each other by areas with a low content of the useful component. Under such mining and geological conditions, a question arises concerning the feasibility of using technologies that provide selective or gross ore extraction, justification of the boundaries between them, depending on the ore-bearing coefficient.

If we assume that the dilution of ore is not associated with the mixing of nonconditional ores, which inevitably break off on contact ores, then when using a technology that provides gross ore extraction, the coefficient of change in ore quality ($K_{q.g}$) is equal to the coefficient of ore content (K_o), and when using a technology that provides selective ore extraction, the coefficient of change in ore quality (K_q.s) is determined by the following expression [2]:

$$K_{q.s}=K_o+(1-K_o)p, \quad (1)$$

where *p* is the part of the internal overburden that is removed to the external dumps, in fractions of units.

The expected profit per 1 ton of balance reserves (V_i, $/ton) for the i-th option (gross or selective ore extraction) is determined by the following formula:

$$V_i=(C_{vi}-C_{Ei})\frac{K_{sibi}}{K_{si}}, \quad (2)$$

where C_{Vi} is the recoverable value of 1 ton of ore for the i-th variant of ore extraction, $ / t; C_{fi} - the total cost of ore extraction and processing for the i-th variant of ore extraction, $ / t; K_{subi} - the coefficient of ore extraction from the subsurface for the i-th variant of ore extraction, in fractions of units; K_{si} - the coefficient of ore quality change for the i-th variant of ore extraction, in fractions of units.

The recoverable value of 1 ton of ore is determined by the following formula:

$$C_{Vi}=\gamma P_c \quad (3)$$

where γ is the yield of concentrate, in fractions of units; P_c - the price of 1 ton of concentrate, $/ton.

$$\gamma = \frac{\alpha K_s - \theta}{\beta - \theta}, \quad (4)$$

where α is the content of the useful component in the ore mass,%; θ - the content of the useful component in the enrichment tailings,%; β - the content of the useful component in the concentrate, %.

Substituting formulas (3) and (4) into expression (2), and taking into account the value of the ore quality change coefficient in the context of the above, we get a profit per 1 ton of balance reserves for gross (V_g) and selective (V_s) ore extraction.

$$V_g = \left(\frac{\alpha K_s - \theta}{\beta - \theta} P_c - C_f\right)\frac{K_{sub}}{K_o}, \quad (5)$$

$$V_s = \left(\frac{\alpha K_{q.s} - \theta}{\beta - \theta} P_c - (C_{o.g} K_m + C_r)\right)\frac{K_{sub}}{K_{q.s}}, \quad (6)$$

where $C_{o.g}$ – the cost of ore extraction at gross extraction, $/t, C_r -the cost of ore processing, $/t, K_m-the ratio of specific production costs for gross and selective extraction of ore.

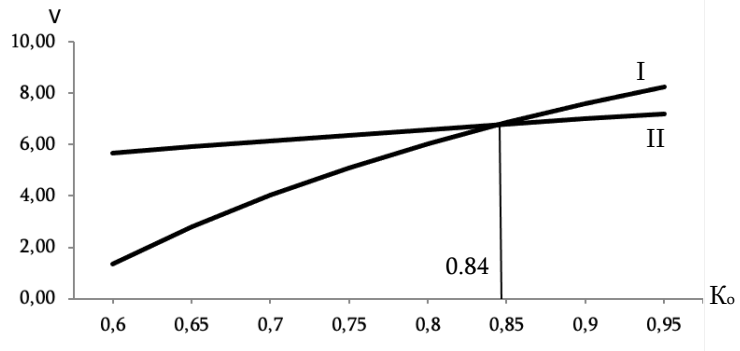
The results of the study. The mining and processing plant operating on the basis of the ore reserves of the Agarak deposit is characterized by the following technical and economic indicators for copper: α_{Cu} = 0.5%, θ = 0.04%, β = 24%, P_c = 1000 $/t, C_f = 10 $/t, $C_{o.g}$ = 5 $/t, K_m = 1.3, C_r = 5 $/t, p = 0.7 and K_{sub} = 0.96.

All other things being equal:

$$V_g = 20{,}03 - \frac{11{,}20}{K_o}, \quad (7)$$

$$V_s = 20{,}03 - \frac{12{,}64}{0{,}3K_o + 0{,}7}. \quad (8)$$

The figure shows the profit per 1 ton of balance reserves for gross and selective ore extraction, depending on the ore-bearing ratio.



I-Gross ore extraction, II-Selective ore extraction

Fig 1. Profit per 1 ton of balance reserves for gross and selective ore extraction, depending on the ore-bearing ratio

The analysis of the graphs shows that under other conditions, up to 0.84 values of the ore-bearing coefficient, the most effective implementation is selective extraction, and at high values of the ore-bearing coefficient - the gross extraction of ore.

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VADIM G. BEKHER
National University of Science and Technology "MISiS"
Assoc. Prof. VLADIMIR V. TALANIN
National University of Science and Technology "MISiS"

JUSTIFICATION OF THE EFFICIENCY OF REGULATING THE TRANSPORT WORK OF THE OVERBURDEN TRAFFIC AT COAL QUARRIES WITHIN THE STAGES OF OPEN PIT MINING

Introduction. The cyclical nature of price fluctuations in the coal market is characterized by periods of maximum and minimum with an overall positive price dynamics. During the operation of coal deposits, with price changes from period to period, it is advisable to promptly change the cost of production by managing operating costs for stripping, as its main part. During the period of the maximum prices, it is advisable to increase the costs of stripping works by increasing their volume or moving the overburden to more distant zones of dump fields, thereby increasing the competitiveness of coal reserves, which will be worked out during the period of minimum prices. In practice, the main task is to minimize the cost of coal mining at each stage of the development of the deposit, which leads to a constant deterioration of the mining conditions for the development of reserves during the operation of deposits [1,2]. Many scientists and mining engineers were involved in the determination of the final contours of opencast mining, as well as the regulation of mining regime: A.M. Terpigorev, I.A.Kuznetsov, A.I. Steshenko, M.I. I. Gorodetsky, N. A. Starikov, P. E. Zurkov, B. P. Bogolyubov, B. V. Fadeev, A. S. Fidelev, M. I. Agoshkov, E. F. Sheshko, V. V Rzhevsky, A. I. Arsent'ev, K. N. Trubetskoy, J. Hill, V. S. Khokhryakov, V. V. Istomin, Yu. I. Anistratov, M. G. Sakantsev, etc.

Main part. The share of transport costs in the total operating costs for stripping work can vary from 20% to 80%, depending on the type of transport and the distance of movement [6, 8]. Automobile transport, which has the highest unit costs per ton (cub) - kilometer of moving quarry cargo, reacts to an increase in the distance of transportation largely, in comparison with other modes of transport. Unit transportation costs are not constant and tend to decrease with an increase in the carrying capacity of dump trucks and the distance of travel.

Ehe use of the indicator of the specific transport work of overburden traffic does not provide the correct level of operating costs for overburden work. This is due to the fact that the same volume of transport work can be determined by different values of the current stripping ratio and transportation distance, while the value of operating costs will differ. A predetermined value of operating costs for stripping works can be achieved by achieving a balance between the level of the current stripping ratio and the distance of transportation of the stripping rocks.

For open-pit mines, mined according to the deepening development system, from the standpoint of reducing the transportation distance in the opencast, it is advisable to locate an exit to the surface and a dump in zones with minimum elevation marks.

Conclusion

1. In the context of cyclical changes in prices on the coal market, it is advisable to develop coal deposits in stages, the duration of which makes it possible to predict prices with an acceptable level of reliability.

2. It is recommended to use the limiting stripping ratio as a criterion for justifying the boundaries of the OGR stage.

3. It is necessary to determine the values of the limiting stripping ratio of the OGR stage separately for each block or section of the field, characterized by different mining and geological or mining conditions of occurrence of a mineral, coal quality, degree of extraction from the subsoil, transportation distance and other indicators that have a significant impact on the change in economic open pit exploitation indicators.

4. It is advisable to justify the boundaries of the OGR stage in the overburden zone by comparing the limiting stripping ratio, which takes into account the standard efficiency factor, with the average stripping ratio of the OGR stage or by ensuring a given level of operating costs for stripping work.

5. The established dependence of the current overburden ratio on the distance of overburden transportation makes it possible to determine the ratio of these indicators, which ensures a stable level of operating costs for overburden operations.

6. To effectively regulate the transport operation of overburden cargo traffic, it is advisable to distribute the current volumes of overburden by exits from the open pit for each overburden block of the model, taking into account the total transportation distance (including over the surface) when placing dumps in zones corresponding to the current overburden ratio.

7. With a significant drop in coal prices, it is possible to ensure a break-even operation of the enterprise by reducing the distance of transportation of overburden by placing temporary dumps within the mining allotment in zones with more valuable coal in terms of quality, or in areas with favorable mining conditions that will preserve the economic feasibility of mining after placing the dumps.

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DMITRY O. BOROVIKOV
St. Petersburg Mining University

APPLICATION OF THE RISK-BASED APPROACH AND THE SAFETY INDEX AS FUNDAMENTAL ELEMENTS OF PROFESSIONAL RISK CONTROL

The assessment of the efficiency and safety of the functioning of modern mining companies in Russia has shown that at the present stage, almost all the main causes crashes and accidents have already been eliminated, but at the same time, various occupational risk factors continue to affect employees, which arise due to the complexity of the existing organization of internal audit of labor protection conditions and, as a result, the applied measures to ensure industrial safety and labor protection are not always correctly oriented [1-2].

An approach to the modernization of the occupational health and safety management system in a Russian mining company was proposed based on the introduction of a risk-based approach that reduces the likelihood of occupational risks [3].

The analysis of the available information on the methods used to assess occupational risks for the purpose of occupational health and safety management is carried out, the disadvantages and advantages of each of them are identified.

The main results and research components of the work are a map of professional risk assessment for the dragline driver, compiled based on real data related to incidents, consisting of 90 dangerous situations, on the basis of which the main causes of injuries at a real mining enterprise were identified, as well as an assessment of the safety index (Elmery index) for the identified factors [4]. The proposed methodology based on the safety index allows us to assess the overall level of safety when exposed to certain hazards, as well as to justify the implementation of appropriate measures in the field of labor protection. The simplicity allows us to recommend the methodology for use to ensure a rapid assessment of the level of safety at individual production sites of coal enterprises, for example, within the framework of supervision by trade union labor protection inspectors.

To prepare the map, the register of violations (incidents) was carefully analyzed, which includes more than 12 thousand cases over the past 10 years in the section, but the study took into account only those cases that are directly related to the work of the dragline driver, which in turn required additional analysis. The opinion of employees directly related to the performance of technological operations, exposed to harmful and dangerous production factors, is taken into account in order to identify the frequency of dangerous situations and the severity of the consequences of the implementation of such events according to the employees of the enterprise themselves. Third-party experts were also involved, whereby it was possible to structure the information obtained during the study.

As part of the modernization of the occupational health and safety management system, it is now necessary to competently manage occupational risks based on the use of assessment maps. At the same time, the Elmery index should be calculated to ensure an operational assessment of the level of safety at the enterprise [5].

The existence of such an integrated approach will allow the company to cover a significant area of control, divide it into components and simplify the monitoring process itself, improving the quality and timeliness of the measures taken.

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PAWEŁ DESZCZ
AGH University of Science and Technology
Dr hab. inż. DARIUSZ OBRACAJ, prof. AGH
AGH University of Science and Technology

THE VERIFICATION OF THE ANALYTICAL MODELING OF THE CLIMATIC CONDITIONS IN THE COAL MINE HEADING BY COMPUTIONAL FLUID DYNAMICS

Technical safety measures gain significance at the underground workplace, where occurs natural threats. In the paper are presented the geometrical model of the head-zone of development heading with auxiliary ventilation. The model will have been using to conduct the computer airflow analysis. The analytical model of microclimate prediction in the underground excavation of a coal mine is presented in the paper. This model was compared to the results of the numerical simulation. The numerical model was made based on real heading with equipment, which is typical in polish underground coal mines.

This research is focused on the air temperature in the mining excavation. This solution was used specific technical solutions, which are applied in Poland. The auxiliary ventilation of the underground heading supplies the air to the face of the heading by forcing duct. The short air duct connected to the dust collector is located in the face zone. This solution of the auxiliary ventilation is called the forcing with exhaust overlap ventilation system. The prepared analytical solution was compared to the measurement results of the climate conditions in the currently driven heading in one of the Polish coal mines. The prediction results for two variants of the solution to ensure appropriate environmental conditions in the heading face zone were showed. These variants refer to solutions without cooling and cooling the air supplied by force ducting to the whirl flow air duct. In both cases assumed the same air stream from the whirl flow air duct and the same operational efficiency of the dust collector.

The possibility of application thermal insulation on both sidewalls was checked using computational fluid dynamics. The numerical model was validated with the measurement data from one of the currently driven heading to check the mathematical model's correctness. The convergence was achieved. In this case, two solutions were proposed to prevent the heating of the air from the rocks. The mathematical solutions have checked these two proposals.

The numerical simulation was conducted as the transient simulation, taking into account the advancing of the face of the heading. Two different time horizons are considered. The obtained results from the numerical simulation told that the application of the insulation on the side walls has a significant influence on the air temperature in the heading, even though the supplied air is not cooled in the fore ducting. The application of the walls insulation in the long term might allow for the use of alternative solutions in the cooling, which would reduce the operational costs and the energy consumption by the mine. The application of the solution would allow reducing the total costs of development works in a coal mine.

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ALINA A. EVSYUKOVA
South-Russian State Polytechnic University (NPI) named after M. I. Platov
Dr. Prof. NIKOLAI V. TITOV
South-Russian State Polytechnic University (NPI) named after M. I. Platov

PROSPECTS AND FEATURES OF IMPROVING PILLAR MINING IN THE MINES OF EASTERN DONBASS

Introduction. The efficiency of the development systems used in the mines of the Eastern Donbass is analyzed in this article. The necessity of switching to the preparation of each lava by excavation workings used once is justified. A safe method for protecting drifts with minimal loss of coal in the pillars with artificially set pliability is proposed.

Main part. As it was estimated on 01. 02. 21 in the Eastern Donbass (Russian part), coal is being extracted at four operating mines, while only anthracite layers are being developed.[1]

The K2 formation with a capacity of 1.05-1.25 m within the mountain branches of the named mines lies hollow, its feature is a low sulfur content (less than 1 %), that is, the coal of the formation has a high export potential.[2] The development of the formation is carried out using a panel method of preparation, the development system is long columns along the strike, the length of the excavation column is up to 2 km, the length of the lava is as a rule, within 200-250 m, and specific work is carried out using narrow-grained combines, often with the cutting of side rocks.

A special feature of the applied development system is the double use of the conveyor drift as a vent for the lower lava flow, the ventilation drift itself moves as the cleaning face is moved, so the security structure here includes shave and an battery stulls that can support the joint of the lava with the drift for a short period of time, and then collapse.

With the deepening of mining operations to significant depths (-500m or more) it turned out that despite the high complexity of the construction of these security structures, they perform their intended function unsatisfactorily.[3]

As a compromise, in the mines, the ventilation drifts began to pass" cut " closely or leaving a pillar, but the effectiveness of this technology was quickly exhausted: the workings come to an emergency state, despite the arched mounting and increased parameters of the pillar (the Obukhovskaya mine); the need to have wider workings for the removal of conveyor drives on the drift also played its role. If on the upper horizons the former conveyor track had to be re-fastened, for normal operation as a ventilation, then on the deeper horizons, where work is currently being carried out, by the time the upper lava stopped, the drift was completely unusable.

Thus, for the normal operation of the lava, objectively there is a need for its individual preparation by two" own " drifts leaving of inter-ststific pillars.

The economy of multi-track preparation is provided by the combine method of cutting a group of workings, since the layers being worked are of medium capacity. In our opinion In our case, when the rocks containing the K2 formation have a high strength (up to 7) and only a drilling and blasting method of excavation is possible, the option with simultaneous ventilation (for the lower lava) and conveyor (for the upper lava) pairs of drifts with a pliable pillar between them is justified.

You can solve this problem sequentially: first, drill the whole well with wells, and then, with some slight lag in time and space, fill the wells with crushed rock, the bearing capacity of which can be increased by pumping the binder along the entire length of the well or some of its parts.

Thus, drawing a conclusion from the conditions of increased gas content and depth of coal seams, the key to effective work and safe cleaning operations at high loads on the faces will be possible to consider in more detail the possibility of moving away from the pillar to multi - track pillar preparation of excavation sites, taking into account gas and geodynamic processes in the massif and in the developed space of the Eastern Donbass.

Conclusion. To optimize the parameters of the dredging column preparation using the "paired drifts" scheme, it is necessary to carry out studies on the stability, first of all, of the ventilation drift of the lower lava.

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ILDAR R. FAZYLOV
St. Petersburg Mining University
Dr. Prof. SEMEN G. GENDLER
St. Petersburg Mining University

ADAPTATION OF THE METHODOLOGY FOR CALCULATING THE AIR TEMPERATURE IN MINE WORKINGS FOR THE CONDITIONS OF OIL MINES

The problems that arise when using the thermos-mine method of oil production at the Yarega field, located in the Republic of Komi are considered. The main problem with this method of extraction is the deterioration of the microclimate parameters in the mine workings. This is due to the fact that the development technology involves the injection of a coolant into the oil reservoir and the selection of an oil-containing liquid through the mine workings. The air temperature in the workings can be rise to 40 °C [1].

This has a negative impact on workers and it becomes obvious that it is necessary to normalize the thermal regime of mine workings. The study of the thermal regime of mining workings in general was carried out by such scientists as Dyadkin Yu. D., Shuvalov Yu. V., Shcherban A. N. The study of the features of heat and mass transfer processes in the mining workings of oil mines was carried out by scientists of the State Research Institute of the Ural Branch of the Russian Academy of Sciences (Levin L. Yu., Zaitsev A.V., Klyukin Yu .A, Semin A.V.), and employees of the Ukhta Mining University.

The author analyzed the field studies of the thermophysical parameters of the mining block, identified the main factors that form the thermal regime of the mining block, depending on the stage of development of the block. It was found that the air temperature in the production gallery can exceed 44.4 °C for the roof of the mine and 40.6 °C for the soil. To predict the temperature regime of the mining block, a mathematical model of heat and mass transfer processes was proposed [2].

A computer simulation of the heating of air moving through the mine workings of the production gallery was performed in the Ansys CFX software package. Based on this, it was assumed that the process of heat exchange between air and rocks can be considered quasi-stationary. Having accepted this assumption, the formula of Dyadkin Yu.D. and Shuvalov Yu. V. was adopted for the calculation of heat releases. The formula was adapted for the conditions of oil mines, heat gains from the transported oil-containing liquid, the heated mass and formation, and the breaking steam were taken into account [3-4].

To test the proposed method of calculating heat gain in the mine workings, field studies of the production block of the oil mine were analyzed. The results of the measurements of the

employees of the State Research Institute of the Ural Branch of the Russian Academy of Sciences were tabulated and compared with the results of the calculations according to the previously proposed method.

According to the results of comparison of field measurements and the obtained values in the calculation of the proposed method, it was found that the data converge, this confirms the adequacy of the application of the calculation method for predicting the thermal regime of the production block of oil mines.

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DMITRIY V. FEDCHENKO
Kemerovo Institute of Coal and Coal Chemistry SB RAS
Dr. Prof. ANDREY A. EREMENKO
Kemerovo Institute of Coal and Coal Chemistry SB RAS

TECHNOGENIC SEISMICITY DURING OPEN-PIT MINE DRILLING AND BLASTING OPERATIONS

Currently, the volume of mining continues to grow, new enterprises are being opened, the volume of drilling and the volume of explosives used in the production of drilling and blasting operations are increasing. All this entails a constant increase of human impact on nature and leads to an increase in the risk of technogenic seismic activity, which can often be caused by mass blasting operations at large mining companies in Kuzbass. Underground or on the surface, such events receiving great public response and widespread discussion in the press and social networks. [1]

Let us consider the definition and classification of the forms of technogenic seismic activity proposed by A.V.Nikolaev and V.V.Adushkin. [2] Micro oscillations, seismic shocks and earthquakes that occur in the earth's crust under any anthropogenic impact on the environment or that appear and develop with the participation of their own energy reserves in the structures of the earth's crust are called technogenic seismicity. The concept of a mass blasting means a blasting of two or more borehole charges mounted in a common explosive network, regardless of the length of the charged unit, as well as single charges in units longer than 10 m. So our goal was to find ways to reduce the negative impact of industrial explosions on the environment.

We distinguished three stages of the production of drilling and blasting operations, such as:

1. Preparation of a draft. (Drafting of a drilling project in accordance with the project documentation).
2. Drilling boreholes.
3. Borehole charge formation and installation of an initiation system. (In accordance with the project of a mass blasting, company documentation and considering all the unique features of the particular area).

We propose a number of methods that allow to decrease technogenic seismicity at each stage of the production of drilling and blasting operations.

1. Depth, shape and pattern of boreholes drilled for blasting. Increasing the size of the grid leads to a decrease in the mass of explosives in the boreholes, which leads to a decrease in seismic activity during massive explosions. [3, 4] Thereby, we receive reducing the explosives consumption, improve the quality of rock fragmentation and also considering all the factors affecting the intensity of the seismic vibrations.

2. Properties of the explosives used in blasting operations. In view of the fact that the influence of the explosives properties is expressed in the distribution of energy costs for fragmentation and excitation of seismic vibrations, changes in the time of exposure of the explosion to the environment and the frequency composition of vibrations, explosives with a lower detonation velocity are more preferable in the reducing the seismic effect of an explosion point of view.

3. Charge formation in the borehole. In order to meet all safety standards at this technological stage, in high-risk areas it is important to use less explosives or to perform additional "dispersal" of explosives in the borehole. With an increase in the number of outcrop planes, the rate of oscillation of rock particles decreases. Compared to blasting in an overconsolidated environment In this case, the seismic effect can be reduced by 4–5 times.

4. Type and speed of the initiation system. To reduce the negative seismic impact it is recommended to use non-electric initiation systems or an electronic initiation systems when calculating the initiation scheme of a surface blasting network. Using these type of systems in the blasting network installation scheme, when a surface initiation device is installed in front of each borehole, it is possible to accurately calculate the actual time of the initiation pulse approach, as well as simulate its passage through the surface blasting network.

Considering all the above factors, at each stage of the production of drilling and blasting operations, it is possible to achieve a significant reduction in technogenic seismicity without deteriorating the planned operation parameters.

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FROLOV NIKITA ANDREEVICH
Norilsk State Industrial Institute
Candidate of Technical Sciences, Associate Professor NATALIA A. TURTYGINA
Norilsk State Industrial Institute

JUSTIFICATION OF THE RATIONAL TECHNOLOGY FOR STABILIZING THE QUALITY OF PRODUCTION IN THE UNDERGROUND DEVELOPMENT OF THE DEPOSIT OF DISSEMINATED COPPER-NICKEL ORES

At the Norilsk copper-nickel deposits, there is a tendency to a decrease in the content of metals in industrial reserves, which is accompanied by an increase in the indicators of variability in the quality of ores. In general, the structure of the reserves of the Norilsk deposits is such that more than 70% of the total amount of metals are in disseminated ores, the proportion of which

increases with the extraction of rich ores. This requires the development of a rational technology to stabilize the quality of ores to solve the problem in the future. The paper proposes a justification for the choice of a rational mining technology ensuring the stability of quality indicators in the ore mass during the development of the Norilsk mineral deposits.[1]

The work studies the conditions and ways of increasing the stability of the copper-nickel ores composition using the example of the Norilsk-1 deposit, which is being developed by the Zapolyarny mine. The production capacity of the mining enterprise is 1200 thousand tons of ore per year. Ore mining is carried out by a system for the development of storey (sublevel) caving with end discharge of ore and the use of complexes of highly productive self-propelled equipment at a depth of 350 to 450 m. Rock pressure control is carried out by means of advanced forced collapse of overlying rocks to a height not less than the sublevel height and not more than 40 m. The advanced mining of high-grade ores and the long period of exploitation of the deposits led to a decrease in the overall quality of ores. At present, ore reserves during the mining of disseminated copper-nickel ores are replenished due to the opening and preparation of the southern section of the Prirezki mine field of the Zapolyarny mine.

Of the technological factors, the development system has the greatest influence on the change in the natural quality of a mineral. The practice of using the development system at the Zapolyarny mine has shown that this technology does not ensure the completeness of the extraction of reserves and the efficiency of mining operations due to the low actual rates of extraction during ore mining (losses up to 20% and impoverishment up to 25%). In this regard, the paper presents design decisions that best suit the mining conditions of development at the present stage of reserves development in the southern section of the Prirezki mine field of the Zapolyarny mine. [2]

The work considers the following options for development systems:

1. the use of a combined development system with the formation of chambers with a flat bottom and subsequent forced collapse of overlying rocks and level excavation of rectangular pillars when they are located along the strike of the deposit. It allows improving the ore recovery rates during mining.
2. the use of a combined development system with the excavation of chambers of increased width and their subsequent filling with waste rock and breaking of trapezoidal pillars together with the collapse of overlapping rocks. This allows improving ore extraction rates to reduce the volume of cutting operations on the rock and operating costs in general. Besides, it ensures the effective use of highly productive self-propelled equipment in all ore mining processes and gives the possibility of placing a significant amount of waste rocks in the dead chambers. [3]

The paper develops the basic design of the mining and technical equipment – a layer-type bunker for mixing finely crushed ore and the reconstruction of the homogenizing blending complex. This design of the bunker makes it possible to mix the ore mass more efficiently than the usual type, since it has a much higher contact area of different-quality layers. The height parameters of the bunker are reduced to 5-7 m, the width is up to 3-4 m, and its length is 27 m. The effectiveness of the proposed solutions is determined by a decrease in the level of losses, impoverishment and the volume of preparatory and cutting operations. All this will significantly improve the completeness and quality of the extraction of mineral reserves from the subsoil and provide an increase in the company's profit by 17% at the Zapolyarny mine. The developed complex of engineering solutions aimed at the practical improvement of the composition of the mined ore mass on the basis of research and engineering developments constitute a conceptual material for the design, reconstruction and operation of underground mines, which can significantly increase the stability of the composition of mined ores. [4]

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YAROSLAV S. GLATKO
National University of Science and Technology «MISiS»
ROMAN V. SULTIMOV
National University of Science and Technology «MISiS»

MINING INDUSTRY ROBOTICS

Working in mining conditions is associated with numerous risks. In turn, the modern industry requires more and more minerals, but the resources are running out. Now mining enterprises must develop deposits with more complex mining and geological conditions. As a consequence, the risks become more dangerous and probability of their occurrence. In the mining industry, fatal accidents are 10 times higher than the industry average. The solution to this problem can be industrial robotization.

The shifts to robotic devices can help create “Humanless Mine”. This means that the work that people used to do, now the technique can perform independently. The main advantage of the implementation of this concept is a limitation in technicians working in hazardous areas. In addition to the risk of roof falls, explosions, fires or flooding, they include the risk of intoxication by toxic gases or suffocation from "black damp". The presence of people in places with insufficient ventilation or high temperatures can be avoided. The creation of an automatically updated map contributes to the operational planning of work, the optimal placement of equipment and is the basis for modelling the ventilation system. By reducing the human factor, the efficiency and speed of production will increase.

However, mining operations are driven by an aggressive environment, higher environmental dust loads, with standing pools of water at low pH values causing premature equipment failure due to corrosion. Temperatures range from low to very high (typically – 40 °C to 50 °C). This determines the high requirements for the strength of the materials for techniques manufacturing. If mining releases methane, the equipment must be explosion-proof.

Analysis of existing robotic installations in the mining industry showed that it is necessary to systematize according to the degree of their autonomy. A similar challenge was already faced in the automotive industry and the J3016 standard was created by the SAE marketing group in conjunction with the Technical Standards Committee. Taking into account the existing examples of systematization of autonomous devices and experience from related industries, we have developed our analogue. In comparison with the existing systematizations, we have proposed a refinement of this classification, taking into account modern solutions.

After analyzing the existing robotic systems in terms of their degree of autonomy, it was found that open-pit mining already has all the possibilities for introducing the concept of a “humanless open pit”. However, underground mining enterprises can only robotize some processes. This is mainly due to the lack of a GPS signal and the difficulty of conducting WI-FI and 5G LTE in mine workings.

The concept of installing target cubes in mine workings for the navigation of robotic systems in mine conditions is proposed. To test this hypothesis, a robot was designed, and the research methodology was proposed.

The technique consists of comparing the accuracy of terrestrial polygonometry traversed with a total station and with a scanner installed on a robotic device. The main and working hanging

polygonometric traverse will be completed. Measurements with the total station will be taken as a reference.

Scanning will be performed 10 times to assess the accuracy of measurements using the Gauss formula. The result of the study will be a certain root mean square error in measuring the coordinates of the points of the polygonometry traversed.

Scientific advisor: Doctor of Economics, Professor A.V. Myaskov

BEKZHAN E. ISSAKOV
Karaganda Technical University
AIZHAN K. AMIRGALINA
Karaganda Technical University

STATISTICAL INDICATORS OF MINE SAFETY

Various types (groups) of statistical indicators are used to quantify the safety level of a team based on the results of technological operations performed at coal mines. They are expressed in physical quantities or the ratio of these quantities obtained as a result of processing statistical data, completed production tasks.

Statistical indicators can be divided into general and particular, absolute and relative [1]. General indicators characterize the level of safety of the team at the facility as a whole, take into account the integral influence of all factors on it, and private ones-only individual factors or groups of factors.

Absolute statistical indicators include: the total number of incidents, accidents and catastrophes, the total number of accidents, the use of personal protective equipment, the inclusion of an accident response plan, etc. However, due to their limited practical application (due to their dependence on the total number of mines, facilities, teams, etc.), the most widespread are relative indicators that can be attributed to a certain period of time of the team, the number of homogeneous technological objects, the number of working shifts, the number of cases of occurrence of any events, etc [2].

Relative statistical indicators can be divided into the following types (groups) of indicators:

- general;
- causality of occurrence of non-standard (emergency) situations;
- distribution of emergency situations by hazard factor;
- distribution of non-standard (emergency) situations by technological operations;
- temporary indicators of non-standard (emergency) situations;
- indicators of personnel's fitness to get out of non-standard (emergency) situations;
- effectiveness of the team's actions to get out of emergency (emergency) situations;
- erroneous actions of personnel;
- additional indicators.

General indicators. The average number of incidents is the average number of incidents of the i-th type (accident, disaster, etc.), attributed to a certain number of work shifts or the time interval of the operation of the technological object (the volume of work),

$$\overline{n_i} = \frac{n_i}{A(t)}, \quad (1)$$

where n_i is the number of the i-th type incidents for the time period under consideration; $A(t)$ is the time or number of working shifts for the time period under consideration.

The main varieties of this generalized indicator are:

a. the number of accidents per one $(\overline{n_{k1}})$, 10$(\overline{n_{k2}})$ and 100$(\overline{n_{k3}})$ work shifts, where n_k is the total number of accidents for the period under review;

b. the number of accidents per one ($\overline{n_{AC1}}$), 10($\overline{n_{AC2}}$) and ($\overline{n_{AC3}}$) working shifts, respectively, where n_{AC} is the total number of accidents that occurred in n_{Σ} work shifts; n_{Σ} - total number of working shifts for the period under review;

c. number of accidents per one ($\overline{n_{a1}}$), $\mathbf{10}$($\overline{n_{a2}}$), 100($\overline{n_{a3}}$) work shifts, where n_a- total number of accidents observed in n_{Σ} work shifts;

d. number of personnel rescues per one($\overline{n_{c1}}$), $\mathbf{10}$($\overline{n_{c2}}$), 100($\overline{n_{c3}}$) work shifts, where n_c- the total number of working shifts out of n_{Σ}, in which the rescue of personnel was carried out through the use of the emergency rescue system.

Another type of indicator (1) is indicators related to a certain number of hours (days) of operation of a technological object

$$\overline{m_i} = n_i / t_{\Sigma},$$

where n_i - the number of accidents (catastrophes, etc.) with the total number of working shifts during the existence of the technological object $t_{\sum}$. These indicators are usually attributed to a certain number of working hours (for example, 10^3h).

The proportion of accidents that have occurred, according to their traumatic factors and causes, is usually determined by a statistical method and allows you to fairly effectively assess the state of safety at enterprises and the most dangerous technological processes and areas [3].

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ALEXEY V. KHOLMSKIY
St.Petersburg Mining University
Ph.D. senior lecturer ALEXANDER A. SANKOVSKIY
St.Petersburg Mining University

FEASYBILITY STUDIES OF UTILIZATION THE TECHNOLOGICAL SCHEMES OF NON-EXPLOSIVE MINING ON THE ROCK BURST HAZARDOUS BAUXITE DEPOSTIES OF "SUBR" COMPANY

"Severouralboksitruda" company ("SUBR" comp.) is conducting an underground mining of rock bump hazardous North Ural bauxite basin [1]. 80% of overall mining methods relates to room-and-pillar mining method. Mining operations are conducted with blasting and situated in the most complicated geological and technical conditions: the depth of operations is 1400 m below the surface, rock bumps, difficulties with the ventilation. The factor of ventilation cause the idle time of equipment for 1 shift (7 hours). This effect negatively on productive capacity of mining operations.

The main goal of studies is to increase the productive capacity and perform a shift to different technological scheme of mining operations, which are applicable for complicated geological and technical conditions of "SUBR" comp. deposits.

Patent search of analogous technological schemes with a focus on safe mining of rock bump hazardous deposits did not shown the scheme, which can be equivalent to what is used at the present moment. New technological scheme should be comparable with an actual scheme, or cheaper, from the economical point of view.

So called “bottle neck” of mining operations is the blasting works. Blasting can provoke the hazardous rock mass to additional human-generated cases of rock bumps. Harmful fumes after the blasting are making the ventilation more difficult, considering the big depth of mining operations.

During the search and analysis of different mining methods the following methods are reviewed: non-explosive systems like “Cardox”, “Nonex”; selective heading machines; hydraulic breakers [2]. The hydraulic breakers are showing high productive capacity on mining operations versatility and simplicity in utilization, reliability and quite low cost. Also, utilization of hydraulic breakers does not have disadvantages, which are related to traditional mining methods. Hydraulic breakers are utilized on tunnel drifting and open-pit mining with different rock mass characteristics [3]. There are three classes of hydraulic breakers: light, medium, heavy. The standards of breakers production are similar among the different names of manufacturers.

Figure 1. Tunnel drifting with hydraulic breaker on an excavator

The productive capacity of hydraulic breakers is defined by the impact energy, however, consideration of just one parameter is not an option in case of underground mining. Multiple parameters should be considered, and these parameters should affect the productiveness strictly. In this manner, the methodic for breaker productiveness determination is formulated. This methodic considers the physical and mechanical characteristics of rock mass, pressure in hydraulic system, dynamic coefficient and diameter of anvil. Based on this methodic, the direction sheet [4] for mechanical stoping is worked out. With such direction sheet the productive capacity of hydraulic breaker in concrete conditions is determined. Utilization of hydraulic breaker will not cause the increase of risks, related to rock bumps. The reason is in more rhythmic redirection of stress in rock mass.

Advantages of hydraulic breakers utilization forwarded to the new technological scheme of mining operations on “SUBR” mines. New scheme does not have cardinal differences with currently utilized scheme, which gives the opportunity to save the same costs for primary and secondary mining. Instead of drill-rigs and scrapers it is proposed to utilize hydraulic breakers, attached to tunneling machine, shuttle cars. Utilization of hydraulic breakers allows conducting mining operations continuously. Continuous mining provides less idle time of equipment, better ventilation of work places and increase of productive capacity in general.

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FARRUKH T. KHUDOYBERDIEV
Tashkent State Technical University named after Islam Karimov
YORKIN T. NURBOBOEV
Tashkent State Technical University named after Islam Karimov
PhD. Ass.Prof. DILMUROD R. MAKHMUDOV
Tashkent State Technical University named after Islam Karimov

INVESTIGATION OF HYDROGEL PARAMETERS FOR USE AS A BOREHOLE DURING DRILLING AND BLASTING OPERATIONS IN THE CONDITIONS OF THE KYZYL ALMA MINE

The bulk of mining operations at coal and ore mines are currently carried out by drilling and blasting, so the issues of improving the efficiency of blasting operations are of paramount importance. Special attention should be paid to improving the efficiency of the explosion when conducting blasting operations by the method of borehole charges, which in fact is the main method in the practice of mining operations.

One of the factors that determine the conditions and the effectiveness of the explosion of hole charges of explosives is the internal hammering of the holes. Its size and quality largely determine the rate of use of boreholes(KISH), the uniformity of the crushing of the massif, as well as the amount of dust and toxic gases entering the mine atmosphere during the explosion.

The quality of the internal driving of boreholes primarily depends on the used driving material. Special studies [1-3] found that the value of the resistance per unit cross-sectional area of the same length, but made of different materials, varies widely. Therefore, the correct choice of the material of the face is of great practical importance. The main requirements for slaughterhouse materials are:

- ensuring high explosion efficiency;
- easy handling;
- the possibility of mechanization of work on the stemming;
- low cost.

According to the physical and mechanical properties and the nature of the resistance that prevents the discharge of gaseous detonation products from the hole, all currently used types of bottom hole can be grouped as follows.

1. Stemming of plastic materials (clay, sand-clay and slaughtering of loam).
2. Stemming of bulk materials (sand and granulated blast furnace slag).
3. Liquid stemming.
4. Stemming holes with plugs made of solid materials.
5. Stemming holes with solutions of fast-hardening binders.

The above mentioned types of slaughters have a number of advantages and disadvantages. To study the parameters of the hydrogel in the conditions of the Kyzylalma mine, experiments were conducted to determine the swelling time depending on the size of the fraction up to 1 mm and in a mixed form, the water/hydrogel ratio under different temperature conditions, the indicators of which are shown in Table 1.

Table 1 – Determination of the hydrogel swelling time, min

Dimensions of hydrogel granules, mm	Hydrogel-water ratio					
	1/10	1/12	1/14	1/16	1/18	1/20
< 1,0 мм	1,22	2,88	8,06	14,05	20,33	36,43
1-3 мм	4,25	6,5	10,8	21,3	46,98	66,93

From Table 1. it can be seen that the hydrogel granules with a size of < 1.0 mm quickly swell and come to a ready state.

A comprehensive study of the impact of hole-driving on the process of explosive destruction of rocks indicates the feasibility and necessity of its use in the conduct of blasting operations in the rocks of any fortress. When blasting in relatively weak rocks, which have low acoustic rigidity and are destroyed mainly due to the kinetic energy acquired by the medium as a result of the impact of the piston pressure of the explosion products on it, the bottom hole has a slightly greater effect on the explosion efficiency than when blasting in strong rocks. However, there is no doubt that even in strong rocks, the use of slaughtering allows you to significantly increase the amount of rate use of boreholes and improve the crushing of the destroyed massif.

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ARTEM V. KOLGANOV
St. Petersburg Mining University
Dr. Prof. VLADIMIR P. ZUBOV
St. Petersburg Mining University

DEVELOPMENT OF ORGANIZATIONAL AND TECHNICAL SOLUTIONS TO REDUCE ORE DILUTION

Improving the production efficiency and competitiveness of gold and silver mining businesses directly depends on the quality of the extracted products. Mining companies pay attention to the volume of the extracted ore, but at the same time they disregard for ore grade [1]. The economic efficiency of the company will depend on reserve grade. At the stage of planning mining operations is necessary to use a full geostructural analysis, based on the quality and physical - mechanical properties of the ore body [2]. All this parameters are closely related to each other, and depend on geomechanical situation. Figure 1 shows a real example of the difference between the contours of the planned and actual excavation.

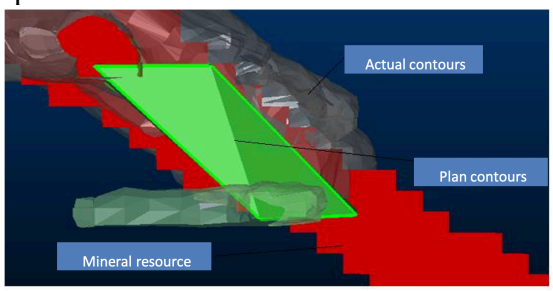

Figure 1 – Planned and actual excavation contours

The aim of the project is to develop recommendations for reducing the volume of dilution and thereby increasing the quality of the extracted metal. The project objectives are creating a block model based on the Rock Quality Design (RQD) parameter [3], selecting domains based on fracturing in the array, evaluating the stability of the considered mining method under different conditions, and applying different mining method in accordance with the domains. The main criterion for applying the development system is sensitivity to changing array parameters in a particular domain Figure 2.

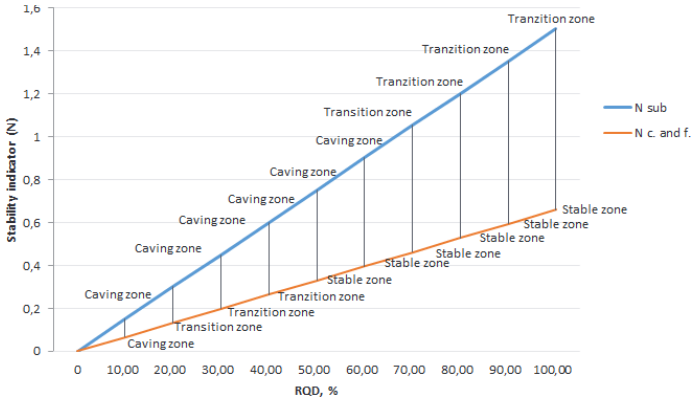

Figure 2 – Sensitive of mining system

Results of the research:

1. The main directions of further research were obtained.
2. An assessment of the sensitivity of mining systems was obtained.
3. The economic assessment of the enterprise was received.

