

**RESOURCES AND RESOURCE-
SAVING TECHNOLOGIES
IN MINERAL MINING
AND PROCESSING**

Multi-authored monograph

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The multi-authored monograph combines promising developments of mining processing ore and nonmetallic minerals by using resource-saving technologies into a single subject.
The book is intended for a broad mining audience of scholars, practitioners, postgraduates and students.

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P R E F A C E



We are glad to present the multi-authored monograph "Resources and resource-saving technologies in mineral mining and processing"

The problem of introduction of resource-saving technologies is one of the essential ones facing the mining and processing industry and scientists looking for its solution.

The multi-authored monograph deals with the essence of resource-saving as well as arising problems of introducing resource-saving technologies and ways to solve them.

The authors consider technologies of mining and processing iron ores, coal, copper bearing poly-metallic and uranium ores.

All the monograph papers are united by a common aim of developing and introducing efficient resource-saving technologies enabling us to mine mineral deposits and process mineral products.

The authors hope that the monograph materials will be of interest to a wide audience of specialists in mining.

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TECHNOLOGY OF UNDERGROUND BLOCK LEACHING AT UNDERGROUND MINES OF “VOSTGOC”

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Annotation

The article is aimed at enhancement of the uranium ore mining technology at underground mines of the state enterprise “VostGOK”. The investigation task consists in determining impacts of various factors on the crown stability when mining uranium ore deposits by vertical double blocks applying underground block leaching.

In the course of the investigation there is used mathematical modelling of the stress-strain state of crowns applying the finite-element technique, analytical study of the degree of crown disturbance caused by mining and laboratory study of uranium ore strength under impacts of block leaching reagents.

To cut costs for final products, vertical double blocks are suggested for underground mining of uranium ores by block leaching.

There are determined impacts of deposit dips and workings on the stress-strain state of crowns. Correction of crown thickness is suggested taking into account the above factors and applying corresponding coefficients.

There is also determined the degree of impact of acid solutions used in underground leaching on uranium ore strength depending on the exposing time.

The determined dependencies enable correcting the crown thickness when mining uranium deposits by vertical double blocks applying the underground block leaching technology and therefore provides safety of works.

Introduction

The state enterprise *Vostochnyi Mining and Processing Works* (SE “VostGOK”) is one of the world’s 28 uranium production centers. It is the largest in Europe and the only one in Ukraine in mining uranium ore and concentrating natural uranium. The enterprise comprises three underground mines: Ingulskaya, Smolinskaya and Novokonstantinovskaya. The enterprise is among the first ten uranium producers (about 2% of the world’s production) supplying uranium raw materials to about 40% of national nuclear power stations.

In Ukraine uranium deposits are mainly exploited in densely populated areas under various protected objects (water bodies, buildings and facilities). To protect the environment from possible emissions of radioactive elements room mining is applied with subsequent backfilling of the dead area with consolidating mixtures.

This technology is cost intensive if the ore body morphology is complex and economically reasonable at deposits with the increased uranium content. For economic and environmental reasons, underground block leaching should be used for mining lean uranium-containing ores to exclude a number of labour-consuming and environmentally dangerous operations from the production process [1, 2]. This enables, on the one hand, reaching maximum values of mineral extraction and, on the other hand, avoiding considerable material expenditures on backfilling mixture preparation and backfilling dead rooms as, when applying underground block leaching, they are almost completely backfilled with the muck pile, and on utilization of waste after the mined ore primary processing (barren rocks and off-balance ores) on the daylight surface.

1. Enhancement of Uranium Ore Mining Technology through Underground Block Leaching

Application of this technology enables further cut of costs through mining deposits by vertical double blocks. Ore body 10 of the Michurinskoye deposit is supposed to be mined in blocks 10-2 and 10-3 at the 325-184 m level at the Ingulskaya mine (Fig.1).

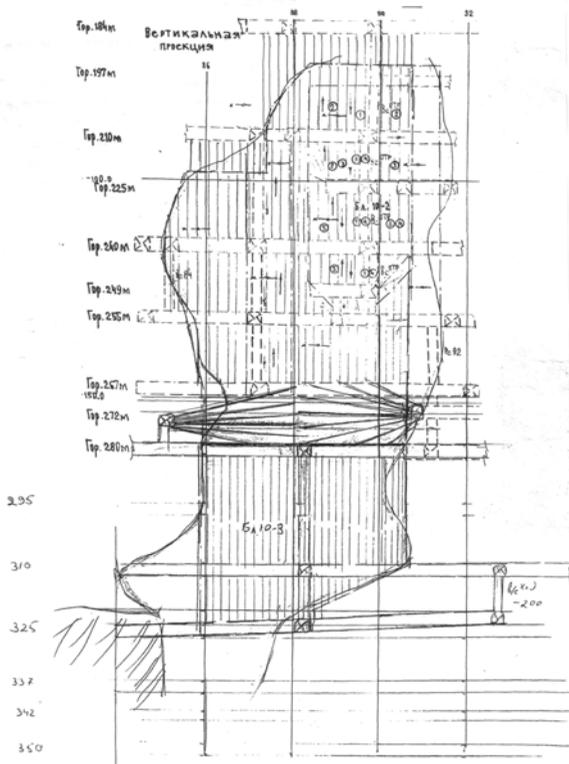


Fig.1. The vertical plane of blocks 10-2 and 10-3 (ore body 10 of the Michurinskoye deposit)

The idea consists in the following. Another room is located under the temporary pillar-crown below the dead room backfilled with the muck pile. Under this pillar in the block located further down the dip a compensatory room is placed to which reserves of this block are broken and the temporary crown is brought down. The solution for leaching uranium ores is fed from the existing workings over the room of the upper block. At this, volumes of mining are cut and pipes are again used for feeding the working solution to blocks.