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DMITRII S. KURENKOV
NUST MISIS
Dr. Prof. YURII V. KIRICHENKO
NUST MISIS

STATUS MANAGEMENT OF MAN-MADE MASSIFS TO ENHANCE OPERATIONAL EFFICIENCY OF MINING WASTE STORAGES

The modern mining industry is characterized by the active involvement of low-grade ores in the treatment process, the growth of production wastes, significant disturbance of territories, and the consumption of plenty of water resources. A further increase in production volumes in the world, as well as an increase in requirements for subsoil use, necessitates a rational approach to the development of mineral deposits and the disposal of enormous quantity of wastes [1]. One of the main requirements is the accident-free operation of mining waste storages and tailings facilities to ensure the environmental and industrial safety of mining [2].

The construction of tailing dumps using traditional technology of hydraulic filling leads to the formation of heavy layers of water-saturated finely dispersed materials in the inner zone of the dump. Excessive pore-water (interstitial) pressure that reveals due to saturation of tailings dams and their sites results in a decrease of the slope stability and creates a threat of flooding of nearby territories and infrastructure facilities with hazardous wastes [3, 4]. Hence, research aimed at

increasing the stability and operation safety level of man-made massifs, folded by hydraulically filled wastes, is a crucial task.

To ensure safe operation of a modern mining enterprise, high-quality information support for status management of hazardous industrial facilities, which include storages of tailing wastes, is of high priority. The identification of the main factors that affect the development of negative mining and geological phenomena in the massif and their interrelation is the basis of the concept of the controlled dumping process. To systematize the factors of mining and geological phenomena, a three-level tree was built, which displays the dependence of the man-made massif state on factors of different nature. The upper level (the root of the tree) is an integrated index of the massif state (stability coefficient of a slope or subsoil bearing capacity). The second level is the characteristics included in the calculation model of the integrated index of the state. The third level of the tree is numerical characteristics that reflect the environmental conditions and the man-made burden intensity.

Also, for high-quality management of the man-made massif state we need a mechanism to assess the degree of impact of a particular factor on the condition of the massif. Due to the wide variety of slope mine engineering structures, massifs, dumps, and tailings facilities a single set of criteria and factors cannot be applied to all objects. Therefore, all the characteristics necessary for assessing the state of a mining object were divided into four types depending on the rate of change of their indicators in time: 1. Dynamic; 2. Relatively dynamic; 3. Relatively static; 4. Static. Application of the developed system allow us to substantiate the frequency of data obtaining on the state of a slope mining object by weight of the value of one or another characteristic to the integral control quality index of the massif state.

The study objects were main dams of tailing dumps. We determined that the main factor affecting the stability of these massifs is the dynamic characteristic, namely the level of the man-made aquifer formed as a result of slurry tailings disposal by hydraulic transportation of wastes. Status management of this massif array is achieved by regulating the level of the man-made aquifer. For this purpose, we suggest the use of vibration technologies that enables efficient thickening of slurry tailings, as well as reuse of clarified water. The principle of operation of the proposed vibroacoustic module is based on the hydroacoustic effect of low-frequency vibrations on the fluid flow. The process of solid phase separation is carried out in one stage, which is a significant advantage of the purification process of different suspensions. This vibroacoustic technology allow effective thickening and dehydration of slurry tailings and thus reduce the hydrodynamic and hydrostatic load on tailings dams that leads to state stabilization such sloping structures.

The solutions proposed in the work provide means to accelerate the process of building up tailings dams and increase their holding capacity, speed up the preparation of the disturbed area for further use, optimize the structure and composition of monitoring activities, and reduce potential environmental, economic, and social damage during mining operations. The introduction of vibroacoustic technology of tailings thickening can significantly reduce the production cost by reducing the cost of tailings storage and obtaining recycled water for the needs of preparation plants.

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KURIKALOVA A.A.
Saint Petersburg Mining University
Associate Professor, PhD, NIKULIN A.N.
Saint Petersburg Mining University

PERSONAL PROTECTIVE EQUIPMENT FOR WORKERS IN THE CONDITIONS OF THERMAL DISCOMFORT

The my article discusses the problems of thermal discomfort for workers. The purpose of this study was to analyze the innovative properties of personal protective equipment for workers in the face of thermal discomfort, to evaluate the effectiveness and comfort of this clothing. The characteristic is given to all types of means of protection against hypothermia. On the basis of the study, the main problem was revealed - not the comfort of protective clothing when performing physical activities in tight and heavy clothing, and this leads not only to danger to the life of the worker, but also reduces his ability to work. After a detailed assessment of the current personal protective equipment, it became clear that workers need to improve their work clothes in cold conditions. The options for the development of comfortable clothing equipped with additional heat sources are considered, with the help of which clothing will become lighter and more efficient for employees and more affordable for employer.

On the basis of the study, the main problem was identified - the mismatch of personal protective equipment when performing physical exertion to comfortable working conditions, and this leads not only to danger to the life of the worker, but also reduces its performance. After a detailed assessment of the currently available personal protective equipment, it became clear that workers need to improve their personal protective equipment at low temperatures. Options for the development of improved personal protective equipment equipped with additional heat sources are considered, with the help of which the protection of workers will become more effective for workers and more accessible for employers.

When analyzing experimental studies in the field of hypothermia at the workplace, it becomes clear that a person who has been working for a long time in uncomfortable temperature conditions quickly loses his working capacity. [5,6] First of all, as experiments show, workers complain of cooling of the legs, head and arms. These parts of the body are most occupied in work, they also conduct the most heat to the body. A comfortable temperature for the hands is a temperature of up to 27-32 °C, when lowering the degrees to 25 °C, the ability to move your fingers is gradually lost. If the thermometer drops to 13 °C, damage to the skin is possible. Therefore, the hands, feet, head can be considered as a kind of “registrars” of human thermal comfort. Table 1 presents different types of fabrics for the manufacture of hand protection.

Particularly evident are the differences in the images of the hands, one of which was wearing a glove. It can be seen that not only the temperature of the fingers is different, which should have been by definition, but also the temperature of the wrists and forearms.

The results of the work have a social effect, which consists in providing consumers with more effective heat-protective personal protective equipment.

A method has been developed to justify the selection of packages of materials of structural elements of personal protective equipment to create comfortable conditions when exposed to low temperatures. The solution to this issue is to reduce the area of local heating. On this basis, a methodology is described for determining the area of a source subject to the thermal comfort of the employee.

A systematic analysis of the characteristics of various types of heat generators for personal protective equipment has been carried out. Based on this analysis, it was concluded that it is necessary to develop new methods with which it would be possible to more effectively protect a person from cooling.

In the course of this study, the principal schemes of means for protecting the head, hands and respiratory organs were developed, taking into account thermal comfort for the employee. This

article may represent solutions to boundary value problems in the field of development of PPE with limited temperature conditions.

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Dr. XIANGGONG LI
China University of Mining and Technology
YU LI
China University of Mining and Technology
ZIWEI FA
China University of Mining and Technology
EASAR ALAM
China University of Mining and Technology

RISK ASSESSMENT OF COAL AND GAS OUTBURST ACCIDENTS IN COAL MINES BASED ON FACTOR ANALYSIS AND LOGISTIC REGRESSION

Coal plays a major role in meeting the energy demands in China. The great consumption of coal forced coal mines to increase the mining depth. As a result, the underground operation environment tends to be more and more complex, which has a great relationship with the occurrence of gas hazards. As one of the fatal hazards in coal mines, coal and gas outburst accidents have been threatening the lives of coal miners and the safe production of coal mines. The complex occurring mechanisms of the outburst accidents, however, make it difficult to evaluate the risk of the accidents accurately [1]. As a matter of fact, the risk assessment of coal and gas outburst accidents has attracted the attention of many scholars. Some focus on investigating the characteristics of coal and gas outbursts to figure out the mechanisms of the accidents and eliminate the dangers [2]. Some concentrate on the main factors causing outburst accidents and inquired into the multiple interactions between them [3]. Others pay their attention to adapting various methods like a mathematical model or a gas-solid simulation software. to explain the outburst process, thus contributing to the safe production of coal mines.

Quantifying the impacts of associated causing factors on coal and gas outbursts, and evaluating the outburst risks accurately can provide a technical guide for safe management in coal mines. Firstly, 20 accident causation indexes were extracted into four factors which constituted the accident causation indicator system. Those four factors are the environment factor, the production factor, the technology factor and the management factor.

Then, in order to eliminate the information overlap of the 30 samples collected, Factor Analysis (FA) was adopted to reduce dimensionality and realize data compression and extraction of feature information. Compared with the four factors formed based on subjective experience above, the accident causation system formed according to FA was composed of six factors,

including the outburst power factor, coal seam occurrence factor, enterprise production factor, stress change factor, gas extraction factor and management factor. Besides, these six factors were adopted as the independent variables in the Logistic Regression (LR) model, to assess the risk of coal and gas outburst accidents. The initial LR model, however, could not fit the samples well, with the R^2 of which was 0.3797. To improve the fitting performance, a derived variable of F_2, $1/F_2$ was introduced into the model. Then, the value of R^2 increased from 0.3797 to 0.7473. The accident probability obtained from the model was mainly concentrated in the interval (0, 0.1] and (0.9, 1]. So, the model could distinguish the coal mines with accidents from the safe coal mines well. Nevertheless, compared with general statistical events, the outburst accidents have a huge occurrence cost and a small number of samples, making it difficult to meet the requirements of classical statistical methods for sample size. As a consequence, the distribution characteristics of the accidents may vary from those of the actual values. What's more, the distribution boundaries of the probability interval between 0.1 and 0.9 were not distinct. Therefore, the Bootstrap method was adopted to expand the accident data samples.

Finally, according to the characteristics of sample distribution obtained by Bootstrap, there were four levels of risk situation in coal mines. And relevant measurements were proposed. When the accident probability interval is [0, 0.26], there is little possibility of an outburst accident, and daily outburst prevention and maintenance should be conducted. As the accident probability interval within (0.26, 0.57], attention should be paid to the anomalies during operations to prevent the risk level from evolving into a worse one. With accident probability interval (0.57, 0.80], importance needs to be attached to the improvement of the outburst hazards awareness and timely elimination of the forebodings of outburst accidents during the excavating and mining operations. When the accident probability interval is (0.80, 1], it is quite possible to be overtaken by coal and gas outburst accidents. In this context, the operation in the working face with a warning should be suspended immediately. Also, itemization of hidden dangers should be conducted to eliminate risk symptoms according to safety management guidance, during which attention should be focused on the prevention of coal and gas outburst accidents and accident emergency management.

Our results suggest that the management factor was determined as the most likely caused factor, considering its contribution rate up to 30.0%. By adopting the Logistic Regression model to assess the risk of outburst accidents, the whole risk condition of coal mines can be accurately assessed, in which the accuracy rate is up to 94%. By dividing the risk level into four grades, corresponding measurements were proposed in advance for risk reduction and the guarantee of safe coal production. The results reveal that the FA-LR model is feasible in investigating the causing factors of the outburst accidents and contributing to reducing the risk of coal and gas outburst accidents.

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RAVIL Z. NAFIKOV
Siberian federal university
Dr. Prof. VICTOR E. KISLYAKOV
Siberian federal university

DREDGE DEVELOPMENT OF PLACER DEPOSITS IN THE FAR NORTH

Gold mining is an essential industry for the economy of most countries. Much of the gold is produced in ore deposits, but placer mining is no less efficient [1-2]. In their development, the dredge method shows the highest technical and economic performance.

About 80% of placer gold deposits are located in the Far North, that is characterized by harsh climatic conditions. During the period of negative temperatures, the operating costs of a dredge increase dramatically, whereas its productivity decreases, which shortens the mining season, which can be 160 to 180 days only.

Today, several methods are known to extend the production season when developing placer deposits using dredges; however, they are not widespread in practice. This is due to the high labor intensity of such operations, their high economic and energy costs, and the environmental damage.

As the most promising way to extend the production season, we have suggested to insulate a dredge open pit from the effects of negative temperatures using a hangar structure made of modern building materials [3]. As a result of studying their technical parameters, we have chosen cellular polycarbonate to be installed using a metal frame (Fig. 1).

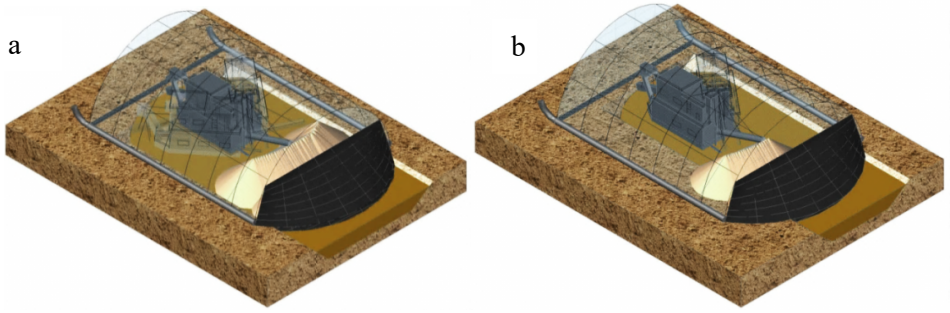

Figure 1 – Designs for insulating a dredge open pit by a hangar during the deposit development:
a – by straight dredging; b – by oblique dredging

To assess the suggested solution effectiveness, we have carried out an experiment using a setup as shown in Fig. 2 [4]. This setup has been designed for the conditions of a 250-liter dredge. The scale is as 1:100; the setup dimensions are as follows: the maximum height is 270 mm, the foundation width is 520 mm, the length is 1,250 mm. The walls are made of transparent cellular polycarbonate 8 mm thick. The hangar is installed on a solid foundation, all gaps being sealed. A hole is made in its end part to install an infrared camera. The camera is designed to record the temperature field distribution and to measure the average air temperature inside the dredge hangar.

In the central part of the hangar, a foil screen is installed to record the temperature field distribution. A 0.01 cu.m water tank is placed under the screen. Temperature sensors are installed in the tank and outside the structure to measure the water and ambient air temperature.

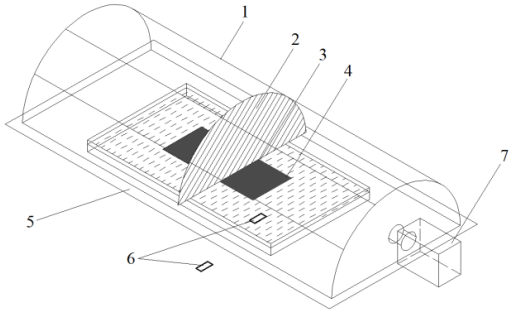

Figure 2 – Experimental setup diagram:
1 – polycarbonate; 2 – foil screen; 3 – dredge model; 4 – water tank;
5 – foundation; 6 – temperature sensors; 7 – infrared camera

The experiment has been carried out in five stages at negative ambient temperatures of -11, -9, -7, -5, and -3 °C. During each stage, a tank with water was installed in the hangar. The water temperature, at which we started recording the temperature fields, was 20 °C. Then, the recording was carried out at water temperatures of 18, 16, 14, and 12 °C. The Guide IrAnalyser software was used to visualize the images from the infrared camera. An example of the temperature field distribution in the experimental setup is shown in Fig. 3.

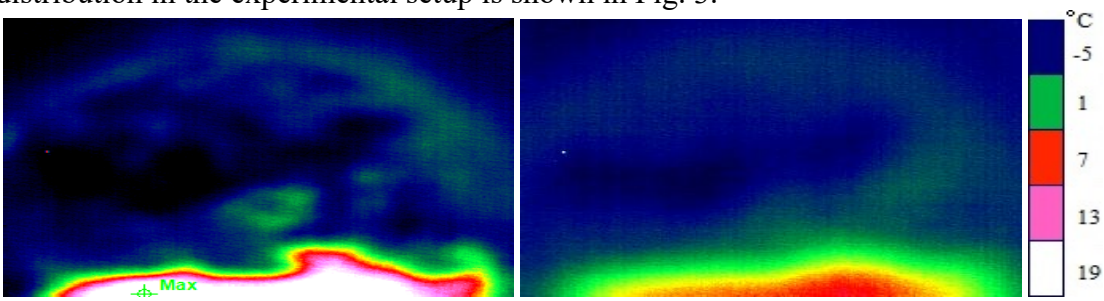

Figure 3 – An example of the temperature field distribution in the dredge hangar

To determine the average air temperature in the hangar, the resulting fields in the images have been divided by isotherms that limit fields with the same temperature using the Guide IrAnalyser software. Then, the images with the isotherms applied have been exported to AutoCAD. This software is used to calculate the surface areas of temperature fields. Based on the data obtained, we have calculated the average air temperature in the hangar for various conditions. The calculations have been carried out using the following formula, ºC:

$$T_h = \frac{T_1 \cdot S_1 + ... + T_n \cdot S_n}{S}, \quad (1)$$

where T_1 is the temperature of the 1st field, °C; S_1 is the surface area of the 1st field, sq.cm; S is the total surface area of all fields, sq.cm; n is the number of temperature fields.

Upon further processing of the experimental data, we have created a mathematical model that allows us to determine the air temperature inside the dredge hangar at a certain point in time, taking into account the water and ambient air temperature, ºC:

$$T_h = (0,03 \cdot T_{a.w} + 0,3) \cdot T_w + (1,5 \cdot T_{a.w} + 7,1), \quad (2)$$

where $T_{a.w}$ is the ambient air temperature, ºC; T_w is the water temperature in the open pit, ºC.

Then, using the example of a conventional deposit located near 65 degrees north latitude, we have determined the annual dynamics of the air temperature inside the dredge hangar. The development was carried out using a 250-liter dredge. The hangar surface area has been found using the graphic and analytical method in the AutoCAD software environment. As an insulating material for the hangar, we have used 10-mm thick polycarbonate.

Based on the temperature data, we have calculated the changes in the mining season duration, which is limited by the period when the daily production capacity of a dredge exceeds the acceptable minimum. Based on these calculations, we have found that, when using the suggested technology, the mining season duration can be increased by 130 days (Fig. 4).

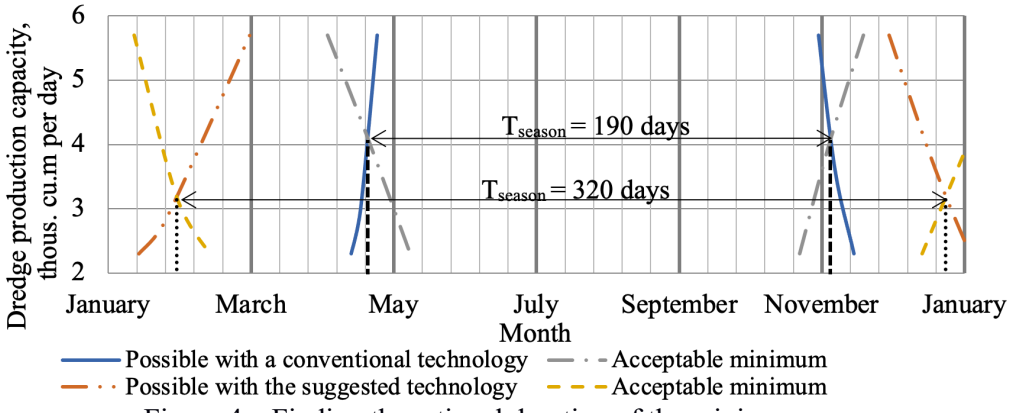

Figure 4 – Finding the rational duration of the mining season

Knowing the air temperature dynamics in the dredge hangar and the mining season duration in the Far North, we have determined the change in the annual production capacity of dredges of different standard sizes with different hangar wall thicknesses values (Fig. 5).

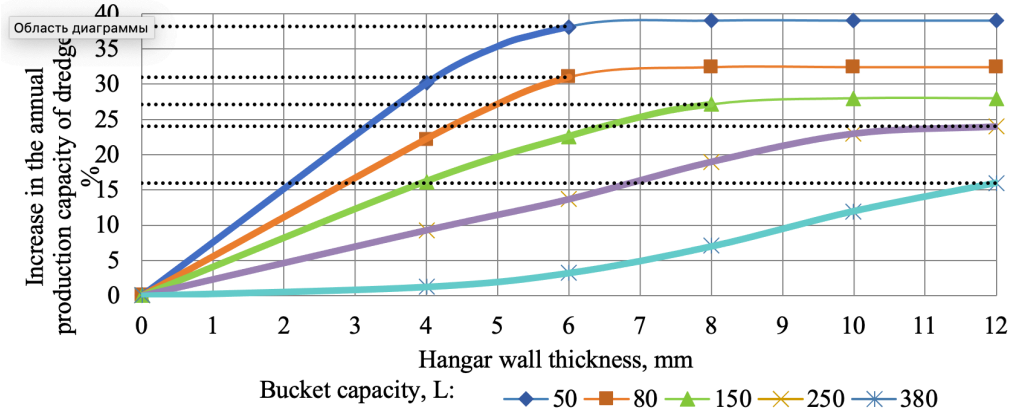

Figure 5 – Change in the annual production capacity of dredges

It should also be noted that insulating a dredge open pit in more southern latitudes allows for a year-round deposit development. Our study allows us to conclude that the suggested solution is highly relevant for the global mining industry.

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PAVLUSHA N. NERSISYAN
National Polytechnic University of Armenia
DAVIT A. HAKOBYAN
National Polytechnic University of Armenia

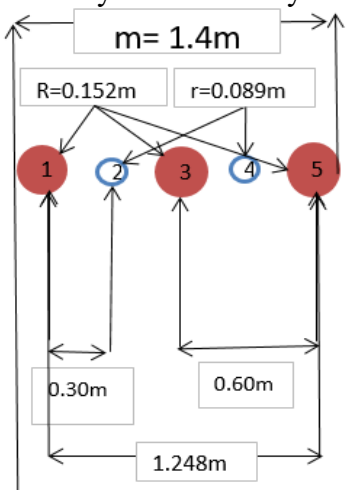
A NEW METHOD OF FORMATION A CUTING SLOT IN THE SHAHUMYAN MINE

Introduction. In the Shahumyan deposit, rocks of the Middle Jurassic age are widely developed, from the engineering-geologic point of view referring to the root base rocks.The ore bodies also outstand with high hardness and stability. Coefficient of rock hardness according to professor Protodyakanov is from 10 to 14. The hardness of the enclosing rocks in terms of drillability is of the XIV-XVI categories. Scarification coefficient is 1.6, a system of development by sublevel drives is applied, which is followed by subsequent dry packing. The sublevel height ranges from 8 to 15 (m). Block development is carried out using a cut-off rise. The minimum width of the mining area is 2.2 m.

Problem statement. Carrying out a cut-off rising with a blasthole method is characterized by lower work safety and drifting speed, as well as higher material and labor costs.Besides, when

the ore breaks into cut-off rise, the width of the mining area is larger than in the project, which leads to an increase in the dilution of the ore. Sometimes it becomes impossible to discharge safely the non-blasted mass, which remains after the explosion of some rows in the blocks, or after an unsuccessful attempt, a large width of the mining area is obtained and further work stops. As a result, this process affects the productiveness of the block. To eliminate the abovementioned drawbacks, it is proposed to create a cutting slot using a braking drillhole.

Investigation results. The figure (Pic. 1) shows a diagram of drilling and blasting operations to create a cutting slot. The length of the holes directly depends on the quality of drilling. Calculations show that if two drillloes are blasted at the same time, the scheme will not work, as the 3rd compensation hole will work simultaneously for the 2nd and 4th blasted holes, and if we apply spacing, then the 3rd compensation hole will work for each blasted hole separately, and only then the scheme will work. When charging holes, it is necessary to take into consideration all the essential measures to improve the safety and efficiency of control of the blasted energy.



_ Compensation drillholes R_ Compensation drillholes radius

_ Blasting drillholes r_ Blasting drillholes radius

m _ the width of the cutting space when using the scheme

The scheme was used in the Shahumyan mine and the results were satisfying (Pic. 2).

Picture after the blast Developed block

This scheme allows to increase the safety and productivity of the block, as well as the quality of the mined ore by reducing the width of the mining area and hence reducing dilution.

In conclusion we can see that this scheme is not only profitable, but also very economical in terms of time.

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DANIIL E. RYADINSKIY
St. Petersburg Mining University

INFLUENCE OF DECELERATION INTERVALS ON THE AMPLITUDES OF STRESS WAVES DURING THE EXPLOSION OF A SYSTEM OF BOREHOLE CHARGES

Currently, many open pits face the problem of obtaining low-quality pieces of rock mass after an explosion. Substandard pieces, most often, occur in the central part of the block, between wells, as a result of poor development of this zone. This problem arises because amplitude of the stress waves from the explosion of charges in it is much lower than near the holes. With the correct delay time, you can increase the amplitude of the stress waves in this zone, thereby improving the crushing of the rock and reducing the percentage of low-quality pieces of rock mass.

There are many methods for calculating the delay time. Scientists and researchers in the field of short-delay blasting hold two opinions: first is to reduce the delay interval, and the second is to increase it. In our work, we made calculations using the method of A.N. Hanukayev. It is based on the condition that the delay time must correspond to the time required for the formation of new surfaces:

$$t_{\text{опт}} = \frac{2W}{C_{\text{р}}} + \frac{W}{C_{\text{тр}}} + \frac{\sigma}{v_{\text{ср}}} \quad (1)$$

$C_{\text{р}}$ – speed of sound in the rock

$C_{\text{тр}}$ – the rate of crack formation, usually accepted $0.05\ v_{\text{р}}$

$v_{\text{ср}}$ – opening speed of the slot, $v_{\text{ср}} \leq 3\text{м/с}$

σ – slot width (0.008-0.01)

Several experiments were conducted in the Ansys Autodyn software package. The difference between the experiments is that different velocities of longitudinal waves were used, adopted by different methods:

- Method №1 - the velocity of the longitudinal wave, measured directly at the Prudyansky granite open pit in the Leningrad region, published by the Interdepartmental Commission on Explosives-4500 m/s, was taken;
- Method №2 - the velocity of the longitudinal wave in an ideal array of granite rocks was taken-5200 m/s;
- Method №3 - the velocity of the longitudinal wave measured by the research team of the Saint Petersburg Mining University at the granite open pits of the Leningrad region – 4710 m/s-was taken.

Substituting the values of the longitudinal wave velocities in the formula of A.N. Hanukaev, the following results were obtained:

Method №1 - 16.9 ms;

Method №2 - 14.92 ms;

Method №3 - 16.28 ms.

Since the velocity of the longitudinal waves in method №2 is considered for an ideal array, an unreliable picture is obtained that underestimates the estimated delay time. So, we then conducted experiments for methods №1 and №2.

For each result, a model was built in the Ansys Autodyn software package, which consists of a granite block with 2 holes loaded with an explosive - Fortis Advantage.

In order for the simulation to be the most reliable, all the constructions were made in accordance to the project of drilling and blasting operations at the Prudyansky open pit. The parameters of the breed were set the same as at the Prudyansky open pit.

Two series of experiments were conducted to consider the process of interference of stress waves from the explosion of hole charges. Each series considered the delay time calculated from the formula given above and the delay time from the standard MS Exel deceleration series.

After conducting two series of experiments, the greatest wave interference occurred when the second charge exploded with a deceleration of 16.28 ms.

In this series, 2 experiments were conducted. The first experiment with a delay time of 17 ms, which is presented in the standard series of decelerations of the MS Exel system, and the second experiment with a delay time of 16.92 ms, calculated according to the method of A.N. Hanukayev.

The peak value of the stress from the initiation of hole №2 in experiment №1 is $1.69*10^5$ kPa, and in experiment №2, at the same point, the stress is $2.079*10^5$ kPa, which is 23% higher. This jump in stress is caused by the superposition of stress waves coming from hole №1 and hole №2, that is, the deceleration interval in experiment №2 is selected in such a way that the frequency of vibration of the stress wave from hole №2 coincides with the frequency of vibration of the stress wave from hole №1 in the zone of possible occurrence of substandard pieces of rock mass.

Based on the performed mathematical modeling, we recommend that for rocks with longitudinal wave velocities from the range $C_{\text{p}} = 5200 - 4500\ m/s$, the delay time should be applied in the range $t_{\text{опт}} = 14{,}28 - 16{,}9\ ms$.

It can be concluded that this method will reduce the yield of substandard pieces of rock mass due to the imposition of stress waves from neighboring holes in the zone of possible formation of substandard pieces. This method of calculating short-time blasting is recommended for implementation in a standard project for the production of drilling and blasting operations at the Prudyansky open pit of the granite-gneiss field "Prudy-Mokhovoe-Yaskinskoe". The chosen method can be applied not only in the conditions of the Prudy-Mokhovoe-Yaskinskoye field, but also in other similar quarries. To ensure the proposed deceleration interval, it is necessary to use the modern Ikon III initiation system, which provides a minimum deceleration interval step of 0.1ms.

ANITA A. TEDIKOVA
National University of Science and Technology «MISiS»
Ph.D., associate professor VASILII V. CHESKIDOV
National University of Science and Technology «MISiS»

APPLICATION OF ONLINE ANALYZERS TO ASSESS THE QUALITY OF MINERAL RAW MATERIALS

At the dawn of the mining era, the problems of decrease in reserves quantity and deterioration of the quality of mineral raw materials were not seen as something important and possible. Now, many centuries later, we are approaching the inevitable - there are fewer reserves in the subsoil, despite the significantly increasing areas of developed territories, and the quality obtained using traditional technologies is not always satisfactory. To find a solution to these problems, miners and scientists are working on the development of new and modification of existing approaches to the extraction and processing of mineral raw materials. But every technology, new or improved, must be comprehensively replicated and tested in the laboratory. Also, the conjuncture of the modern economy dictates that the costs and maintenance of innovation should be recouped and profitable for the enterprise that decided to introduce it.

This paper discusses one of the approaches that can significantly affect the planning of mining operations and quality management of mineral raw materials. The basis of the approach is the receipt by a modern enterprise of up-to-date data in real-time. This goal can be achieved using a group of instruments called online analyzers. It is designed to collect data on several parameters (structure, moisture, rock size, etc.) of mineral raw materials and overburden.

The principle of operation of such devices is based on various methods of analysis: X-ray fluorescence, neutron activation, laser, etc. The first method is the most studied and used, the last one is the least. Despite this, there are several conditions that limit the applicability of analyzers

based on a particular method. Therefore, the choice of the optimal device depends on the mining and geological conditions of the field and the equipment used and the task, the solution of which is paramount for the enterprise. This can be the task of quality control - ore, marketable products, tailings. Or the task of bulk sorting - redirection ore to a particular warehouse, depending on the content of any chemical element. There is also the task of preparing the charge - if obtaining the structure of a given composition is needed. All the above are united by a more global task - tracking and forecasting the characteristics of mineral raw materials.

It is important not just to obtain data on the composition of the material entering, for example, a conveyor belt but also to predict what characteristics the subsequent portions will have. And in case of deviation from the predicted or desired parameters, it becomes necessary to promptly inform employees for decision-making.

Currently, a few companies are already introducing the above technology to their enterprises. For example, at OJSC Novolipetsk Metallurgical Plant, online laser analyzers are used to control the composition of mineral raw materials during enrichment processes and to automatically correct the flux consumption [1]. Foreign experience can be provided by First Quantum Minerals Ltd. and their mine Pyhäsalmi, on the conveyors of which X-ray fluorescence analyzers are used [2].

For the most complete assessment of the technology and possible problems associated with its implementation, the work provides a comparative table containing information about a significant part of enterprises that have made the transition to online analysis. The table shows both the types and brands of the analyzers and the places of their placement.

The purpose of the work, in addition to answering the question posed about the influence of online analyzers on planning, control and averaging, is to create a diagram of the locations of possible arrangement of devices in production. The scheme considers both underground and open-pit mining operations and includes mining, loading, transportation and processes occurring at the ore-processing plant . Reflected data flow based on cable connections associated with a local area network (LAN) and connected virtual private network (VPN) to provide secure remote control and support. Such a system allows not only storing data and predicting it, but also correcting the forecast, considering the collected characteristics of mineral raw materials.

The accuracy of the method and the coverage of sampling are considered, which vary depending on the analysis technology and the location of the analyzers.

Due to the fact that the most common place to install online analyzers is the conveyor belt, such a system can become one of the stimulating factors in the transition to conveyor transport in enterprises [3].

This technology can significantly reduce the decision-making time, and the data, when processed in additional software, can be displayed in the form of graphs and reports for their subsequent use by employees of various industries, for example, marketers for making presentations.

The creation of a table of enterprises, the development of a diagram of the installation sites of sensors and the analysis of the available overview information before them lead to a result that demonstrates the possibility of creating a minimal and sufficient system of online analyzers applicable to a part of mining operations. The need to develop this scheme is dictated by the time and money spent on installing equipment and additional software, calibrating the analyzers, training personnel, and then maintaining the system in operation.

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YERNUR TOLEUBEK
D. Serikbayev East Kazakhstan Technical University
Dr. Prof. GULZHAN Yu. ABDUGALIYEVA
D. Serikbayev East Kazakhstan Technical University

SCHEME OF ORE TRANSPORTATION BY VERTICAL CONVEYOR

The Tishinskoye deposit is located in East Kazakhstan. Polymetallic deposit represented steeply dipping (85-90 °) and the large and middle thickness orebodies, mining depth approximately of 1000 meters and heavy geological conditions. The orebodies by the dip angle are divided into levels with a height of 60 m.

The deposit is developed by sublevel-caving and layered excavation with backfilling mining method and the use of high-performance self-propelled loading and hauling machines (LHD) at ore production and delivery. Currently, the ore is transported at the mine in the following ways:

– Broken ore from drilling drifts, driveways of marks -310m, -330m, -350m is delivered by means of LHD CAT R 1600-1700 to the driveways at marks, in which it is loaded into a CAT AD-30 dump truck and transported along an inclined ramp to mark - 210 m., Then into ore passes: № 1 and 12/29, with its transfer to the 16th concentration level. On the 16th level, the ore is delivered by an electric locomotive K-14 in VG-4.5 wagons to the ore dosing chamber of the Tishinskaya shaft and issued by skip to the surface.

– The rock from the stope faces of marks: -310m, -330m, -350m during mining operations with the help of the LHD machine CAT R 1600-1700 is delivered to the ramps at the marks, from which it is loaded into a CAT AD-30 dump truck and transported along an inclined ramp -210m., then with its bypass to the 16th level. Then it is transported by electric locomotive transport in VG-4.5 wagons along the 16th level to the rock dosing chamber of the Tishinskaya shaft and issued by skip to the surface. The considered methods of transporting broken ore have a set that reduces the efficiency of work: increased operating costs due to the consumption of fuels and lubricants, deterioration of the environmental situation and pollution of the mine atmosphere of underground mine workings with harmful substances generated during the operation of the diesel engine of a dump truck. Large staff of drivers and repair workers. Difficulty of maintenance, repair and refueling of fuels and lubricants. Large tire wear and their high cost.

One of the ways to solve these disadvantages is the transportation of the broken ore by a vertical conveyor.

At the same time, the ore is transported to the 16th level by vertical conveyors of the POCKETLIFT type, then the ore is loaded into electric locomotives and delivered to the ore production complex of the Tishinskaya mine shaft. Conveyor shaft № 1 is to be driven from level 16 to level 20. Conveyor shaft № 2 will be driven from level 20 up to level 24. From the levels, the ore will be delivered to the conveyor, and then on the 16th level it will be reloaded into electric locomotives and fed to the ore production complex of the Tishinskaya mine shaft. Transportation of ore to vertical conveyors will be carried out by LHD.

Ore and rock in a medium crushing chamber are crushed to a fraction of -50-0 mm and then transferred to a vertical conveyor of the Pocketlift type. Medium crushing will provide more reliable operation of the vertical conveyor and eliminate the average crushing in the concentrator.

The POCKETLIFT® system delivers lift heights and productivity unattainable today with any other continuous conveying system. The wide field of application of this system, in particular,

in the development of mineral deposits, has confirmed the concept of the superiority of continuous vertical transportation in comparison with periodic (cyclical). The design advantages of the POCKETLIFT® system are based on the high tensile strength and low mass of its tensile elements and the combination of various connection options with the proven POCKETLIFT® solid rubber buckets. In-depth studies on the further development of the POCKETLIFT® system allowed tensile elements to be made of ropes based on aramid fibers (instead of metal rope belts, the tensile strength of which can hardly be further increased), which, with comparable strength limits, weigh about 80% less than steel ones. The tension / tension ratio for these ropes, which are not subject to tension, is linear and the tension at the break point is comparable to metal cables.

The elements secure the shock-free pivot connection around the rope drums, and the detachable permanent connections allow adjustment in the event of differences in the length of the supplied aramid ropes forming the tensile elements.

It should be noted that the permanent connections of aramid ropes are detachable and therefore offer installation advantages and more convenient transportation of the rope sections.

The use of a vertical conveyor for transporting ore is the most optimal due to the small volume of excavation, and also a lower amount of capital costs compared to the option using an inclined conveyor. It also excludes the use of dump trucks, which in turn will significantly reduce the air pollution of the internal combustion engine on the levels.

DICKSON WACHIRA
Taita Taveta University
HILLARY MENGICH
Taita Taveta University

MONO ROPE WINCH AS A SOLUTION FOR UNDERGROUND HAULAGE IN SMALL SCALE AND ARTISANAL MINING: A CASE STUDY OF KENYA

Artisanal and small-scale mining (ASM) has continued to increase in recent years. According to reports, small-scale mining is expanding rapidly in developing countries[1]. The ASM has been identified as a considerable economic contributor to the Countries economy. This has seen many developing countries recognize ASM by enacting rules and regulations to formalize the sector and govern it. For instance, Kenya is a developing country that has seen a continued increase in ASM.

A primary characteristic of the ASM is that the mining operations are predominantly simplified forms of exploration, extraction, processing, and transportation. While these forms are relatively cheap, there are categorized with safety issues. For instance, the material handling for underground mining is done manually by individuals who move both waste and ore from the underground to the surface[2]. This approach has seen several deaths in an event of a collapse of the poorly supported shafts and entrances to the mines.

A solution to this challenge is the advancement of mining methods utilized in artisanal and small-scale mining to improve safety. While this is the best-placed solution, the ASM is faced with the fundamental challenge of lack of capital to invest in equipment. With the informal nature of the sector, financial organizations are reluctant to offer loans for the initial investment during the development of the mines.

Due to this, relatively cheap solutions are necessary to minimize the safety challenges encountered in the ASM. In the haulage of materials, a mono rope winch is a plausible alternative to the current manual methods. The mono rope winch is comprised of a motor, roof bolts, pulleys, and a rope (twine)[3]. The motor can be either electrically driven or diesel-powered. It drives the twine from the surface to the underground and back. The pulleys are used to ease the movement of the twine. The roof bolts are used to hold the rope in place on the roof. The waste is loaded in

the waste bags then hooked to the rope which is continuously in motion[4]. It hauls the material to the surface, where there two to four people are placed to unload and dump the waste.

While using the case studies of gemstone mines in Taita Taveta County, Kenya, it was found that mines that had opted to use the mono rope winch system had recorded success. It was found that the system allowed up to tens of tons of material hauled in a day while drastically reduced the number of employees working in the sector by 75%. Furthermore, there was a reduction of mine accidents by 95%. The mono rope winch also facilitates ventilation and removal of underground mine water which overall resulted in overall mining efficiency.

In conclusion, the use of mono rope winch as the haulage system in artisanal and small-scale mining is the best plausible alternative to the current approach. The system's initial cost is cheap and it is also easy to operate. These give mono rope an upper hand as the best choice. Furthermore, the study found that the system has a higher safety factor hence solve the current trends of accidents. Therefore, this paper recommends the installation of mono rope winches in underground artisanal and small-scale mining.

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MIKITA M. YESMAN
Belarusian National Technical University
YAUHENIYA R. DZERAPOUSKAYA
Belarusian National Technical University
TATSIANA S. ASTAPENKA
Belarusian National Technical University

OPTIMISING THE PARAMETERS FOR MINING OPERATIONS IN POTASH DEPOSITS WITH UNFAVOURABLE GEOLOGICAL CONDITIONS

The development of hard-to-recover reserves is now becoming a prerequisite for a successful mining business. In the last century, people tried to explore deposits with favourable geological conditions, which had an impact on the economics of the final product. Over time, there have been fewer and fewer "easy-to-reach" deposits, and humanity has been forced to return to those deposits that were previously not economically viable to exploit. The economic viability of a deposit depends not only on the natural conditions of the mineral deposit, but also on the choice of extraction and beneficiation technology.

The development of hard-to-recover deposits involves many factors at the planning stage. The technology chosen will influence parameters such as panel width, panel length, length of the extraction tunnels and others. The technical characteristics of the equipment will influence the choice of parameters for the extraction technology. The final price of the product will depend on the selection and efficiency of the required equipment. This article describes the methodology by which the subsoil user can most effectively use the potential of the selected equipment, depending on the specific conditions of the mineral deposit.

The essence of this methodology is to calculate and determine the compatibility of the selected equipment. The synergy of the equipment used at JSC "Belaruskali" is investigated, which will reduce energy costs, as well as accelerate the process of cleaning excavation of mineral resources.

This research is intended to attract the attention of subsoil users to the rational and environmentally friendly exploitation of mineral deposits.

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Session 7. GEOMECHANICS AND MINE SURVEYING IN MINING AND UNDERGROUND CONSTRUCTION

CLEMENT A. AMAGU
Graduate School of Engineering, Hokkaido University, Japan
CHENG ZHANG
Graduate School of Engineering, Hokkaido University, Japan
ASSOC. PROF. JUN-ICHI KODAMA
Graduate School of Engineering, Hokkaido University, Japan

FIELD INVESTIGATION AND NUMERICAL STUDY OF A ROCK SLOPE DEFORMATION: A CASE STUDY AT HIGASHI-SHIKAGOE LIMESTONE QUARRY, JAPAN

The stability of rock slopes subject to continuous excavation is a major challenge in an open-pit mining, mostly in a region with wide varieties of annual weather conditions. Slope excavation and rainfall are often plays key role in causing instability of rock slope over time [1]. Deformation of rock slope often occurred owing to the excavated process of rock mass within an area subjected to considerable redistribution of the initial stress state [2]. Rainfall infiltration resulted in the rise of groundwater level, and the increase in the pore-water pressure, consequently decreases the shear strength of rocks, and possibly leads to landslides and slope failures [3]. Thus, continuous field measurement of the rock slope deformation is essential in assessing the slope stability. However, it is admittedly important for the validation of the measured results by numerical analysis. This provides a good check on the degree of slopes stability, not only for economics purposes, but also to ensure safety operation [4].

In this regards, both field measurement and numerical simulation were employed to clarify mechanism and the causes of the rock slope deformation at Higashi- shikagoe limestone quarry, Japan. Geologically, the quarry is a small-scale mine operated by bench cut method for more than 100 years, with rock slope height of about 130 m. The rock mass is mainly consisting of limestone, schalstein and slate rocks with clay of about 70 m thick distributed at foot wall of the rock slope of the quarry. However, the quarry has experienced four slope failures from 1996 to 2017. Therefore, an understanding of the long-term deformation mechanism of the rock slope at the quarry is therefore a crucial issue to assess the rock slope stability.

At first, an automated polar system (APS) was set up to monitor the rock slope deformation since July 2002. The measured change in distances between the beam generator and mirrors located at various elevations along the slope surface were analyzed. The results revealed that the distance between a beam generator and all mirrors decreasing gradually with time, but the tendencies and the decreasing rate of the distance differs at left, centre and right-hand side of the quarry. This suggests that factors influencing the slope deformation depend on the position of the quarry. Furthermore, the comparative time series analyses of rainfall were analyzed to evaluated effect of water infiltration on the rock slope displacement. The result confirmed that distance tends to decrease with increase in the rate of rainfall accumulation.

To clarify the causes of the rock slope deformation at the quarry, effects of excavation of limestone at the foot of the rock slope, deterioration of the clay of about 70 m thick at the foot wall of the rock slope and shear failure due to influence of rainfall infiltration were investigated by 2-Dimensional Finite element method (2D FEM). The numerical results show that the slope deformation at left-hand side and centre of the quarry are induced by deterioration of the clay whereas that of deformation observed at right-hand side are induced by excavation on the floor and/or shear sliding. So far, it has been concluded that the slope is stable although it still exhibit continuous deformation.

However, the height of rock slope at the quarry is believed to continue increases as the altitude of excavation level decreases. In such case, future study on the slope deformation with a

3D numerical model is necessary. Future study on the optimization of rock supports under such geological configuration is also needed.

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NIKITA D. BARSUK
Donetsk National Technical University
Dr. Prof. SERGEY V. BORSHEVSKIY
Donetsk National Technical University
Ph.D. Prof. IVAN V. KUPENKO
Donetsk National Technical University
Ph.D. IVAN F. MARIYCHUK
Donetsk National Technical University
ANTON J. GRITSAENKO
Donetsk National Technical University

RESEARCH OF THE STRESS-DEFORMED STATE OF THE SYSTEM "ROCK MASSIF–ANCHOR–MODIFIED CONCRETE" SUPPORT OF EXCAVATION

With an increase in the depth of development of coal deposits, in addition to the complication of a number of technological processes, the conditions for the construction and maintenance of support are also significantly deteriorated. In this regard, there is a need to develop methods for calculating the support of deep mine workings. At present, three methods for solving volumetric problems are mainly used to study the stress-strain state of underground structures: finite-difference, finite elements, and energy using the variational principle. Despite the widespread use and versatility of the finite element method, it has the following disadvantages: the complexity of the mathematical description, the long duration of the solution of the problem, which increases with the shredding of the mesh of elements. This method is inferior to the finite difference method. Recently, variational methods have also been widely used, which are direct methods for solving boundary value problems, since in the variational equation, under the double integral is the differential equation of equilibrium of the system under consideration, and under the single integral, the boundary conditions. The most common variational methods for solving boundary value problems are the Bubnov-Galerkin and Ritz methods. A significant advantage of these methods is the automatic fulfillment of the deformation compatibility conditions. With the use of these methods, a number of problems of mining geomechanics have been solved over the past few decades. [1, 2].

To study the stress-strain state (SSS) of the system "rock mass - anchor - modified concrete", the authors proposed a design scheme presented in the form of a multilayer thick shell with transversely isotropic layers, which is under the action of a distributed load from rock pressure, four edges of which are pinched or two edges are pinched and the others are hingedly supported. To solve the problem of stress-strain state of the system "rock mass - anchor - modified concrete", the variational methods of Ritz and Bubnov-Galerkin were used. In this work, a technique is used that consists in representing the total deflection as the sum of two components -

due to bending and shear. From the hypothesis of non-deformable normals, it follows that, regardless of the location of the coordinate surface of the shell, all internal forces and moments in the general case depend on the deformations of elongation and shear, and on the parameters of changes in the curvature of its coordinate surface. In this regard, it does not matter what location the initial coordinate surface of the shell has. Coordinate functions are selected in the form of power polynomials according to the Ritz method, which satisfy the geometric conditions, as well as Bubnov-Galerkin for the boundary conditions that correspond to the conditions of the support.

The algorithm for solving the problem is implemented as a structured software module consisting of several blocks: assignment of initial values; determining the position of the neutral surface of the rock mass, determining the reduced characteristics of rocks and concrete (fiber-reinforced concrete) [3], stiffness parameters (depending on the position of the neutral surface), dimensionless quantities and constants; parameters of the sought functions: deflections due to bending, shear and forces; solving a system of linear algebraic equations; determination of stresses and deflections; visualization of results in the form of three-dimensional and two-dimensional graphs.

Based on the developed program, the results of studies of the stress-strain state of the rock mass of an unsecured mine working were obtained, from which it followed that its stability at a depth of about 1000 m and more under two boundary conditions is not ensured. Using the given mechanical characteristics of the rock mass, fixed with anchors and lining of the mine working made of modified concrete, it was found that the mine working is stable, and the movements on its contour are significantly reduced. Based on the studies carried out, the dependences of displacements on the mine tunnel contour on a number of different parameters were obtained.

The research results showed that the dependence of the displacements on the ratio of the distance between the anchors to their diameter and the ratio of the thickness of the anchor-rock shell to the length of the working; displacements from the ratio of the distance between the anchors to their diameter and the ratio of the load to the maximum reduced modulus of elasticity are linear, and displacements from the ratio of the thickness of the rock mass to the length of the mine tunnel and the load to the maximum reduced modulus of elasticity are nonlinear. At the same time, with an increase in their values, the displacements increase.

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ANNA V. DEMENTEVA
St. Petersburg Mining University
Dr. MAXIM A. KARASEV
St. Petersburg Mining University

DESIGN OF YIELDING SUPPORT SYSTEMS IN SALTS

Salt rocks tend to creep, that phenomenon occurs in large deformations of the excavation boundaries. Salt creep does not decrease during the time and causes difficulties in mining operations. Shotcrete as a support material cannot be used in such cases because the brittle failure is expected. To increase stresses in rock-support systems it is necessary to use yielding supports.

The calculations are executed with numerical method. A big cross-sectional chamber located in more than 1 km depth is obtained. The suggested support system is a combination of shotcrete and flexible elements. The elements are located with a certain spacing. Such combined support act both as a rigid and a yielding one. Acting as a rigid, support bearing capacity is determined as a shotcrete strength while the resistance of yielding elements specifies yielding support capacity.

Based on finite element method Abaqus CAE software is used for solving this problem. Being elastic and rheological one, salt rock is described by “Creep-Power Law” model, that provides power law of the creep behavior. To decrease the convergence of the rock mass properties in the model and in reality, deformations of the excavation boundaries in the model have been compared to deformations of the excavation boundaries in the formerly constructed mines.

The material of yielding elements is foamed concrete, including polystyrene and gas voids. The material is assigned with “Crushable foam” model with volumetric hardening. The model is based on yielding surface, that is described with elliptical dependence of deviatoric stress on pressure. The variation of the surface is produced due to volumetric plastic deformations. The adjustment of the model is done with compression test diagrams.

The support molds the excavation boundary. It is made from shotcrete and yielding alternant elements. During the calculation, the support system is meshed on rectangular elements. Yielding elements are meshed on finite elements, which are of the same width in maximum force direction to improve the convergence of the model.

The use of combined support system improves the stability of the excavation. At the same time stress condition depends on both the number and the material of yielding elements. Stress, that accumulates in yielding elements, should be less than the bearing capacity of the shotcrete. Otherwise, shotcrete will be overstressed. The configuration of stiff and flexible element also affects the support system bearing capacity. In particular, in stress points (mining site) it is necessary to put a yielding element, since a shotcrete one tends to fail under the critical load.

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ZULAY K. GÓMEZ M.
Petroleum Engineer Escuela Politécnica Nacional
FRANKLIN V. GÓMEZ S.
University of Miskolc Escuela Politécnica Nacional

GEOMECHANICAL COMPONENTS IN SACHA SHUSHUFINDI CORRIDOR WELLS

Geomechanical models represent the numerical behavior for mechanic and strength rock properties, state of stresses and pore pressure at depth [4]. Knowledge of present-day geomechanical components provides the starting point for improvement in oil production. In Ecuador, structural and stratigraphic model was presented in [1] giving a general view of the main sediments, deposition cycles and structures at depth in a qualitative way. However, geomechanical studies for Ecuador, specifically at Cuenca Oriente, haven't been developed. By the way, taking into account that the zone of Cuenca Oriente is the main crude productive one in Ecuador, and that underground conditions have changed since production began; geomechanical components should be analyzed for initial and current conditions. Besides, in order to recover oil trapped in different formations, it is important to apply processes which modify reservoir properties. There is where fracking takes place, because it lets to increase permeability, recovery factor and hydrocarbon production from stress models and fracturing plans. Thus, the next procedure described allows to generate this model from electrical logs. It includes the estimation of pore pressure and rock properties, which are the base for stress polygons and let to infer faulting regime and faults direction. Nevertheless, taking into account the regional regime, it is possible to compare the results of Stress Polygon and Geomechanical model with previous studies about dominant failure regime for Cuenca Oriente.

The Central Corridor is one of the three tectonic domains in Cuenca Oriente. The structural model [1] describes it as a zone with transform faults inverted from extensional ones. Its stratigraphy consists of sedimentary and volcanic sequences deposited on a Precambrian substrate

[1] with intercalations of shale, limestone and sandstone. In this zone, the studied fields are characterized by anticlinal structures, reverse, and strike-slip faults which follow an approximately N – S direction. By the way, the geomechanical model constitute a new view for underground behavior, due to mechanic properties and pore pressure provide the stratus state, resistance and elasticity of the rock, and reservoir pressure estimation. Furthermore, the stresses, that complete the geomechanical model, describe the possible behavior of sediments when a pressure change is produced. For example, new lifting technologies improvements like fracking severely influence the porous and its effects could be better estimated with the data from the proposed model. In fracking case, the stress polygon limits the scale for least and maximum horizontal stresses. The Polygon method is based on Anderson's frictional theory and two dimensions Mohr's diagram [4]. Furthermore, the author [4], includes the wellbore wall stresses and failures as indicators of stress changes and its propagation through formations. So, the points of least compression are where drilling induced tensile fractures take place, and a value of applied pressure slightly higher than uniaxial compression resistance let that breakouts begin.

The present Geomechanical model construction employed logs information from one or two wells in seven different fields at Central Corridor: Atacapi, Shushufindi, Sacha, Guanta, Lago Agrio, Auca and Libertador. As first step, location, formation tops, average density, matrix type, apparent porosity were established for each well, and compressional and shear waves' velocity were estimated from sonic logs [1]. All of the parameters, mentioned before, were applied for elastic and strength properties correlations [4], depending on formation characteristics. However, pore pressure estimation and stress calculation needed lithostatic load and normal pore pressure which were calculated with formation and fluid density respectively. The fact that "the porosity is an indicator of effective stress and pore pressure, particularly for the overpressures generated from under-compaction and hydrocarbon cracking" [3, p. 21], let to obtain this pressure based on porosity data. By the way, normal compaction line will follow the relation $\emptyset_T = \emptyset_o e^{-\beta\sigma vn}$ [4]. In

it empirical parameters (β & $\emptyset_o$) had been adjusted for studied fields according to shale compaction trend. Pore pressure can be finally estimated understanding that normal vertical stress (σ_{vn}) results from the difference between lithostatic load and pore pressure; so, Athy's equation is reorganized [4]. As part of results verification, the estimated pore pressure was compared with reservoir pressure for productive sandstones. Once, pore pressure and vertical stress are defined,

Polygon stress method lets to calculate least and maximum stress. At the same time, breakouts and drilling induced tensile fractures should be analyzed, through stresses around the wellbore wall. The data obtained for them, shows the maximum stress produced and its change with depth. The same procedure was applied for actual reservoir pressure obtained from other documents. The final model consists of eight equations as function of depth. However, for it, only two points per productive sandstone in each well were extracted. Then, pore pressure, mechanic properties (elastic and strength properties), initial stresses, actual stresses, and cross-point between breakout and tensile fracture lines stresses were plotted. The most relevant fact is that, the full data per well, showed the following tendency: $S_{hmin} < S_V < S_{HMAX}$.

Finally, the geomechanical model equations proposed for Sacha Shushufindi Corridor let to calculate rock properties and stresses at different depths for the main porous, productive and clean sandstones. But there are some considerations for its application due to results. For example, properties like porosity, UCS and tensile strength do not depend only on depth, so the values obtained through model equations do not provide the most suitable results. However, the conditions for elastic properties are different. Equations, obtained from sonic logs, provide a good approach to real values for Young and shear modulus – which increase with depth – and Poisson modulus – which decrease. It is important to emphasize this change witnessed as a result of sediments deposition, depending on the field and sandstone studied. Regarding pore pressure, the equation results let to estimate a pressure with values that may had been overestimated. Nevertheless, this error could be reduced by increasing the number of sample wells, adjusting the NLC and gathering more information from Central Corridor's fields. Based on these data and including horizontal and vertical stresses, a strike-slip regime is identified. It plus the fact that regional stresses present an Shmin with E-W direction [2], released that fractures might probably be generated at N – S direction or following the pre-existent faults at the Corridor (NNE – SSO). Also, the polygon analysis combined with wellbore wall stresses for Central Corridor sandstones with more than 1000 psi pressure lost, indicate that simultaneous breakouts and drilling induced tensile fractures formation is impossible.

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V. V. HOVAKIMYAN
National Polytechnic University of Armenia

IN TECTONICALLY STRESSED ROCK MASS THE UNLOADING EFFECT ON OPEN PIT SLOPE STABILITY

For a long time, the rock mass in open-pit slopes have been undergone by different type of geological repeated processes, such as tectonically movements, weathering and so forth. After these processes, it has been formed a geostress equilibrium state into the rock mass under tectonic and gravitation stress conditions. Any excavation processes dislocate the previous stress equilibrium state due to which it is formed unloading geomechanical condition. Other way round, the 3D stress-strain state turns into 2D state into the rock mass of the open-pit slopes under unloading conditions.

The unloading geomechanical condition into the rock mass consists of in-situ gravitation stress field (compressive stress) and unloading stress (tension stress) [1]. Under unloading condition, the tension cracks start to initiate and propagate mainly into the toe rock mass of the open-pit slope due to tension unloading stress. When man-made activates are going to start, into rock mass of the exposed mining slope the tension stresses develop normally to minimum horizontal stress or parallel to maximum effective vertical stress [2]. After mining activates, it is formed a damage zone, the horizontal and vertical extent of which depends on the tension strains magnitude. Depending on confining pressure reduction rate, the shear stress start to concentrate into the damage zone of the toe rock mass of the mining slopes towards to exposed area of the open pit. These concentrated shear-stress-damage-zones are considered to be the vulnerable zones and are the root reasons of developing progressive failure mechanism.

It is mandatory and necessary to take into account the concentrated shear-stress-damage-zones under unloading geomechanical conditions into the rock slope stability analysis. On the other hand, if there is major geological feature, such as tectonic fault which is dipping nearly parallel to the exposed mining slope, these type of damage zones combine with tectonic fault are considered to be major threat a point of view of failures. Such an object in our thesis by numerical modeling, we took the south-west wall of the 'Zangezur CMC' CJSC open-pit in Armenia. From the outputs of numerical modeling based on finite element method, it has been approved that the damage zones due to tension strains mainly depends on deformation characteristics of the rock mass expanding within mining slope toe, geometric parameters of geotechnical constructers, horizontal to vertical stress ratio (K_0) and domain size. I has been compared 2 type of criterions by numerical modeling to estimate tension strain magnitudes and expending zones into the rock mass of the south-west wall of Qaja8an open-pit mine. The current exposed open-pit depth and the results of Stacey's and Diederichs's criterion are shown on figure 1.

The tectonically stressed south-west wall with fault undergoes vertical loading and horizontal unloading effects, due to which it is formed hard geomechnical environment. This hard geomechanical environment leads to two conditions:

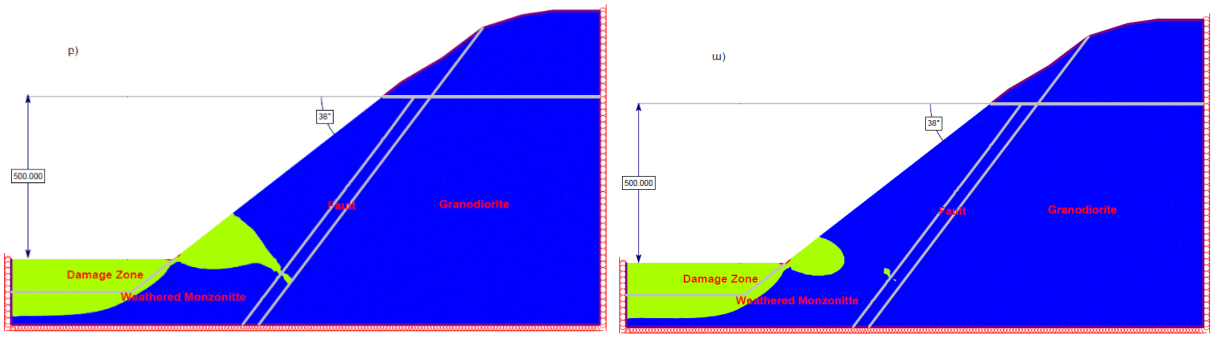

Figure 1. The tension strain extension zones into the rock mass of the current south-west wall depth of the Qajaran open-pit mine under unloading geomechanical condition by a) Stacey's and b) Diederichs's criterions ($K_0 = 1$, $\alpha = 38°$)

- Into the toe of the deep open-pit mine, the maximum component of this high stress condition is acting normally to structural blocks in concentrated shear-stress-damage-zones. On the one hand, it prevents the tension cracks to develop and on the other hand, enhances the friction forces on the contacts of elementary blocks which result the increment of the shear resistance forces and as a result the factor safety of geotechnical constructers increases,
- When the minimum component of this high stress condition exceeds the tension strain limits of the intact rock, the concentrated shear-stress-damage-zones are developing due to tension crack initiation and propagation mechanisms. This type of damage zones combined with major geological structures (such as fault) is considered to be progressive potential failure surface.

The results from numerical modeling of the south-west wall of the Qajaran open-pit mine are the following:

1. In the first excavation stage of Qajaran open-pit mine, when the depth of mining slope is 200 m, there is no damage zones by tension strain criterions under unloading conditions,
2. During future deepening, when the depth of the mining slope reaches 400 m, there are tension strain extension zones by 2 type of criterions, however, in this depth, the magnitude of the tension strains are billow the limiting value of tensile strength of the intact rock, and it is appropriate to point out that under this condition tension cracks start initiating,
3. In the current depth of the south-west wall (500 m), the damage zones due to tension strains exceed the limiting tensile value of the intact rock based on Stacey's and Diederichs's criterions, and there is high probability to form the potential failure surface which is combined as a tectonic fault and toe tension-crack-damage-zone,
4. It has been confirmed the limiting depth of the open pit mine (not deep 500m), above which the tension cracks initiation, propagation and development mechanisms will start intensively,
5. The in-situ stress condition, e.t. horizontal to vertical stress ratio (K_0) has an important influence on tension magnitude and expending zones and it has been confirmed, the higher the K_0 ratio, the higher value of the tension strain and the deeper the expending zones,
6. There Is a conceptual good agreements between Stacey's and Diederichs's criterions, and recommend to estimate tension cracks development mechanisms based on the above mentioned criterion together.

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PAVEL N. IVANOV
National University of Science and Technology «MISiS»
Dr. Prof. ELENA B. CHEREPETSKAYA
National University of Science and Technology «MISiS»

EXPERIMENTAL STUDY OF DEFORMATION PROPERTIES OF COALS OF VARIOUS DEGREES OF TECTONIC DISTURBANCE BY LASER-ULTRASONIC TOMOGRAPHY

At the current pace of coal mining, conditions are becoming very difficult. At great depths of development, one of the dangerous geodynamic phenomena are sudden emissions of methane from coal beds, which limit the safe mining of coal. There are three main factors that cause dangerous gas-dynamic phenomena in the mine. These include the stress-strain state of the massif, the mineral composition of coals and the structural features of the geomaterial [1]. It should be noted that coal has a complex system of cracks and pores, which transforms when the natural stress-strain state changes as a result of the development of the massif. This "structurally modified" [2] coal is characterized by a low density and increased gas saturation. This leads to the emergence of geodynamic phenomena. Moreover, exceeding the limiting level of defectiveness, which is observed during coal mining, leads to mechanochemical destruction and uncontrolled geodynamic phenomena. At the same time, the degree and increase in structural changes differ depending on the stresses, maceral composition and mineral additives. Thus, to predict the dynamic phenomena in coal mines, it is necessary to control the stress distribution in the zone of a gas-bearing coal seam and the strength properties of coal, since destruction can begin at the most weakened contacts: natural cleavage cracks, macropores, defects. These contacts are catalysts for the desorption of methane upon a change in the stress state. Therefore, taking into account the extreme heterogeneity of coals, it is necessary to study their internal structure at various scale levels, including macro-, meso- and micro-levels. In most studies, the structure of coal is described on the basis of optical and electron microscopy, where the distribution of cracks along the depth of the sample is not evaluated. This information can be provided by X-ray tomography and ultrasound investigation [3].

In this work, we investigated coal samples from the Kuznetsk coal basin, taken from a seam that is dangerous in terms of possible gas-geodynamic phenomena (sudden outburst and rock burst). The studies were carried out on an automated laser-ultrasonic structuroscope "UDL-2M". The principle of operation of such a structuroscope is based on the registration of signals obtained as a result of reflection and partial scattering of broadband acoustic pulses from the rear surface, as well as various sample defects [4]. From the time delay of these signals relative to the reference signal, the longitudinal wave (P-wave) velocities at each scan point were calculated. However, due to the attenuation of acoustic waves in coals, the registration of shear wave (S-wave) pulses in the echo mode was difficult. Therefore, the method of transmitted waves was used to measure their velocities. In this case, S-waves were excited by refraction of an ultrasonic pulse of longitudinal waves incident from the liquid onto the front surface of the sample. In this case, shear waves were excited by refraction of an ultrasonic pulse of longitudinal waves incident from the liquid onto the front surface of the sample. Then, S-waves propagated into the sample and converted into P-waves on the rear surface of the sample.

Based on the scanning principles, the velocities of elastic waves in the samples under study were measured. In this case, the scanning of the samples was carried out for two directions of the wave normals with respect to the visual layering of the samples. The obtained results of the values of the velocities were verified using the empirical equations of Makroth-Rios and Greenbeg-Castagna. Further, for each of the coal samples, the local values of the dynamic modulus of elasticity were calculated. These values were used to build maps of their distribution. Based on the parameters obtained, images of the internal structure in three planes were obtained.

Similar studies were carried out for coal seams where the degree of influence of stresses and temperatures is lower. It was revealed that their structure is more anisotropic with orthotropy manifestation in elastic characteristics. It was concluded that with an increase in the degree of disturbance of coals, due to the influence of various tectonic processes, its elastic characteristics become more and more isotropic. Based on the results obtained, using the "Matlab" software package, 3D images of the samples under study were built. Due to the broadband signals obtained by laser generation of ultrasound, the orientation and geometric dimensions of cracks were recorded in the image throughout the entire volume of the samples.

This work created tasks for further research. It is known that due to the high attenuation of acoustic waves in coal samples, at all points it was possible to reliably determine only the velocity of the longitudinal wave. Whereas the signal of the shear elastic wave at a number of points was visible, but not distinctly. It is also known that the generation of longitudinal waves is much more efficient than the generation of shear waves, which arise during the conversion of longitudinal waves at the interface "generator-sample" and the free surface of the sample. Therefore, an urgent task is to develop a new laser-ultrasonic transducer that will effectively generate shear waves. Solving this problem would expand the capabilities of methods for determining the dynamic elastic moduli of not only coals, but also other rocks and geomaterials.

Thus, the method of laser-ultrasound tomography is a promising direction in the field of coal research. This method allows you to obtain and store information about the internal structure and deformation characteristics at each point of the test sample. This is of practical importance in the field of further numerical and computer modeling of the state of coal under various external influences.

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KLIMOCHENKOV M.D.
National University of Science and Technology "MISiS"
Ph.D., associate professor CHESKIDOV V.V.
National University of Science and Technology "MISiS"

DESIGN OF SOFTWARE FOR ASSESSING THE STABILITY OF SLOPE STRUCTURES

Calculation of rock mass stability is one of the fundamental problems of geomechanics. The experience of previous generations made it possible to improve this process almost to perfection, but the increased accuracy of calculations entailed an increase in the complexity of this process. Such calculations can take more than one month, and in matters of security delays can be dangerous. Rock mass that composes the sides of quarries, slopes of dumps, dams of reclamation structures are a serious danger, landslides and collapses are a threatening reality that must be dealt with.

The mining industry has already acquired special software that simplifies the assessment of the stability of slope structures. Most of the programs on the market perform calculations by sections, which in general makes it possible to assess the stability of the whole mass. But it would be interesting to get a 3D model of a potentially critical area so that it is possible to predict the volume of the sliding mass and the area that it can cover. This information would help in assessing the danger of an emergency and also serve as a sufficiently serious justification for taking measures to prevent a possible disaster.

The Python programming language was used to write code capable of solving this problem. To provide an easier way to enter the initial data, it was decided to use a block model of the slope array. The block model can be created in geological information systems such as Micromine and Datamine. After creating a block model, it is loaded into the code, where it is sequentially divided into profiles. Calculations include determining the shear (T) and holding (N) forces (stresses) and establishing, based on a comparison of these forces, the safety factor stability of the slope of a given profile:

$$\eta=\frac{\sum Ni}{\sum Ti}.$$

If $\eta > 1{,}0$ - the slope is stable, $\eta = 1{,}0$ - the slope is in equilibrium, $\eta < 1{,}0$ - the slope is unstable [1].

For calculations, the method of circular-cylindrical sliding surfaces is used, by enumerating various parameters, the program searches for the most unstable of all and then continues the calculation on the next profile in order.

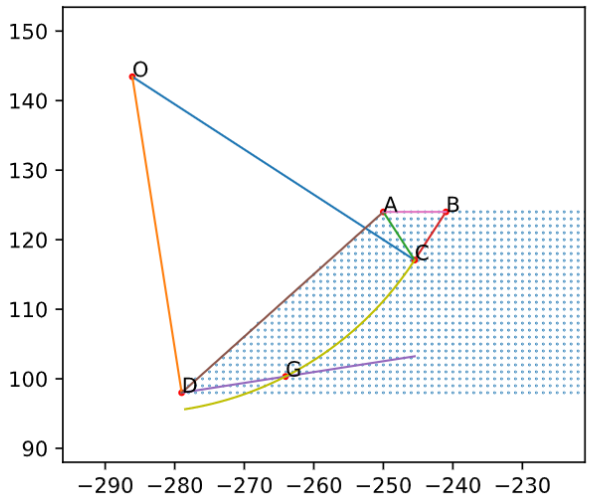

Figure 1 - An example of constructing a circular-cylindrical sliding curve

Within each profile, the program splits the block model into "columns" 1m wide, which corresponds to the width of the model block. After constructing the slip curve, the calculation of

the shear and retaining forces within each column begins, according to which the stability coefficient is then calculated. It is also planned to add accounting for hydrostatic pressure in the presence of a depression curve in the body of the slope structure.

After calculations for each section from the block model, at the exit from the program we have the relative coordinates of points on the sliding surface, which can then be visualized in the Blender program, analyzed the resulting model, and calculate the total volume of the sliding rock mass.

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OLESYA O. LEBEDEVA
Perm National Research Polytechnic University

GEOMECHANICAL MODELING OF ROCK STATE AT VERKHNEKAMSKOE SALT DEPOSIT AS AN EXPLOITATION SAFETY MEASURE

Exploitation safety at any deposit is one of the vital topics. Development system parameters should satisfy needed safety conditions. In case of Verkhnekamskoe potassium and magnesium salt deposit such parameters are chamber width, safety block width and height, also its loading level, allowable deflection of waterproof covering rocks, etc. These values are regulated by the project documentation [1]. Even if there is an accident the regulations should take into account any changes of these parameters. Therefore, it is reasonable to understand, firstly, how different deformational processes start and propagate and, secondly, what impact on the openings, mass rock, surface and undermined objects in the whole it brings. In order to study this issue more clear complex approach is suggested. It is based on joint application of geomechanical modeling, instrumental results and geophysical investigation data.

Nowadays geomechanical modeling is one of the best using methods [2, 3]. It should be noted that modelling is just a step of the complex approach. In the beginning, deep analysis should be done in order to obtain input parameters of the model. The quality of the input data influences the final result.

First of all, input data includes geological information, physical and mechanical properties of the rocks, development system parameters. Geological information is gained from geological and exploration wells. Rock properties is mainly compressive strength obtained from laboratory tests. Development system parameters are calculated and regulated by the project documentation.

Then, the strong advantage of this complex approach is that using geophysical investigation data helps to detect different layers and also trace them within the whole investigated section for the overlaying rocks. This method was wildly used for hydrocarbon deposits, but currently modern equipment allows realizing this method for salt deposits. Field seismic survey observations are done with the prior art seismic reflection method of common middle point by method for underground shear-wave seismic of geological structure with separation of reflections [4, 5].

Another point is the presence of instrumental results. As the rule, they include instrumental observations on the surface (leveling) and vertical or/and horizontal convergence measurements underground. On the one hand, such results complement the model. On the other hand, they help to assess the modeling results, their validity and fitting the real observations.

Besides, the model assumptions should be chosen correctly. It means that the model must be similar to the real mass rock properties, mining situation, and reflect the nature of the deformational processes developing underground. It is known that salt rock has creep properties. Therefore, the best suitable model is the rheological one. It allows seeing the deformational processes in time. What is more, the background research experience tends towards using distinct

element method as it better represents such processes as well as filling both under regulations and under opening fracturing after excavation works.

Finally, as the result of the geomechanical modeling there are zones with weak properties where water-conducting cracks can occur or propagate. The worst effect it can lead to the total flooding of the underground mine. It should be noted that modeling can be done for any period of the time. It can be seen how these zones develop.

Complex approach allows full investigating of the stress-stain state of the rocks under mining. It is not only shows deformational processes in time but also allows formulating timely recommendations for the change of development system parameters. It is done on the basis of the analysis of modeling results in order to enhance exploitation safety.

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ZHIGUO LI
Northeastern University
TAO XU
Northeastern University
LICHUN ZHAO
Zhaha Naoer Coal Industry Co. Ltd.
TENGFEI FU
Northeastern University
YONGJIE LIU
Tongliao Branch, State Power Investment Corporation Inner Mongolia Energy Co. Ltd.
BO Zhao
Northeastern University

OPEN-PIT SLOPE STABILITY ANALYSIS BASED ON COLLABORATIVE MONITORING AND NUMERICAL SIMULATION

The northeast wall of Zhahanao’er open-pit coal mine has undergone a large deformation and makes the north wall of the open-pit mine unable to continue mining since the freeze-thaw season in 2020. In order to understand the deformation and failure mechanism of the northeast wall of the open pit, and provide theoretical guidance to slope control. The three-dimensional refined geological model of the northern Zhahanao’er open pit including the information of weak layers, strata and surface is established [1].

A surface and underground cooperative monitoring scheme of surface slope radar monitoring, GNSS monitoring, and underground inclinometer monitoring were developed and

then the deformation boundary of the slope is determined based on the monitored results from different monitoring methods. The potential sliding surface and deformation pattern of northern slope was identified through the analysis of monitoring results, and the deformation of the northern slope was also numerically investigated. The numerical simulation results were in good agreement with the field monitoring results.

The studies show that the deformation pattern of the northern slope is a composite multi-stage landslide with low slope stability, and the low factor of safety (FOS) of the slope indicates that the northern slope is experiencing a potential slide, and some controlling measures should be taken to ensure the stability of northern slope. The collaborative monitoring scheme combining different field monitoring methods with numerical simulation to determine the deformation pattern of slope could provide the basis for the treatment of the open pit slope.

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Professor MICHAEL A. ZHURAVKOV
Belarusian State University, department of theoretical mechanics
SIARHEI N. LAPATSIN
Belarusian State University, department of theoretical mechanics
MIKHAIL A. NIKOLAITCHIK
Belarusian State University, department of theoretical mechanics

COMPUTER-AIDED MODELING OF THE DAYLIGHT SURFACE SUBSIDENCE UNDER THE INFLUENCE OF MINING NEAR TECTONIC IRREGULARITIES

The daylight surface subsidence under the influence of mining is a very common issue in modern geomechanics [1, 2]. Such subsidence may significantly change the overlaying landscape, making mathematical modeling of such problems a crucial factor in the design of mining complexes. This problem is especially relevant for the Republic of Belarus due to the large mining of potash salts in the country. We also mention work [3] to highlight the importance of geomechanical monitoring during the construction of mining complexes and mining operation conduction.

The particular research deals with predicting the daylight surface subsidence with the use of computational tools. The main aim of the research is to calculate the values of vertical displacement in some reference points on the ground and compare the results with the field data.

A peculiarity of this work is that we use the finite element method [4] to predict daylight surface subsidence in the neighborhood of a large tectonic discontinuity (rock fault) as long as considering a multilayered structure of the underlying rock mass. In addition, we demonstrate methods of mathematical modeling of the tectonic discontinuity behavior in different cases. Computer-aided modeling is performed based on a real mining schedule.

The finite-element model of the problem in question includes a large section of the rock massif (3X1 km) together with the tectonic discontinuity, which is modeled via different contact conditions. In this research, we consider two basic cases of the rock fault behavior, which are the case of “active” rock fault and the case of “inactive” rock fault. In addition, we consider the fact, that mining operations are conducted on both sides of the rock fault during different periods of time.

As mentioned previously, the rock mass in the area of a considered section has a multilayered structure. As per the borehole log, there are more than a hundred rock layers of small thickness. To build the finite-element model of the entire section we use an analytical technique, which allows us to calculate effective mechanical properties for the whole rock mass. This

technique reduces the resulting model to three effective layers. The results of the effective mechanical properties derivation are verified with initial data.

The results of the research include a mathematical model of the system "rock mass-mining excavations-tectonic rift" as well as a full-scale computer-aided design model of the system under consideration. The comparison of the results with the field data shows decent quality match. Moreover, the results of the finite-element modeling allow concluding that there are no activation processes due to the mining operations in the considered section of the rock mass near the tectonic discontinuity.

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YASMANY MEDIA ZALDIVAR
Moa University
PhD. MADAY CARTAYA PIRE
Moa University

SLIDE SOFTWARE FOR THE ANALYSIS OF SLOPE SEISMIC BEHAVIOR

In the study of slope stability, phenomena of ultimate state or breakage of soil masses are addressed. Geological-geomorphological reconnaissance techniques are, in these cases, of great help to identify disturbed areas and to quantitatively estimate landslide risks [1]. However, the quantitative determination of risk or safety indices requires the use of techniques and models specific to soil or rock mechanics. Slope stability is the main problem in the conception and design of open pit mines, both from an economic and safety point of view. For the design of these, among the factors that are taken into account, is the seismic coefficient, which responds to the coefficient that characterizes a telluric movement taking into account the magnitude, intensity and focal distance in a type of material or materials [2]. This work proposes to determine the seismic behavior of mining road slopes in the Moa nickel deposits with the use of the Slide software, the determination of the safety factor under different conditions using modeling with the real conditions present in the slopes. The calculation of the factor of safety and the use of software modeling was not used when projecting the slopes of the mining roads in the nickel deposits of Moa.

Due to different factors, slopes do not always maintain their stability. These factors include heavy rains, seismic activities, material weight, material resistance parameters to shear (cohesion, internal friction angle), human intervention [3]. The factor of safety is assumed to be the same for all points along the failure surface, therefore this value represents an average of the total value over the entire failure surface [4]. This factor must be taken into account and represents, depending on the design characteristics of the slope, when it may or may not fail. Slope stability programs are used for the design and calculation of slopes, for the analysis of all types of slopes, embankments, earth cuts, anchored retention structures, reinforced soil walls. The slip surface can

be considered circular (Bishop, Fellenius / Peterson, Janbu, Morgenstern-Price or Spencer methods) or polygonal (Sarma, Janbu, Morgenstern-Price or Spencer methods).

Slide is a powerful slope stability analysis program, easy-to-use, using 2D boundary equilibrium methods for all types of terrain and rock, slopes, reservoirs, earth dams, and retaining walls. Slide includes construction on finite groundwater infiltration analysis, probabilistic analysis, multi-view modeling, and design support. Slopes can be found in the lateritic deposits of Moa; they have been designed in the projects of the access roads to the different start-up fronts without taking into account, many times, the seismic coefficient before which these slopes could fail [4]. Two types of scenarios were modeled in the Slide software, one that did not take into account the seismic coefficient of the slope and another that did take it into account. The Slide software allows, knowing the characteristics of the terrain and the lithology, to define which materials are affected by the instability of slopes. Four different lithologies were defined and their corresponding values of physical-mechanical and geotechnical properties were inserted, including cohesion and internal friction angle. In addition, the water table level, the maximum piezometric level that these can reach were taken into account and an external load was placed that simulates the weight that the slope receives when heavy mining equipment passes.

It was appreciated that without taking into account the seismic coefficient, the safety factor is 1.7. A fairly high safety factor for this type of slope, so it is unlikely to fail. When the seismic coefficient is taken into account, the safety factor drastically decreases 0.662 in the case of analysis and the fault zones through which the slope can fail increase. The Slide software allows that after obtaining the safety factor and the possible fault zones, some of the stabilization methods and measures are applied to the slope. For the case study, it is recommended to place a TEXCEL geotextile cover on the slope on which it will proceed to revegetate the same, using this method the safety factor amounts to 1,250. The geotextile mesh to revegetate the area of the face and crest of the slope also makes it possible to reduce erosion due to the effects of intense rains.

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ALEKSEI G. MEDVEDEV
CROC, Inc.

GEOTECHNICAL RADAR MONITORING IN WINTRY CONDITIONS

Across some of the coldest parts of the world including Russia, Canada, USA, and Scandinavia, we can face an extreme weather condition. In particular Siberia's climate the weather is very extreme. By Köppen climate classification the region relates to subarctic climate. This type of weather characterizes short, cool summers, whilst the winters are long, harsh and have an annual average temperature of 0.5 degrees Celsius with thick layers of snow remaining on the ground for at least six months of the year, but mostly from late September until mid-May.

To overcome extreme climate, and function at -40 degrees Celsius and below, a radar should be properly prepared and protected. Snow and ice can also affect a data monitoring interpretation. The poor coherence and deformation noise added to the system during heavy

snowfall suggests that the radar systems would be of limited value in alarming for rapid brittle failure during periods of heavy snowfall [1].

Snow accumulates and melt spatially and produce a pattern, therefore, the displacement related to snow events differ from the real slope movement and sometimes can be easy to interpret [2]. The snow depth is inverse to what we see in the data. So, if the snow is melting away you should see movement towards the radar. If the snow depth is accumulating you should see movement away from the radar. Corner Reflectors could help us to overcome poor coherence and deformation noise. The specular reflection property of inner sides guarantees that a beam will reflect back to the source.

In the case of using InSAR monitoring we have the very same obstacles. The poor coherence and deformation noise added to the system. Snow is a mixture of air, ice crystals, and if melting, liquid water. In wet snow, attenuation occurs due to the presence of liquid water, and the interaction is complicated owing to the fact that even a very small amount of liquid water drastically influences the phase and amplitude of the backscattered field. When snow is dry, liquid water is absent, and at longer wavelengths, it can be considered almost transparent with a moderate volume scattering depending on observed frequency and the incidence angle. Higher frequencies show a good sensitivity to dry-snow properties, but they have a limited penetration into snow cover. In the case of dry snow at low frequencies, sensitivity of the amplitude of backscattering to variations of the depth of a dry-snow-pack is weak [3].

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DANIIL S. MEDVEDEV
National University of Science and Technology MISIS
Dr. Prof. MIKHAIL S. PLESHKO
National University of Science and Technology MISIS
Dr. Prof. ALEKSANDR N. PANKRATENKO
National University of Science and Technology MISIS

APPLICATION OF BIG DATA TECHNOLOGY TO IDENTIFY THE CAUSES OF WATER SEEPAGE IN THE MAIN LINE TUNNELS OF THE MOSCOW SUBWAY

The process of digitalization today affects all sectors of the Russian economy. In the construction industry, it is primarily aimed at implementing project procedures and document management in a digital format, which makes it easier to work with documentation. The other side of digitalization is a huge amount of unorganized data. The rapid search and analysis of such information causes significant difficulties and leads to serious time loss. The solution of the problem may be an effective use of artificial intelligence and machine learning.