The technology is distinguished from the traditional one by both levels of stress in main structural units and in the enclosing rock massif and the condition of the crown (the degree of its disturbance

caused by workings and deep holes). Besides, the crown is affected by reagents for underground block leaching. Due to all that, factors impacting the crowns' stability and mine safety on the whole require urgent investigations.

Main regulatory documents on determining permissible dimensions of main structural units of room mining systems [3, 4] do not consider the impact of the ore body dip and are not intended for determining the safe thickness of a crown. The technology of underground block leaching of uranium ores in vertical double blocks has not been used at VostGOK underground mines and requires scientific support.

2. Study of the Stress-Strain State of Crowns When Mining Uranium Ores by Vertical Double Blocks

The stress-strain state and stability of crowns depending on the ore body dip angle was studied by mathematical modelling applying the finite-element technique. There were studied conditions of the above mentioned blocks but the range of boundary conditions of the impacting factors included values characteristic of all the underground mines of "VostGOK". Uranium ore hardness varied from 9-11 to 14-16 on the Protodyakonov scale, that of the enclosing rock - 13-15, the ore body dip made from 60° to 90° (in increments of 10°). The stress-strain state was registered for crowns of 10 to 14 m thick. For calculating the stress field characteristics *Ansys 18* was used.

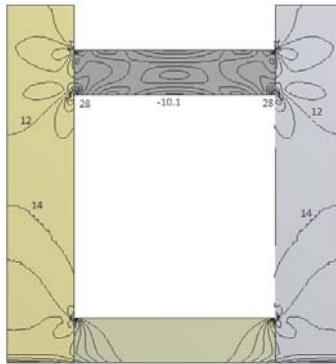
Fig 2, 3 and 4 exemplify results of modelling the stress-strain state of 10 m thick crowns in ores of various hardness with the ore body dip angles of 90° , 70° and 60° .

As the figures show, the tension stress zone in the lower central part of the crown is the most dangerous. This corresponds to the classical concepts of stress field development in the so called "stress relief arch" that occurs when the massif is undermined by the lower block room. As ore hardness reduces, absolute values of stress in the crown decrease slightly (by 0.1...0.5 MPa, i.e. from 1...2 to 6...7%). This can be explained by the fact that less hard ores are less liable to accumulate stress as they get relieved through deforming towards a free surface (i.e. the room) and, on the opposite, harder ores tend to accumulate stress due to smaller deformations. However, stability of

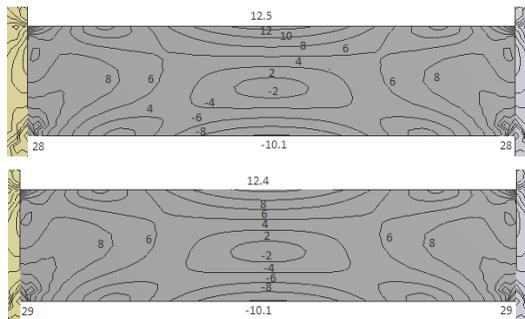
less hard ore crowns decreases due to reduction of their ultimate strength.

For instance, with the ore body dip angle $\alpha = 90^\circ$ and hardness of 14-16 points, the value of tension stress in the lower part of the crown reaches 10.1 MPa (Fig. 2,a). However, as ultimate tension stress of such ores is about 11 MPa, these stresses will not cause failures. When the crown is made of ores of 10-11 points (Fig. 2,d), the tension stress level makes 9.9 MPa. With the ultimate strength of the ores of 7.7 MPa this will cause rock falls of about 100...150 m³ (according to “Instructions...” [4] used at “VostGOK” mines, rock falls of over 250...300 m³ are considered critical).

a



b



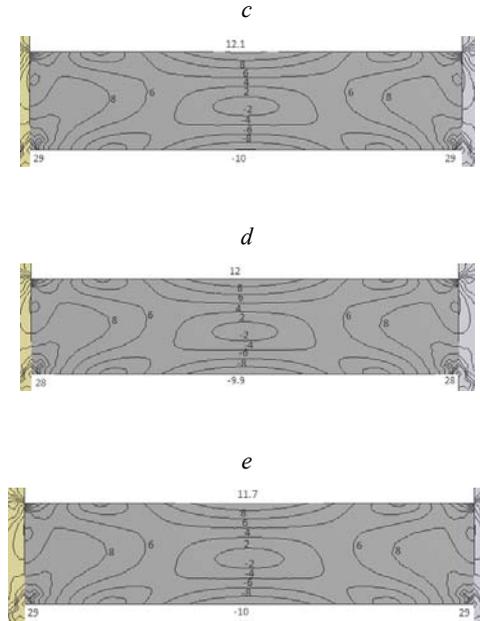
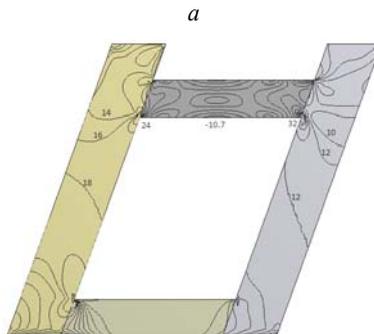