Let me consider their application on a specific example. Within the framework of scientific activity at the academic Department of Construction of Underground Structures and Mining Enterprises of NUST MISIS, the research topic is carried out: "Determining the causes of water seepage and developing solutions for ensuring the effective parameters of waterproofing of tunnel lining made of high-strength reinforced concrete blocks". All identified defects of high-precision lining were systematized into the main groups: Type A – cracks in the lining blocks; type B –

water seepage at the joints of the blocks; type C – water seepage in bolted joints; type D – chipped edges of the blocks; type F – excess ledges at the joints of the blocks. A total of 4102 lining rings were visually and instrumentally examined. Defects and water occurrences were detected in 19% of the rings. At the same time, an interesting feature is that 78% of water occurrences were observed in the key blocks (type K) or adjoining to them (types A and F).

For each ring, the influencing factors are also systematized: tunneling speed, parameters of the geometrical accuracy of mounting rings (ellipticity), parameters of solution injection, geological conditions, engineering aspects of the lining and rubber seals. During the analysis, a representative data set was formed. Besides that, an additional sample of unorganized data was made from the logs of the sinking, survey reports, data from the manufacturer of the lining, passports for rubber seals, etc. All the information was combined into a single table array, which could not be analyzed by standard MS Excel tools or similar software packages.

In this regard, machine learning algorithms Random Forest and SVM were used for the analysis. Random Forest is a machine learning algorithm based on the set of decision trees, which can be considered as a series of "yes/no" questions about the incoming data. The result of the training and data processing is a certain prediction based on the revealed patterns between the input data and the obtained observation results. The process of learning the algorithm is splitting the original data set into nodes using straight lines. This creates a non-linear model using linear constraints. [1] SVM (Support Vector Machine) is a machine learning algorithm designed to find the most accurate hyperplane that can divide the input data into two classes. During processing, the algorithm builds a graph based on an array of input data, after which the points located as close to the possible separation line are found. These points are the reference vectors. Then the distance between the reference vectors and the separating hyperplane is determined. The gap distance in the end should be the maximum. [2]

The resulting graph shows the accuracy metric, depending on the attribute number. Most of the results are either negative or equal to the class ratio in the test sample (~81%). However, two results are slightly better – number 5 and number 23. These results can be categorized as random deviations. However, it is worth considering that just these two attributes carry a lot of physical meaning. Attribute number 5 is the third radius that looks vertically up from the center of the tunnel. Attribute 23 – the maximum deviation of the diameters. More about the training method: the machine learning library "Scikit learn" was applied using the "Numpy" package. For the general validation of model training using all attributes (excepting the seepage position), was used component GridSearchCV for the selection of the characteristics of the learning algorithms. Cross-validation according to the k-fold method for k = 5. For training in the study of single attributes were used the Random Forest algorithm with the test sample equal 20% of the total number of rings, without cross-validation, the ratio of classes on the test sample and on the training data was equal. To visually verify that there are no significant dependencies in the input data, histograms of the distribution of individual values and histograms of relative frequencies were constructed. They show data from the entire sample, as well as rings with water occurrences. Below each histogram is its relative frequency histogram. The main deviations from the flat distribution on the relative frequency histograms occur in cases of lack of data. In addition, it is also possible to consider the graphs of deviations from the normal distribution, which, in combination with the histograms above, can be used for expert evaluation. A straight line shows the normal distribution. Each point on the graph is a value that should be on the straight line displayed on the graph. Points that are not on a straight line cannot be assigned to the normal distribution. Graphs for data taken by modulus can be ignored, since the modulus of the normal distribution is not a normal distribution. Based on the analysis according to the described methods, the negative impact of increasing a tunneling speed above the optimal value was proved. It negatively affects the quality indicators of the installation of rings and the frequency of water occurrences along the route of the main line tunnels. An indirect sign of a violation of the work technique in this case is an increase in the proportion of rings with water occurrences in the key blocks (type K) to 26.6% of the total number of defective rings. The reason for this is the lower

pressure of the rubber seals in the key block, which reduces the water resistance of the joint of the key block with the adjoining blocks of the ring.

Considering the results, recommendations have been developed for improving the technical process of manufacturing high-precision lining blocks. It is aimed at improving the mechanism for gluing rubber seals to concrete blocks, introducing advanced materials and concrete compositions, as well as new-generation rubber seals with anchor and hydrophilic elements. In conclusion, it should be noted that the obtained results demonstrate the possibility and prospects of using machine learning methods in the field of underground construction. The algorithms can be further applied in solving similar problems for the widest class of transport infrastructure objects and mining enterprises.

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NGUYEN TAI TIEN
St. Petersburg Mining University
Dr. Assoc. Prof. KARASEV M.A.
St. Petersburg Mining University

A PROCEDURE FOR DETERMINING THE OPTIMAL CROSS-SECTION OF SUB-RECTANGULAR TUNNEL

The circular tunnel is the one of most popular tunnels, due to the fact that this shape is the most stable [1]. On the other hand, circular TBMs have a less complex structure than other TBM shapes. Nevertheless, the biggest disadvantage of the circular tunnel is the small space utilization ratio. Today, with the development of machine manufacturing technology and material technology, TBMs can be used to excavate any tunnel shapes not only circular tunnels and the lining structure with high bearing capacity. Sub-rectangular cross-section is one of the non-circular shapes which recently researched by Huang et al. [2], Du et al. [3], Do et al. [4]. A similar cross-section called quasi-rectangular tunnel shape has also been studied a lot by experimental test [5,6], numerical and analytical methods. However, this quasi-rectangular tunnel shape has an interior column in the center that divides into two separate lanes. This cross-section has a higher space utilization ratio than circular ones. All the above literatures do not mention how the sub-rectangular tunnels were designed. This study mainly focused on the effect of geometry parameters of the sub-rectangular cross-section on tunnel lining behavior. Therefrom, the optimal geometry parameters for the sub-rectangular tunnel are determined.

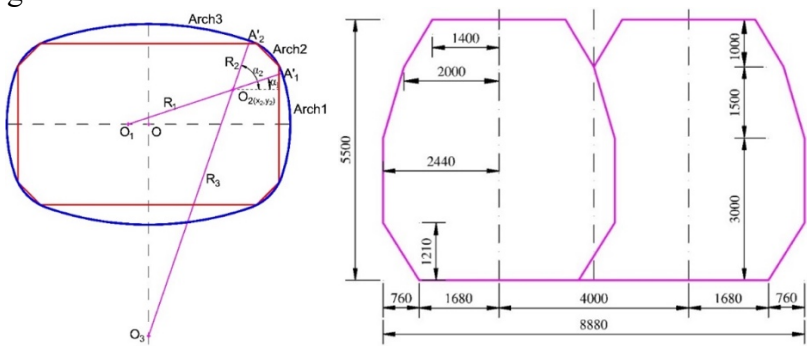

Figure 1 – The construction clearance of double-track and the geometrical configuration of sub-rectangular tunnel

The algorithm determined sub-rectangular shape follows these steps: (1) The center O2 selection and calculate radius R2: The center O2(x_2, y_2) of Arch 2 is located on the line segment bisector of the line A1A2 which is the linear equation: $y = x + (h_1 - d_1)$; (2) Determine the location of center O1; The center O_1 of Arch1 is the intersection between the line O_2A_1' and the horizontal axis, x Therefore, the x_1 value is determined by the following equation; 3) Determine the location of center O3. The center O_3 of Arch3 is the intersection between the line O_2A_2' and the vertical axis, y.

$$R_2 = \sqrt{(d_2 - x_2)^2 + (h_1 - y_2)^2} \quad (1)$$

$$R_1 = \sqrt{\left(x_{A_1'} - x_1\right)^2 + \left(y_{A_1'}\right)^2} \quad (2)$$

$$R_3 = \sqrt{\left(x_{A_2'}\right)^2 + \left(y_{A_2'} - y_3\right)^2} \quad (3)$$

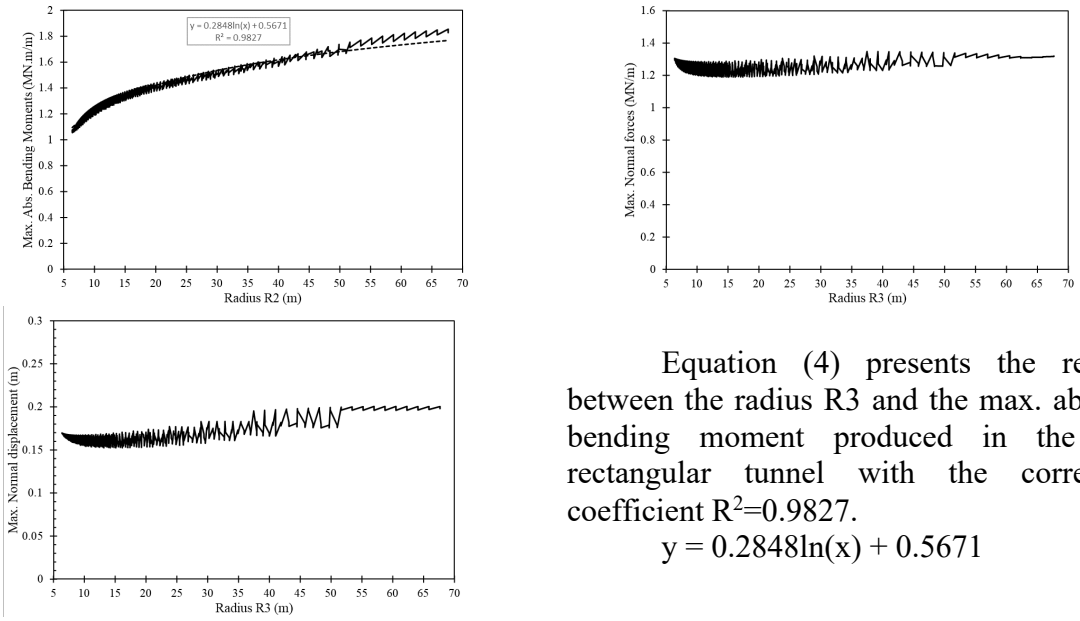

Figure 2 – The effect of radius R3 on internal forces in the lining and max. normal displacement

Equation (4) presents the relation between the radius R3 and the max. absolute bending moment produced in the sub-rectangular tunnel with the correlation coefficient R^2=0.9827.

$$y = 0.2848\ln(x) + 0.5671 \quad (4)$$

Equation (2) presents the relation between the radius R_1, R_2, R_3 and the max. absolute bending moment induced in the tunnel structure with the correlation coefficient R^2=0.98665.

$$Z = 0.610393 - 0.02505\ln(R_1) - 0.00059\exp(R_2) + 0.287735\ln(R_3) \quad (5)$$

From two Regression equations (4) and (5), it can be shown that the max. absolute bending moment is mainly affected by the radius of crown (bottom) part and is slightly influenced by the radius of shoulder and sidewall part.

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IRINA OTKUPSCHIKOVA
St. Petersburg Mining University
NIKITA BELYAKOV
St. Petersburg Mining University

COMPARATIVE ANALYSIS OF METHODS FOR PREDICTING THE STRESS-STRAIN STATE OF SHAFT LINING IN SALT ROCKS WITH CONSIDERING THE TIME-DEPENDENT BEHAVIOUR

During excavation in salt rocks mass there is a risk of stability loss associated with the manifestation of rheological properties. Due to the continuous creep, the deformations of the excavation contour and excavation lining loads continue to rise in time, so the design of walling should include the prediction of the stress-strain state of the "lining-mass" system using various long term deformation empirical laws. Thus, in order to ensure the normal operation of the mine, it is necessary to determine the lining load at the time of the end of the excavation service life. The scientific significance of the research topic is explained by the fact that the existing methods of prediction of excavation contour displacements are overestimated which leads to the use of irrational design solutions for excavation lining. The purpose of the study is to compare different methods for predicting the stress-strain state of the "lining-mass" system.

A solution based on the nonlinear creep theory is considered as the basic analytical solution, it was developed by Protosenya A.G. Graphical method for solving a system of equations by constructing an implicitly defined function in the Maple software was used to obtain the results. It was checked with an iterative calculation.

Alternative solutions were obtained with finite-elements method in Abaqus software. In the first case, the rock mass properties are set by the Drucker-Prager linear model with creep module. The creep strains rate time dependence was described by a power law. The creep properties of salt rocks were determined by approximating the data of long-term tests in the Origin software. The elastic properties were defined by a linear approximation of the stress-strain diagram. The parameters of the Drucker-Prager model were defined by the results of triaxial sample tests.

The second case of numerical solutions was based on the application of the Double Power Law model defined by the modified Norton creep law. It sets the dependence of the creep strains rate with respect to equivalent stress and by this way it gives the possibility to set the creep strains dependence with respect to time indirectly. In scientific work was proposed to realize this model by binding the temperature parameter to the time and setting the corresponding change in the temperature field.

To quantify the obtained solutions the modelling was also performed with using the linear-hereditary creep law model. Method for determining of mechanical properties for this model was described in scientific work.

In all analyzed cases creep laws describes only the primary and secondary creep stages.

Virtual tests were conducted to verify the parameters of the models. The author estimated satisfactory convergence of the experimental data for the samples with data obtained as a result of the modelling. Also, in the scientific work the comparison of predicted by finite-element method stress-strain state of the "lining-mass" system with experimental data was performed.

For future development of scientific work, it is planned to use a creep model based on the Empirical Power Law, which allows to include the tertiary creep stage; to perform the modelling in 3D with taking into account the geometry of individual tubes; to take into account physical non-linearity of salt rocks plastic behaviour.

STEPAN V. SHEVCHUK
Gazprom UGS, LLC
NUST MISIS

A NEW APPROACH TO THE INTERPRETATION OF GEODYNAMIC MONITORING DATA AT UNDERGROUND GAS STORAGES

The paper considers the results of geodynamic monitoring at the Shchelkovsky underground gas storage (UGS) and substantiates a new approach to the assessment of geodynamic activity of fault zones within the mining allotment, which allows reducing the systematic surveying and geodesic observations at the geodynamic site to once a year.

Stable operation of the Russian fuel and energy complex, along with other factors, to a great extent depends on the reliability and uniformity of natural gas supplies via the country's gas transmission system. As a rule, these supplies are regulated by withdrawing gas from UGS facilities, which are classified as hazardous industrial facilities. Moreover, the operation of UGS facilities is explicitly recognized as one of the types of engineering activities that cause induced seismicity.

As an example, let us consider the most famous seismic events caused by the operation of UGS facilities. In 1988, the Gazliyskoye UGS was created at one of the large gas fields. The existing seismological network covering the studied area allowed us to establish the relationship between seismic activity and cyclic operation of the UGSF. When the pressure in the reservoir increases, there is an increase in seismic activity events, and, on the contrary, when gas is withdrawn, their number decreases. Between October 2009 and November 2010 three seismic events were detected at the Czech UGSF at depths comparable to that of the storage facility and within its boundaries. Three more events occurred at a distance from the storage facility in 2014-2015. Thanks to the established seismological network it is possible to reliably state that the events were caused by the operation of the gas storage facility. From June 9, 2013 to October 22, 2015, 273 seismic events within a radius of 10 km of the storage facility and at a depth equal to the depth of the storage facility were recorded in China. The most striking example of induced seismicity is the 2013 earthquakes in Spain, the epicenters of which were located in the vicinity of the UGS facility. During the period from September to October 2013, about 511 events of different magnitudes were recorded. It is noted that pilot gas injection was carried out in June 2013, after which no seismic events were registered. Full-scale gas injection was carried out from September 2 to September 16. During this period there were registered minor seismic events, and starting from September 24, when gas injection operations were stopped, earthquakes with maximum magnitude 4.2 were registered. Thus, we can conclude that the greatest seismic activity at the UGS is recorded in the period after gas injection [1].

According to the current legal acts of the Russian Federation regulating the issues of safe and rational subsoil use, the subsoil user must conduct a set of geological, surveying and other observations sufficient to ensure the normal technological cycle of works and forecasting of dangerous situations, timely identification and drawing of dangerous zones on the plans of mining works.

Draft geodynamic polygon includes all the necessary mining and geological information, as well as regulates the issues of frequency, methods and accuracy of measurements [2].

To understand the process of displacement caused by UGS operation, analytical methods are used to calculate the subsidence of the earth's surface during the development of hydrocarbon fields. This issue was addressed by such scientists as: A.S. Maznitsky, L.M. Serednitsky, S.G. Avershin, R.A. Muller, E. Litvinishin, Y.P. Borisov, Y.O. Kuzmin. The proposed assessment of Y.O. Kuzmin is widely used, including for UGS, as it is simple enough and allows with high accuracy to predict the values of settlements. According to the performed calculation the maximum values of land surface subsidence within the limits of the mining allotment of the Shchelkovo UGS have been determined, which do not exceed 10 mm. This confirms the absence of possible

extensive subsidence of the ground surface caused by UGS operation. It should be noted that the proposed method does not take into account the tectonic features of the massif. It is known that the largest settlements, as a rule, are confined to the faults and are associated with the activity of these zones. In this regard, special attention during geodynamic monitoring at UGS should be paid to the shear processes in the zones of dynamic influence of faults.

During the period from March 2019 to November 2020, 4 observation cycles (2 series per year) were performed at the Shchelkovskoe UGS. According to the results of the study of "pulsation" and "evolution" plots, it was found that the shear vector in the zone of dynamic influence of the fault has two components: geomechanical, caused by changes in pressure in the reservoir, and geodynamic, caused by the activation of the fault zone. Constructed "pulsation" and "evolution" graphs allow to fully describe the geomechanical processes caused by the cyclic operation of UGS, however, create difficulties in interpreting the behavior of fault zones. The main reason for this is the pressure difference in the reservoir reservoir between measurement cycles. Based on this pattern, and taking into account the absence of large values of subsidence of the earth surface, the author proposed to estimate seasonal "evolutionary" and seasonal "pulsation" plots, which excludes the geomechanical component caused by the pressure difference and with the required reliability allows to estimate the values of deformations caused by geodynamic processes [3].

The obtained results prove that one autumn observation cycle per year is sufficient to identify geodynamic processes at UGS, taking into account the previously described fact about the increase of seismic activity exactly in the period after gas injection. At the same time, this does not exclude a possible fixation of geomechanical processes caused by irreversible deformations. The economic calculation performed showed that the savings from one cycle of observations per year at the Shchelkovsky UGS will be more than $35,000 per year.

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RONGHUA SHU
Jiangxi University of Science and Technology (China)

COMPARISON OF MECHANICAL PROPERTIES IN HIGH TEMPERATURE AND THERMAL TREATMENT GRANITE

A hot topic, namely the effect of temperature on rock properties, has drawn the attention of researchers, given an increasing mining depth of underground resources. Up to now, many studies have related to deep exploitation of hard rock metal mines. And, it has been recognized that temperature is one of the vital factors influencing the mechanical behavior of rock. Temperature plays a significant role in many engineering practices, such as the disposal of highly radioactive nuclear waste, the underground storage and mining of petroleum and natural gas, the development and utilization of geothermal resources, and the post-disaster reconstruction of underground rocks engineering. In order to solve the engineering problems, many researchers

studied the effect of temperature on physical and mechanical properties of various rocks [1-4]. There were already some rock mechanical properties studies related to temperature, but barely came down to static mechanical properties of rocks under high temperature. And, the mechanical properties of rocks after high temperature treatment and under high temperature can certainly be different. Thus, research on the mechanical properties of rock after high temperature treatment and under high temperature is extremely urgent. By using an electro-hydraulic and servocontrolled material testing machine with a heating device, uniaxial compression tests on granite samples after high temperature treatment and under high temperature, from room temperature to 800℃, were carried out. The variations in apparent form, stress−strain curve, compressive strength, peak strain, elastic modulus and failure modes under the two types of conditions with the change of temperatures are analyzed and compared. The results can provide a reference for problem-solving related to high temperature rock engineering.

The peak stresses under both types of temperature conditions show a significant correlation with temperature and a trend of gradual reduction with the increase of temperature, but the patterns of change under the two types of temperature conditions are different. The peak stress of granite under high temperature is lower than that of granite after the high temperature treatment but decreases more obviously with the increase of temperature. For granite after the high temperature treatment, when the temperature ranges from 100°C to 800°C, the peak stress shows a decrease of 5.67%, 27.68%, 32.81%, 45.69% and 52.85% respectively compared with room temperature. Although the peak stress of granite after the high temperature treatment at 200°C is higher than that at 100°C, the difference is only 5.67%, still in the normal dispersion range and possibly the result of rock sample heterogeneity. For granite under high temperature, when the temperature ranges from 100°C to 800°C, the peak stress shows a decrease of 14.00%, 31.32%, 42.29%, 49.86% and 61.31% respectively compared with room temperature. Compared with granite after high temperature treatment, the peak stresses of granite under 100, 200, 400, 600 and 800°C decrease 11.67, 4.84, 13.29, 5.84 and 13.17 MPa, which decrease by 8.83%, 4.79%, 14.12%, 7.68% and 17.95%, respectively.

The amount of granite fragments after and under high temperature produced in static tests is changed as the temperature increases. The failure modes of granite under the two types of temperature conditions both change, apparently with the increasing temperature. Along with the increase of temperature, small blocks and powder come out; in addition, two to three large blocks appear. However, there are also some differences. Granite after the high temperature treatment, before 100°C, shows the same failure modes. The specimen failure in two main blocks, along with a failure plane at a certain angle to the axis of the rock sample, presents a splitting failure. When the temperature reaches 200°C, the specimen failure occurs in three or more main smaller blocks, along with the parallel failure planes at a certain angle to the axis of the rock sample, still presenting a splitting failure. As the temperature continues to increase, reaching 400°C or higher, the specimens failure occurs in two to three main blocks, along with the main failure planes at different angles to the axis of the rock sample, but the failure modes still exist in terms of certain differences with the increase of temperature. Compared with 400°C, the two failure planes of the rock specimen after 600°C join in a deeper plane relative to the top plane. When the temperature reaches 800°C, the two failure planes join in the bottom plane of the specimen. For granite under high temperature, the failure modes present a great difference; from 100°C to 600°C, the specimen's failure into two main blocks, along with the main failure planes at the different angles to the axis of the rock sample and some little blocks and powder, presents a shear failure. From 100°C to 600°C, the two main failure planes join in middle plane of the specimen; one stop in the middle plane of the specimen, and another continues to expand until it occurs through out the specimen. When the temperature continues to increase, reaching 800°C, the specimen's failure into one main block and more small blocks and powder, compared with 100°C to 600°C, presents a conjugate shear failure. For granite under 100°C to 600°C, there are some small blocks.

1) For granite under high temperature, the peak stress is lower. 2) The failure modes of granite after the high temperature treatment and under high temperature show remarkable

differences. Before 100°C, the failure modes of granite under both conditions are the same, present splitting failure. However, after 100°C, the failure modes present splitting failure and shear failure respectively. Also, for granite after high temperature treatment, the two failure planes of the rock specimen join in a deeper plane relative to the top plane when the temperature reaches. When the temperature reaches 800°C, the two failure planes join in the bottom plane of the specimen. For granite under high temperature, the failure modes present a great difference; from 100°C to 600°C, the failure modes are the same, present shear failure. When the temperature continues to rise, reaching 800 °C, the failure mode presents a conjugate shear failure.

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FRIEDERIKE TIEDTKE
TU Bergakademie Freiberg

HYDROTHERMAL COUPLED FLUID FLOW SIMULATIONS USING 3DEC AND DFN.LAB

Numerical modelling is an essential tool for analyzing the processes of the subsurface. The models can in a way compensate for the uncertainty that is accompanied with field investigations and laboratory tests by carrying out sensitivity analyses and including multiphysically coupled processes in the model. These couplings take into account that the mechanical (M), hydraulic (H), and thermal (T) processes depend on each other and control the underground behavior [1]. THM – Coupling is investigated in different projects associated e.g. with nuclear waste repositories or Enhanced Geothermals systems. In this study a hydrothermal (HT) coupling is tested with two different numerical codes (“3DEC” [2] and the new software code “DFN.Lab” [3]). The results are compared against an analytical solution. Both numerical approaches are discussed and advantages and disadvantages are pointed out.

To describe the behavior of crystalline rock mass, knowledge about the joint network is required. An approach to systematically implement the joint network in a numerical model is the generation of a stochastic “Discrete Fracture Network” (DFN). In a DFN the fractures are represented as 2D-geometries in a 3D – system. The program “DFN.Lab” combines the possibility of generating complex fracture networks, analyzing network properties and calculating fluid flow within the network very fast. An additional feature of the DFN.Lab is a thermal calculation associated with fluid flow.

To verify the hydrothermal calculation in DFN.Lab and 3DEC, an analytical solution (“Injection into an Infinite Rectangular Fracture”) presented in [4] is used as a reference. The analytical model describes the fluid temperature development along a single fracture with a specific aperture during the injection of a cold fluid. The initial temperature of the model is T_0 = 90 °C. The injection temperature at x = 0 (left model/fracture boundary) is T_{in} = 20 °C. With the DFN.Lab software a model of the single fracture with a 2D-Discretization is built analogue to the

analytical reference and a steady – state flow is established. The comparison of the fluid temperature along the fracture after 1, 4 and 10 years shows good agreement with the analytical solution. A sensitivity study showed, that the relative error between numerical and analytical solution depends on the difference between the initial and injection temperature. The relative error increases with increasing temperature difference. The maximum relative error for a temperature difference of 70 °C lies after 10 years at around 10 %.

The same single-fracture model with additional 3D - discretization of the rock matrix around the single fracture is built with 3DEC. After establishing a steady-state fluid flow, the temperature T0 is initialized in the rock matrix and the fluid. To control the heat exchange between fluid and rock matrix, the Heat–Transfer–Coefficient (HTC) needs to be defined. The analysis showed, that the influence of the HTC – value is increasing with high temperature gradients in the system. The 3DEC calculations show under "Local Thermal Equilibrium" conditions a slightly higher heat exchange between rock and fluid, than the analytical solution implies. The maximum relative error in 3DEC increases with time. With an appropriate model configuration (HTC, Zone Size) a relative error between numerical and analytical solution under 10 % after 10 years of injection can be achieved.

Both numerical codes showed good agreement with the analytical solution for a time period of 10 years. Since the rock matrix is not explicitly modelled, the computation with DFN.Lab is very fast, which is especially for large-scale models a great advantage. The maximum relative error depends mainly on the temperature difference between initial state and injection. In 3DEC the results are more sensitive to the input parameters. A pre-analysis of the order of magnitude of the HTC-value is a prerequisite for hydrothermal coupled simulation in 3DEC, which can be time-consuming. For further studies, a combined modelling approach with DFN.Lab and 3DEC is investigated.

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IGOR D. TORBIN
Saint-Petersburg Mining University
Dr. Prof. PETR A. DEMENKOV
Saint-Petersburg Mining University

RISK IDENTIFICATION AND MANAGEMENT IN THE MATTER OF MECHANISED TUNNELLING

Introduction. Generally, the main purpose of designing and constructing the tunnel is to gain a stable and long-term result. Moreover, it has to meet the requirements of the contractor and design specification. We need to underline the fact that today many underground construction projects are suffering from cost overruns, delays and, therefore, the lack of funding. In 2016, Grasso estimated that approximate overrun in money defines as 35 % and overrun in time as 20 months (due to geotechnical risks) [4]. International companies decided to use risk methodology techniques in order to fix this problem. We need to underline that it is a new way of designing and constructing, which formed in the late 90s. Risk management methodology helps us to increase the quality of the design and construction, to estimate real cost and time for the realisation of the tunnels. Once the risk identification is done, we design risk reduction measures. Although, we cannot prevent some risks of the realisation, we can pre-design countermeasures. This way, even if the risk has occurred, we now know what to do.

Main part. We can define several groups of geotechnical risks in the matter of mechanised tunnelling, such as: geological, hydrogeological, design and construction risks [1]. There are different ways to prepare qualitative and quantitative risk assessment. The main problem of the risk assessment in underground construction is geological uncertainty. Currently, the most rational tool for the risk management in underground construction is a Risk Management Plan (RMP).

The causes of the geological uncertainty are the global diversity of geological and hydrogeological ground conditions. Moreover, we underline the scale factor, which is due to the difference between laboratory test and in situ situation of grounds. Nevertheless, we define the lack of geological information, the lack of experience of geology engineers, the lack of monitoring systems etc.

The causes of design risks are the lack of experience of the designers, problems with lining and TBM, the lack of monitoring systems. The presence of RMP leads us to decrease of technical risks linked with wrong technical decisions. We have to define carefully the control parameters and levels of alarm in RMP in order to manage risks properly. Therefore, we have to decrease the level of risk connected to low-quality risk management to the minimum.

The causes of constructions risks are, as always, the lack of experience, wrong decisions, incorrect advancement of the TBM, TBM issues, wrong face pressures, difficulties due to ground conditions. We need to compare the practical data to the theoretical scenario continuously. Therefore, it is extremely important to have several monitoring systems. Finally, we have to lead TBM through the “learning curve” carefully.

The presentation collects the experience of risk identification and management in the Saint-Petersburg Metro case study based on GEODATA Spa information. Therefore, the author is grateful for the shared data and shows gratitude to the company and ex-director and project manager Maccan S.

Conclusion. In conclusion, we are going to state that risk methodology is worth implementing by providing the points of success. We are going to underline some basic rules of Risk Management Plan. We will compare the laws in Russia and France in the sphere of geotechnical risk assessment.

In further research, it is natural to dig into the mathematics of qualitative risk assessment in order to understand the methods of comparing variety of designing and construction methods. Although, the practice shows that the “easy” qualitative risk assessment methods as risk matrix are enough, it is important to provide, for example, a Monte-Carlo simulation or Bayes networks

in the situation when we need to choose a construction technique by the exact possibility of cost and time overruns.

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QUAN ZHANG
China University of Mining and Technology
Dr. Prof. MANCHAO HE
China University of Mining and Technology (Beijing)

STUDY ON A NOVEL DIRECTIONAL ROCK-BREAKING TECHNOLOGY

Introduction. Directional rock breaking is a key common problem in mining and geotechnical engineering. The main directional rock breaking technologies include shaped charge blasting, static crushing agent, and directional hydraulic fracturing. Shaped charge blasting has a wide range of applications and great power[1], but it has the disadvantages of low safety, and complicated approval procedures. The static crushing agent uses water to react with CaO[2], and the volume increases several times, which produces a large expansion force to break the rock. It has the advantages of no vibration and no harmful gas, but its response time is longer, which restricts engineering efficiency. Directional hydraulic fracturing is to open radial wedge grooves or axial grooves on the hole wall to control the direction of the expansion of hydraulic fractures. It is no spark generation, and the cracking range is large, but its orientation range is limited[3]. Therefore, a new type of non-explosive directional rock breaking technology, instantaneous expansion with a single fracture (IESF), has been developed. It consists of four parts: a slit-oriented tube, a slitting agent, a coupling medium and a current initiator (Fig. 1). After the solid slitting

agent is excited by the electric current, it quickly becomes gas within 0.05-0.5 s, and the gas pressure rises sharply in the limited space. Then the rock fractures directionally along the direction of the energy-concentrating hole[4].

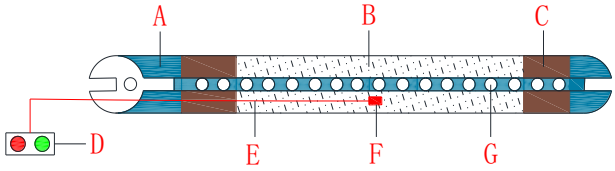
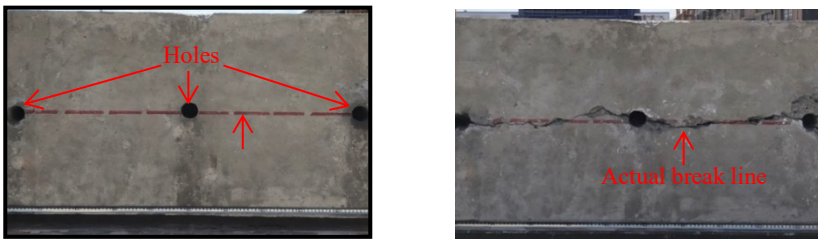


Figure 1 – Structure of IESF: A-Slit-oriented tube; B- Slitting agent; C-Coupling medium; D-Current initiator; E-Wire; F-Initiating head; and G-Energy-gathering hole[4]

Main part. The 2000×600×600 mm^3 concrete sample had three holes. The three IESFs were placed in the holes, and the direction of the energy-gathering hole was along the red dotted line. The holes were sealed with a special sealing device. After the current triggered IESFs, the concrete sample cracked along the pre-crack line, and the directional rock-breaking effect was excellent (Fig. 2).



(a) Before the experiment (b) After the experiment

Figure 2 – Laboratory experiment of directional rock breaking by IESF

According to the mechanical parameters of concrete, the corresponding numerical simulation model was established. The dynamic evolution process of cracks was simulated by COMSOL software. As shown in Fig. 3, the rock around each borehole cracked directionally, and finally the cracks between adjacent holes penetrated together.

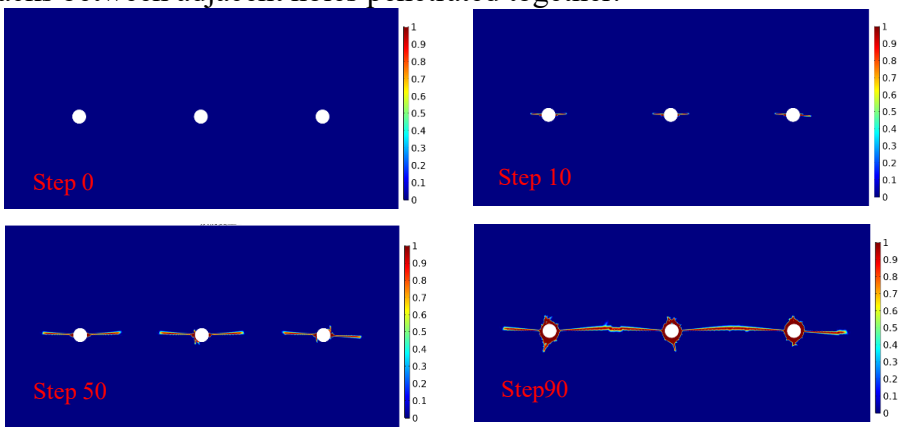


Figure 3 – The evolution of damage variables during the directional rock-breaking process

Directional roof cutting tests were conducted at in the Guotun coal mine. The drilling depth was 8.5 m. The total length of the five IESFs was 6.5 m, and the sealing length was 2 m. The roof lithology was limestone. After the test, two single-wing cracks were generated inside the hole and on the surface of the hole (Fig. 4) along the pre-splitting direction, achieving the effect of directional roof cutting.

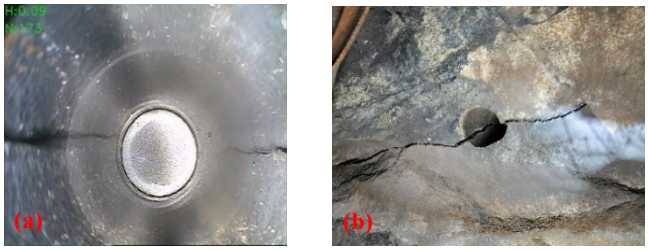


Figure 4 – The effect of directional roof cutting: (a) inside the hole; (b) orifice

Conclusion. A novel directional rock breaking technology, IESF, is developed. This technology has superior directional rock-breaking performance, high power, low vibration, fast response time and high security. In the future, the technology can be applied to different rock types (such as granite, mudstone, etc.) and different engineering fields (such as tunnels, non-coal mines, etc.).

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JIAN ZHAO
Geotechnical Institute, TU Freiberg
Dr. Prof. HEINZ KONIETZKY
Geotechnical Institute, TU Freiberg

GROUND SURFACE UPLIFT DUE TO ABANDONED COAL MINE FLOODING: CASE STUDY LUGAU-OELSNITZ

Mining induced environmental problems always accompany the entire mining process, even for decades after mining. Traditional mining and post-mining induced problems include: ground surface subsidence; long-term residual subsidence; damage of groundwater and surface water systems; induced earthquakes and exhausting greenhouse gases such as methane. In recent years flooding induced uplift for abandoned coal mines gets increasing attention. A lot of case studies from European countries reveals that (1.) uplift is related to the end of mine water drainage and restoration of natural water table [1]; (2.) uplift evolution is nearly linear to groundwater level increase [2] and (3.) uplift pattern is discontinuous near fault zone [3]. In recent years, the InSAR (Interferometric Synthetic Aperture Radar) technology became a popular approach to monitor ground surface movements above abandoned mines. InSAR data can provide a good overview, but they are less accurate and they are sometimes in conflict with more precise geodetic levelling results [4]. The traditional geodetic survey technique has a higher accuracy, but it is time- and labor- consuming. Hence, it is necessary to propose a general research flowchart for studying and predicting flooding induced uplift.

The Lugau-Oelsnitz coalfield is an exhausted hard coal mining area located between Chemnitz and Zwickau in southwest Saxony, Germany. Mining began in 1844, and was finished in 1971. Coal seams are mined over an area of 5 × 5.5 km, about 27.5 km^2. After mine closure, due to flooding the Lugau-Oelsnitz abandoned mine, groundwater level rose about 10 m every year, causing an inhomogeneous surface uplift, but a small part of surface shows still some settlements. Geodetic survey results show that continuous uplift are mainly distributed in the western and northwestern part of mining area. General total uplift is about 20 - 80 mm in about 40 years between 1972 and 2014, corresponding to an uplift velocity of about 0.5 - 2.0 mm/year. First subsidence followed by uplift is distributed in the south central mining area. Only a few monitoring points show still continuous subsidence, located in the western mining area.

Zone related InSAR data indicate that ground surface uplift is still occurring in the central and western mining area between 2014 and 2019. But due to the limited accuracy of the satellite

data, it is difficult to deduce accurate surface movement velocities. Point related InSAR data present some similar surface movement phenomenon as geodetic survey results: in the central part, ground surface is continuous uplift or first subsidence followed by uplift. In the western mining area, residual subsidence still exists.

According to the geological and hydrological situations of the Lugau-Oelsnitz mining area, continuum and dis-continuum based numerical models are set-up to reproduce the ground surface movement in the past, and to predict the movement trend in the future. Calibration results show that simulated uplift mainly appears in the northwestern area between 1971 and 2011, and general uplift is 20 - 80 mm. corresponding to 0.5 - 2.0 mm/year. The numerical simulation results have a good consistency with in-situ measurements. Besides, numerical simulation results can provide more details of past ground surface movement. Based on calibrated numerical models, future trend of surface movement is predicted. In the future, residual subsidence gradually disappears, and maximum uplift position moves from northwest to south. General uplift velocity will change to 0.5 - 3.0 mm/year.

The Lugau-Oelsnitz coal field is located in a wing of syncline basin, inclined from east to west on the whole, which is an important reason for future uplift over time and space. Uplift firstly appears in the northwestern mining area, and gradually extend to the east. After 1991-2001, maximum uplift position transfer to the south. Uplift velocity between 1971 and 2011 is about 0.5 - 2.0 mm/year. Water level rising velocity is about 10 m/year. Based on numerical simulations, in the future, general uplift velocity will change to 0.5 - 3.0 mm/year, Maximum uplift position will be located in the southern mining area. Surface movement predictions are provided up to the year 2051, when water level reaches the surface.

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MAXIM S. ZHELNIN
Institute of Continuous Media Mechanics of the UB of the RAS
Dr. Prof. OLEG A. PLEKHOV
Institute of Continuous Media Mechanics of the UB of the RAS

THERMO-HYDRO-MECHANICAL SIMULATION OF ARTIFICIAL FREEZING OF SOILS FOR VERTICAL SHAFT SINKING

Overlying strata of the largest deposits of potash salts often include unstable, water-saturated weak soils. As a result, vertical shaft sinking is possible only using special methods. One of the most effective ways to conduct shaft construction in difficult hydrogeological conditions is artificial ground freezing. This is an environment-friendly technology that increases the strength properties of soils and protects excavation from groundwater inflow without pollution of the environment [1].

The artificial freezing technology assumes drilling of freezing wells around the designed section of the shaft in which freezing pipes are installed [2]. Refrigerant circulates inside freezing pipes, which leads to the outflow of heat from the soil and the formation of ice cylinders around the wells. Diameters of the ice cylinders continuously increase with time, therefore, after a time period, the ice cylinders around neighboring wells close, and a continuous closed frozen wall is formed. Shaft sinking begins when the frozen wall attains a certain thickness. Since the formation of ice crystals in pore space couples soil particles together and prevents water inflow, during excavation works the frozen wall has a function of waterproof temporary lining which takes the pressure of the surrounding unfrozen soils and protects the shaft from being flooded.

A frozen wall is an important protective structure, the integrity of which determines the success of shaft construction. For this reason, monitoring of its state is performed during freezing [3]. Field measurements contain important data about frozen wall formation. However, accurate interpretation of measurements requires mathematical modeling of artificial ground freezing, which enables to assessment state of the soil using a limited amount of data and gives an adequate forecast of its development depending on engineering and technological decisions [4].

This study is devoted to the development of a mathematical model which describes freezing in water-saturated soil taking into account interaction between heat transfer, moisture migration, and a stress-strain state evolution. The developed model includes the heat and mass transfer equations as well as the equilibrium equation. To calculate simultaneous evolution of the stress-strain state, porosity, pore pressure of water and ice, constitutive relations of poromechanics theory, the Darcy's law, and the Clausius-Clapeyron equation are applied. Moreover, constitutive relations for inelastic strain induced by frost heave are incorporated into the model. In order to describe frozen wall deformation under the lateral pressure during shaft sinking, constitutive relations for creep strain are also included in the model.

The model was verified by three different laboratory experiments on artificial freezing of soil samples in open and closed systems. Numerical results were compared to measurements of porosity, temperature, and deformation.