Fig. 2. Stress field development in 10 m crowns with the ore body dip of 90°, MPa; *a-e* – the crown of ores of 14-16, 13-15, 11-13, 10-11 and 9 points respectively



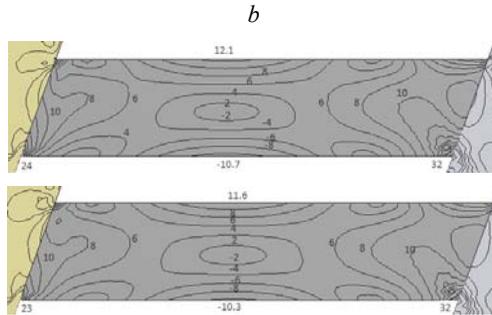
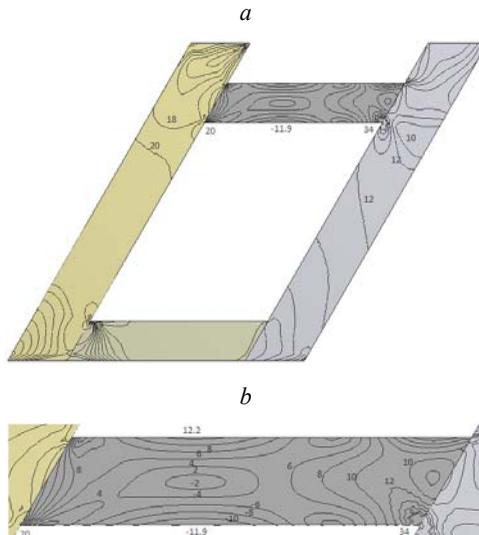


Fig. 3. Stress field development in 10 m crowns with the ore body dip of 70° , MPa; *a-b* – the crown of ores of 14-16 and 10-11 points respectively

With the dip angle $\alpha=70^\circ$ and ores of 14-16 points crown failures do not practically occur (Fig. 3*a*), with $\alpha=60^\circ$ small rock falls (3-5 m^3) may occur even in crowns of ores of the same hardness (Fig. 4*a*). In crowns of ores of 10-11 points with $\alpha=70^\circ$ (Fig. 3*b*) and $\alpha=60^\circ$ (Fig. 4*b*) the volume of rock falls will make from 150 to 200...220 m^3 , sometimes to 400...450 m^3 respectively. These values testify to the critical condition of the crown at angles about $\alpha=70^\circ$, at about $\alpha=60^\circ$ the crown will fail.



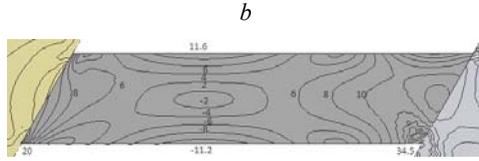


Fig. 4. Stress field development in 10 m crowns with the ore body dip of 60° , MPa; $a - b$ – the crown of ores of 14-16 and 10-11 points respectively

Thus, the obtained results testify to the considerable impact of the ore body dip angle on the stress-strain state of crowns and their stability. On the basis of the research conducted to be sensitive to this impact we suggest to apply the correction factor K_a , whose numerical values are given in Fig. 5. So, when determining the minimum permissible thickness of the crown in certain conditions, its value obtained without this factor should be corrected through multiplying it by the corresponding value K_a .

Technological workings in the crown rock cause changes in the existing stress fields, increase of absolute values of current stresses and, consequently, decrease of the crown stability.

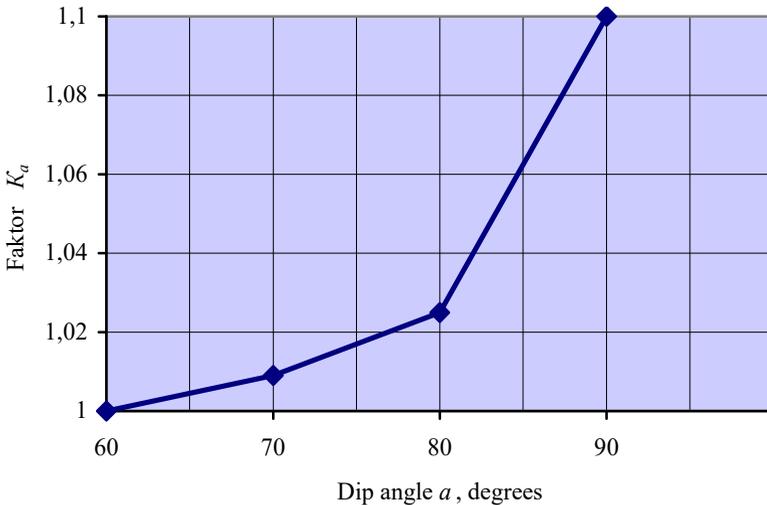


Fig. 5. K_a values depending on the ore body dip angle a

According to this, when determining safe dimensions of exposures and pillars, they are corrected considering the accepted criteria. In the first case, the crown thickness is determined according to conditions of the room mining order in compliance with the instructions developed by NIGRI (Research Ore Mining Institute) [3]. In the second case, the correction factor is applied.

We suggest correcting thickness of the crown with workings using the expression, m

$$h_{cr}^n = h_{cr} \cdot K_{dist}, \quad (1)$$

where h_{cr} is thickness of the monolith crown, m; K_{dist} is the factor considering disturbance of the crown resulted from mining, unit fraction.

As the disturbance degree of the crown depends on the number of workings in it, their geometrical dimensions and thickness of the crown itself, we suggest determining the numerical value of K_{dist} as the product of separate universal factors. Each of these factors differentially takes into account the impact of a particular working on the crown stress-strain state and, consequently, on its stability, as follows, unit fraction

$$K_{dist} = K_1 \cdot K_2 \dots K_n, \quad (2)$$

where n is the number of workings in the crown.

Numerical values of these factors calculated individually for each working can tentatively be determined as follows, unit fraction

$$K_i = \sqrt{1 + \left(h_i^w / h_{cr} \right)}, \quad (3)$$

where h_i^w is the i -th working height (width), m.

For instance, according to the calculations, the minimum permissible thickness of the crown not disturbed by workings is $h_{cr}=10$ m. In case of workings of 2,5, 3,0, 3,5 and 4,0 m, the correction factors for each of them determined by (3) will equal 1,12; 1,14; 1,16 and 1,18 respectively. Thus, the crown thickness should be increased to 11,2; 11,4; 11,6 and 11,8 m respectively.

If there are 2 workings of 3,0 m and 3,5 m in the crown, the correction factor will make $K_{dist}=1,14 \cdot 1,16=1,32$. Correspondingly, the disturbed crown thickness should be increased to 13,2 m.

If there are 3 workings of 2,5 m, 3,0 m and 3,5 m in the crown, the correction factor will make $K_{dist}=1,12 \cdot 1,14 \cdot 1,16=1.48$. Under such conditions the crown thickness should be half as much as that of the monolith crown and make 14,8 m.

So, the crown thickness should be corrected considering decrease of its stability caused by workings. This will help avoid its complete or partial failure.

1. Study of Impacts of Underground Block Leaching Reagents on Uranium Ore Strength

One of the main components of underground block leaching of uranium ores is shrinkage stoping with sulphuric acid treatment. When applying the vertical double block technology, the crown separating the rooms will also be exposed to the sulphuric acid.

The research conducted enables the authors to assume that the longstanding (from 3-4 to 6 months) exposure to the sulphuric acid may negatively impact strength properties of the ore massif of the crown. This assumption is substantiated by data on the physical and mechanical properties of rocks of the Michurinskoye deposit, particularly albitites and migmatites which are the most representative rocks in uranium ore occurrence zones. Thus, the average compressive resistance of rocks in their natural humidity conditions and when water-saturated makes 164,4 MPa and 127,5 MPa for albitites and 153,1 and 112,4 MPa for migmatites respectively. That is, if compared with the natural state, water saturation of rocks reduces their compressive resistance by 22...27%.

To confirm the impact of the sulphuric acid solution on the crown stability the authors conducted the following investigation. Forty ore cubes with 50 mm sides were divided into two groups. The first group of 10 cubes was used to determine the uniaxial compressive resistance in the natural conditions, the remaining cubes were used for determining the degree of the sulphuric acid solution impact on the samples' strength.

To provide conditions of the crown contacting the acid solution, in the laboratory environment only one face of an ore sample contacted the acid solution. The other faces of the cubes were covered with two coatings of paraffin. These cubes were placed in a vessel

with the sulphuric acid solution which is used for spraying the shrunk muck pile in underground mines of “VostGOK”. Tests of uniaxial compressive resistance were carried out 2.5, 4 and 6 months after dipping to determine the impact of the exposing time on the uranium ore strength. These periods correspond to the minimum and maximum time of the reagent impact in real conditions.

The laboratory bench for the research was equipped with a hydraulic press able to produce pressure up to 50 t. In relation to the cubes' surface $S=25 \text{ cm}^2$ the corresponding pressure makes about 2000 kg/cm^2 , or 200 MPa. The press is coupled with a computer that sets the loading rate for the samples and forms the loading diagram for each of the samples with the automatic recording of the current load, maximum pressure at the moment of their destruction and calculates ultimate strength of each sample depending on its sizes. During the tests the minimum loading rate of 1 kN/s was set according to corresponding standards (from 1 to 5 kN/s).

Tests of the first group of the samples demonstrated that the average value of the uniaxial compressive resistance made about 130 MPa. According to the instructions [3] this value corresponds to the rock hardness ratio of 11 points. For the samples exposed to the sulphuric acid solution during 2,5-4 and 6 months, average strength values made 82...84.5, 79,5...805 and about 78 MPa respectively, i.e. their ultimate strength decrease (in relation to the samples of the first group) made 35...37%, 38...39% and about 40%.

The obtained results confirmed our assumption about the considerable impact of the acid solution on the uranium ore strength that will, no doubt, influence the stability of exposures and pillars. Thus, the determined dependencies should be considered in defining the safe crown thickness when applying the technology of underground block leaching of uranium ores.