After verification, the model was applied to numerical simulation of vertical shaft sinking in water-saturated soil strata using the artificial ground freezing technology. At the first step, a three-dimensional numerical simulation of artificial freezing was conducted for silt and sand strata, which are parts of the rock mass at one of the potassium deposits in the Republic of Belarus. Physical and mechanical parameters of soils were determined by laboratory experiments on core material sampled from the considered rock mass. Some parameters were identified by numerical simulation of experiments on frost heave and uniaxial creep tests.

Results of the numerical simulation enable one to study the effect of frost heave and cryogenic suction on the frozen wall structure and stress-strain state of the soil layers. It has been shown that frost heave in the sand is induced only by freezing of original pore water. In this soil stratum, the distribution of porosity along the thickness of the frozen wall is uniform, and an increase in porosity in the frozen zone is 9%. Frost heave in the silt stratum develops more intensively due to the water migration to the frozen zone induced by cryogenic suction. An increase in porosity in the frozen zone attains 21%, but the distribution of ice content along the thickness of the frozen wall is non-uniform. The rise in porosity in the frozen zone is accompanied by a volumetric expansion of soil, which induces compression of unfrozen soil inside the frozen wall. As a consequence, after the closure of the frozen wall, the pressure of pore water increases with the movement of the internal boundary of the frozen wall towards the center of the designed shaft. Thus, the obtained results have shown that the developed model enables one to predict the rise in groundwater level with an increase in the thickness of the closed frozen wall, which is necessary for the interpretation of hydro-observation data.

The next step was a numerical simulation of the deformation of the unsupported sidewall of the excavation in artificially frozen silt and sand strata. The modeling was carried out with and without a change of the natural stress-strain state of the soil strata induced by the frozen wall

formation. As a result, it has been shown that neglecting frost heave and cryogenic suction leads to underestimation of the wall displacement.

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DMITRY A. BYKASOV
St. Petersburg Mining University
Dr. Prof. MURAT G. MUSTAFIN
St. Petersburg Mining University

APPLICATION OF THE NEWTON METHOD IN SOLVING OF THE OPTIMIZATION GEODETIC TASKS

In solving some geodetic problems (scanning moving objects, calculating transition keys, calculating deformations of various structures), the speed of obtaining the determined parameters, as well as automation of the computing process, plays a special role. The development of geodetic instruments has put the solution of many geodetic problems at a new technological level. So in his works A.A. Kuzin and others [1], as well as Tsvetkov V. Y., & Oznamets V. V used satellite and laser equipment in solving classical geodetic problems. Thanks to modern scanning systems, robotic tacheometers, the surveyor in a short period of time is able to obtain a huge array of data about the object without direct contact with the object [2]. The presence of a large amount of source data provides the ability to calculate the desired parameters repeatedly, which increases the reliability of the obtained parameters. As is known from the theory of mathematical processing of geodetic measurements, nonlinear problems for which it is necessary to create nonlinear target functions with redundant measurements need to optimize the process of calculating the determined parameters. Therefore, the question of the use of computer technologies in geodesy is very relevant. Since it is most often necessary to create software modules for information processing to implement new measurement processing methods.

It should be noted that using nonlinear programming methods, it is necessary to calculate partial derivatives of various orders to find the extremum of the objective function [3]. This should be taken into account because if there are a large number of defined parameters, it is not always possible to calculate the derivatives of the objective function in a simple, analytical way. Therefore, many nonlinear problems require a lot of time to prepare for the solution – this includes writing special software modules for the iterative process, calculating derivatives and compiling matrices (Hesse and Jacobian), as well as determining their sign. Shevchenko G. G. notes these disadvantages in her works and suggests using direct search methods (which do not use derivatives in the iterative process) when solving optimization geodesic problems. We can say that the use of non-linear programming methods in geodetic production is a very relevant topic, because a large class of geodetic problems is associated with the processing and obtaining of the desired parameters by solving nonlinear equations [4]. An example of such problems is: finding parameters of communication between different coordinate systems, this problem was solved by J. Yan etc., as well as other authors. The design and equalization of geodetic networks, and the construction of digital models of terrain, the importance of accurate solution of these problems is justified in the works. The determination and prediction of deformations is also an important aspect of geodetic production. In solution of these problems nonlinear equations are used, methods of deformation determination are considered in works. All the above mentioned problems are related to solving nonlinear equations, as well as to processing a huge amount of data array.

The basic theory of nonlinear programming methods has been considered in the article. The application of methods in solving optimization geodesic problems has been substantiated. The second-order Newton method has been studied in particular detail. It is worth noting that methods that use higher-order derivatives in the search process have a wide range of applications in geodesy. To check the possibility to implement the second-order Newton's method in geodesic production, the equalization of linear intersection in space has been made. In the course of solving this problem, the main advantages of the method have been confirmed, namely, the high

convergence rate (compared to methods using first-order derivatives) and the possibility of using rough values of preliminary parameters for the iterative process. On the other hand, the main drawbacks of the method have been confirmed: it is a highly complex computational process (forming the Hessian matrix and controlling its sign). In the future, it is planned to create a software package that will automate the process of equalizing various spatial intersections, using the second-order Newton method. In the future, special attention should be paid to quasi-Newtonian methods, in which the Hessian matrix is replaced by an approximating factor, the use of which makes it easier to implement the method, but may affect its performance.

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PAVEL S. DOLHI
Polotsk State University
Cand. Sc. (Technology) GALINA A. SHAROGLAZOVA
Polotsk State University

LINEAMENT ANALYSIS OF FREE DISTRIBUTED SPACE IMAGERY IN LEFA SOFTWARE

Nowadays, remote sensing is the most important tool for research in various Earth sciences, including geodynamics. Remote sensing can provide continuous spatial data of an areal nature. Resources with free access to data (USGS, remotepixel.ca, scihub.copernicus.eu et al.) allow us to obtain information about the earth's surface in any territory in different epochs. Methods of processing remote sensing materials used in geodynamics can be divided into two groups:

– estimation of vertical displacements of the Earth's surface by interferometric processing of a pair of radar images (the most known project that provides freely distributed radar images is Sentinel-1, which consists of two satellites: Sentinel-1 A and Sentinel-1 B);

– identification of active structural elements in images in the visible and infrared bands.

Active structures identificated on space images can have a linear stretch (lineaments), or be expressed in the form of ring. These structures can be distinguished on space images both by visual decoding and by using various automated algorithms. One of the software products that allows automated lineament analysis – LEFA (Lineament Extractor and Fracture Analysis) - was developed by Sergey Shevyrev at the Far Eastern Federal University (Vladivostok city, Russia). The product is developed on the MATLAB platform and allows the user to perform image preprocessing by binarization (edge selection), selection of lines by the Hough method, combining lines into linear structures (faults), calculating the fractal dimension of fault systems, building rose-diagrams of the distribution of lines in length and direction; export the lines into a shapefile.

As the input data, the program can use grayscale images in the form of a digital terrain model (DEM), and in the form of a single-band space image. The program's effectiveness in processing the SRTM DEM and Landsat-8 satellite images (obtained from the resource remotepixel.ca [4]) has been experimentally proven. Landsat-8 data has a resolution of 15 m in the panchromatic mode, 30 m in the visible, near and short-wave infrared, and 100 m in the thermal infrared. The sensing period is 16 days.

Among the possible alternatives, we can consider the images of the Sentinel-2 satellite, which have a spatial resolution in the visible range of 10 m, 20 m in the short-wave infrared, as

well as data from meteorological satellites (TERRA (MODIS), SUOMI-NPP) with low resolution and large spatial coverage.

As the author of the program recommends, we used the 7th band of the Landsat-8 image (short-wave infrared, with a wavelength of 2.1-2.3 microns) on the territory of the northern part of the Vitebsk region, including the Polotsk district, on various dates from 11.04.2015 to 06.04.2019. Preference was given to spring and autumn images with poorly developed or withering vegetation.

Each of the images is preprocessed according to the Canny algorithm [2]. This algorithm is consideredto be optimal [3]. Next, we perform the Hough transformation, leaving parameters as default.

After finding the lines, the program joins the collinear lines into faults. We set custom parameters of the union. The final fault will include at least 5 lines, with the minimum length of the fault being 2 km.

We displayed the resulting faults for each epoch in the GIS-project in QGIS. As expected, the pattern of the fault network differs for different images due to different vegetation conditions, cloud cover conditions, and light conditions. However, comparing the images for different epochs, we can see that our study confirms the existence of a large latitudinal strike fault to the north of Polotsk, as well as a number of north-west – south-east strike faults. It should be noted that a number of identified structures correspond to linear objects of clearly anthropogenic origin – roads, forest clearings, etc. Such lines will not be taken into account when interpreting the result.

We compared the resulting pattern of the fault network with the one presented on the cosmotectonic map by Garetsky, Karataev, et. al. We can note that the directions of the main linear structures obtained by us in this region coincide to the data according to the cosmotectonic map. It can be concluded that the LEFA software product is informative for the study of the fault network based on images from the Landsat-8 satellite. Further study requires the tuning of algorithm parameters, as well as the development of the possibility of processing survey data from thermal, magnetic, gravimetric and other sensors.

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VLADIMIR A. ISYPOV
Nizhnevartovsk State University

ANALYSIS OF EROSION OF LICENSED AREAS IN NIZHNEVARTOVSKY DISTRICT

The paper presents an analysis tension under the influence of exogenous processes in license areas in the Nizhnevartovsk region. Shown cartographic material obtained during the study.

Exogenous processes, external processes occurring on the surface of the Earth and in the uppermost parts of the earth's crust, are mainly due to the energy of solar radiation, the force of gravity and the vital activity of organisms. These include: weathering, fluvial, glacial, aeolian, permafrost and other processes [1].

Analytical and cartographic methods were used to assess the state of the geological environment. [2].

Cartographic method - based on the analysis and generalization of cartographic information about the study area with the subsequent assessment of environmental indicators based on the information received. In our study, the work was carried out with a map of exogenous processes in the Nizhnevartovsk region [3], which was vectorized and transferred to the Gis environment. MapInfo Professional (figure. 1).

The analytical method consisted in calculating the degree of erosion susceptibility in license areas by calculating the ratio of the total area of all exogenous processes within the boundaries of a specific license area to its total occupied area. Each exogenous process was accounted for equally.

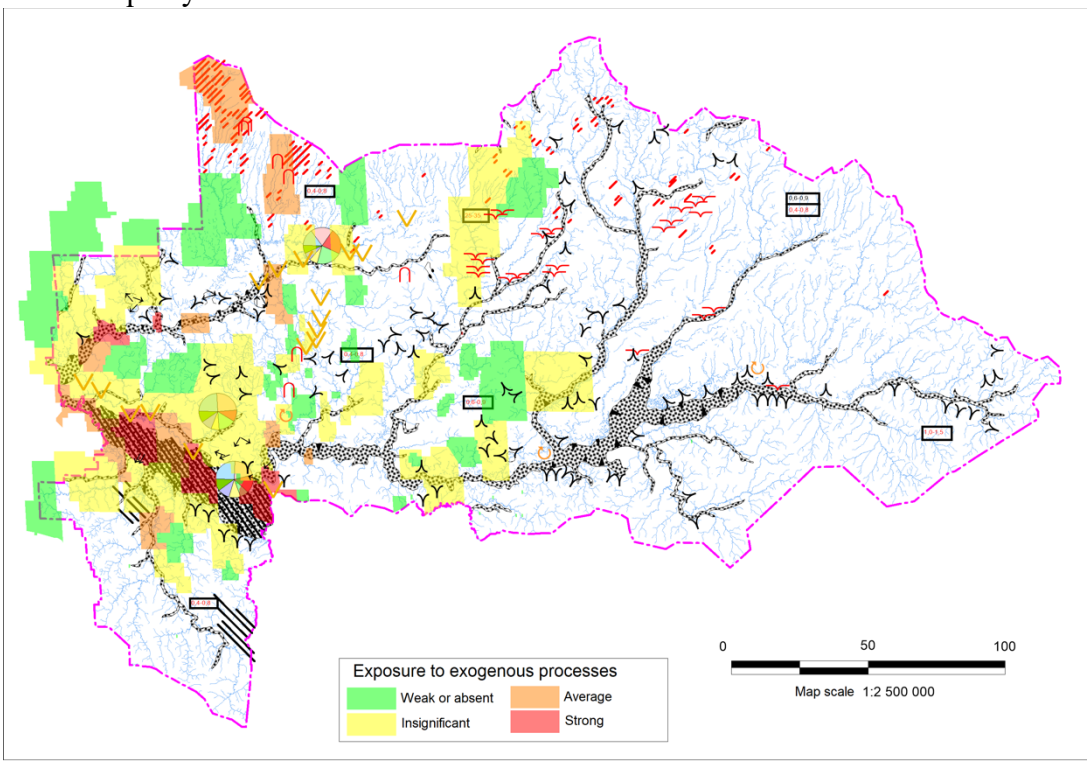

Figure 1 – Map of the degree of exposure to erosion for the Nizhnevartovsk region

Talking about the impact of exogenous and other natural processes on oil and gas production. We must not forget about the opposite effect. In view of the vast oil industry in the district, the study of the anthropogenic factor affecting the natural environment is underway. A digital map of the oil industry for the Khanty-Mansi Autonomous Okrug-Yugra was compiled, the map is partially presented using the example of the Samotlor license area (Figure. 2.).

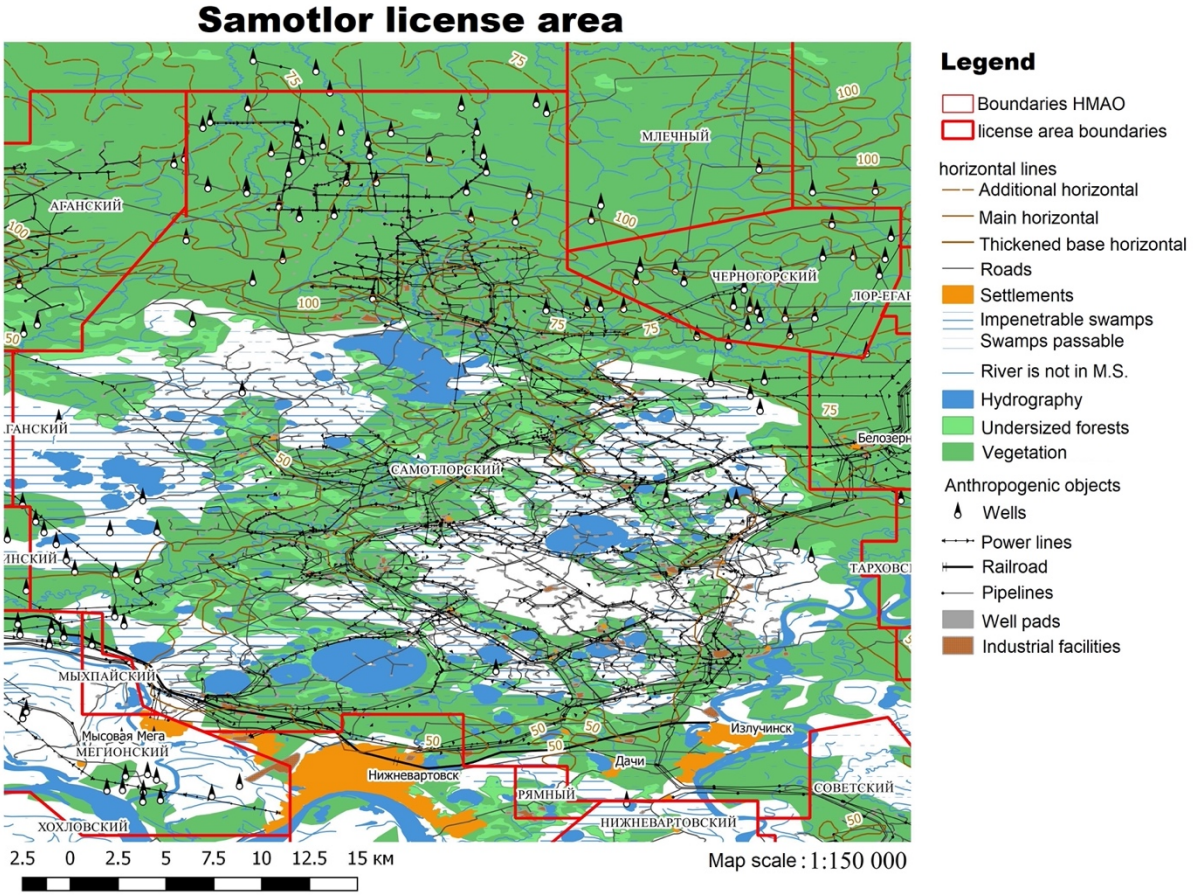

Figure 2 – Schematic map of the Samotlor license area with anthropogenic objects

This study shows the mutual influence of the human factor on natural processes and vice versa. When planning, building and operating industrial facilities, it is necessary to analyze possible natural processes in a given area and make engineering-geological forecasting, compilation of probabilistic models to study the dynamics of the development of geological and engineering-geological processes.

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KEMENTUROVA NURZADA
Kyrgyz State University of Geology, Mining and Natural Resource Development named. academician U. Asanalieva
USENOV KENESH
Kyrgyz State University of Geology, Mining and Natural Resource Development named. academician U. Asanalieva
Ph.D. prof. CHUNUEV ISHIMBAY
Kyrgyz State University of Geology, Mining and Natural Resource Development named. academician U. Asanalieva

USE OF AERO PHOTOGRAPHY METHODS FOR MONITORING AREAS OF HIGH MOUNTAIN MINERAL RESOURCES: PROSPECTS FOR DEVELOPMENT

Annotation. The widespread use of unmanned aerial vehicles (UAVs) has led to the development and improvement of various sensors, which, according to the requirements of the time, have become more miniature and intelligent. Smart sensors are nowadays an important approach for acquiring spatial data. Many advantages, such as low cost, short data acquisition and processing cycle, flexibility and high accuracy, have made UAVs powerful tools for geological, agricultural, environmental and forestry growth monitoring and assessment.

UAVs are now a hot spot in scientific research. Their use in high mountain mining areas mining areas is still in its infancy, but is rapidly evolving in the face of rapid growth in the scale and volume of services.

This article discusses aspects such as UAV platforms, various sensors and their fields of application, as well as an overview of the achievements of scientific research in this area to date. Combining current research and the functions of several sensors, an application framework for monitoring UAVs in the mining industry is built, the problem, prospects and development of UAVs and sensors are also considered, as well as practical experience in the educational process and in the development of high-altitude deposits. In particular, the issues of using UAVs in solving a set of tasks – issues of reclamation after the development of upland coal deposits in a combined way, drawing up a topographical basis for the development of a project for geological exploration in high-altitude conditions, surveying the areas of sinkholes of areas of settlements worked by underground mining operations.

Features of the development of high-altitude deposits from traditional ones – height, the presence of glaciers, inaccessibility, cramped conditions of the gorge, sharp weather variability, geodynamic processes (traditional geodetic and surveying work is very limited in time and space, air flow, etc.).

In this regard, we offer a complex of GIS applications for creating digital maps:

- At the initial stage-use the following software products-Google Eath, Global Mapper, OpenStreetMapArc, GIS (non-commercial web mapping), geological and topographic maps at a scale of 1:100 000 (GUGK).
- Conducting surveys with the help of UAVs, zooming.
- Building digital maps for various purposes.

The aim is to provide a technical reference that expands knowledge and recognition of the use of UAV monitoring in the mining industry for the assessment of mining, land reclamation, ecology and geodynamic processes.

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ANDREY V. KORNOUHOV
Astrakhan State University of Architecture and Civil Engineering
Cand. Sc. (Biology), Assoc. Prof. SVETLANA R. KOSOBOKOVA
Astrakhan State University of Architecture and Civil Engineering

OBSERVATIONS ON THE GEODYNAMIC POLYGON OF THE TERRITORY OF OIL PRODUCTION

The importance of crude oil materials in the economic complex of any country is well known. Long-term exploitation of these oil deposits leads to geodynamic consequences of the territory. One of the most dangerous consequences is the deformation of pipeline systems.

While studying the scientific literature, we have determined that both environmental and socio-economic consequences can be divided into direct and indirect. This circumstance requires special attention from the customer and the contractor when exploring the territory of the observation. Direct consequences include: contamination of the geological section and groundwater resources with hydrocarbon components and drilling products. Indirect consequences contain the development of landslide processes that are changing the landscape, waterlogging of territories with irreversible changes of ecosystems and the transfer of hydrocarbon components through aquifers [4].

Putting aside the environmental consequences, specialists are being attracted with complex geodetic surveys in oil production areas. When designing an algorithm for geodetic surveys, it is necessary to consider the difference in the negative consequences of solid and liquid sources of extracted minerals. The main form of negative deformation consequences of solid mineral deposits (ore, coal) is extensive subsidence of the earth's whole surface, while at liquid hydrocarbon deposits the most dangerous deformation processes are intense local anomalies of vertical and horizontal movements in fault zones that were provoked by the exploitation processes [5].

Nowadays, among the methods of geodynamic polygons monitoring, geodetic ones are primary. These methods relate to complex types of monitoring, because they can be supplemented with gravimetric observations. In this report we analyzed the complex of engineering and geodetic works during monitoring of the geodynamic polygon (hereinafter referred to as the GDP) of the Mamontovskoye oil field in the city of Pyt'-Yakh. After researching the technical report on the observation at the GDP for 2016-2019, we have discovered an observation algorithm. It consists of the following steps:

- preparatory work;
- inspection of points of the GDP network;
- satellite observations at the GDP points (pic.1);
- reconnaissance of the leveling section and II class leveling of the profile lines;
- gravimetric observations at points of the GDP network;
- performing radar interferometric survey;
- analysis and interpretation of the observation results of the GDP network (pic.2);
- preparing of a technical report after the work is done.

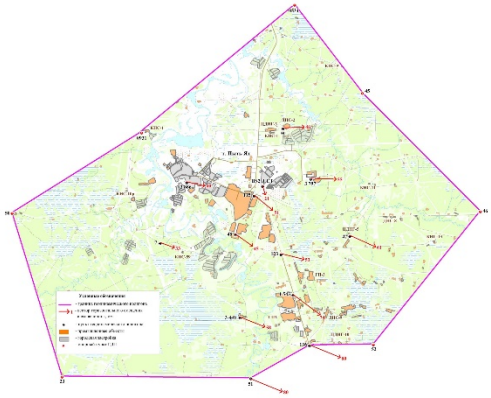

Figure 1 – Layout of satellite observations at the GDP

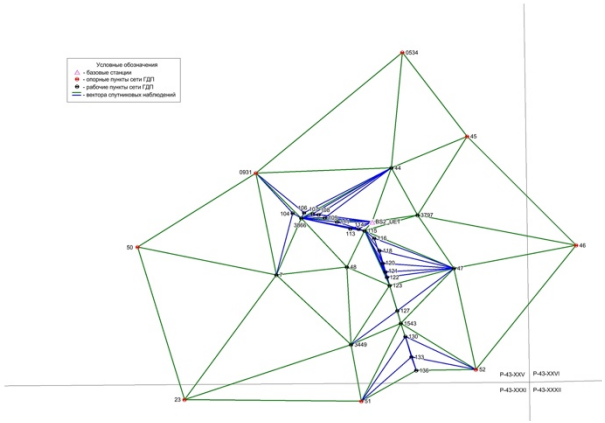

Figure 2 – Layout of horizontal displacements of observed GDP points (2016-2019)

The leveling of the highest (I, II) classes is definitely the most informative type of geodetic work. The requirements for this type of survey can be found in regulatory documents (Geodetic, cartographic instructions, standards and rules (hereinafter - GCISR) 03-010-03 [1]).

Conducting high-precision satellite observations for determination the components of the vector of movement of the earth's surface should be carried out at the points of the GDP network. It should also be performed to carry out additional control of the deformation processes of the earth's surface.

At the end of the field work, the office processing of the measurement results for the II class leveling included:

- verification of Trimble data and results;
- registration of field journals;
- drawing up a list of elevations and heights of leveling points;
- assessment of the leveling quality based on the differences of the measured exceedances.

The general network includes different points of satellite observations: a permanent base station (BS2_UET), 7 control points (23, 45, 46, 50, 52, 0534 and 0931) and 29 work points. Satellite measurements were carried out in a static mode with a duration of synchronous observations for 4-8 hours. At the same time, special attention was paid to the choice of the most advantageous time intervals when the simultaneous visibility of satellites is 8 or more. Afterwards there were performed:

- pre-processing;
- post-processing;
- equalization;
- interpretation of results (including the chart of horizontal displacements of the observed points).

There are some results listed below:

1. The maximum horizontal displacement vector of 80 mm for the observation period 2016-2019 is observed at points 136 and 51. All points received a slight displacement in the horizontal plane (visualized on the slide desk). The value of the coordinate measurement is related to the structural accuracy of the applied geodetic equipment.

2. According to the pictures above, the southeastern direction of movement of the point's centers dominates on the explored GDP.

3. It is necessary to take into consideration that the uplift of the main part of urban development was confirmed by using three geodetic methods (geometric leveling, high-precision satellite observations and radar interferometry).

4. Using the obtained coordinates, we found out that the relative horizontal deformations of the GDP points, which are in the range from $-3.31 \cdot 10^{-5}$ to $8.82 \cdot 10^{-6}$, do not exceed the maximum and permissible deformations according to PB 07-269-98 [2].

5. The estimation of vertical ground displacement from satellite observations should be done using WGS-84 ellipsoidal heights. The reason for this is that the orthometric heights can change due to the redistribution of the subsoil masses. This will affect the distortion of the real picture of the displacement [3].

In conclusion we can say that:

1. It is recommended not to determine the heights of leveling networks using satellite technologies in static method, since different methods of leveling are used in this case: the method of geodetic leveling and the method of satellite geodesy.

2. To achieve a high degree of predictability of geodynamic processes occurring on the territory of the city of Pyt'-Yakh - Mamontovskoye oil field, it is necessary to take into account the following recommendations:

- produce satellite observations once a year, since no other method with an accuracy of 3-5 mm will allow tracking planned displacements (horizontal deformations);
- make gravimetric observations once a year;
- carry out geometric leveling once a year;
- if possible, create and develop the network of permanent base stations within the GDP territory. It will probably reduce (but not exclude) the time and labor costs for classic leveling. Continuous monitoring will allow assessing the speed and nature of displacements in the real time and make conclusions on the need of leveling individual most active sections.

The analysis of the data of these three types of the surveys will make it possible to better determine the nature of the movements of the earth's surface - tectonic or technogenic. The development of permanent base stations will have a positive effect on the quality of the obtained data on the movements of the earth's surface in the area of the oil field exploitation. Having data for previous observation cycles, we can predict expected deformations in certain areas and locate permanent base stations for satellite observations on the optimal sites (watch the slide desk) what will pay off in the long term.

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HIBA I. MOUSSA
St. Petersburg Mining University
Dr. MOHAMMAD ABBOUD
Lebanese International University
MOHAMMAD NASRULLAH
St. Petersburg Mining University

DETECTION OF FOREST FIRE IN EL MESHREF AREA AND ITS SURROUNDING

Forest fires is one of the primary problems that impacts the vegetation composition and structure of any location disturbing the environment, economy and social life and risking all communities living in the vicinity of the forested landscape. The frequency of these kind of fires are increasing day by day amidst prevailing local and global climate changes marking them as a complex phenomenon to deal with. Forests have been an essential part of Lebanese history. The woodlands have various functions bringing in diverse goods and services that in return provides support and cultural meaning to the country. Lebanon is one of the countries in the Mediterranean regions that has been subjected to forest fires due to dry weather. With exceptionally high temperatures and strong winds, hundreds of forest fires have spread over large areas of Lebanon, affecting large areas of forest and residential areas.

In Lebanon, forest fires frequency increase during the summer season (June-October) with a highest frequency recorded in August (25%) and September (27%). The burned ranges are exposed to intense precipitation, leading to more water erosion incidents. Yearly, timber losses from fires can reach up to 20,000 USD/ha specifically within the pine woodlands. Even with this disturbing circumstance, there is a need for an upgraded national wildfire risk map, which is needed for viable avoidance of wildfires and pre-suppression activities.

The study area selected is “El Mechref” and its surroundings in El Chouf – Mount Lebanon. El Chouf extends from the Mediterranean coast to the west to heights of the mountains of Barouk (two thousand meters over sea level). the estimated area is 495 square kilometers, proportionate to 4.7 percent of the whole range of Lebanon country.In this study, fire prone area will be analyzed using QGIS and ArcMap to assess the classification of the vegetation on the basis of density of the forest. Besides that, the study will cover detection of forest fire in El Mechref and areas nearby in EL Chouf – Mount Lebanon.The results show the places that have been affected by the fire caused in El Mechref area and its surrounding, as well as statistical outcomes. It also displays the percentage of barely and highly damaged areas depending on each class, and this helps in the understanding of the fire expansion that happened back on October 2019.

Lebanon is one of the most forested countries in the Middle East as percentage of its area. However, forest fires or wildfires are at some points hard to be controlled in regions of flammable vegetation. There are various reasons that ignite forest fires, especially the case that this project discussed in Chouf. Yet there are many ways to stop forest fires from happening or diminish the size of the areas affected. The approach done in this project is the detection of forest fires, where an application of severity is done on Chouf district before the forest fire and after it, then on El-Mechref and its surrounding after the forest fire, and finally on El-Mechref alone. To show that the percentage of severity in Chouf was 0.25% before the fire ignited and 6.39% after the forest fire. The severity in El-Mechref and its surrounding is 20.36% after the forest fire, and El-Mechref village alone is 40%. These all results will benefit decision-makers and official authorities in inhibiting, pre-suppressing and combating futuristic incidents.

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MOHAMAD S. NASRULLAH
St. Petersburg Mining University
Dr. MOHAMAD R. ABBOUD
Lebanese International University

TRANSFORMING CASTLE TO 3D MODEL USING 3D LASER SCANNING AND DIGITAL PHOTOGRAMMETRY

Archaeologists use a wide range of reconnaissance techniques to locate archaeological sites and to investigate sites without excavating them. Some archaeologists predict that future advances in these non-invasive, and non-destructive, methods may see them emerge as an alternative to excavation [1]. For that, and because of the importance of archaeological sites for humanity, these sites should be well preserved so that these sites and monuments remain a living witness to history and a legacy for future generations. Lebanon's location in the ancient Near East made it a land on which many civilizations flourished thousands of years ago, leaving behind them many great archaeological sites, those sites should be preserved and protected especially due to the presence of wars and terrorism threats that destructed many sites in the middle east in the last 2 decades in addition to the location of Lebanon above some major and minor faults and the dangers coming from natural disasters due to the global warming and the climate changes. **Sidon** *(Saida in Arabic)*, is a famous name in ancient history for a mysterious city in Lebanon. In the 13th century (specifically between years 1227 and 1228), the Crusaders came and built a castle on a small island dominating the sea. It is said that this island was formerly the site of a Phoenician temple. It is connected to the mainland by a narrow but fortified 80 m long causeway built on nine arches [2].

Terrestrial 3D laser scanning will become the future standard tool for high-resolution 3D documentation of archaeological excavations, but its capabilities are still underestimated by professional archaeologists and providers of scanners or scanning services. The new tool forces archaeologists to consider extension of archaeological stratigraphy theory [3]. A combination of aerial Photogrammetry using an imaging drone and a terrestrial 3D laser scanner is a successful method for a full 3D documentation and modeling of an archeological site with high accuracy results. To create a 3D documentation and model for Sidon sea castle, the 2 techniques mentioned above have been adopted in this study. In the first stage an exploratory visit to the site was carried out, and after identifying the site, the field works were planned and the equipment and techniques needed were determined, taking into account the obstacles and the difficulties that may face the survey, especially because the location of the castle on an island and the inaccessibility to many places. The next stage was to create an accurate control network in and around the site by fixing many control stations, the 3D coordinates of those stations were measured accurately using GPS receivers operating in open sky areas and a total station instrument operating inside the rooms and the halls of the castle. The following stage was the site survey and this was done by aerial Photogrammetry using a drone holding a camera and flying at an altitude of approximately 100m. The camera captured 65 images from different locations covering the entire site using 5 ground control points where their 3D coordinates were measured accurately before the flying mission. The captured images were processed using photogrammetric software to generate a 3D model for the entire site. After the aerial Photogrammetry, the site were fully scanned and imaged from ground using a professional 3D laser scanner instrument. The 3D laser scanner was operating by selecting the stations of the control network as occupation and back sight points, and by applying 13 scanning and imaging sessions at different locations inside and around the site, the castle was fully

scanned with high resolution. After field data collection, the large data were extracted and processed using specific software, creating the point cloud data and the panoramic site map. Finally, the aerial Photogrammetry and terrestrial 3D scanning data were analyzed, compared and integrated together in order to generate a single accurate 3D model for the entire castle.

The study shows that applying each method alone is an unproductive way, where the terrestrial 3D laser scanning shows a high rate in vertical data collecting, while the aerial Photogrammetry generates high level planned point cloud. Such tools have proved them efficiency in scanning archaeological sites since they can determine the physical conditions and topographical features using Ortho-image. Also, the terrestrial laser scanning has higher positional accuracy than aerial Photogrammetry. Photogrammetry could improve the 3D model by complementing the point cloud data for the upper parts of buildings which are difficult to be surveyed through laser scanning, and the overall discrepancy of the two technologies was sufficient to generate convergent data. The photogrammetric point cloud data was aligned and merged based on the laser scanning results. As a combination for the result of both technologies they increase the accuracy and shape of the castle to get a professional work and perfect result of the data. This study should not stop here; nowadays the 3D documentation for all the archeological sites and historical buildings is a duty that has to be assigned to engineers and surveyors.

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AGNIESZKA OCHAŁEK
AGH University of Science and Technology in Krakow

HANDHELD 3D LASER SCANNING IN UNDERGROUND HERITAGE DOCUMENTATION

Underground Heritage, both natural and anthropological origin, is a huge and important part of Cultural Heritage. More and more objects which spread knowledge about the history, geology of the region or mining industry become a part of digital collections (virtual museums, scientific repositories, digital libraries). Today, because of the pandemic situation, it is even more important to share such information in a digital way, publish them on the Internet and make them available for tourists without living in their houses. The process of collecting and managing such specific digital data requires engineers and researchers to search for a more efficient way of spatial mapping solutions and ways of making documentation. A comprehensive inventory of Cultural Heritage, especially underground objects, should be adapted to its type (e.g. richly geometrically featured environments, enclosed spaces, places without lightening), and also respect its uniqueness and historical significance. Therefore, the measurements carried out there, cannot make any damage [2]. The development of modern technologies for reality-based 3D surveys provides effective and affordable methods for an inventory of underground environments. The most popular now is Terrestrial Laser Scanning (TLS), which does not require any light to perform the measurements. TLS enables to obtain a high-resolution spatial representation of an inventoried object - point cloud with spatial X,Y,Z coordinates of each point (adding Intensity and eventually

RGB colour) [3]. However, it requires many scanner stations in case of large objects, which means longer measurement shifts. Recently, Simultaneous Localization and Mapping (SLAM) technologies are growing and developing faster [3]. Different methods of SLAM (visual, LiDAR) allow collecting the measurement data simultaneously with the navigation data. It uses a camera or scanners to map the surroundings and IMU components to navigate. One of the biggest advantages of using SLAM is that it can do what GPS cannot. GPS relies on triangulates between satellites, it requires seeing satellites. Therefore, it is useless underground. SLAM does not have this problem, because it operates within the space itself, recording the surroundings and remembering the route.

Complex Riese (German the Giant) is located in the Owl Mountains, in Lower Silesia near the Polish-Czech border. Command troops of the Third Reich believed that it is the furthest and the most unreachable place in their country. Despite the fact that during II World War no aircraft was able to fly this place from outside Reich, it was completely covered by forest. It was surrounded by mountains from south, west and east. Complex was linked by rail and roads with Wroclaw and Walbrzych, so authorised person could reach it easily. The construction work was done by forced labourers, POWs and prisoners of concentration camp Gross-Rosen. Drilling the corridors in hard gneiss rock cost many lives. The whole project was kept in secret, even the beginning of the construction work is unclear so the purpose of Riese is still rather the hypothesis than the fact. The only verified information is that the project was abandoned at the intermediate stage due to the approaching of the Red Army. Before that Nazis put a lot of effort to hide all information about Riese. Today we can see how successful these efforts were. Nowadays, six underground structures are discovered in Walim and Głuszyca area: Włodarz (3000 meters of tunnels), Osówka (1743 meters of tunnels), Sokolec (called also Gontów, 800 meters of tunnels), Soboń (740 meters of tunnels), Rzeczka (560 meters of tunnels), Jugowice (500 meters of tunnels) and about 600 meters of tunnels under Książ Castle in Walbrzych [5]. It has been discovered that many of the tunnels in some structures have a dead end, and there is a theory this might prove that all complexes were supposed to be combined. It is believed that many kilometers of the underground tunnels are still to be discovered [6]. The biggest object of Riese is Włodarz Complex which is available for tourists as an underground museum. It contains 3000 meters and two levels of underground adits, some of which are flooded.

In this paper, the Author presents the results of inventory measurements with the usage of a hand-held laser scanning system - the GeoSLAM Zeb Horizon - for the 3D digitization of underground drifts of Underground Włodarz Complex and further documentation. GeoSLAM Zeb Horizon with a range of 100 m, as the producer assures [7], is a great device to make spatial models of any space in a more efficient and faster way with an accuracy of 1-3 cm. The scanner was used in a very difficult environment – an adit with many straight corridors and two levels of drifts (some of them were flooded). The measurements took 5 hours and the post-processing (so obtaining the full point cloud using dedicated software after surveys) one day. Additionally, measurements were carried out with the usage of a stationary laser scanner – Faro Focus 3D in one of the drifts. Thus, the accurate evaluation of hand-held technology and TLS technology was able to carry out. Consequently, in the paper, the results are critically presented and discussed. The author focus on the advantages and disadvantages of using both TLS and SLAM technology depicts differences between methods. The possibilities of using the final product – point cloud – in the documentary of Underground Heritage is also crucial - calculating volumes, surfaces and visualization of the data, geometry analyses. It is worth mentioning that this kind of data can be easily used to make a virtual museum.

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CHRISTIAN RADACH
TU Bergakademie Freiberg
Institute of Mine surveying and Geodesy

HIGH-PRECISION DISTANCE MONITORING OF ARTIFICIAL STRUTURES WITH RADAR DATA

Both airborne and terrestrial radar sensors have a wide range of possible applications in geomonitoring. The technology Interferometric Synthetic Aperture Radar (InSAR) as a satellite-based method has been established for decades in remote sensing for the detection and monitoring of ground movements on the earth's surface, such as volcanism, glacier movements, earthquakes, mining-related subsidence and different types of landslides (debris flow, creep, earthflow) [1, 2, 3, 4, 5]. The area to be monitored is recorded several times by repeated overflights and from different viewing angles and evaluated interferometrically, whereby changes can be detected [6, 7].

In terrestrial radar interferometry, also known as ground-based InSAR (GBInSAR), the measuring principle of the InSAR technology is largely adopted in order to be able to measure long-range geometric changes of objects directly from the earth's surface. The difference and advantage to airborne and spaceborne radars, in which the direction of movement often is unfavorable to the viewing direction of the satellite, consists primarily in the adaptable observation direction of the radar relative to the expected movement of the object [3, 4].

In addition, terrestrial radar sensors offer the possibility of a continuous and extensive detection of deformations, even without direct access to the measuring object [4]. Though, commercially available GBInSAR measuring systems are currently still very expensive.

A different type of ground-based radar devices are also used at close range for distance measurement in the automotive sector or other technical applications, such as level or door sensors. Frequency-Modulated Continouis Wave (FMCW) radar sensors are usually used for this purpose. Such low-cost FMCW-devices have extremely high distance accuracies in the sub-mm range down to below 1 µm and are therefore an order of magnitude more precise than laser measurement technology [8, 9]. Therefore, FMCW sensors from industrial measurement technology are suitable for high-precision, short-range, as well as continuous and non-contact measuring geomonitoring.

In this study, a non-contact and time-continuous measurement method is described that includes an FMCW radar sensor for 1D distance measurements. The measurement setup used here is also in the low-cost segment, compared to the high-precision deformation measurement technology available on the market, such as terrestrial laser scanners. The aim of this study is the investigation of the system with regard to its accuracy in 1D distance measurements under

laboratory conditions and for use in 1D monitoring of engineering structures. In the static measurement setup with a defined target object, measurement accuracies of up to ±10 µm could be determined. As a case study, the movement of a headframe is followed over the course of a day. Absolute movements of the headframe in the range of about 1 mm could be observed. Using a statistical test procedure, movements of around 0,2 mm with an assumed certainty of 95% could be detected significantly.

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RAGUZIN I.I.
St. Petersburg Mining University
Ph.D Lepihina O.U.
St. Petersburg Mining University

A SPATIAL APPROACH TO IDENTIFYING METHODOLOGICAL MISTAKES MADE IN THE PROCESS OF CALCULATING THE CADASTRAL VALUE

Abstract. In this paper, we propose a spatial approach to localization of unaccounted for parameters that affect, to one degree or another, the value of an object, including consideration of methods for interpolating point values, as well as various methods of clustering their values to justify the application of a certain type of approach. The purpose of this study is to improve the accuracy and objectivity of the results of the cadastral assessment based on the application of a spatial approach to the localization of absent parameters.

Introduction. Due to the application of a mass approach by the majority of budgetary institutions authorized in matters of determining the cadastral value, for assessing a significant number of objects, the problem of discrepancies between the calculated values of values and the data characterizing the state in the market as of the date of assessment appears. Statistical models do not provide for a complete coincidence of the values of the cadastral and market values, which causes dissatisfaction on the part of citizens taxed on the cadastral value. There are statistical

criteria for assessing the accuracy of the results obtained, for example, the coefficient of determination, standard deviation, coefficient of variation, Fisher's test. However, in the case of a significant point deviation of the calculated value from the market value, a problem arises in identifying methodological errors. There is no way to separate a point release (a unique object) from an area with an unaccounted factor (an array of sites next to an unaccounted landfill). In this paper, we propose a spatial approach to localization of unaccounted for parameters that affect, to one degree or another, the value of an object, including consideration of methods for interpolating point values, as well as various methods of clustering their values to justify the application of a certain type of approach.