Conclusions

So, the research conducted enabled determining the degree of impact of major factors (ore body dip, crown integrity loss caused by technological workings, impacts of reagent used when applying underground block leaching of uranium ores) on the crown stability. These factors should be taken into account when determining safe

dimensions of exposures and pillars using corresponding correction factors. As a result, in concrete conditions it is necessary to correct parameters of structural units of blocks, particularly the crown thickness, considering the value of its stability changes caused by the above factors. This correction enables avoiding the crown failure and provides safety of works. The determined dependencies can then be corrected considering practical experience of “VostGOK” underground mines.

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Instruksia iz vyznachennya stijkosti hirs'kykh porid pry prokhozhenni hirnychykh vyrobok v umovakh uranovykh rodovyshch, shcho rozroblyatsya DP «VostGOK». – Kryvyi Rih gopredeleniyu ustoichivosti gornykh porod pri provedenii gomnykh vyrobok v usloviyakh uranovykh mestorozhdeniy, razrabatyvayemykh GP “VostGOK” [Instruction on the determination of the stability of rocks during mining operations in conditions of uranium deposits developed by SE “VostokGZK”]. - Kryvyi Rih: “NIGRI DVNZ ”KNU”, 2012. - 28 s. [in Ukrainian].

**INFORMATION AND ANALYTICAL SUPPORT
IMPROVMENT FOR PRODUCTION
RISK ASSESSMENT IN MINING
AND PROCESSING INDUSTRY**

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Summary

Subject of research is production risks, methods of their appearance and evaluation, methods of preventive measures substantiation.

Purpose. Methodological principles working out for assessing production risks for practical use at different industries enterprises, algorithm developing for managerial decision justification based on production risk indicators, the economic effect estimating from the implementation of preventive measures.

Methodology for assessing production risks aimed at establishing the dependence "harmful effect - result". Different methods, such as statistical analysis, quantitative risk assessment methods, expert methods, can be used to identify the dependence.

We analyze the existing approaches to the assessment of production risks, in particular, the risks of accidents. We propose Elmeri method as the simplest and most acceptable for use in different industries enterprises due to a large number of existing methods for assessing risk. The algorithm of the managerial decision substantiation is designed for the scientifically substantiated recommendation preparation on the activity planning to achieve the accepted level of occupational risk.

Conclusion. The research presents methodological principles of the production risk assessment. The production risk analysis shows the injury risk level depends on possible combinations of the specif-

ic weight values of causes and types of events that led to an accident using the developed algorithm on the example of coal industry enterprises. The impact on the injury risk is due to the technological process peculiarities in the metal processing at the machine-building enterprises. The approach to the economic effect estimation obtained because of the justified planning and further implementation of preventive measures is proposed.

Introduction

Novelty and topic relevance. The role and importance of risk management is constantly increasing as an effective tool for increasing the level of production safety and reducing the losses associated with occupational injuries and occupational disease, nowadays. The European experience shows growing of this tool value due to the risk growth itself first of all and the complication of all spheres of the modern society functioning.

Ukrainian legislation on labor protection adapts to European and international legislation. The usage of world-wide scientific and practical experience in Ukraine grows and deepening of international cooperation in the field of labor protection are intensifying, that will increase the level of labor protection and production safety, prevention of accidents and accidents at work, strengthening of preventive maintenance of production traumatism and occupational morbidity [1]. The choice of methods and ways of the integrated solution of the enterprise development problems was carried out primarily on the basis of economic cost minimization in previous periods, the question of assessing the possible negative consequences of their exploitation and the level of production safety is becoming relevant nowadays. One of the most important directions of the problem solution is the adoption of technical and organizational decisions set based on the risk theory concepts [2]. The realization of the production risk measurement requires on-site control implementation, analysis of the management entity performance indicators, provides the its condition data collection in different environmental conditions, forecasting the dynamic changes of indicator and main development trends. Logical approaches to risk management do not imply the need for creation and operation a single analytical center that processes and collects

statistical data on the level of risk and factors affecting it [3, 4, 5]. Use for estimating production risks of leading and managed indicators (like economic research) has recently become widespread in the field of occupational safety and health management [6, 7].

State policy changes in the field of labor relations, occupational safety and health have identified the need for reform of the relevant sector of state executive bodies. By the Resolution of the Cabinet of Ministers of 10.09.2014 № 442 "On Optimization of the System of Executive Power Central Bodies", the State Service of Ukraine for Labor (State Labor Service) was created. One of the directions of European approach successful implementation of control, supervision and management functions of the State Labor Service is a comprehensive modernization of the system of informational and analytical support. The reform of state authorities requires modernization of the system for information and analytical support the inspection work of the State Labor Service. That is why the issue of developing and introducing mechanisms for assessing production risks at the state level has become particular importance on the basis of information systems that function in the structural units of the State Labor Service.

Purpose. Methodological principles working out for assessing production risks for practical use at different industries enterprises, algorithm developing for managerial decision justification based on production risk indicators, the economic effect estimating from the implementation of preventive measures.

Research tasks: research occupational injuries indicators at the enterprises of leading economic activity types, analysis approaches to the assessment of emerging risks, formation the algorithm of management decision substantiation on reducing production risks.

Methodology for assessing production risks is aimed at establishing the dependence of "harmful influence - result", which is expressed ultimately in determining the harmful effects on specific workers of certain professional groups. The production risk is the probability of damage to the health of the employee in the course of work, taking into account the damage, damage is physical or other damage to the health of people and/or damage to property or the environment or their combination (In accordance with DSTU 2293-06 "Labor protection. Terms and definitions of the main concepts").

The presentation of the research begins with an analysis of the state of occupational injuries at enterprises of Ukraine, the need to improve effective mechanisms for managing production risks, for the practical implementation of these mechanisms proposed an appropriate algorithm, as well as a method for calculating the economic effect from reducing the losses associated with a high level of production risks.

Material and results of research

Current approaches to assess production risks. The current level of domestic developments in the production risk assessment is not sufficient to allow the system of state regulation of the risk management process to be improved.

Existing methods for analyzing injuries and assessing production risks by commonly used methods (statistical, topographical, economic, expert assessments, etc.) and based on traditional indicators do not allow full account of changes that occur in the country economy, have low predictability and accuracy of received estimates. The indicated methods do not allow to scientifically substantiate operative administrative decisions on reduction of production traumatism level.

Effective occupational safety and health manage, choose and application of reliable and affordable measures and means of accountability for workplace accidents, it is necessary to know what factors, causes and sources of hazards can cause in specific conditions at a particular workplace (district, enterprise, industry or the whole state) injuries to the laborer. Therefore, causative relationships in the injury detection process analysis and evaluation is one of the most urgent tasks in the labor protection for scientific research and practice of labor safety and working environment management.

The problem of determining the occupational injuries causes is key to ensuring effective prevention of this undesirable phenomenon at all levels of occupational safety management. Despite the fact that the problems of improving the management of occupational safety and effective development of preventive measures traditionally paid much attention to both scientists and practitioners, unambiguous responses to the question of how the general characteristics of production affect the occupational injury, the state-owned funds, state supervision of labor protection and the re-securing of the labor safety

needs. That is, there are no external factors potentially capable of influencing occupational injuries today (except for general considerations based on logical generalizations and subjective notions). The well-known researches and practice of analysis based on taking into account the influence of external factors on injuries, are used: comparison of dynamics of gross domestic product and levels of injuries, estimation of injuries by indicators of the number of injuries per unit of manufactured products, expert assessments of external influences factors for occupational injuries and so on. Only certain characteristics of external factors are prevented. That does not allow carry out a comprehensive assessment of the impact on the traumatism of the entire spectrum of production and socio-economic factors, which significantly weakens the results of the analysis and does not allow for taking into account the trends of changes in external factors for adjusting the production traumatism prevention.

The unified classification of the traumatism causes is used to analyse the causes of occupational injuries, in particular, the state mandatory statutory form of enterprise reporting on production herbalism is used. It should be noted that the classification of the causes of injuries in these forms has often changed, which partially reduces the value of information accumulated through these forms. The statistics data in these forms are practically the only official source for generalized assessments of the causes of occupational injury in Ukraine. However, due to the imperfection of the methods for assessing these data, their information potential is not fully utilized.

The research propose to use indicators of accident and injury calculated based on estimation probability of the event occurrence during the process of forming managerial decisions aimed at ensuring safety of work in the coal industry. In this case, the dependence of accidents and injuries, obtained by expressing the parameters of their distribution in time function allows predicting the average values of accident probability indicators and accidents in coalmines. The research propose criteria of material incentives for labor protection measures, which consist in taking into account the generalized indicator of the labor protection state and the coefficient of employee labor participation in creating safe working conditions. The criteria for assessing the labor safety determines the value of reducing the actual rate of accidents and injuries in comparison with their pre-

dicted values. The proposed approach implements by constantly updated databases on accidents and injuries, as well as means for automated calculation of predictable assessments of the management action results.

The correlation analysis (in case of presence of occupational injuries data) allows measuring the tightness of communication and determine the form and parameters of the equation of this connection, provides solutions to the following tasks:

- the average change in the effect of the attribute determining under the influence of one or several factors;
- the dependence degree characterization of the resultant attribute on one of the factors with a fixed value of other factors included in the correlation model;
- the closeness of the link between the productive and factual features determining (as with all factors, and with each along without the influence of others);
- the total volume of the variation of the resultant trait to the corresponding parts definition and decomposition and the determination of the role of each individual factor in this variation;
- statistical estimation of sample correlational indicators.

Despite the considerable number of scientific works devoted to the issue of improving the occupational safety management efficiency at various levels, it should be noted that there is no single, scientifically grounded approach to solve this problem.

It should also be noted that the developed methods to improve the labor protection management effectiveness have been focused on the needs of specific enterprises or some industries with a high level of occupational injuries, which did not allow them to use them for the whole state. The scope of occupational safety is considered separately from the branches of production, which prevents the promptly taking into account the changes taking place in Ukraine during the last years (in most enterprises production programs, technological processes, equipment have changed). Therefore, the consideration of indicators characterizing the labor protection state is separated from the indicators characterizing production, which greatly complicates the process of formation decisions for the labor protection management. For the practical implementation of the above-mentioned approaches it is necessary to create specialized information systems for

automation of calculations, to formulate and update the databases for operational planning of labor protection measures and control over their implementation.

The main indicators characterizing production herbalism remain:

- the heaviness coefficient (K_T) calculates as the ratio of the number of days of non-workability in the victims (for cases with loss of capacity for 1 and more days) to the number of unfortunate cases without a fatal outcome;

- frequency factor ($K_{\text{ч}}$) calculates as the ratio of the number of accidents without a mortal consequence to the total number of workers multiplied by 1000.