Description of the spatial approach. The practice of building regression models shows that often the analysis of the situation does not provide a complete list of wobbling variables. The researcher already at the stage of model calibration reveals a significant weight of the residual variable. This may be due to the omission of an important component of the study area under consideration, which prompts the search for a spatial solution of methodological problems.

As a solution to the problem of identifying methodological errors in the existing model for assessing land plots, it is proposed to check the cadastral values obtained from the model by geometric comparison of polygons formed by the point ratio of the cadastral value to the market value.

Spatial polygons characterizing the isolines of the values of the cost ratio can be constructed by different algorithms: interpolation methods (for example, Delaunay triangulation, distance weighted method (IDW) [9], radial basis functions (RBF)), as well as clustering methods (hierarchical, c -means, selection of related components, layer-by-layer clustering, k-means [4], minimum spanning tree). The spatial representation of the relationship between cadastral and market values allows the appraiser to conduct analytics for the discrepancy between the idea of the socio-economic environment of objects and the real situation. An example of a problem area obtained using radial basis functions is shown in Figure 2.

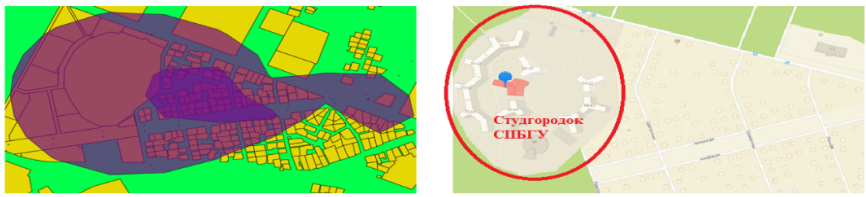

Figure 2 - Analysis of the problem area

As can be seen from the figure, a large value of the ratio of the cadastral to market value can be caused by a complex of dormitories of the institute. What prompts the evaluator to revise the influence of objects that are hostels of higher education institutions.

Conclusion. The existing mechanisms of methodological control of the state cadastral assessment, by processing geospatial data, are characterized by low knowledge. The existing solution methods have several drawbacks - the complexity of implementation, a high probability of error, high costs of human resources, imperfection of the tools used, etc. [1, 2, 3]. To select a working methodology, various interpolation methods were analyzed (Delaunay triangulation, inverse distance method, and radial basis functions), as well as clustering methods (hierarchical, k-means). According to the results of the analysis, as a solution, it is proposed to use the RBF interpolation method, which will allow implementing an effective mechanism for methodological control of calculating the cadastral value by identifying "problem" areas for their further study. A program for the estimated zoning of land plots has been developed in the Python 3.7 programming language, which implements the considered interpolation methods. Some scripts have also been written to implement clustering methods. The calculated data were tested on the land plots of the Petrodvortsovy district of St. Petersburg. The result obtained showed the unaccounted for variable in the "problem" areas, which will allow the appraiser to make the most accurate calculation of the cadastral value.

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ANZHELIKA A. SHARAFUTDINOVA
Emperor Alexander I St. Petersburg State Transport University
Dr. Prof. MICHAEL JA. BRYN
Emperor Alexander I St. Petersburg State Transport University

THE USE OF LASER SCANNING AND BIM TECHNOLOGIES AT DIFFERENT STAGES OF THE INDUSTRIAL FACILITY LIFE CYCLE

From the viewpoint of the digital environment, an industrial facility represents a considerable amount of complex information about the assets of the company. Such assets include information about buildings, structures, technological equipment, utilities, technological regulations, specifications, and other technical documentation. An industrial facility goes through successive stages of the life cycle during the process of development. Among them there are: engineering surveys, design, construction, operation, and decommissioning. Therefore, the amount of information about the assets of the facility grows exponentially at each new stage of the life cycle. Practice has shown that digital tools are increasingly being used for the management of the asset information to ensure the business continuity of facilities. BIM is one of such tools, and it can be a unified source of relevant data about the assets and provides access to data relevant for the process participants at each stage of the facility's life cycle. BIM is a complex of interconnected digital information points describing the physical, functional, and other properties of an object, based on its three-dimensional representation and it is a source of information for the timely management and operational decisions.

Creating BIM can be divided into two stages. The first stage is creating a 3D model containing information about the size and location of the structures and equipment. The second stage is the filling of attributes based on technical documentation. The source of data for creating the 3D model can be both technical documentation and geodetic measurements. Since the industrial facility appears to be a complex technical object, which is characterized by a high density of construction structures, equipment, and pipelines, it is appropriate to apply terrestrial laser scanning (TLS) to collect geodetic data about the facility. Unlike the traditional measurement methods, the TLS provides data source with a high level of detail at the lowest time costs, which is confirmed by a considerable number of studies in world practice [1-4].

It should be noted that there is no connection between TLS as a method of geodetic works and the formation of BIM in the official technical documentary governing such works. In this regard, based on the analysis of the official documentation and practical experience, the authors identified a series of tasks that can be solved using the TLS and BIM at various stages of the

industrial facility life cycle. Based on the analysis, it can be concluded that the Russian official technical documentation regulates only the general issues of creating and using BIM. Given that BIM is created on the basis of the TLS results, it is necessary to investigate the accuracy of 3D model elements creation. Also, the official rules don't regulate the accuracy of the TLS methodology and requirements, depending on the tasks being solved. According to the authors, the requirements for the accuracy of the TLS and the creation of the BIM should be established in the terms of the special calculations based on the requirements for design, construction, and operational tolerances, depending on the type of tasks being solved.

The examples of solving various tasks using TLS and BIM at the different stages of the industrial facility life cycle, implemented by the authors, will be described in this thesis. These tasks were solved during the implementation of the project in which engineering survey was conducted and 20 facilities across one company were designed, constructed and commissioned.

The implementation plan of the project includes the following stages:

Stage 1. TLS at the construction site. Laser scanning was carried out at all sites allocated for new construction, to create a digital terrain model and BIM of the adjacent buildings and structures. On the basis of the data obtained, the precise setting of the construction boundaries and connection with the existing facilities was carried out.

Stage 2. Creating BIM according to design documentation. BIM was created according to the blueprints of the design documentation and which made it possible to carry out clash detection between all elements of the 3D model. The clash detection was performed automatically in the CAD system by searching for intersecting BIM elements. As a result, a report containing information about sections of design documentation, structures involved in clash detection, and their visual display in BIM was generated. The clash detection revealed 350 errors in the design documentation for one of the objects.

Stage 3. Creating BIM according to TLS data (as-built BIM). Laser scanning was carried out at all reconstruction sites to obtain relevant data on existing construction structures, equipment, and communications. On the basis of the obtained data, the as-built BIM was created based on the TLS data which made it possible to analyze the absence of clash detection between existing structures as well as the structures and communications being designed before the start of actual construction and installation works. The report on clash detection, which was generated based on the results of the work and it contained data on the number of detected collisions, visualization of their locations, and structures involved in collisions. 82 collisions with existing structures were identified in design documentation for one of the reconstruction objects.

Stage 4. Creating reports on deviations from the project in the mounted structures. TLS was periodically performed at the facilities during the period of construction and installation works. The purpose of the TLS was to identify the real location and size of the mounted structures, equipment, and communications for a certain date. The as-built BIM was updated based on the TLS and as a result it contained the data about mounted structures at the time of the TLS. Further, the analysis of deviations in the size and locations of structures was carried out by combining design BIM and as-built BIM. Reports containing information on actual and permissible deviations in dimensions and location of structures were formed upon completion of the analysis according to the terms of reference. 9 cycles of scanning of one of the objects were performed during the period of construction and installation works. At the same time, it was revealed that 605 structures out of 1596 were assembled with unacceptable deviations from the project.

Stage 5. Creating reports on the quantity of the completed construction and installation works. The as-built BIM identified deviations of the mounted structures from the project, and as well made it possible to analyze the volume of construction and installation works performed. For this purpose, the attributive component of the BIM, which contains the information necessary to calculate the volumes of each building structure was used. The analysis was carried out on the basis of data on the volumes of assembled structures provided by the construction organization and data on the volumes contained in the as-built BIM.

Stage 6 Creating the operational BIM. The final TLS was completed upon completion of construction and installation works, which made it possible to supplement the periodically formed executive BIM with all mounted structures, equipment, and communications. Attributive information which contained the data required during the operation of the facility was generated for each element in the BIM.

The results obtained during the implementation of the project showed the effectiveness of the use of TLS and BIM technologies in engineering solutions needed throughout the life cycle of an industrial facility. The use of these technologies made it possible to identify design and construction errors at an early stage, increasing the quality of the works performed. It should also be noted that the formed BIM made it possible to provide access to engineering data about an industrial facility to all participants in construction, design, and operation. Further in-depth study of the joint application of TLS and BIM technologies will expand the list of tasks required to optimize the design, construction, and operation of an industrial facility.

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ROMAN V. SHEVCHUK
Geophysical Center RAS
NUST MISIS
Dr. Sci. degree, Vladimir I. Kaftan
Geophysical Center RAS
Dr. Sci. degree, Victor N. Tatarinov
Geophysical Center RAS

EXPLORING OF CRUSTAL MOTIONS AND DEFORMATIONS OVER SEVEN YEAR INTERVAL BEFORE STRONG SEISMIC EVENTS 2016 KUMAMOTO, JAPAN

The number of continuously operating Global Navigation Satellite System (GNSS) network stations is increasing every year. This makes it possible to increase the accuracy and to obtain more detailed information about seismic processes taking place nowadays. As a result of processing data from continuously operating stations, it is possible to trace all stages of the seismic cycle, and it is also possible to detect and study deformation processes that are precursors of earthquakes [1].

In this paper, we processed data from permanent stations in Japan on Kyushu Island, obtained from the Nevada Geodetic Laboratory. A series of strong earthquakes hit Kumamoto City and its surroundings in April 2016. The seismic events consisted of two strong foreshocks Mj 6.5 (14.04) and Mj 6.4 (15.04), as well as the following main shock Mj 7.3 (17.04) with a hypocenter at a depth of 10 km. It is worth noting that the earthquakes were confined to the Futagawa and Hinagu faults [2].

Determining slow elastic deformations is one of the main tasks in the study of seismic cycle stages. However, it should be understood that GNSS point displacements expressed in the global

reference frame are largely a consequence of global tectonic plate motion. This fact creates difficulties in interpreting the data of local movements caused by the accumulation of elastic deformations of the Earth's crust in the vicinity of the epicenter of the seismic event. As a solution of the described problem, the authors (Kaftan V.I., Tatarinov V.N., Shevchuk R.V.) propose to determine displacements of points in a local reference system, allowing with high accuracy to determine mutually differently directed movements of the sides of local faults. Offsets of points in the global reference system is the difference of plan coordinates in the UTM projection. To switch from the global reference frame to the proposed local frame, it is necessary to determine for each epoch the average value of displacements associated with global tectonic processes, and subtract the resulting value from each displacement determined in the global reference frame.

A dense network of GNSS stations has been developed on Kyushu Island, Japan. Based on the results of the study of publicly available materials on the satellite network, a Delaunay triangulation network of 70 points was formed on Kyushu Island. The radius of the study area is about 180 km, which allowed to cover the territory with epicenters of strong earthquakes that occurred from 1889 to 2016. The studied materials allow us to make assumptions about the duration of the seismic cycle of the sequence of seismic events studied here and the time of accumulation of elastic deformations in the Earth's crust.

Considering the horizontal and vertical displacements caused by the preparation of seismic events, there was definitely a slow accumulation of horizontal displacements oriented in the northwestern direction, whose values reached about 10 cm the day before the first foreshock (Mj 6.4), the vertical displacements in this time period indicate a sinking of the entire study area to 5 cm, the exception is the southeastern part of the area, where a slight elevation is recorded. When forshocks occurred in the vicinity of their epicenters, dip values exceeding 5 cm were recorded, with horizontal displacement vectors slightly prolonged. The study of coseismic horizontal and vertical displacements caused by the event with magnitude Mj 7.3 allowed us to determine right-lateral displacements with an amplitude of more than 1 m, simultaneously with the distance of territories on both sides of the seismic rupture to 1 m from each other, as well as to identify elevations greater than 20 cm and dips of both sides of it, reaching also 20 cm.

According to the results of the studies, the information value of mapping seismically active areas based on the values of total displacements of GNSS points has been proved. The zone with the smaller displacement vector length is the location of seismic stresses.

Thus, for Kumamoto in the areas of future earthquake epicenters, the displacements did not exceed 2 cm and were minimal for the entire study area.

The obtained results demonstrate the possibility of registering the waiting area of strong seismic events, where intense coseismic shear deformations of the Earth surface occur as a consequence of an earthquake. However, these areas extend for hundreds of kilometers, in connection with which further study of occurring events should be aimed at more accurate localization of the zone of probable earthquake occurrence.

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MAŁGORZATA ZONTEK
AGH University of Science and Technology

THE USE OF AUGMENTED REALITY TECHNOLOGY IN THE MULTITEMPORAL PRESENTATION OF MONUMENTS IN BIELSKO-BIAŁA

The combination of the image of the real world with virtual elements created with the use of IT methods is increasingly used in many areas of life, e.g. in navigation maps or educational applications. Using the location data of selected objects, we can present to the recipient the location of the selected element in relation to the environment in which it is located. Technological progress has allowed for the development and improvement of augmented reality technology, based on GIS technology on mobile devices. A proprietary Android mobile application has been developed, which allows users to familiarize themselves with the former appearance of the monuments of Bielsko-Biała. The user in the field can see the former appearance of the buildings after finding the right place, and there, based on GPS geolocation data, the virtual reality module is launched. The application was written using the Unity program with the Vuforia plugin. The application contains elements of gamification and due to its similarity to Pokemon Go applications, it is a modern tool in learning about the history of the city.

The work began with creating the application's native interface in Android Studio, implementing Google maps and importing the output database, which consisted of two tables. The first is a table in which data is stored in the form of object names, descriptions and links to the sources from which the archival photo was taken. The database prepared in this way with 50 selected historical objects of the city of Bielsko-Biała was later divided into three groups, creating further categories in the Menu class (Churches / Monuments / Streets). The second table contained a list of the coordinates of those places from which current photos were taken, and whose coordinates were obtained using the ArcGIS Collector mobile application. The collected data in the form of coordinates made it possible to place MapMarkers on the implemented Google map. For all archival photos, their current equivalents were taken from as similar perspective as possible in order to emphasize the changes taking place over time. Three of the six menu subcategories, ie Churches, Monuments, Streets, are constructed in the same way. After selecting one of the previously mentioned components, a window with many historical photos is displayed with their description, which can be viewed by scrolling the screen. After clicking on the selected archival photo, it is possible to move to the next class, which includes a description of the selected object, its current photo taken in the same perspective as the archival photo and a short description. After selecting the Scoring menu, the user can preview which historical objects he has managed to see and which are still "to be found". This subcategory is linked to the Unity program that checks whether the user is in the virtual item's pop-up area or not. By selecting the last of the menu subcategories - Map, the user is presented with a city map with many MapMarkers located at the location of historical objects.

In the Unity program, work began with adding appropriately marked archival photos. Compatible Vuforia plugin and ARCore plugin were implemented and the game elements were created. An initial user panel was created with the default Unity tools, and a virtual cube element was also created. A created texture was added to the cube (cuboid), which was an archival photo. A script in C# was written for the texture component surrounding the cuboid. In this script, a formula has also been added to calculate the distance between the current location of the user and the location of the selected object. As the distances between the user and subsequent objects are smaller than approx. 100 km, the sphere was adopted as the reference surface. In order for the program to calculate the distance between the user's current location and the location of the selected historical object, the relationship between the geographic ((, λ) and polar (α, δ) coordinates was used [1]. The calculations were based mainly on the cosine formula [2]. A button has been created, and when pressed, the Unity program is launched from the Android Studio. After clicking the button, four arguments are passed: the coordinates of the selected object, the name of the object

and the selected item. The Unity program receives the data sent by Android Studio, displaying the name of the selected object, the GPS signal reception status and the distance to the target on the Unity start screen, and then if the condition (distance to the target <30 m) is met, a virtual element is activated, i.e. a cuboid with texture photos of an archival object.

While working on the program, the activation of the virtual element was based on geolocation data through the use of a GPS receiver built into the device. Using the GPS receiver, you can determine a specific position from code and phase measurements. The code method (used in GPS receivers in Smartphones) is based on measuring the reception time of C/A and P codes on one or two frequencies L1 and L2. This time multiplied by the speed of propagation of electromagnetic waves allows to determine the exact distance from a point on earth to the satellite [3]. The ionospheric and tropospheric refraction and reflections from obstacles adversely affect the course of the measurement signals, so the accuracy of this method is (depending on the measurement conditions and the class of the receiver) about 3-5 m. For navigation purposes, this accuracy is sufficient [4]. In order to increase the accuracy and reliability of the position obtained from GPS, the EGNOS system can be used. The accuracy of the GPS receiver on the user's device may vary depending on its version or model. Therefore, it would be impossible to embed a virtual item in a specific location and display it by different mobile devices in the same place. The element would show up at a point slightly away from its parent coordinates or "jump" around this region. For this reason, the area of appearance of the virtual cuboid to the circle has been increased, the center of which is in the original coordinates of the object and the radius is 30 meters.

The use of augmented reality technology, which is based on geolocation data, shows that it is possible to create a modern tool for learning about the history of selected cities. The presented final product, which is the proprietary application, allows to disseminate knowledge in the field of geodesy, cartography and geoinformation in an interesting way. The use of geolocation data made it possible to present interesting places in Bielsko-Biała to users. For older residents, the application can be an opportunity to recall memories based on images showing what individual places in Bielsko-Biała used to look like. For children and young people, it is a modern tool to learn about the history of the city, thanks to the use of gamification and creating a substitute for the Pokemon Go game. The application allows you to get acquainted in an accessible and simple way with the history of Bielsko-Biała, and is also a kind of innovative guide around the city.

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MAHMOUD ABDELLATIF
Miskolc University

2D NTERVAL INVERSION METHOD FOR ESTIMATING LATERAL CHANGES OF LAYER BOUNDARIES

Introduction. In well logging applications, the local inversion method gives an estimate only for the petrophysical parameters at a given depth point and does not contain information about the layer boundaries. In this case, the determination of the rock interfaces is considered using another non-inversion procedure. Taking into consideration, the entire measurement datasets collected from a greater depth interval contains information about the layer boundaries and since the interval inversion method processes the entire data system in a joint inversion process, it is possible to define the layer boundaries by developing an appropriate algorithm within the inversion [1, 2].

Main objective . A new innovative 2D interval inversion approach which integrates data set of several neighbouring deep wells has been developed to delineate the lateral variation of layer boundaries, thus the morphology of hydrocarbon reservoirs can be determined.

Methodology. In this study, a Legendre polynomials based 2D interval inversion method is tested both on noise free and noisy synthetic measurements. A set of Gearhart Ultra-response equations [3] are used to generate the synthetic well logging data. The series expansion-based inversion method (Eq.1) is used to discretize the model parameters similar to the one used in the 1D variant of the interval inversion method

$$m_i(z,x) = \sum_{q=1}^{Q_i} \boldsymbol{C}_q^i \boldsymbol{\Psi}_q(z,x), \quad (1)$$

The unknowns of our inverse problem are the series expansion coefficients C_q, which represent the unknown layer boundary coordinates as well as the petrophysical parameters treated as constant. Linear optimization method [4] is used to solve our inverse problem by minimizing an L_2 norm based objective function.

Results. Two models of multilayers structures related to hydrocarbon bearing reservoirs have been used in the investigation. The first model is a three-layered anticline structures made up of shale and hydrocarbon bearing-sand formation and the second model is a four layered pinchout structure. The layer boundary variations between the wells are described as quadratic Legendre polynomials over the $x \subset [-1,\ 1]$ interval. The polynomials degree is settled as 5 and the initial models for the first and second layers of the first model are 6 and 12, respectively. While they are 2, 8, and 15 for first, second and third layer of the second model. In case of the free noisy data, the inverse problem is stable while with noisy measurements, we can get reliable results. However, increasing the number of unknowns, linear inversion should be complemented by global optimum search for a more reliable and initial model free estimation.

Conclusion. The lateral variation of layer boundaries has been successfully estimated with help of series expansion-based polynomials coefficients. A synthetic experiments datasets (noise free and noisy) of multilayer structures have been used in the study. Consequently, the algorithm will be applied in field data and further developed to estimate the lateral variation of petrophysical parameters at the same time.

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BAKYT AIGERIM
Karaganda Technical University
DR. Ph.D. KOPOBAEVA A. NYGMETOVNA
Karaganda Technical University

MINERAL IMPURITIES IN THE COMPOSITION OF COALS

Coal is a single system of organic substances (macerals) and inorganic components (minerals). The mineral components of coals are conditionally divided into two groups: macro - and micro-components (respectively, when their content is more or less than 1% in the mineral substance). The macro-components include the compounds Si, Al, Fe, Ca, Mg, S, and in some cases — Na, K, and Ti. Almost all chemical elements, except for inert gases, platinum group metals, and some radioactive and rare-earth elements, have been found as micro-components in coals [1].

The study of trace elements in coal provides information about the deposition environment, and is also important for predicting the behavior of toxic elements during coal purification, combustion, and leaching.

Mineral inclusions in coals are represented by clay minerals, iron sulfides, alkalis, carbonates, silicon oxides and other minerals.

Over 40 minerals were found in the coals [1]. Mineral components are found in coals in the form of rock layers, lenses, nodules, fine-dispersed material, and organomineral compounds. The most common mineral formations in fossil coals are sulfides (pyrite, marcasite, chalcopyrite), carbonates (calcite, siderite, aragonite), sulfates (gypsum, celestine), silicates and aluminosilicates (kaolinite, feldspar, hydrosludes, etc.). It can also be fragments of minerals and rocks such as mudstones, siltstones, sandstones and limestones. Ash-forming components that are part of organic compounds are found in coals mainly in the composition of humates.

According to the assessment of J. Clay minerals and quartz account for 80-90% of the total amount of mineral matter [2]. And it is these clay minerals that are enriched with rare elements.

The presence of rare metals in the composition of clay minerals, thanks to modern technologies, can be determined by various geochemical methods. The main methods for studying the micro-components of coals are petrographic analysis, thermal analysis, X-ray diffraction analysis, infrared spectrometry, and low-temperature salinization. Based on the results of these methods, it is possible to control the amount of impurity elements and assess their industrial significance.

Currently, the complex of analytical studies is based on highly sensitive instrumental neutron activation analysis (INAA) with irradiation of samples with thermal neutrons of research nuclear reactors.

In order to assess the geochemical specialization of the Shubarkol coal deposit and the industrial potential of the impurity elements in the coal composition, INAA and microscopic studies were conducted [3]. The samples were studied by the INAA method to determine the average contents of 28 elements Sm, Ce, Ca, Lu, U, Th, Cr, Yb, Au, Hf, Ba, Sr, Nd, As, Br , Cs, Ag, Tb, Sc, Rb, Fe, Zn, Ta, Co, Na, Eu, La, Sb [3].

According to the results obtained, the average contents of impurity elements in the samples taken in the coals of the Central section of m III have mainly near-clarke values, only some elements (Ce, Ba, Sr, Sc, Zn) in some samples have average contents higher than Clarke.

Microscopic studies were also carried out on a scanning electron microscope (SEM) Hitachi S-3400N and as a result, the presence of mineral inclusions of various compositions was detected. For example, the inclusion of ferrochromite in the form of angular grains of irregular shape (Fig. 1).

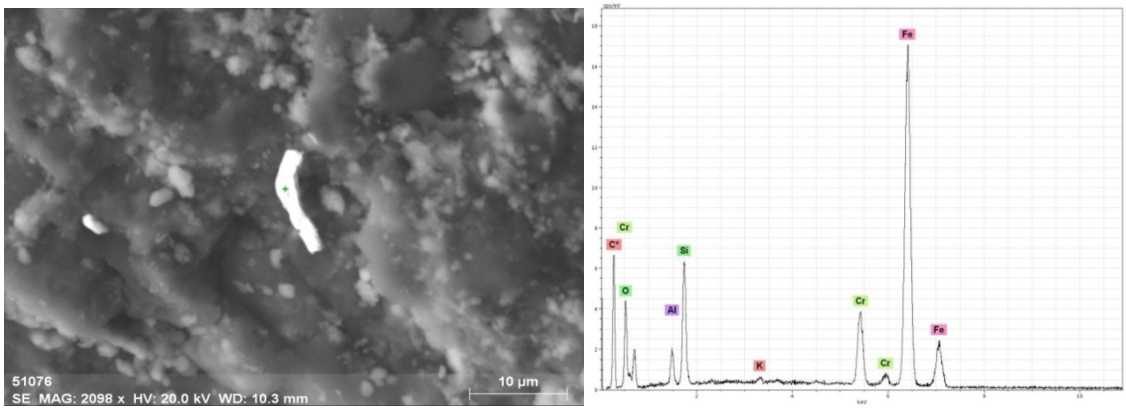

Figure 1 – Ferrochromite in the coal sample Centr-1-1 (Central section) and its spectrogram

With modern technologies, it is quite possible to create an economically profitable production for the extraction of impurity elements from coal. The most promising ones for the Shubarkolskoye field are U, Sc, Ba, and Yb.

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ARTURO H. BRAVO
TU Bergakademie Freiberg
PROF.DR. GERHARD HEIDE
TU Bergakademie Freiberg
DR. OLEG POPOV
TU Bergakademie Freiberg

MINERALOGICAL AND MECHANICAL STUDIES IN GNEISS AND THEIR RESPONSE TO INDUCED CRACKS

A systematic analysis of crack propagation in rocks with appropriate analytical techniques, delivers valuable information when striving to understand the behaviour of raw materials. With this knowledge is viable to obtain parameters to optimisation, for example the comminution processing using the natural crushing behaviour of the raw material and reduce mining related energy costs and environmental damage.

This study is carry-out on saxony´s major mining district, the Erzgebirge (Ore mountains) in Germany. The Ore mountain area has served as international reference material for mineralogy, petrography, and geochemistry, which provides a good base for accumulating reliable information

on their mechanical behaviour [1]. The area is mainly composed of metasediments (grey gneisses) and metamagmatites (red and grey gneisses) and those samples are the based on this study [2].

The first results of the investigation are presented using gneiss drill core samples from Reiche Zeche. The gneiss samples present a challenge because of their anisotropic nature and because several studies have shown that they respond in a particular way to fracture [3]. To characterize such effects, the investigation of the rock involves X-ray diffraction analysis, dilatometry experiments, petrological description of thin sections, the numerical description using QMA (quantitative microstructure analysis) and 3D characterisation by using computed tomography.

In QMA, the statistical evaluation of three orthogonal thin sections allows a quantitative assessment of the mineral phase composition and the size, shape, and orientation of mineral grains in a given rock, which can be used to approximate its mechanical properties [4]. This analysis was performed at the facilities of the Institute for Mineral Processing Machines and Recycling (IART) at the TU Bergakademie Freiberg.

The microcomputer tomography (micro-CT) is considered for investigating cracking behaviour, its dependence on the rheological structures in gneiss, its research possibilities, and the test engines for uniaxial compressive loading at the Institute of Rock Mechanics at the University of Mines in Saint Petersburg. This technique gives us an overview of the stability of the rocks in the dependence on its texture under static conditions.

The fracture formations at different speeds are evaluated under uniaxial test with constant loads, where the drilling core samples will be arranged in different orientations. It is intended to evaluate if the fractures growths are intra-granular (split mineral grains) or intergranular (between grain boundaries).

Upcoming studies will focus on stress loads will be compared with nondamaged microstructures and microstructural parameters on the rocks.

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LIUSKA FERNÁNDEZ DIÉGUEZ
Moa University
YEXENIA VILTRES MILAN
St. Petersburg Mining University

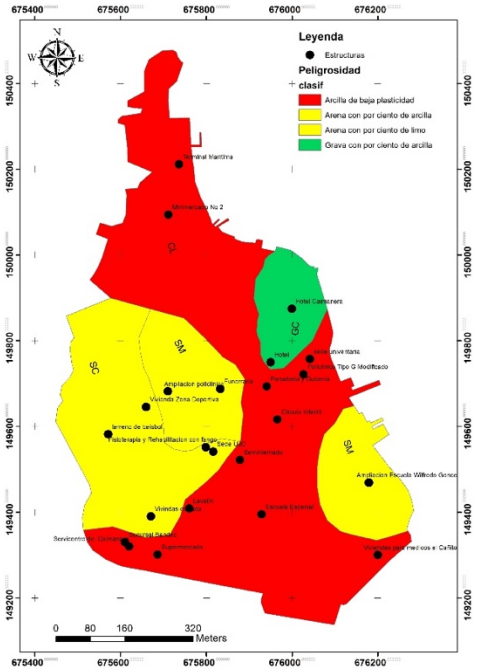
LOCAL SEISMIC RESPONSE OF THE SOIL OF THE URBAN SECTOR OF THE CAIMANERA MUNICIPALITY, GUANTÁNAMO PROVINCE, CUBA

A quantitative prediction of the seismic movement of the ground is a key element in evaluating and mitigating seismic disasters. Examination of destructive earthquakes revealed a close relationship between the distribution of damage and that of impedance contrasts near the surface. Geological, soil stiffness, and topography effects can significantly affect the frequency-amplitude relationship and duration of motion at a site relative to the underlying rock. The effects of siege have contributed greatly to human deaths and construction damage in earthquakes for more than 70 years. In Cuba, studies of this type are aimed at making a forecast of the damages to be expected in the event of a strong earthquake in order to suggest the appropriate standards for construction, and thus mitigate the impact it would have on the national territory. The present case study is located very close to the Bartlett-Caimán seismic generator zone capable of generating strong earthquakes. The local seismic response of the soil from moderate earthquakes was studied. The research was given by the need to know the local seismic response of the soil from the geological engineer conditions. It was done with the objective of evaluating the local response of the soil and its correlation with the geological engineering conditions, in such a way that the seismic danger in the urban sector of the Caimanera municipality can be zoned.

The study was carried out from the correlation of a system of indicators that summarize the most influential characteristics such as: geology, seismicity, geomorphology, depth of the water table and physical and mechanical properties.

The city of Caimanera is considered to be located within a geological engineering zone. Geologically it is located in the Quaternary marsh deposits. It has alluvial clay soils on limestone and sandstone. The coastline is surrounded by a swampy, boggy area and mangroves that have disappeared over time due to the action of man. The area occupied by the head town and its surroundings is extremely low, with values up to 1 meter above sea level. Generally, due to the hydraulic characteristics of this aquifer complex, groundwater is predominant. (Fernández-Diéguez, 2015).

The increase in seismic intensity was evaluated using the method of categories by typical geological profiles (Popov 1959) described by Zapata (2003). Finally, a description is made of the main factors that influence the local seismic response, such as geological conditions, geomorphology, depth of the water table, engineering-geological conditions.



The conjugation of all these indicators described above results in a scheme of seismic microzones, (See Figure 8) that shows the sectors of the Caimanera municipality where the seismic signal can be amplified. A diagram was obtained that illustrates three zones: north, central and south; being the one with the greatest seismic danger the central zone, since it is composed of filling material, not very compact, of low resistance, saturated, compressible, with abundant organic matter.

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DIANA A. IBRAGIMOVA
Karaganda State University
Dr. Prof. VASILIY S. PORTNOV
Karaganda State University

ELEMENTS OF IMPURITY IN THE COAL OF THE SHUBARKOL DEPOSIT (CENTRAL KAZAKHSTAN)

Objective data on the content of valuable and toxic elements-impurities in the coals of the Shubarkol deposit are one of the main ones for considering their commercial value as energy raw materials, raw materials for their use in such technological processes as coal chemistry, metallurgy for the production of silicon, aluminum, ferroalloys. During exploration and operational work at the deposit, an assessment of their content and impact on the environment in the process of coal mining and use was carried out. The work carried out in the second half of the 80s showed that individual coal seams have high, sometimes industrially significant concentrations of Sc, Co, Se, Y, Sr, Zn, rare earth and other valuable impurity elements. These data were obtained from the results of semi-quantitative spectral analysis and single samples studied by the INAA method. The studied list of elements does not include a number of valuable and toxic impurity elements such as Ge, Re, Ga, Nb, Zr, Hf, Y, Au, REE and PGE, which meets modern requirements for geological and environmental study of coal deposits and makes it possible to objectively evaluate and predict the quality of coals in accordance with the requirements of the environmental safety of the fuel

energy. This is especially true of toxic impurities, since a significant amount of them accumulates in ash and slag waste, and a number of elements are carried out with the gas phase or fly ash into the atmosphere.

Coal sampling was carried out according to the methodology of the National Research Tomsk Polytechnic University (Arbuzov S.I., Ershov, 2008) and the study of the mineral composition of coals and coal ash in the research laboratory for the integrated use of combustible minerals in Western Siberia of the Department of Chemical Engineering of TPU.

At the outcrops of coal seams under sediments, the oxidation of coals with a high content of humic acids occurs. The coals of the oxidation zone are enriched in U, B, V, Ge, Au, La, Co, Cu, Ni, Pb, Se, Hg and Zn, reaching industrially significant values. Given the locality of such anomalies, they have no industrial significance, but they can significantly affect the quality of coal products, contaminating them with toxic elements.

Yudovich Ya.E. and Ketris M.P. calculated the clarke contents of these elements in coals [4]. Maslov S.G., Trofimov A.B., Arbuzov S.I. performed a comprehensive assessment of the metal content of oxidized coals by neutron activation analysis, and a high concentration of trace elements in bitumen and fulvic acids was noted [1]. Of interest are the works of S.I. Arbuzov and employees of the National Research Tomsk Polytechnic University (NR TPU) S.S. Ilyenok, S.I. Arbuzov, on a detailed study of coals, which made it possible to identify both minerals common for coals (zircon, monazite, etc.) and completely unique ones, such as Si, Al, Na, Ca, Zr, Sc , Ti, V, Fe, O [2].

The Shubarkol deposit is a Jurassic trough with a length formed on dislocated Paleozoic deposits. Coal-bearing deposits occur with sharp angular unconformity on the underlying Carboniferous terrigenous-carbonate deposits with an admixture of tuff material [3].

A wide range of trace elements in coals, coal ash and coal-bearing rocks of the Central-2 site of the Shubarkol deposit has been investigated. The studied spectrum includes all the main toxic and valuable elements-impurities.

The average content of trace elements for the section as a whole is lower than the clarke values determined by M.P. Ketris and J.E. Yudovich for the world's bituminous coals (Ketris, Yudovich, 2009). The exception is cobalt, the increased contents of which are noted throughout the section, especially in contrast to layers 2B1 and 2B3. Cesium and barium are also characterized by superclarke contents.

An increased content of Co and Ni in comparison with clarke was noted in reservoir 1B22. Layer 2B2 has elevated contents of zirconium, silver and cesium, while formation 2B4 has strontium, barium and cesium.

In general, the formations are characterized by the following features: Formation 1B21 is characterized by a reduced content of most of the elements, which is due to its abnormally low ash content. As noted, it is fortified with iron and manganese. The latter may be related to the specificity of the region's metallogeny. The Fe – Mn hydrothermal-sedimentary mineralization of the Atasu type is widespread here. Layer 1B22, on the contrary, is one of the most enriched in trace elements. At the same time, its ash content is relatively low (Ad = 5.9%). The coal of the seam, especially the upper member, is enriched relative to the clarke in Be, Sc, V, Co, Ni, Zn, Y, Zr, Mo, Ag, Cd, Sb, Cs, Ba and Hg. As can be seen, both lithophilic and chalcophilic elements are combined here. The former are probably associated with the presence of granitoids in the basin framing, and the latter, with the volcanogenic-hydrothermal mineralization is also in the frame of the basin. The coals of this layer are distinguished by the maximum average content of Co, Zn, Cd, Hg, Cs, Ba and Th. Layer 2B2 is characterized by the ordinary grades of most of the elements. The content of Zr, Ag, Sb, Cs and Hg is slightly increased in comparison with the clarke. At the same time, it has a higher ash content than the underlying layers. Layer 2B3 is characterized by anomalous composition It is distinguished by the highest contents in the section of Be, Sc, Co, Zr, Mo, W, Ag, Sb, and U, with V, Cs, and Hg contents also higher than the clarke for coal. Layer 2B4 is distinguished by the highest strontium content for the section and high concentrations of barium and cesium.

For the production of semi-coke or medium-temperature coke, coals of seams 1B21, 2B1, 2B2, 2B3 with low ash content, Ad = 2.6–9.3% and stable sintering capacity required for lump coking are of interest.

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KARPENKO A.G.
St. Petersburg Mining University
Dr. Prof. REGINA E. DASHKO
St. Petersburg Mining University

SCIENTIFIC AND PRACTICAL ASSESSMENT OF THE POTENTIAL IMPACT OF THE CONSTRUCTION AND OPERATION OF LOCAL LOW-RISE BUILDINGS ON THE PETERHOF WATER SUPPLY SYSTEM OF FOUNTAINS

The history of the creation of the hydraulic system of fountains dates back to 1705, when Peter I decided to start building a suburban summer residence in Strelna Manor, but soon transferred it to the area of the future Peterhof. The main decoration is planned to build a "fountain town" similar to the French Versailles. To ensure the resources of the hydraulic system, it was decided to use karst springs in the Ropsha Heights area (absolute elevation 110-120 m (up to 130 m)), which allowed the supply of the required amount of water to the fountains of the Lower Park without additional work of pumps due to a significant difference in altitude. In 1722, the construction of a fountain water conduit was completed, including 2 canals and numerous ponds. In the period 1825-1854. the improvement of the Peterhof water supply system (hereinafter referred to as PWSS) was carried out by means of additional laying of canals and reservoirs [3]. By the beginning of the XX century. the main hydraulic structures received a complete architectural appearance. From 1944 until 1991, major repairs of the damaged and destroyed during the war sections of the PWSS were carried out. During this period, in 1969, the last element, the Shinkarsky pond, entered the structure of the water conduit, after which no global changes were made again. To date, PWSS is represented by 37 main water bodies: 9 canals, 12 rivers and streams, 16 ponds, the total length of which reaches 56 km [3].

The purpose of the work is to predict the impact of the construction and operation of a local residential complex of low-rise buildings on an area of 40 hectares, located at absolute elevations of 22-27 m in the immediate vicinity of the Troitsky stream and 1.3 km from the Samsonievsky water conduit, located to the west and east, respectively. Sites and being part of the System. Taking into account the rather low absolute elevations of the construction area, its possible impact will be on the water bodies of the PWSS, much lower in relation to it. In the section of the proposed development, Quaternary lacustrine-glacial (sands, loams) and moraine (loams, less often sandy loams, with nests and lenses of sand) deposits are distinguished. Technogenic formations have a very local development, since the territory has almost never been used for engineering and economic purposes. Quaternary formations with a thickness of 2.5 to 13 m and more lie on bedrock deposits, represented by the Lower Cambrian "blue" clays with interlayers of weathered

sandstones. Since the main hydraulic structures feeding the PWSS are located at high absolute elevations on the Pre-Glint Lowland, backwater and submergence processes develop, leading to waterlogging. According to the research, the main direction of groundwater within the construction area goes in the north-western direction to the Troitsky stream and partly to the drainage ditches. Consequently, the formation of the chemical composition of waters, determined by the presence of waterlogging and, accordingly, by biochemical processes, is of great importance in solving this problem. In addition, on the south side, the old Babigon cemetery (abs. Elevation 27-28 m), which has been functioning for more than 160 years, adjoins the territory of the future construction. Due to its higher position, the effect on the composition of waters is mitigated by a drainage trench and is realized in the form of nitrogen compounds (partly in the form of NH4 +), reduced sulfur (manifestation of H2S), and an increase in BOD and COD values in water [2].

According to the results of microbiological studies on the territory of the planned construction, among the organotrophic forms of microorganisms, sulfate-reducing, iron-reducing, iron-oxidizing and ammonifying bacteria have the greatest abundance. The total microbial number of these bacteria exceeded 106 colony-forming units (hereinafter referred to as CFU), while the largest number 107 CFU was determined in a water sample from a reservoir located near a sewer. Among aerobic microorganisms, the leading positions are occupied by silicate bacteria (number 102-103 CFU), actinomycetes and micromycetes, most of which are considered as destructors of building materials. Thus, according to the data obtained, the underground environment will have a biocorrosive capacity, and the soils under the influence of the vital activity of microorganisms will be characterized by specific properties: sands - quicksand, clay deposits - thixotropic [1]. All this must be taken into account at the design and construction stages, in particular, when justifying the choice of structural materials for the underground part of the designed buildings. At present, the territory of the proposed development does not have a negative impact on the state of Troitsky Brook, in contrast to the Babigonsky cemetery located on its right bank, and on the left bank - a now defunct bus depot with gas stations and an adjoining garage cooperative. During the construction of residential buildings, the possibility of influencing Troitsky Creek will be fully determined by the organization of construction work at the zero cycle stage: storage of soil during the construction of foundation pits can lead to pollution of the surface watercourse with finely dispersed material; during the operation period, the negative impact will be determined by the state of the drainage-storm and sewer systems. The drainage of water from the drainage ditches must be directed towards the existing treatment facilities, and not into the Black Pond. In order to avoid leaks from sewerage systems in conditions of development of biocorrosion processes in the underground space, it is recommended to use pipelines made of polymers of materials at the stage of selection of construction materials. The existence of the feeding hydraulic system, consisting of 37 water bodies, creates the conditions for the development of groundwater backwater throughout the entire territory of the water conduit and local flooding, leading to the formation of swamps and waterlogging. Waterlogging leads to the development of a rich biocenosis, characterized by a variety of physiological groups of microorganisms, which leads to the formation of biocorrosion of building materials, which must be taken into account when drawing up construction projects.