Table 1 presents data on the basis indicators characterizing occupational injuries in the leading types of economic activity of Ukraine for 2015 ... 2017 years are presented.

Table 1. Indicators of occupational injuries in Ukraine

Type of economic activities	2015		2016		2017	
	K_T	$K_{\text{ч}}$	K_T	$K_{\text{ч}}$	K_T	$K_{\text{ч}}$
Coal industry	36,32	6,62	33,89	8,98	33,45	8,71
Mining and non-metallic industry	47,13	1,33	53,06	1,26	48,05	1,38
Metallurgical industry	19,16	1,14	19,08	1,22	19,33	1,27
Road transport	25,2	0,55	26,71	0,53	24,54	0,65
Engineering	21,01	0,51	24,89	0,54	21,22	0,61
Construction and industry of building materials	29,12	0,55	24,89	0,49	28,73	0,59
Self-extracting industry	80,57	0,17	22,47	0,41	43,41	0,35
Agriculture	26,70	0,25	26,06	0,26	26,86	0,23
Socio-cultural sphere and trade	20,89	0,18	22,55	0,21	20,86	0,20
Light, textile industry	28,64	0,10	17,22	0,17	24,7	0,16

The analysis of these indicators shows the presence in the coal, mining and nonmetallic, metallurgical industry, as well as in the engineering of a large number of accidents with severe consequences, since the value of K_T exceeds the average value of K_T for the enterprises of Ukraine. High $K_{\text{ч}}$ level shows that in the analyzed types of economic activity, accidents occur more often than in other enterprises.

The statistics show that occupational disease in Ukraine remains a complex problem for many years. There has been an increase of occupational disease indicators in agriculture, mechanical engineering, light industry and chemical industry during recent years. The worst work conditions are observed in the mining industry (coal) and processing (chemical, metallurgical, mechanical engineering). Pile pathology is at the forefront among occupational diseases. There are cases of exceeding the actual concentration of dust above the maximum permissible concentration, and prolonged action of dust on a person can lead to silicosis and other diseases. There is a violation of the production environment micro-climate conditions, exceeding the limit levels of electromagnetic radiation, which also has a negative effect on humans, at the different time periods. The number of workers employed in hazardous working conditions at the enterprises of the processing industry exceeds a quarter of the number of state employees.

The research results of domestic and foreign scholars convincingly testify to the combined effect of the production environment factors on human health, and the mentioned factors can be considered the most important in terms of unfavorable influence on the workers. In order to form the composition of hazardous and hazardous production factors that affect the production risks, it is necessary to analyze the features of technological processes, equipment and organization of labor at enterprises. Quantitative methods for assessing risks involve identifying potential hazards, assessing the probability of implementing each i -th hazard P_i and the expected severity of the consequences of its implementation C_i

$$R = \sum_{i=1}^n P_i C_i, \quad (1)$$

R is the risk of causing damage associated with the possible realization of the i -th threat identified.

The complexity of such an assessment lies not only in the fact that the number of accidents at work decreases (as evidenced by official statistics) therefore, it is virtually impossible to estimate the probability of their occurrence with acceptable accuracy. It is necessary to analyze the potential dangers, in particular, the events that resulted in injuries with temporary loss of work ability and fatalities,

cases of violations of the requirements of current legislation in the field of occupational safety, which may cause injury, etc. In addition, it is inevitable to calculate the probability of occurrence of one of the options for the implementation of each hazard. Also, it is not always possible to estimate with a reasonable accuracy direct material damage for the employer and for the employee as a result of the realization of the same danger.

Improved method to calculate Elmeri index. All the more important are indirect methods of quantitative assessment of production risks due to the disadvantages inherent in direct methods. One such method is the Elmeri method (system) developed in the EU [8]. Finnish Occupational Health Institute and Ministry of Social Security and Health of Finland developed this method. In this method, the level of risk in the sub-section (at the enterprise) is evaluated by security index (Elmeri index), that represents ratio of the production factors number that meet the existing documental requirements to the total number of factors affecting the personnel of the selected unit or a company multiplied by 100 %

$$I_E = \frac{q^v}{q^v + q^n}, \quad (2)$$

I_E is Elmeri's index, q^v is number of production factors whose level corresponds to the requirements of normative documents, q^n - number of production factors whose level does not meet the requirements of normative documents.

The disadvantage of the Elmeri method is that all factors affect labor safety are assumed as equivalent. Such assumption distorts the actual picture of the identified risks and does not allow for the development of plans taking into account the knowledge of the existing risks. Nevertheless, use of Elmeri's method allows planning measures for the labor protection with a specific purpose - to eliminate the discovered potential hazards sources.

Expert method allows assign each danger to a certain group. The event aims to eliminate the danger will have a weight factor accordingly the danger risk level.

Improved Elmeri index version can better assess production safety. It proposes to group threats identified at the enterprise by three risk levels: high, medium, low. Measures belonging to the first

group (high-risk level) are the most important ones; failure to fulfill these measures can directly lead to injury or occupational disease, etc. This group have to include measures aimed at improving working conditions at workplaces with dangerous working conditions. In addition, this group have to include measures that are formed basis on State Labor Inspectors orders and contain references to specific points of the normative documents in force.