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KASSYM AYAULYM ERKINKYZY
Karaganda Technical University
K of g.m.s. T.V. KRYAZHEVA

FORMATION PATTERNS, PLACEMENT CONDITIONS AND FEATURES OF LEAD-ZINC ORES OF THE DYUSEMBAY DEPOSIT

The lead-zinc deposits of the Karaganda region began to gain fame from the eighteenth century, when the Dzhezkazgan, Alaigyr, Kurgasyn, Akzhal and many others were discovered in the footsteps of ancient mining. On average, the nineteenth century. They served as the basis for the construction and operation of a number of small mines and factories, first by Russian industrialists and then by English societies.[1]

In terms of explored reserves of polymetals, the Karaganda region can serve as the largest base for the lead-zinc industry of the Republic of Kazakhstan.

The study area is located in the central part of the Karsakpay uplift (Dyusembay site). As is known, there are few ore occurrence sites on the area of this territory. The Balbraun and Keregetas iron deposits are located not far from the work sites (5-12 km), the ore occurrences of the Akbastube, Karamola polymetals and rare metals (tantalum) -Nasymbai were previously identified directly at the site.

However, the formation analysis and study of the regularities of the distribution of ore matter made it possible to establish links between mineralization and specific geological formations and to determine the ore-controlling factors for different types of structures.

Within the study area, various granitoids and granite-gneisses, as well as intrusive rocks of basic and ultrabasic compositions. Intrusive and granitized formations of the area are different in their structural confinement, relationships with the host strata, petrographic features, contact changes, vein series, etc. Among them, the following complexes are distinguished: 1 - Middle Proterozoic granite-gneiss complex, 2 - Late Proterozoic complex of amphibiolitized gabbro-diabases, 3-Late Ordovician complex of granitoids, an analogue of the Krykkuduk complex.

Recently, more and more researchers of the Karsakpay uplift have doubted the reality of the existence of 36 formations of the detailed stratigraphic section of the Karsakpay Precambrian, identified by geologists of Moscow State University (Filatova, Zaitsev 1971-75) .The consolidated stratigraphic section of the Precambrian of the Karsakpay uplift was compiled by them from a number of sections. The mapping of the Precambrian formations by these researchers was carried out by continuous description of the section with the determination of the sequence of the deposition of deposits. In this case, only the data of lithological and stratigraphic studies were taken into account.[2]

The thematic party DGRE (Suleimenov, Kogai et al. 1983), while summarizing geological, geochemical and geophysical materials, drew attention to the fact that lithological and petrographic homogeneous rocks in the stratigraphic scheme of L.I. Filatova (1971) are repeated many times in different parts of the Precambrian section. Meanwhile, in rocks of similar petrographic composition, belonging to different parts of the Precambrian section, the inheritance of geochemical and petrochemical features is traced. Analysis of the nature of the gravitational field of the Karsakpay region shows that the maximum due to the greenstone strata is traced to the west of their conclusions. This circumstance indicates the continuation of these rocks at a depth further to the west, which does not correspond to the ideas of Zaitsev and Filatova. The ambiguity of identifying the Precambrian stratigraphic section ultimately affects the attitude towards the prospects for finding minerals in this area.

In the geological development of the Precambrian fold system, two eras are distinguished: Proterozoic and Riphean-Vendian.

In the Proterozoic era, the continental crust was fragmented with the formation of eugessynclines (suboceanic) on it. The Riphean – Vendian epoch is characterized as a period of

cratonization, i.e. the withering away of the geosyncline and the transformation of e into a platform.[1]

The eugeosynclinal stage is characterized by the following geological formations: green-shale-spilitic.

- early, flyschoid and volcanic-shale-middle, volcanic and molassoid - late stage of development.

The platform stage is characterized by the accumulation of highly mature sediments. The platform complex consists of deposits of carbonaceous-terrigenous, carbonaceous-terrigenous-shale, carbonaceous-terrigenous-siliceous and carbonaceous-siliceous-shale formations.

Metallogeny of this formation is expressed by occurrences and deposits of ferruginous quartzites (Bolbraun deposit, Dyusembay) and sulfur pyrite ores (Vostochnoye myk ore occurrence, Sarytube)

The flyschoid formation includes the metamorphic formation of the Savisk, Dusen, Balgin, Artashin, Ishan, Baikazha formations of the Aralbay region, the Kankarasuy, Aitek and Upper Talayryk formations of the Bekturganseries, terrigenous part of the Akkiyksay, Sholak Formation of the Beleutin Group, Biitskaya Formation of the Karsakpay Group. The metasediments in the formation are represented by two-mica feldspar, sericite-chlorite-biotite quartz feldspar schists. The sediments of this formation are characterized by calm, low gravimagnetic fields.

The volcanic-shale formation occupies a significant part of the area of outcrops of the Precambrian formations of the territory. This formation includes deposits of the Kosobinskaya, Zhiydinskaya series, the Krasai and Belkuduk formations of the Bozdak series, the Ashchitastinskaya, Ishanskaya, and Koskolskaya formations of the Aralbay series. According to the petrochemical characteristics, the volcanics of the described formation are geosynclinal.

The common features of the rocks of the platform complex are the same chemical composition, the presence of horizons, ferruginous quartzites and brown iron ores, the carbon content of the rocks, and general geochemical specialization for Cu, Ni, Co, Cr, V, Mo.

The carbonaceous-terrigenous-shale formation is composed of carbonaceous-quartz schists of the Zhaunkar, quartz sandstones and quartzite schists of the Zhaunkar, quartz sandstones and sericite-feldspar-quartz schists of the Koldybaishokinskaya, quartz sandstone and brownstone series, the upper part is represented by The lower part of the section of the formation is composed of light gray quartz sandstones, the upper part is represented by layers of brown iron ore and carbonaceous-argillaceous shales. The formation is characterized by a high degree of carbon content and is of practical interest in relation to prospecting deposits of lead and zinc.

The metallogeny of the geosynclinal complex proper (A1, A2-3, A4) is characterized by the siderophilic-chalcophilic type, the presence of iron-ore, sulfur-pyrite and copper-pyrite ore occurrences and deposits.

In terms of the mineral composition and the nature of the near-ore alterations, rare-metal-rare-earth mineralization is represented by two types: 1) formation of rare-metal pegmatites; 2) hydrothermal-methosamatic rare-metal feldspar-fluorite-phenakite formation.

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KHLEBNIKOV D. D.
Astrakhan State University of Architecture and Civil Engineering
Candidate of Geographical Sciences KARABAEVA A. Z.
Astrakhan State University of Architecture and Civil Engineering

DESTRUCTION OF HOUSES ON THE TERRITORY OF THE TOWN OF WALLETS OF THE CITY OF ASTRAKHAN DUE TO THE IMPACT OF GROUNDWATER

Underground water often causes slopes, rolls and cracks in multi-storey buildings. This is primarily due to changes in the physical properties of the soil, which under the influence of water becomes softer and thus provokes the movement of the building at extreme angles that can lead to. This phenomenon is especially dangerous in areas where soils, due to the internal composition, for example, salts, can form various deposits inside themselves, which in turn can lead to the collapse of the surface. Salt deposits and coastal erosion are not uncommon in the Astrakhan region. It is also not uncommon for cracks to appear on multi-storey buildings located in the zone of high exposure to groundwater. In this paper, the town of Wallets in the Astrakhan region was chosen because of the frequent cases of five-story houses receiving the status of "emergency buildings".

In this work, studies were carried out on the survey of the territory for signs of the presence of groundwater close to the surface, the study of existing maps of groundwater in order to obtain a more complete picture of the situation, as well as on the analysis of satellite images of the area at different times [3].

During the survey of the territory, I found large thickets of reeds, which is an extremely moisture-loving plant and grows only near reservoirs and not deep underground waters up to 5 meters deep. The results were also obtained by studying old geological maps of underground water occurrence [1], according to which it can be understood that the area in which the research was conducted is located in an area with a small, but very mineralized well flow rate. Another proof was brought by different-time images. According to them, on the territory of the current shopping center "DEXTER", formerly called" GrandRiver", there was a small swampy area, which, most likely, was fed by underground water.

With the help of all this data, a map of potential emergency houses in the Bumazhnikov tower was built, which included all those buildings that have already been declared emergency, buildings that are not included in the risk zone for a certain number of reasons, as well as buildings that have not yet been declared emergency, but are still among the buildings that can be assigned this status [2]. This division is based on the statistics of buildings and structures that were declared emergency. All of them, high-rise buildings, whose height exceeds 5 floors and their age is more than 30 years. For this reason, dacha plots and private houses, as well as garages and individual low-rise buildings were not included in the number of buildings included in the risk zone. Also included in the number of safe buildings were buildings that are less than 30 years old. They are based on much more modern materials and fastening systems, which are much less likely to be subjected to subsidence and destruction for at least the next 30-40 years.

In conclusion, we can highlight how strongly ground water affects various buildings and structures, as well as how it is possible to determine the area of distribution of these waters using indicators located directly on the surface of the earth, which do not require the use of specialized equipment.

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ARON KNOBLICH
TU Bergakademie Freiberg
Dr. REINHARD KLEEBERG
TU Bergakademie Freiberg
Prof. Dr. GERHARD HEIDE
TU Bergakademie Freiberg

IMPROVING THE PREPARATION METHOD AND STRUCTURAL DESCRIPTION OF SMECTITES FOR X-RAY POWDER DIFFRACTION ANALYSIS

Traditionally, oriented specimens are used in X-ray powder diffraction (XRPD) analysis to characterize clay minerals with diagnostic tests, to differentiate swelling clay minerals from non-swelling ones. On the other hand, textured specimens are insufficient for quantification because of the unknown phase-specific degree of orientation. However, the preparation of the required powder samples is one of the most critical steps in quantitative XRPD analysis [1]. One challenge in preparing clay rich samples is to avoid preferred orientation of the clay particles. In addition, the diagnostic tests are difficult to perform on powder samples.

The goal of this study is to improve the differentiation of smectites even in texture-free X-ray diffractograms. Therefore, the spray-drying method of Hillier [2] was used in combination with glycerol intercalation for a stable expansion of smectitic layers in one step within the production of powder samples. Furthermore, modified three-dimensional structural models including glycerol solvated interlayers were applied for a successful quantification via the Rietveld method using the recursive description.

Different samples of smectites and smectite rich rocks were investigated. Liquid glycerol was added to the sample-ethanol-suspensions direct after McCrone micronizing. Glycerol solvation was completed within a few minutes at room temperature, and spherules of the sample particles were formed after spray-drying and characterized by XRD. The amount of added glycerol is the critical factor. If insufficient glycerol was added, no complete intercalation occurred. If too much glycerol was added, the sprayed spherules stuck together, which hampered any further preparation significantly. For all investigated samples a range of amount of glycerol revealing stable intercalations in the diffraction patterns was found.

For the structural description in the Rietveld approach, the glycerol molecule was integrated in the interlayer space of already published structural models [3] via the interpreter language using BGMN [4]. These modified three-dimensional structural models are in general suitable and successful pattern descriptions with these structures will be presented.

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KONDRASHIN K.G.
Astrakhan State University of Architecture and Civil Engineering (GAOU AS VO "AGASU")

RANDOMNESS OF THE MIGRATION OF GROUNDWATER IN THE BUILDING AREA

In the scientific literature, as well as in design, groundwater is considered in the context of its impact on planned or already constructed buildings and structures. The variants of groundwater drainage from the sites of construction and large-scale earthworks (laying of underground pipelines, development of objects of the mineral and raw materials complex, etc.) are investigated. However, there is no unified system for analyzing the impact of the structures themselves, construction and other earthworks on groundwater, as well as algorithms for predicting their possible migration.

Ground water is radically different from surface water – chemical, physical composition, its distribution, impact on the environment, etc. It is only known that the ground water under the influence of gravity moves down the slope (even if this slope is under the ground), under the influence of the forced pressure rises up.

We put a building in the path of the ground water, and they will begin to bend around it, close the exit to them, and they will begin to accumulate and come to the surface.

What is happening within the framework of urban developments, where does the ground water tend-enclosed in the concrete claws of houses and walled up with asphalt? Unfortunately, no one deals with these forecasts. And here, for the first time, we observe the chaotic nature of groundwater migration in an urban environment.

When designing construction and other works, no one includes in the calculations the possibility that ground water, for example, will suddenly change its route and begin to wash out small particles from the ground-changing its physical properties, or no one expects that salt water will approach fresh water – to which the materials of structures will be vulnerable.

The answer to a seemingly very complex problem can be a drainage system-as an extreme solution, that is, we will remove the vast majority of ground water from the equation, but here we are faced with a huge cost of these works and consequences (such as pumping wells of the drainage system, the death of vegetation from which we take the life-giving moisture, and more). Ground water monitoring, that is, laying a grid of wells in which the water level and salinity are constantly measured, will help in research, but to a lesser extent will affect the migration of ground water in the urban environment.

Conclusions. The construction of massive complexes, buildings and structures, as well as the open-pit mining of mineral resources has an immeasurable degree of impact on underground and ground water.

At the moment, an algorithm for monitoring groundwater is being developed, as well as a model for the correlation of groundwater migration and physical and chemical processes of the soil cover of the buildingzone. An experimental site was identified, observation wells were laid and a monitoring plan was formed, and construction work on this site is currently expected to begin.

Scientific advisor: Doctor of Biological Sciences, Professor V. N. Pilipenko

GLEB O. KUZMIN
SEI HPE "DonSTI"
Ph.D. VALERIY I. PAVLOV
SEI HPE "DonSTI"

HARDWARE AND SOFTWARE BASED COMPLEX FOR HYDROLOGICAL MEASUREMENT MEANS

Eastern Donbass is a territory of scarce water sources. The available groundwater resource is not fully used due to changes in the hydrological characteristics of known underground aquifers because of existing coal undermining. Repeated hydrological studies on the existing network of exploration wells can become an urgent solution of the problem. Hydrological surveys are carried out by geophysical methods, but they are rather laborious and time-consuming. The most acceptable is the charged body method (CBM) [1]. The advantage of CBM comparing to other geophysical methods is that only one well is used, instead of three or four. The disadvantages of CBM consist in continuous and labour-intensive observations (6 to 8 hours during 2 to 5 days) and the difficulty in ensuring the continuity of the water flow salinization. Magnetometry-based measuring method is proposed, considering the measuring instrument as a hardware-software complex (HSC).

Measurable hydrological characteristics:

- static water level;
- the aquifer depth;
- the direction of the aquifer water flow.

The design of the HSC includes three blocks:

- block for determining the static water level in the well;
- magnetometer to control the direction of flow in the horizontal plane;
- control and power supply unit.

The device consists of two structural units: a probe-cylinder lowered into the well and a data acquisition node on the surface (each one is shown in the figure). On the lower probe base there are two electrodes distanced 3 mm from one another. These electrodes are isolated from the probe shell and have two contacts: one analog contact from the microcontroller board, the second contact – 5V power supply. The static water level in a well is determined by electrodes' touching the water table. The analog input of the controller board receives a contact closure signal. This signal is processed by the probe controller and sent to the data acquisition node controller via the 1-Wire transmission protocol. The cable length when receiving the contact closure signal fixes the exact position of the static level.

A magnetometer mounted on a weather vane determines the direction azimuth of the surface and continuously transmits digital data via the I^2C protocol to the probe controller, thereby indicating the exact direction of water flow movement as well as its depth. The probe controller sends this data to the data acquisition node controller via the 1-Wire protocol.

To display information, a data acquisition unit is provided with another microcontroller board, a display module and a separate power supply placed in a common housing. There are two contacts for data exchange between the two controllers in the data acquisition unit and in the probe. The software for collecting data and displaying information is written in C++.

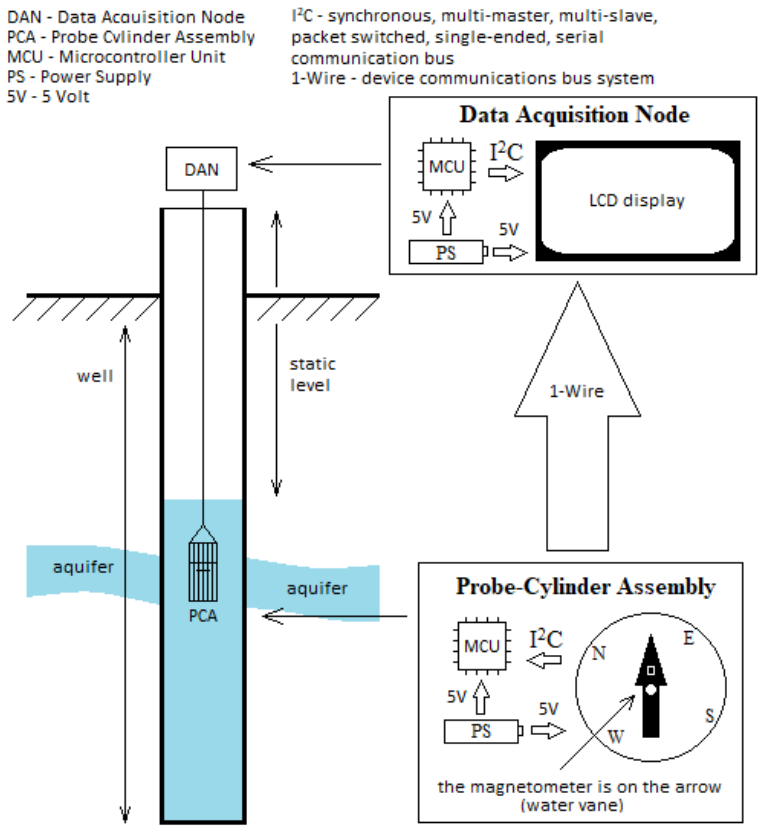

Figure 1 – Scheme of measurements and construction units

The proposed hardware and software complex have the following advantages e.g. high accuracy in determining the static level and the depth of the aquifer as well as the direction of its movement, ease of manufacture and upgrading for obtaining additional hydrological characteristics.

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YELENA S. LI
KSTU, Karaganda, Kazakhstan;
Candidate of Technical Sciences MARINA V. PONOMAREVA
KSTU, Karaganda, Kazakhstan

MINERALOGY OF THE MAYATASS ORE REGION (NORTHERN ULYTAU, KAZAKHSTAN)

The Karaturgay and Mayke types of ores are confined to the diabase-picritic Karaturgay complex widely represented in the Karaturgay river basin and to the carbonatite complex, which is exposed on the right bank of the Mayke river, within the Mayatas ore region [1, 2].

Detailed mineralogical studies using electron probe were conducted, to investigate mineral composition sulfide ores taking in mind that the knowledge of ore composition of ores and general characters of precious metals (platinoids, rare and rare earth elements) occurrences can significantly affect the economic value of the Karaturgay and Mayke ore occurrences.

Significant outcome of this studies is a discovery of accessory siegenite (Co,Ni)3S4, platinum telluride - moncheite (Pt,Pd)(Te,Bi)2, silver telluride - hessite Ag2Te, lead telluride - altaite PbTe, lead selenide PbSe, solid solutions of metals of the iridium group (Ir, Os, Ru), REEs (Dy, Er, Y, Ce) (table 1), reported for the first time from picrites of the Karaturgay complex,

where they occur in association with previously known sulfides (pyrrhotite, pentlandite and chalcopyrite). These sulfides form three mineral associations: the first two occur in liquation droplets of rounded and elliptical shape; the third association forms droplets of irregular, subangular shape. Platinoids in sulfides of copper and nickel are present only in sulfide droplets of the first association, composed of pyrrhotite, chalcopyrite, pentlandite, and sphalerite. Sulfides from the two other associations do not contain platinoids. The second mineral association includes pyrrhotite, chalcopyrite and sphalerite, while the third - pyrrhotite, chalcopyrite, sphalerite and pyrite. All three mineralogical associations contain magnetite and are usually confined to the most differentiated horizons of picrites and apopicrite olivinites [1, 2].

Table 1 – Comparative characteristics of the mineral composition of picrites, picritic diabases and carbonatites from Ulytau

Magmatic group	Carbonatite group
Liquation class	Hydrothermal fluid magmatic carbonatite class
Picrites	Alkaline picrites
Main ore minerals	
Pyr- Pyrrhotite (FeS) Pln- Pentlandite (Fe,Ni)9S8 Vi- Violarite (Fe,Ni)3S4 Ccp- Chalcopyrite (CuFeS2) Cpl- Sphalerite (ZnS) Mt- Magnetite (Fe3+,Fe2+)Fe3+ 2O4	Ccp- Chalcopyrite (CuFeS2) Vi- Violarite (Fe,Ni)3S4 +Er, Co Py- Pyrite (FeS2) Cp- Sphalerite (ZnS) Pyr- Pyrrhotite (FeS) Gn- Galena (PbS)
Microinclusions	
Moncheite (Pt,Pd)(Te,Bi)2 Hessite (Ag2Te) Lead selenide (PbSe) Altaite (PbTe) (Ru,Ir)Os (Ru,Ir)2Os (Pt,Bi)2(Te,Ag)3Mo3 Arsenides: (Os,Ir)As (Ir,Pt)As Oxides: titanohematite and manganoilmenite	Minerals of cobaltite-gersdorffite series with Pt, Ir, Rh, Ru, Os Cob- Cobaltite (CoAsS) Ni- cobaltite NiCoAsS(Ru, Rh, Pt, Ir, Os) Fe- cobaltite (FeCoAsS) Gersdorffite (NiAsS) Ull- ullmannite (NiSbS) Silver telluride β-Ag2Te, γ-Ag2Te Lead telluride (PbTe) Sperrylite (PtAs2) Tes-Testibiopalladite Pd(Sb,Bi)Te Native Silver Ac- Acanthite (Ag2S) Mel- Melonite (NiTe2) Vav-Vavrinite (Ni2SbTe2) REE-bearing phosphates and fluorophosphates Previously undescribed rhenium minerals

Numerous mineral microinclusions identified in present study show unusual mineral associations not previously documented in the region, including cobaltite-gersdorffite minerals with Pt, Ir, Rh, Ru, Os; ullmannite NiSbS, silver telluride – hessite Ag2Te, lead telluride - altaite PbTe, sperrylite PtAs2, testibiopalladite Pd(Sb,Bi)Te, native silver, acanthite Ag2S, melonite NiTe2, vavrinite Ni2SbTe2, REE-bearing phosphates and fluorophosphates. A special group of micro-inclusions is formed by the rhenium minerals first found in Kazakhstan (table 1).

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GEORGIY A. LOKHMATIKOV
St. Petersburg Mining University
Dr. Prof. REGINA E. DASHKO
St. Petersburg Mining University

FEATURES OF GEOTECHNICAL ASSESSMENT OF THE BEDROCK ARGILLACEOUS SOILS AS THE FOUNDATION OR HOST SPACE OF VARIOUS PURPOSES STRUCTURES: A SAINT PETERSBURG CASE STUDY

Highly lithified argillaceous soils of Upper Kotlin horizon of the Upper Vendian System and Lontova Formation of the Lower Cambrian System seem as reliable absolute impermeable layers and stable foundation or host medium for various purposes buildings and structures at the underground space of Saint Petersburg. At the same time, as perennial research data of R.E. Dashko shows – neglect of bedrock clays fissuring has the potential probability of hazardous events occurrence. Observations that were made at tunnels, quarries, or excavation pits allow us to visually assess the fracturing grade of these clay types and in the case of water sources existence (artesian aquifers, bodies of water) to study clay permeability and the filtration along fissures impact on the slope stability, as it was performed at the Lower Cambrian clay open pit "Krasniy bor".

Fracturing formation in these soils related to structural and tectonic area conditions, fissures generation in stiff clay strata during denudation of overlying sediments layers, weathering agents' activity including altering temperature, and at Quaternary period – cyclic changing of glacial and interglacial stages, that defined high range of pressure oscillations from zero values to 20-30 MPa. Clay fissuring rises in the areas of the tectonic faults to which the buried valleys are confined. Therefore, the thalweg zone should be marked in a special category by clay state and properties: the highest fissuring intensity, and as a consequence – higher permeability, lower strength, and strain module. Primarily these features of soil state should be identified during behavior predictions of underground structures – for instance, Saint Petersburg subway tunnels that have been constructed in Upper Kotlin Clay [1, 2].

According to the results of a few subway tunnels state inspections, the tight link was figured out between seepage intensity due to ascending overflow of the high-head Lower Kotlin aquifer and tunnel linings destruction activity under thalweg zones. In these zones, argillaceous aquitard has a minimum thickness that allows for active filtration of underground water due to the high gradient effect. So, the highest amount of seeps that accompany by large dripstones generation, leaching cement from concrete and reinforced concrete linings, graphitization of cast iron linings there. It was proved by using particular microbiological methods that underground water of Lower Kotlin aquifer has not only chemical or physicochemical impact on surrounding media but also biochemical. Based on the results of metagenomic analysis 16S rRNA it shows that there is an active microbial community, foremost anaerobic, in this aquifer. These microorganisms are corrosive to construction materials that use for subway tunnel linings, a basement of different buildings, and various underground enclosing structures. The aquifer has also less aerobic forms amount – for instance, silicate bacteria that increases concrete degradation.

Observations that were made on the subsurface constructions of the newly built structures and during the restoration of architectural and historical monuments gave an opportunity to ensure that lack of accounting of water biochemical aggression to construction materials leads to their premature progressive failure even before exploitation beginning. Designing of buildings and structures on Upper Kotlin clay without concerning the activity of high head Lower Kotlin aquifer can cause known difficulties during construction exploitation, which links to mineralized water infiltration inside there through foundation and basement walls. The consequences of this filtration – the necessity of constant water pumping from foundation sumps in the condition of continuing upstream overflow and progressive corrosion of the foundation reinforced concrete [3].

Hence, fissures in consolidated stiff clays in the case of their geotechnical assessment as host media or foundation should be studied at the beginning (investigation stage). During well drilling, core description must be conducted with the determination of character and intensity of clay fracturing. It is recommended to get oriented core, determine fissure module, values of rock quality designation (RQD), etc. For permeability investigations in this soil type, it has to undergo infiltration tests with obligatory addition of non-sorbing by clay blocks dye – eosin, for instance, for tracing filtration paths. Such field works give data about block size, permeability in relation to the clay fissuring. Moreover, it has to perform research of interactions between groundwater and clay blocks without their swelling in predictions of feasible upstream or downstream overflow through fissured clay strata. Received indicators of strength and deformability changing should be used in building and exploitation projects of surface and underground structures. Determination of groundwater corrosion activity to construction materials, including damp-proofing, must consider not only the requirements of normative documents but also physicochemical and biochemical features of aquifers.

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GUSTAVO MIRANDA-DÍAZ
Technische Universität Bergakademie Freiberg / Universidad de Atacama
Dr. KARL RIVEROS JENSEN
Universidad de Atacama
Dr. Prof. GERHARD HEIDE
Technische Universität Bergakademie Freiberg
+

AEOLIAN PLACER'S SAPPHIRES CHARACTERISATION FROM THE PORTEZUELO DE PAJAS BLANCAS, NORTHERN CHILE

Introduction. The aluminium oxide corundum (Al_2O_3) may crystallise in Al-rich and Si-poor igneous/metamorphic environments [1]. When minor amounts of Fe^{2+}, Fe^{3+}, and Ti^{4+} replace the Al in the crystal structure (Fe- and Ti-bearing corundum), the colour of this mineral turns blue, light blue and yellow, and respectively this mineral is called sapphire [2]. In 2003 the company Exploraberg discovered the first primary sapphire-rich metasomatites (sapphirites) [3], which are composed of five sapphire-bearing metasomatites which different amount of granoblastic sapphires (from 30 vol. % to more than 90 vol. %) [4]. During the field trips in 2017, a few meters to the northeast in the middle of the Atacama Desert, a sapphire-bearing placer deposit was discovered. This desertic aeolian placer display a regular North-South elongation of 370m length related to Quaternary non-consolidated dune fields. The sapphire' concentration represents less than 5 vol. % being around ~90 vol. % of silicate minerals (e.g., Plagioclase and quartz) and around ~5 vol. % of magnetite, hematite and rutile.

Methodology. Approximately 60 kilograms of non-consolidated sediments were collected from 3 sampling sites located around the primary corundum-bearing deposit to obtain

representative samples. For this, it was necessary to excavate ~0.5 meters deep holes in each sampling site. All samples were sieved in order to obtain sizes between 3.35mm and 1mm for further analysis. Finally, the JIG density separator was used to obtain corundum-rich sands from each excavation. The corundum-rich sands were mixed and quartets to get representative corundum crystals, allowing to select 600 well-preserved corundum crystals weighed and photographed for recording. Subsequently, the crystals were classified by their colour distribution.

Results. The sapphires from the Portezuelo de Pajas Blancas area are characterised by their colour heterogeneity distribution varying according to the colour predominance and sizes, which has allowed to classified five groups of sapphires, which are described as (i) Dark-blue, (ii) Blue, (iii) Light-blue, (iv) colourless or yellow. The crystals have differences in their sizes and exist a correlation between size and colour predominance. The biggest crystals are generally dark-blue or blue generations, whereas the smallest sapphires are colourless and yellow. The colour distribution is also remarkable due to the differences which are presented as (i) Colour core, (ii) Colour layers perpendicular to the z-axis, (iii) Hourglass colour, (iv) Specials, and (v) Irregular (Figure 1). From the 600 crystals has been determined the abundance according to its colour predominance, being from more to less abundant the dark-blue (43%), blue (35%), light-blue (16%), and colourless (5%).

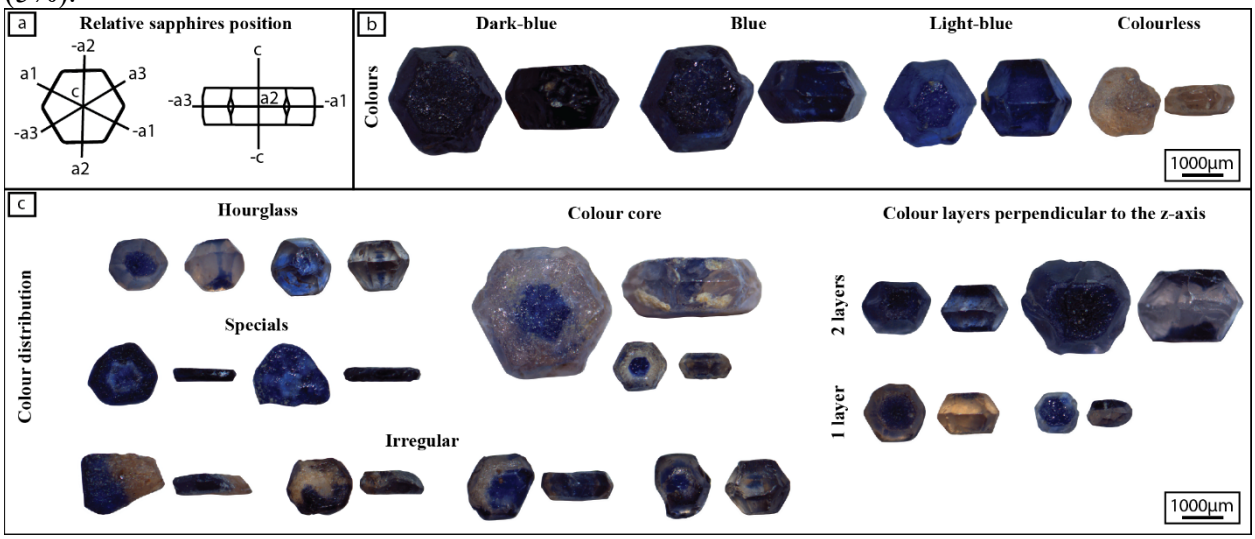

Figure 3.- Placer sapphire characterisation from Portezuelo de Pajas Blancas. (a) Relative sapphires position in the photographs. (b) The sapphires display dark-blue, blue, light-blue and colourless colours. (c) Sapphires' Colour distribution shows hourglass, colour core, colour layers, specials and irregular types

Discussions and conclusions. The proximity between the sapphirites and the placer deposits and the similarities between the sapphires discovered in both places allow it to determine that the placer deposit is derived from the sapphirites deposit. The physical differences between the analysed sapphires could be explained by the anisotropy in the forming conditions or by overlapping forming events. The information obtained from the released sapphires allows understanding the forming conditions of the sapphire-rich metasomatites.

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ESLAM M. HEMID
Miskolc University
Dr. TAMÁS KÁNTOR
Miskolc University

THE IMPACTS OF CLIMATE CHANGE AND URBANIZATION ON THE SLOPE STABILITY: A CASE STUDY OF THE EASTERN SLOPE OF AVAS HILL, MISKOLC, NORTHEAST OF HUNGARY

Introduction. Landslides are one of the natural hazards, that have a destructive impact on the environment and humans. Hungary subjects to several landslides such as on the eastern slope of Avas hill, Miskolc, NE of Hungary. In the 70's before the urbanization in the study area, soil movements were taking place, which had become more frequent with the built-up expansion of constructions [1, 2], for example of these soil movements in the study area, slipping on the west side of Youth Road (1974), damaging to the church of Tamás Elek (1985), damaging to the Avas Gymnasium (1988), and some recent indications such as tilting of trees and fence, and cracks and fractures of constructions. These constructions affect slope stability due to the increase of the overload on the soil. Moreover, the study area witnessed a substantial climatic change via the fluctuation between arid and humid periods [3, 4]. This climate change affects the groundwater fluctuations and shear strength of soil, and then the slope stability [4].

Main objective. Currently, there is very little movement on the hillside, but any higher levels of surface movement could endanger the surrounding buildings. For our modeling, we used the approximate loads of the recently built Reformed Church."

Methodology. This study is investigated based on site investigations and modelling. The site investigations were related to the field observations such as monitoring the rate of soil movements and the change of groundwater level through time by using the inclinometer and groundwater level measuring devices and detecting the soil movements indications such as tilting of fence and trees, fractures in construction, and grown cracks. These measurements were measured from the observation wells of the slope monitoring system in the investigated area. The modelling work was based on the GEO5 program to analysis the slope stability under different conditions such as change of the groundwater level and construction effects, and using of the gravity retaining wall system.

Results. The measurement data obtained from the monitoring system in the study area illustrated that the rate of soil displacement is slow and equal to 2.5mm/year. The soil displacements occurred several times instead of one time, and this indicates the soil movements continue with time. Hence, there are current indications of the soil movements such as tilting of fences and trees, and fractures and cracks nowadays in the Avas Gimnázium, Miskolc, Hungary. Furthermore, the measurements of the groundwater level from the observation wells showed that there are groundwater fluctuations in the study area with time. The groundwater fluctuations are the result of two main factors: the natural factors via climate change such as the changes of the rate of rainfall and snowball, and the lithologic composition of the soil (contents of montmorillonite minerals). The artificial ones via the artificial drainage system and cracks in the asphaltic layer.

The simulated analysis models of the study area based on the Bishop Optimization method by using the GEO5 program illustrate that the groundwater fluctuations have a detrimental effect on slope instability. This is owing to two main reasons: firstly, the increase of groundwater leads to yield pore water pressure which decreases the shear strength of soil and reflects on slope instability. Secondly, the montmorillonite minerals have a detrimental effect when interacting with water, this mineral swells with increasing water and shrinkages with decreasing water as a result, the consumption of the slope strength, and then the possibility of occurrence landslides. On the other hand, the constructions have a destructive effect on slope instability due to adding extra loads to the soil.

Based on the simulated data obtained from the GEO5 program based on the Bishop Optimization method, using the gravity retaining wall system has a useful effect on increasing the slope stability and minimize and/ or prevent the effects of the groundwater fluctuations and constructions in the long term.

Conclusion. Based on the field observations and the simulated results, the effects of groundwater fluctuation and urbanization have deleterious impacts on slope stability, they decrease the shear strength of the soil. These are owing to the release of pore water pressure, the composition of soil, and extra loads of construction to the soil, respectively. On the other hand, the construction of the gravity retaining wall system prevents the triggering of landslides occurrence.

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ADIB V. MUKHAMETSHIN
Kazan Federal University
Dr. Prof. OLEG N. LOPATIN
Kazan Federal University
Ph.D. RUSTAM I. KHAIBULLIN
Kazan Physical-Technical Institute

OPTICAL SPECTRA AND CRYSTAL CHEMICAL FEATURES OF QUARTZ IMPLANTED WITH IRON, COBALT AND VANADIUM IONS

Since ancient times, humanity has tried to change the color of different minerals to increase their attractiveness and value. On another side, the nanostructured 3d-metal oxides are attracting great attention for their unique physicochemical properties for various technological applications. The ion implantation method lets introduce any metal impurity in solids with high concentration to synthesize the nanoscaled metal oxide phases inside a crystalline mineral matrix. In the given work the different ions of the 3d-transition metal group such as iron, cobalt and vanadium were implanted into the crystal structure of natural colorless quartz (rock crystal) in order to change its color after post-annealing. The origin of the induced color and the crystal-chemical features of rock crystals with the implanted 3d-impurity was investigated by using optical spectroscopy which was supported by other research methods including energy-dispersive X-ray (EDX) microanalysis, X-ray photoelectron spectroscopy (XPS), Mössbauer conversion electron spectroscopy (MCES) and differential thermomagnetic analysis (DTMA).

The single charged 40 keV Fe^+, Co^+, or V^+ ions were implanted into quartz targets presenting either double-sided polished quartz plates or the faceted rock crystals. For ion implantation experiments we used high purity colorless mineral (quartz) taken from the Svetlinskoye deposit in the South Ural. According to EDX microanalysis total element impurity contention in the virgin quartz was less than 1%. The implantation with 3d-ions was carried out at room temperature by using an ion-beam accelerator (*ILU-3*) to a dose range of $(0.75\text{-}2.0)\times10^{17}$ ion/cm^2 at a constant ion current density of 10 mA/cm^2. After the high-dose implantation, the

content of 3d-implants in the surface layer (about 100 nm thick) of rock crystal was at the level of 20-25 atomic %. For the annealing of radiation defects and the optical activation of the implanted 3d-impurity, the post-high-temperature treatment of the implanted quartz samples was carried out in a chamber electric furnace in an air atmosphere. The optimal regimes of thermal post-annealing (temperature and time) were found experimentally for each type of the implanted sample.

The implantation with Fe^+ ions into rock crystal samples was done at a dose of $1.0 – 1.5 \cdot 10^{17}$ ion/cm^2. XPS and MCES studies showed that high-dose implantation with iron results in the formation of an ultra dispersed phase of metallic iron at a certain depth of the irradiated matrix. Immediately after implantation, the color of the surface of the implanted crystal layer turned dark gray with a metallic sheen. Post-implantation annealing at a temperature of 950°C for 60 min in an air atmosphere induced a cardinal change in the color of the sample to yellow-orange, close to natural citrine. In the optical spectra, a broad absorption band is observed in the blue and green region of light wavelengths, which causes a yellow-orange color. The analysis of XPS and MCES data made it possible to conclude that nanoscaled clusters of hematite (α-Fe_2O_3) are formed in the irradiated layer inside the rock crystal after annealing. Thus, the nature of the orange-yellow color of the quartz implanted with iron and sequentially annealed is explained by the formation of an ultra dispersed hematite phase concentrated in the surface layer at a depth of 16 nm [1].

The Co^+ ions were implanted into rock crystal to the implantation dose of 1.5×10^{17} ion/cm^2. DTMA studies showed the ferromagnetic behavior of quartz plates with the implanted cobalt due to the formation of metallic cobalt nanoparticles in the irradiated layer of crystal. Post-implantation annealing was carried out at 583ºC, 800ºC, and 950ºC for 60 minutes in an air atmosphere. The annealing leads to discoloration of the pale gray quartz crystal layer containing the implanted cobalt nanoparticles. An analysis of optical spectra of these annealed discolored samples made it possible to conclude that all absorption bands observed in the spectra are associated with electronic transitions in cobalt ions (Co^{2+} and Co^{3+}), coordinated at octahedral and tetrahedral sites of the crystal lattice. The absorption bands of the Co_{VI}^{3+} and Co_{IV}^{2+} ions dominate in the spectra. The presence of these absorption bands and the ratio of their intensities in the optical spectra indicate that cobalt spinel $Co^{2+}\,Co_2^{3+}\,O_4$ (chemical formula Co_3O_4) is formed in the implanted surface layer of quartz after annealing. The fact of the formation of this spinel nanoscale phase is confirmed by the fact that the configuration of the observed absorption spectra of cobalt-implanted quartz is identical to the configuration of the absorption spectra of polymer compositions containing nanofibers of cobalt spinel $Co^{2+}\,Co_2^{3+}\,O_4$ [2]. Spinel formation in the implanted quartz layer is initiated by post-implantation annealing and intensifies at temperatures of 590-750°C. At temperatures of the annealing above 900°C, the finely dispersed spinel phase dissolves in the rock crystal matrix and its absorption bands disappear. Taking into account the quantum-optical properties of cobalt spinel, the implanted quartz samples can be used to fabricate laser shutters.

Implantation with V^+ ions into rock crystal was carried out at the dose range of $(1.0 – 2.0)\times10^{17}$ ion/cm^2. To anneal radiation defects and activate the vanadium impurity, post-implantation annealing was carried out in an air atmosphere in the temperature range of 300–1000°C for 30 min. In the context of optical measurements, the most informative was the absorption spectra of samples annealed at 383°C and 585°C. After annealing at a temperature of 383°C, a quartz sample with an implanted vanadium impurity reveals an olive-green color, which is a consequence of the formation of vanadium oxide nano precipitates with different valences, as it was established by XPS. The olive green color in quartz was formed as a result of the superposition of the yellow V_2O_5 complex together with the blue colorimetric parameters of the VO_2 complex. The optimal temperature regime of post-annealing to obtain an olive-green color in quartz is a narrow range of 375- 385°C. During heat treatment at higher temperatures, vanadium-doped quartz crystals are discolored. Thus, nanoclusters of various vanadium oxides (VO_2, V_2O_3, V_2O_5) were successfully synthesized in the surface layer of a crystalline quartz matrix by the high-dose implantation of impurity with subsequent annealing. Note that the above vanadium oxides reveal insulator-metal transition (IMT) at near-room temperature and can be used as perspective materials for energy or memory storage devices [3].

In conclusion. Our experiments and research results show that high-dose implantation with Fe, Co or V ions into quartz with subsequent thermal annealing is an effective way of changing the color of natural initial colorless quartz. These color-changings are induced by the formation of nanoscaled phases of transition metal oxides such as Fe_2O_3, Co_3O_4, VO_2 or V_2O_5, respectively, in the implanted surface layer of quartz matrix. Moreover, ion implantation is an outstanding method not only in jewelry but also in creating new functional nanocomposite materials based on natural (or synthetic) quartz for various practical applications.

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ORESHKOVA MARIA YUREVNA
St. Petersburg Mining University
FERNANDES MAMANI ALBERT NIKOLAS
St. Petersburg Mining University

REEF STRUCTURES IDENTIFICATION OF THE TIMAN-PECHORA PETROLEUM BASIN THROUGH THE RESULTS OF INTEGRATED INTERPRETATION OF MAGNETOTELLURIC SOUNDING AND SEISMIC EXPLORATION DATA

It is noted that Saint Petersburg Mining University conducted electrical exploration using MTS method (magnetotelluric sounding) in August of 2006. The research area is located in the central part of the Khoreyver Depression. The exploration work was carried out using MTU equipment of the company 'Phoenix Geophysics' (Canada). The equipment has become widely used for studying sedimentary basins in the recent decades.

During the processing MTS we used 50 observation points in two parallel profiles. The length of these profiles is 7000 meters, the distance between profiles is 2000 meters and the distance between these points is 200-250 meters. Both processing and interpretation were carried out by us in the laboratory of Saint Petersburg Mining University using specialized programs such as SSMT 2000, MT-Editor and WinGlink. We also used data of the seismic reflection survey CDP 2D on the same profiles as MTS profiles for geological interpretation. The length of the seismic profiles is 20 kilometers. The materials of 2D seismic surveys were obtained by seismic parties of the 1980s and early 1990s. In the year of 2006, 'Central Geophysical Expedition' company (Moscow) performed re-processing and reinterpretation of those materials on assignment of Mining University.

The purpose of the present research is to identify reef structure, trace reservoirs and study structural and material features of the section of sedimentary basin of the Timan-Pechora oil and gas province in the Novozemelsky work site under a complex data interpretation such as the magnetotelluric sounding method (MTS) and seismic exploration.

The objectives are as following:

1) Data processing from points of geoelectric observations using special programs SSMT 2000, MT-Editor and display an interpretative geoelectric section using the program WinGLink;

2) Execution of correlation of reference horizons on seismograms with the most contrasting geoelectric boundaries and thicknesses;

3) Implementation of a complex geological interpretation according to the MTS data and the seismic reflection survey CDP 2D of two geophysical profiles. The core objective is to prove the reef structure presence that is typical for this region, and evaluate features of manifestation of the reef structure in seismic and geoelectric sections.

The relevance of complex studies for the identification of reef structures is due to the fact that there are certain difficulties in identifying oil-promising formations of the 'reef' type using only seismic survey. Applying high-resolution electrical exploration technology allows us to obtain additional information, improve quality of interpreted materials, and ultimately give a more accurate forecast of localization of an oil and gas deposit [2].

The study area of the Timan-Pechora oil and gas province is located on the Pechora syneclise in the North-Eastern part. Moreover, this area is located in the central part of the Khoreyver Depression in Kolvavisovskaya stage.

The sedimentary cover of Khoreyver Depression is represented by rocks of the Paleozoic and Mesozoic eratem and Quaternary systems. Sedimentary deposits lie on the foundation of the Vendian age. The foundation can be traced in the central part of the Bolshezemelsky paleo-uplift at depth greater than 4500 meters. Oil and gas deposit of the Upper Devonian age is presumably located at depth of 3200 meters [1].

As a result of our re-processing and own interpretation of the MTS data, a geoelectric section was obtained, on which the reef structure is clearly marked. The reef structure appears to be more contrasting and it has a larger size on the profile Pr 04 in comparison with the same structure on the Pr02. The resulting geoelectric section correlates very well with the seismic section. During this complex interpretation, the main lithological and stratigraphic horizons are recognised; they are comparable to the zones of geoelectric section. The reef structure is clearly distinguished on both sections and its boundaries coincide; the depth of the upper boundary of the reef body (3200 m) and the lower boundary (3400 m) are determined. The methods used in this area confirm each other well and make a resulting geological model more reliable and accurate. The use of MTS allows to perform the detailed section in the part of lateral inhomogeneities. Using MTS data with structural constructions of a seismic survey together is an effective way to detect oil and gas deposits.

A section at depth of 3300 meters was constructed focusing on the results of 2D of MTS data inversion using interpolation method. An anomalous zone of the apparent electrical resistivity parameters is identified on the geoelectric section at a depth of 3300 m that corresponds to the reef structure.

A comprehensive analysis of electric and seismic data let us identify 3 promising complexes:

1. Assel-Sakmar carbonate complex. In the time section, a positive phase is observed, travel time is 1.655-1.720 seconds. The average apparent electrical resistivity of horizon is ~ 900 Ω·m.
2. Famennian complex. It is characterized by terrigenous and carbonate rocks. The average electrical resistivity of horizon is ~ 700 Ω·m.
3. Domanic carbonate complex. For carbonate buildings, travel time is 1.895-2.030 c, a negative phase. This horizon is extremely interesting for searching reef structures that are promising for hydrocarbons. The reef structure is characterized by an increase in velocity of elastic waves. The average apparent electrical resistivity is >1000 Ω·m.

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DIAS A. ORMAGANBETOV
Kazakh-British Technical University
Prof. Valeriy V. Korobkin
Kazakh-British Technical University

GEOLOGICAL EXPLORATION METHODS FOR URANIUM DEPOSITS IN SOUTH KAZAKHSTAN

According to the IAEA's 2020 data, Kazakhstan maintains the world's second-largest uranium reserves. The types of uranium deposits in Kazakhstan include sandstone (infiltration), vein stockwork, and volcanic stockwork. Most of the uranium deposits are of the infiltration type and located in South Kazakhstan. The uranium deposits are located in Chu-Sarysu uranium province [1, 4].

The Chu-Sarysu's depression extends for more than 1,000 km from the foothills of the North Tien Shan Mountains and northwest to the ancient Ulutau Mountains. The depression is up to 250 km wide, bordering on the Karatau ridge in the southwest and the Chu-Iliy Mountains in the east. The cover of the Chu-Sarysu uranium province consists of Cretaceous and Paleogene sediments, which contain several complexes, sinuous "roll fronts" formed under redox conditions, at the interface of stagnant and dynamically active groundwater. Ore-bearing continental sediments consist of sand and siltstone strata and are screened by clayey sediments. Unique deposits of uranium Inkai, Budenovskoye, Mynkuduk, Moinkum, and others are located on the regional oxide fronts. These deposits are currently being actively developed by uranium mining companies operating the in-situ leaching method. [1-6].

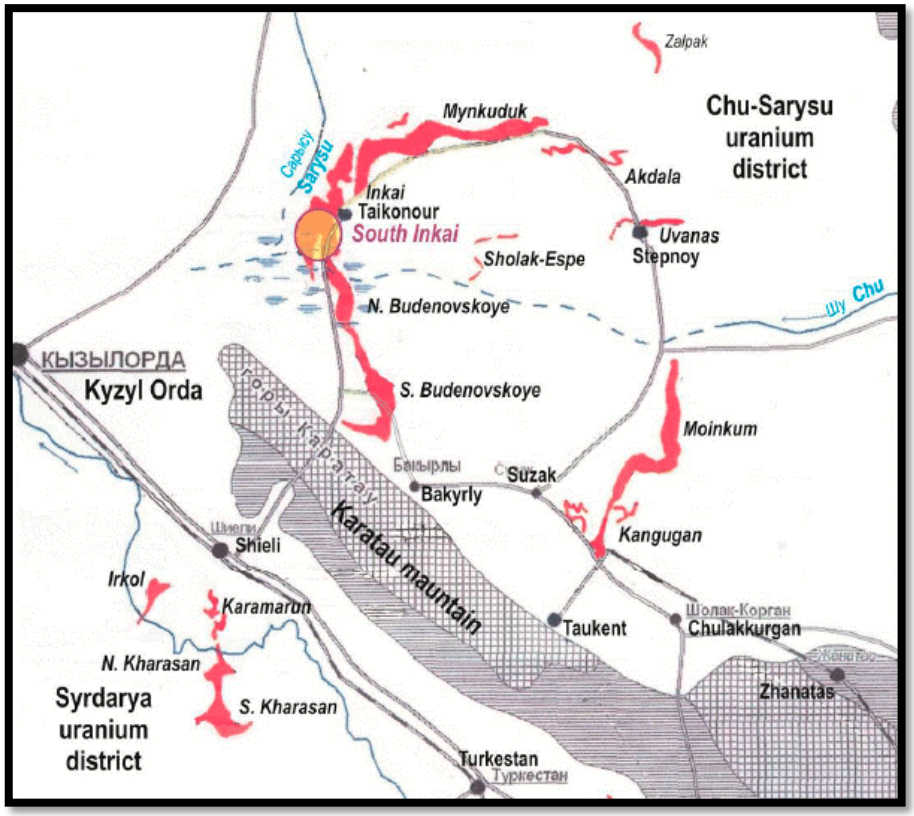

Figure 1 – Location Plan of South Inkai Deposit in Southern Kazakhstan Uranium District. The red area is uranium roll-front mineralization (Uranium One inc., 2013) [3]

For instance, roll fronts represented by sediments in the Inkai uranium deposit are located within the Incuduk and Mynkuduk horizons and composed of fine-, medium- and coarse-grained sands, gravels, and clays. The ore deposits in the horizons average approximately 35 to 40 km in length, 200 to 350 meters wide, 314 to 390 meters deep, and 200 to 250 meters thick. The oxidation-reduction boundary is diagnosed in the core by a distinct color change from greenish-

gray in the reduced environment to light-gray with yellowish spots in the oxidizing environment associated with oxidation of pyrite to limonite [1-4].

Geological exploration works were carried out to discover uranium deposits, and to determine distribution and depth of occurrence, using the following fundamental methods:

I) Core samples were used for laboratory analyses, such as routine core analysis (RCAL) and special core analysis (SCAL). According to the results of these two analyses were determined: 1) uranium and radium content; 2) grades of associated elements; 3) specific gravity and humidity of uranium-bearing rocks in the solid core; 4) acid-alkaline balance of rocks in the solid core; 5) mineral composition of ore mineralization and host rocks; 6) testing for uranium leachability.

II) Well logging, which includes the following logging methods: 1) gamma-ray logging (GR); 2) resistivity logging (RL); 3) spontaneous polarization logging (SP); 4) directional survey (DS); 5) induction logging (IL); 6) calliper logging (CL); 7) neutron logging (PFN). These GR, RL, SP, and DS logging methods are mandatory and are performed in all wells drilled. Furthermore, PFN is used as a control method and for the determination of radium halos [3].

Based on the results of the geological exploration work, data was obtained, which suggests there are several highly promising areas containing uranium deposits in the Chu-Sarysu uranium province. Additional resources in areas are likely to be delineated in the future, as exploration in this region is still focused on the hydrogenous type of deposits [1-6].

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ALEKSANDER K. PYZIK
AGH University of Science and Technology
TOMASZ F. PACHÓŁ
AGH University of Science and Technology

THE ACCURACY OF SELECTED MOBILE GEOLOGICAL COMPASS APPLICATIONS

The development of technology and smartphones brings new possibilities in various geological surveys. Several sensors installed in smartphones allow them to be used as an alternative to analogue geological compasses. The issue of accuracy of such measurements collected with mobile devices has been discussed over the last decade [1,2]. Studies have shown that using mobile devices exhibit promising results, allowing for quick and effortless survey conduction in comparison to those performed with analogue compasses. However, there is some uncertainty associated with accuracy of such measurements. While using smartphones during geological surveys, it is possible to receive results varying from each other, depending on what device and mobile application were used. Differences in the construction of mobile devices and

their components, made by various producers, together with differences in the software, might have an impact on the results [3]. The aim of our study was to assess the accuracy of measurements made with selected mobile geological compass applications in field conditions.

Usually, to collect structural data such as dip angle and dip direction of surfaces during fieldwork, an analogue geological compass is used. A smartphone using its sensors such as a magnetometer, an accelerometer and a gyroscope can imitate an analogue compass and can be used for measurement. Moreover, thanks to the connection to GSM, a well-written mobile application can locate the device in the world and calculate magnetic declination that is taken into account while conducting the survey. During analogue measurement, results need to be manually recalculated considering declination. Additionally, different applications have a variety of useful functions facilitating fieldwork, such as the possibility of saving and exporting results, including locations of sites, notes, and photos of exposures.

We conducted the study using a Freiberg geological compass and a mobile device with Android OS with four applications installed from Google Play Store, available at the time of the survey. The following applications were utilized in the study: FieldMove Clino, GC Free, Geological Compass and Structural Compass Pro. The survey was conducted in the Carpathian Mountains in southern Poland. Structural surfaces such as bedding and fractures' surfaces of thick-bedded sandstones were measured at 40 sites. At each site, every measurement was made twice. In total 400 measurements were collected; 80 measurements were made using each application and the compass. The collected data were subjected to statistical analysis.

The applications with the best match of measurements to these obtained with an analogue compass were GC Free and FieldMove Clino. The arithmetic mean of the deviation between the measurements were 6˚ and 7,9˚ respectively. The median deviation in both cases equalled 5˚. The less accurate results were achieved by Geological Compass and Structural Compass Pro. The mean deviation equalled 8,2˚ and 10,3˚, and the median deviation equalled 5,8˚ and 7˚, respectively. The measurements of dip angle for each application showed low deviation from the measurements obtained with analogue compass, with a mean deviation not exceeding 2˚ in all cases.

The study shows that software can greatly influence the results of structural data collection. However, there are easily accessible, free to use applications which allow the collection of reliable data. Taking into consideration both accuracy of measurements and the functionality of the software, the most accurate application used in the study was FieldMove Clino. One must take into account the impact of the device used, as well as its quality. Measurements collected with smartphones made of low-quality components might result in invalid or less accurate measurements. We recommend further research on the impact of the chosen device on the accuracy of measurements.

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EUGENE S. SATSUTA
Belarusian National Technical University

LABORATORY RESEARCH AND CALCULATION TECHNIQUE OF HYDRAULIC ELEVATORS FOR CLEANING BOREHOLE FILTERS FROM SAND PLUGS

A decrease in the water wells yield that penetrate water-bearing gravel-sand deposits, and the failure of these wells, are usually caused by colmatage and sanding. The sand settles in the mud sump, forming a so-called sand plug, partially or completely overlapping the filter. To extract them, it seems promising to use pumps - hydraulic elevators capable of pumping pulp and contaminated liquids [1,2]. Since most of the water wells in the Republic of Belarus were drilled in the Dnieper-Sozh water-bearing stratum and have, as a rule, depths of up to 100 m, the purpose of this article is to formulate requirements for the parameters of the equipment of a hydraulic elevator installation for cleaning two-column wells based on the refinement of the method for calculating a hydraulic elevator. Consider the schematic diagram hydraulic elevator installation applied to a two-column two-filter water well design [3], which is represented in Figure 1.

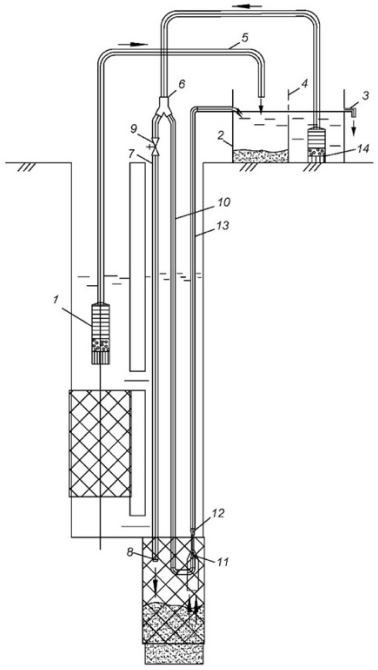

Figure 1 – Schematic diagram of a hydraulic elevator installation during the repair of a two-column two-filter water well

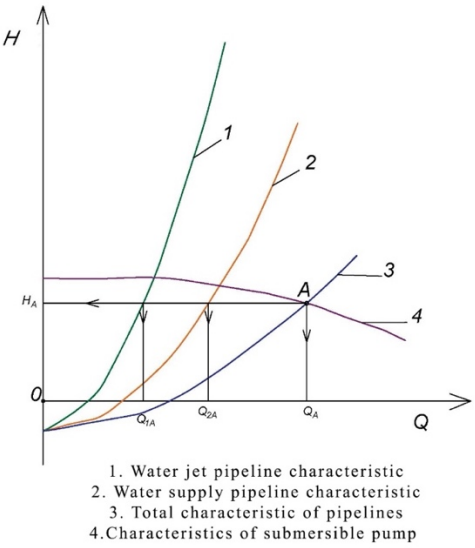

Figure 2 – Characteristics of submersible pump and working together two pipelines: supply and jet

Let one of the filters of a two-column two-filter water well be covered with sand. The hydraulic elevator is lowered into this filter. Tank 2 is filled with water using a submersible pump 1, which is mounted in the first well column, through pipeline 5. From tank 2, by operating pump 14, water is fed into tee connecting two pipelines: a jet 7 with a washout conical nozzle 8 and a valve 9 and into a supply pipe 10 with an active nozzle 11. The active nozzle is fixed coaxially inside the body of the hydraulic elevator pump 12, which feeds the mixture of sand and water into tank 2 through the pulp line 13. Tank 2 is divided by a partition 4 with openings into two compartments. The sand settles at the bottom of the first compartment, water is supplied by the pump 14 to the tee 6 and the process is carried out until the sand is completely removed from the filter. Excess water will be removed outside the tank through the idle drain 3, which serves to maintain the water level in the tank 2 at a constant level. To select a working pump and pipe diameters, according to the specified geometric dimensions of the hydraulic elevator installation, the position of the operating point is graphically found when the pump is working together on the pipeline (Fig. 2).

As a result, according to the dimensions obtained, a hydraulic elevator was designed and manufactured, the design of which makes it possible to adjust the distance from the outlet section of the active nozzle to the inlet section of the mixing chamber. Its laboratory [2] tests were carried out as part of a hydraulic elevator installation. The method for calculating a hydraulic elevator unit for removing sand plugs from water intake wells, which contains a jet pump, a hydraulic elevator and a jetting pipeline with a nozzle, which ensures the erosion of the sand plug, has been clarified. An example of calculating the parameters of the installation for wells with a maximum depth of 100 meters is given. The technique allows, at a given depth and diameter of the well, to graphically select a working pump, the diameters of the supply and jetting pipelines, and then calculate the dimensions of the jet pump - hydraulic elevator and supply pipeline, and analyze the efficiency of the installation.

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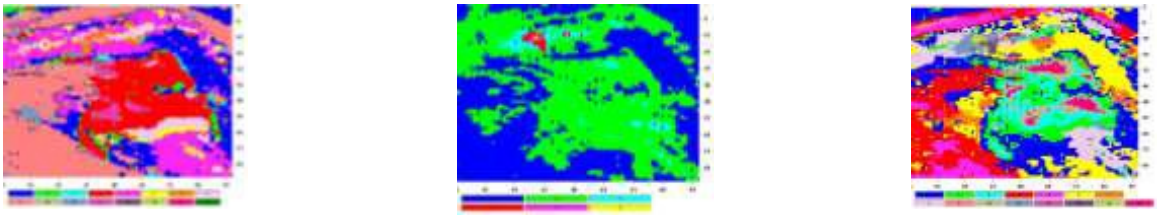
DARIA D. SEKERINA
St. Petersburg Mining University

APPLICATION OF CLASSIFICATION AND TRANSFORMATION OF POTENTIAL FIELDS IN ORDER TO CLARIFY THE MOST PROMISING ORE-BEARING AREAS

Introduction. Currently, the urgent task of interpreting geophysical data is the use of new methods for modeling the localization of ore objects. For this purpose, this paper considers a technique for integrating the transformation of potential fields by filtering, separating and classifying the initialgrids based on the results of magnetic and electrical exploration. As an example of using the mentioned method, a prospecting and evaluation model is given, compiled according to the data of geophysical surveys in an area promising for copper-nickel mineralization and platinum groupmetals [1].

Main part. The algorithm for transforming the original data is performed in the following sequence:

1. At the first stage, the bank of a priori information is considered in detail, including information on the geological, geochemical and geophysical study of the site of work. Reports, maps of various scales and physical and geological models are used as the main information materials.
2. Further, taking into account the information received, the potential fields are divided into regional and local components using software such as "Surfer", "Oasis Montaj", "Coscad 3D" [1,2]. After that, in the same programs, the transformation of the original grids is calculated. As a result of filtering, the most informative maps suitable for further analysis are identified. Thefinal step in the complex transformation of fields is the application of the classification in the Coscad 3D program [3]. Examples of transformations are shown in Figure 1.



А) Б) В)

Figure 1 – An example of the classification of the combined model of potential fields: a) "Sign classification" by 4 signs, b) d) "According to AV Petrov" (with an automatically matched palette), c) "Signed classification" (with an automatically matched palette).

3. After sequential execution of operations, a complex analysis of a priori and transformed information is carried out. At this stage, the most detailed models are selected and structural-material schemes of the study area are formed, which contain information about the geological structure and physical properties of the rocks that make up the site.

Conclusion. Thus, as a result of the work, the advantages and disadvantages of the methodology for combining various methods of transforming fields are highlighted. In this case, it was revealed that the most informative transformations of potential fields are the following: division into local and regional components; calculation of transformants (using low- and high-frequency filtering, as well as the use of linear and nonlinear filters based on the software "Surfer"); classification of the combined model of maps of magnetic and electrical properties using the program "Coscad 3D". The main result of the above operations can be called the fact that the structure previously declared as the apophysis of the anomalous body in the northern part of the tablet has an identical location on all transformed maps, which confirms the assumption about the nature of the formation of the anomalous area and the possible continuation of the structure outside the study area.

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ALI SHEBL
University of Debrecen, Hungary
Tanta University, Egypt
Prof. ÁRPÁD CSÁMER
University of Debrecen, Hungary

GOLD PROSPECTIVITY UTILIZING REMOTE SENSING DATASETS, AT ATALLA AREA, EASTERN DESERT, EGYPT

Introduction. Targeting gold deposits depends mainly on lithological, structural, and geochemical criteria. Remote sensing datasets can efficiently discriminate lithological units, detect structural pathways and assign geochemical characteristics by articulating alteration zones. Consequently, an efficient, reasonable, low-cost exploration framework could be articulated using remote sensing methods. Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data is widely used in detection of alteration zones and mineral exploration studies, due

to its prominent VNIR and SWIR bands that can strongly recognize alteration minerals [1]. Sentinel 2 data, with its higher spectral and spatial characteristics, is also implemented to distinguish mineralized zones [2,3] and confirm ASTER results.

Main objective. Locating promising zones of gold deposits, based on the integration of lithological, mapping, structural framework delineation, and alteration zones specification.

Methodology. In this study False-colour combinations (FCCs) are used for rock unit discernment. Band ratio (BR) and Selected Principal Component Analysis (SPCA) are implemented for highlighting hydrothermal alteration; advanced argillic (b4/b6), argillic-phyllic (b5/b6), gossan (b4/b2), and hydroxyl-bearing minerals (b4/b9) utilizing ASTER data, and identification of gossan (b11/b4), ferric oxide (b11/b8a), ferrous silicate (b11/b12), hydroxyl (b12/b11) minerals, using Sentinel 2 data [4]. Constrained Energy Minimization (CEM) technique is applied to map calcite, muscovite, quartz, epidote, and chlorite.

On the other side and utilizing greyscale ASTER band 3 image, determining algorithms and the frequently used LINE module of PCI Geomatica, tectonic lineaments were automatically extracted, and lineament density map was created.

Results. Advanced argillic, propylitic, argillic, and phyllic alterations, besides tectonic structures, are mostly associated with gold deposits [5]. All the previously mentioned outputs are georeferenced and used as multilayers in a GIS automatic environment that allows visualization and perfect integration. This hybrid visualization effectively reflects areas of exhaustive alteration, structural dissection, and convenient lithological composition as expected zones of gold potentiality. These results are confirmed by reconnaissance fieldwork, and the location of two ancient gold mines, which in turn strongly recommend further investigation of the other highlighted zones.

Conclusion. Combining diagnostic alteration minerals and structural density maps with lithological units can efficiently predict gold mineralized zones. Increasing the integrated techniques and datasets sharply decreases the uncertainty of targeting and narrowing the zones to be further investigated. The study highlights four potential zones for detailed exploration based on relations between lithology, structures, and reconnaissance field verification.

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VLADIMIR A. TERESHCHENKO
Southern Federal University
YURI V. POPOV
Southern Federal University

RESULTS OF THE STUDY OF SERPENTINITES IN THE WESTERN PART OF THE FRONT RANGE OF THE GREATER CAUCASUS

In the Greater Caucasus, apohyperbasic serpentinites are confined mainly to the structural-tectonic zone of the Front Range, where they tectonically associate with the Hercynian nappes (of an island arc nature) or faults between blocks of crystalline uplifts and conditionally belong to the Upper Proterozoic. The main issues of their geology, including the reconstruction of the conditions of metamorphic transformations, the formational and geodynamic affiliation of the protolith, have been debatable for several decades. An important argument in the discussion can be the data on mineralogical and petrographic features obtained by precision methods.

The author has carried out a detailed study of two outcrops of serpentinites: Kishinskij, located between the plates of the Kizelkol and Atsgarinsky tectonic nappes, and Dakhov, on the flank of the Front range zone, associated with the faults of the edge part of the crystalline ledge of the same name. Both outcrops are composed of completely serpentinized rocks converted into lenses and tectonic breccias.

Electron probe studies, X-ray phase (XRF) and simultaneous thermal analysis (STA) results indicate differences in mineral composition. The Dakhov serpentinites are characterized by a micro-loop structure with iron-enriched inner parts of the loops and the precipitation of pulverized magnetite; endothermic effects in the temperature range of ~ 640–660 ° C and XRF data indicate a substantially lizardite composition (β-lizardite with chrysotile varieties predominate; chrysotile-antigorite in the zones of fluid circulation). Kishinskyj rocks are distinguished by the predominance of tangled fibrous or lamellar microstructures, the shift of the endothermic effect to a higher temperature region, and the significant presence of both lizardite-chrysotile and antigorite varieties. Typical minor minerals are chlorites, brucite, chrome spinels. The relict structures and composition confirm the prevailing point of view about the apoperidotite composition of the protolith.

The Mössbauer spectrum of a typical Dakhov serpentinite contains components typical of serpentinites, Fe-chlorites, magnetite; the values of the hyperfine magnetic field are in the range of values observed for hematite (α-Fe_2O_3); the proportion of ferrous ions in the sample is about 33%. Serpentinites of the Kishinskyj massif are distinguished by a higher proportion of Fe^{2+} (over 40%) and the absence of effects characteristic of hematite.

The loss of the original mineral composition determines the importance of studying accessory Cr-spinels, which carry important genetic signs [1]. Electron-probe mapping reveals zoning in them, which arose during metamorphic transformations. The compositions of the cores of chrome spinels from serpentinites vary in a wide range - from chromepikotites - alumochromites to subferrichromites [4], in accordance with the trend characteristic of ultramafic ophiolite associations, the rims of the cores are depleted in magnesium and aluminum and correspond to ferrichromites, chromemagnetites and magnetites. The cores of Cr-spinels, the compositions of which, on the whole, correspond to magmatic varieties and are considered to be approximately corresponding to the primary compositions, indicate a similarity with Cr-spinels of ultrabasites of ophiolites of supra-subduction zones (SSZ).

Analysis of the data obtained indicates that the formation of serpentinites took place under conditions that did not go beyond the parameters of greenschist metamorphism facies. At the same time, relatively increased PT values and decreased saturation of the geological environment with fluids (judging by the direction of isomorphic substitutions in Cr-spinels [3] and by the ratio Fe^{3+} / Fe^{2+} - of reducing composition) are reconstructed for serpentinites spatially associated with the Kizilkol tectonic cover. Serpentinites associated with the fault zone on the flank of the Dakhov

uplift were formed at lower PT and higher oxygen activity in hydrothermal solutions. In general, the outcrops can be regarded as associated with Hercynian obduction, but not with protrusion along deep faults from the upper mantle. In spatial association with serpentinites of the Front Range, there are tectonic plates considered as fragments of an island arc and, possibly, a back-arc basin [2], which is consistent with the peculiarities of the composition of Cr-spinel cores characteristic of subduction hyperbasites. In this case, the protolith of serpentinites should be considered as a substrate of the Early-Middle Paleozoic subduction system. The results obtained are a new argument in favor of the pre-Paleozoic age of apohyperbasites and their obduction origin.

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DARYA I. VDOVKINA
Karaganda technical university
Cand.Sc. PONOMAREVA V. MARINA
Karaganda technical university

ARTIFICIAL INTELLIGENCE METHODS FOR ASSESSING CLAY SWELLING

Introduction. The active construction sector development of the Republic of Kazakhstan leads to the fact that territories with difficult geological conditions are being developed (high level of groundwater, specific soils) [1]. Specific soils are soils that with increasing humidity increase in volume - swell. Volumetric soils deformations can lead to disruption of buildings and structures foundations [2]. The study of specific soils requires great investment of time and financial resources. In this regard, it is relevant to study the swelling properties of clay soils for the safe construction of buildings and structures. During conducting geological-engineering investigations, the physical and mechanical characteristics of the rocks, that make up the section of the study area are specified in the laboratory. Determination of the physical properties of rocks is a relatively simple procedure and can be carried out even in the field, while determining the relative swelling of soils is an expensive and time-consuming process [3]. At the moment, a large number of studies have been carried out around the world to identify the dependence of the clay rocks physical properties on their swelling. The presence of a correlation between the physical and swelling properties of rocks would significantly reduce costs at the pre-design stage of construction work. The purpose of this study is to develop a predictive model for the clay rocks relative swelling.

Methods. To determine the dependence of the clay rocks relative swelling, 150 samples of clays and loams were taken in the city of Karaganda. The following characteristics were determined in the laboratory: water content (W), liquid limit (W_L), plastic limit (W_P), plasticity index (I_P), liquidity index (I_L), soil density (p), dry soil density ($p_{ск}$), void ratio (e), degree of saturation (S_r), relative swelling (ε_{sw}). These soil properties were the input data to develop a predictive swelling model. The entire dataset was split by 80%, which was used to train the model, and 20% of the data was used for validation, according to the Pareto theorem. The following

artificial intelligence methods were used as tools for creating a predictive swelling model: multiple linear regression, Random Forest, Decision tree, Gradient Boosting, Support vector machines (table 1)

Table 1 – Methods efficiency evaluation of predictive model development

Model	MSE value
Decision tree	97.8
Random Forest	30.5
Gradient Boosting	62.6
Support vector machines	59.6
Multilinear regression	105.9

The model's effectiveness was estimated using the Mean squared error (MSE) parameter, which the closer to zero, the better the predictive model. The best indicator of the above methods is the model developed by the Random Forest method.

The scatterplot (figure 1) shows the correlation between predicted and measured relative swelling values. The coefficient of determination (R2) was 0.16. Correlation coefficient (R) – 0.40. This shows that the relationship between variables (swelling and physical characteristics) is average.

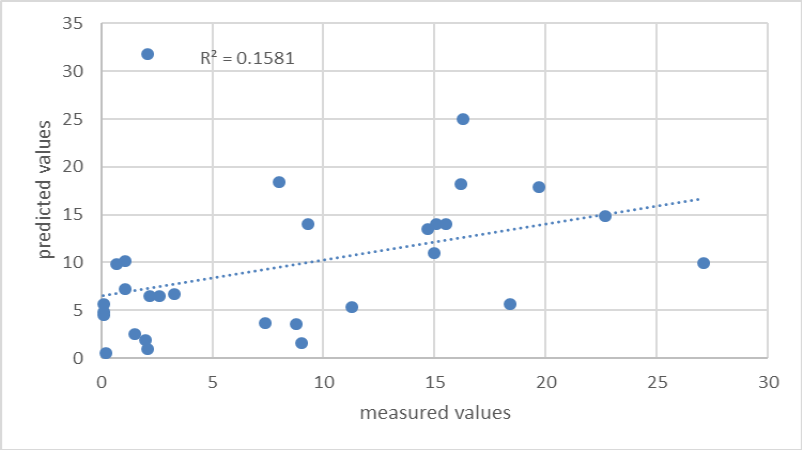

Figure 1 - Scatterplot

Results:

– this study is aimed at developing a predictive model for the clay soils swelling using machine learning methods in order to reduce the consumption of time and money resources at the pre-design stages of construction work;

– the study has shown that the most effective predictive model of soil swelling is the model constructed by the Random forest methods. MSE index is the smallest and is 30.5.

– the correlation coefficient (R) of this model is 0.40, which indicates the average relationship between the predicted and measured values, but is not high enough for the practical use of the model.

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YEXENIA VILTRES MILAN
Cuban National Center for Seismological Research
Dr. Prof. REGINA E. DASHKO
St. Petersburg Mining University
Dr. ENRIQUE D. ARANGO ARIAS
Cuban National Center for Seismological Research

EXTERNAL GEODYNAMIC PROCESSES AND PHENOMENA GENERATED IN THE WEATHERING CRUSTS OF MOA. CUBA

The Moa region is characterized by the development of extensive weathering crusts, which constitute the most important nickel and cobalt deposits in the country. These deposits have their origin associated with the external geodynamics that our planet presents, where several exogenous processes and phenomena are observed, which act on rocks chemically susceptible to weathering processes.

The research aims to identify the exogenous geodynamic processes and phenomena that influence the modeling of the terrain and that promote its instability. Several works carried out describe the main weathering agents that influence the generation of powerful weathering crusts; water, relief, humid tropical climate, temperatures, etc. Serpetinized ultrabasic rocks constitute the main source rock, from which these transformation processes have been generated.

In correspondence to several field works, the bibliographic review of several investigations carried out in the study area, it was possible to determine that the main processes and phenomena developed in the study area, are chemical and physical weathering, erosion, landslides and the activity itself. anthropic of man (Picture 1). To which attention should be paid due to its negative consequences on the stability of the soils, causing accidents that are harmful to man and the country's economy. Chemical weathering is of great importance in the region represented by the laterization processes where primary minerals are transformed and secondary lateritic minerals that carry nickel and cobalt are formed, from chemical reactions of oxidation, hydration and hydrolysis, which act with faster due to the high degree of cracking and fracturing that serpentinized ultramafic rocks have as they allow water to pass through them.

It is valid to emphasize that there are internal geodynamic phenomena, which although it is not the objective of the research, but if they are important in the studies of instability of soils and rocks, in this case it is the seismicity of the area, since you are in a moderately seismic-generating zone active, with the occurrence of significant earthquakes that can cause human and material damage.

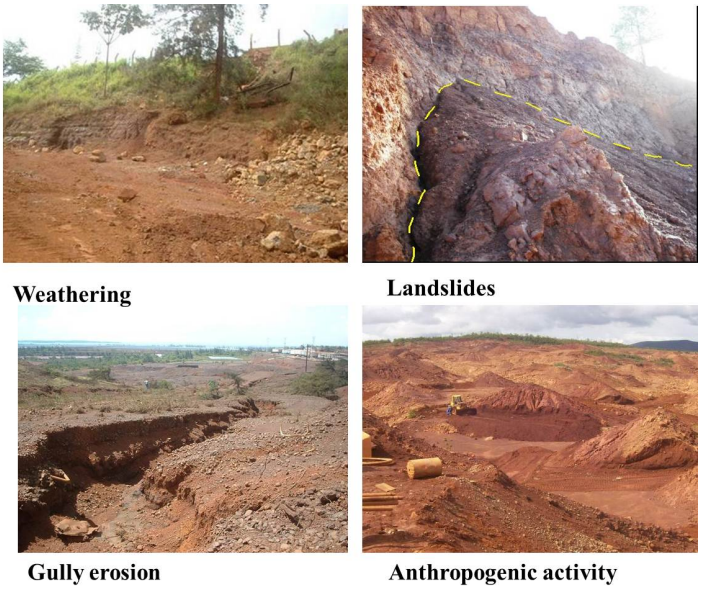

Figure 1 – External geodynamic processes and phenomena generated in the weathering crusts of Moa

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ALENA A. ZAKHAROVA
St. Petersburg Mining University
Dr. Prof. YURI L. VOYTEKHOVSKY
St. Petersburg Mining University

STATISTICAL MODELING OF ROCK STRUCTURES AND TEXTURES

The structure and texture are the most important characteristics of the rock because they reflect the peculiarities of its organization and genesis. Today, various characteristics are used simultaneously to determine structures and textures: shape, grains sizes, relationships between grains and aggregates, and even genetic representations. This descriptive approach generates a huge number of structural types with no clear boundaries between them. The descriptive (classical) approach appeared in the second half of the 19th century, it was developed by G. Rosenbusch, A.P. Karpinsky and I.V. Mushketov [1]. Quantitative methods for the analysis of structures have existed in petrography for over 150 years, and the first of them was the planimetric method for measuring modes by M. Deless [2]. Quantitative methods for analyzing structures are widely used today. However, they are aimed at clarifying the questions of the genesis of rocks, but do not solve the problem of creating a strict classification of structures.

This paper proposes an original technique for modeling structures and textures. It is based on the calculation of intergranular contact statistics. The modeling of classical structures and textures was carried out on the basis of determining the shape of the cluster and the modal composition of the rock. A hexagonal grid was chosen as a model of the structures. For binary and ternary contacts in bimineral rocks, rectilinear trends were obtained that are regularly located in barycentric diagrams (when replacing black grains with white grains, the opposite part of the diagram is filled symmetrically, Fig. 1).

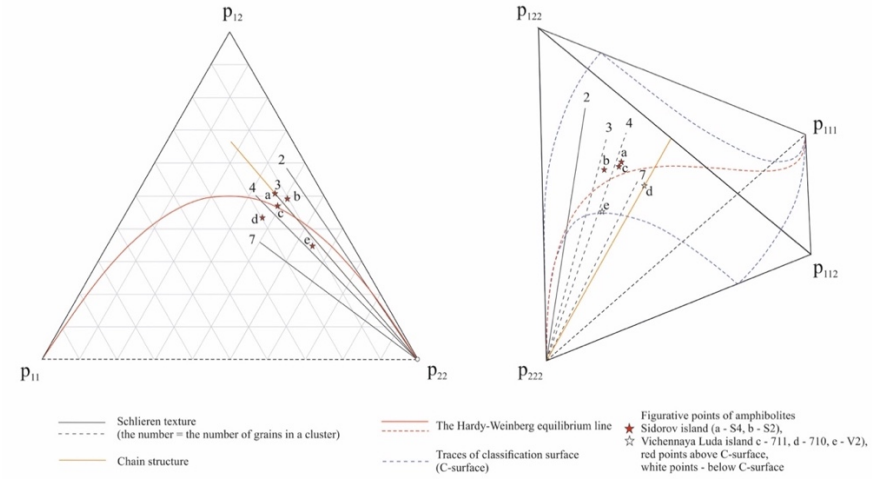

Figure 1 – Modeling results for binary (left) and ternary (right) contacts in bimineral rock

An important characteristic of the organization of rocks is the Hardy-Weinberg equilibrium, which corresponds to massive textures in their statistical sense (ideal mixing of mineral grains). The equilibrium line divides the barycentric triangle in two fields, where mono- or polymineral contacts predominate (Fig. 1, left). This is not observed for ternary contacts, since the line is located in the body of the tetrahedron. Based on the expression of binary contacts in terms of ternary contacts, traces of the classifying surface on the faces of the tetrahedron were obtained, which divides it in two regions, similar to those in the triangle (Fig. 1, right).

The proposed barycentric diagrams were applied to study the amphibolites of the Keret archipelago [3], which consist mainly of amphibole (up to 90 vol. %) and quartz. Thus, amphibolites can be successfully squared to bimineral rocks. The statistics of binary and ternary contacts were calculated for thin sections of amphibolites. The resulting figurative points are shown in Fig. 1. The position of the points of amphibolites relative to the trends coincides in both diagrams and also agrees with the classical description of thin sections (the samples contain small schlieres of amphibole grains and a chain arrangement of amphibole and biotite grains).

The development of rigorous mathematical approaches to the determination of structures and textures is a topical task of petrography. This paper proposes the modeling method enables to identify patterns in the trends arrangement of classical structures and textures for binary and ternary contacts. Any structures and textures can be modeled given the type of cluster and the modal composition of the rock. The figurative points of real rocks will be located between the model trends. Barycentric diagrams of a new type are proposed on the basis of the modeling. The diagram for ternary contacts was obtained for the first time. The correctness of the proposed approach is confirmed by the study of the position of the figurative points of the amphibolites of the Keret archipelago for both binary and ternary contacts.

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АКТУАЛЬНЫЕ ПРОБЛЕМЫ НЕДРОПОЛЬЗОВАНИЯ

XVII МЕЖДУНАРОДНЫЙ ФОРУМ-КОНКУРС СТУДЕНТОВ И МОЛОДЫХ УЧЕНЫХ

Под эгидой ЮНЕСКО

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РИЦ Санкт-Петербургского горного университета
Адрес университета и РИЦ: 199106 Санкт-Петербург, 21-я линия, 2