The second group of measures (medium risk level) includes measures those does not directly lead to trauma or disease if failed but indicates insufficient organization of occupational safety level for certain reasons and may increase the probability of detected danger realization. This group should include measures aimed to improve working conditions at workplaces with harmful working conditions.

The third group of measures (low risk) includes measures implementing recommendations on the organization of jobs and the labor process. Such measures are not binding, but testify managers and worker attention to labor protection issues, the level of production culture and labor discipline. This group include measures aimed at improving working conditions at permissible working condition workplaces.

The calculation of the security index takes place basis on filled the questionnaire for security index. The questionnaires are a quick and easy way to identify the dangers occurred in the workplace. Each questionnaire mentions the factors of danger or dangerous situations. Danger factors are distributed using subheadings to facilitate processing. The questionnaire may be the only or divided to individual block questionnaires used separately. Together these various thematic questionnaires form the entire range of risk assessment, which takes into account all private factors of the production environment and labor process. The thematic questionnaires can be used to emphasis risks at major importance enterprise areas or in the assessment of which there are obvious and significant disadvantages. The top part of the questionnaires contains the following information: name of the enterprise, evaluation object description, evaluated factors and date.

Each of the three questions mentioned in the questionnaire corresponds to three altreasons. Each item have to be analyze by ticking

each of the corresponding lines in accordance to the following alternatives:

- satisfied - the factor does not endanger the injury or damage to worker health or does not occur at work. No action required;

- not satisfied- the factor poses a risk of injuries or damage to the worker health or provides security measures for other reasons. Necessary estimation of the risk value;

- not defined - the factor and its influence is not known or insufficient information. Further clarifications, measurements or assistance from other experts (experts) are required. A responsible person is assigned to clarify the issue. The question is reexamine due to new additional information.

Given the weighting factors (r_i) that determine the risk level (high, medium, low) we can offer an improved method for calculating the Elmeri index

$$I_E = \frac{\sum_{i=1}^3 r_i q_i^v}{\sum_{i=1}^3 r_i q_i^v + \sum_{i=1}^3 r_i q_i^n}. \quad (3)$$

Proposed Elmeri's index is not directly applicable to the identification and evaluation specific production risks.

The use of this index first will allow count the severity of the consequences associated with the realization of the identified dangers and secondly to conduct a comparative the risk level analysis for different enterprises.

The sources of data necessary for calculating the Elmeri index will be not only the results of the survey but also data functional information systems State Labor Service.

Data on inspection activities on labor relations and occupational injuries should be used first.

Substantiation of decisions to reduce production risks. State regulation for choosing production risk assessment objects is possible at industries, groups of enterprises with similar technological processes and equipment, enterprises of one type of economic activity, etc.

The production risk assessment allows to identify and assess the factors determine the production risk, identify the main trends of changes in conditions and safety of labor, depending on the specificity production programs and, most importantly, develop well-founded and acceptable for different enterprise measures to reduce production risks.

Figure 1 presents the algorithm for substantiating managerial decisions on reducing production risks.

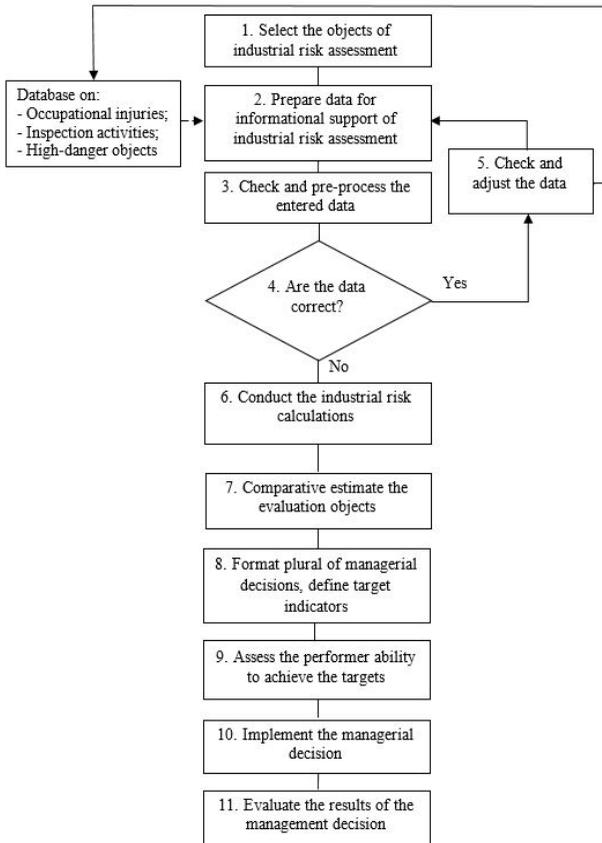


Figure 1 - Algorithm for substantiating managerial decisions on reducing production risks

Selection of objects for the production risk assessment is carried out at the first stage. E.g., an entity can be a group of enterprises in

one industry that has similar equipment, technological processes and similar operating conditions. Data is being prepared for information support. Data on occupational injuries, inspection activities, high-risk objects and others are used first. Data from questionnaires are used in addition. Necessary calculations are carried out if the available data satisfy requirements. Obtained calculation results allow formulate a general idea of the production risk level at the investigated objects. Using the resulting estimates of production risks allows companies to organize themselves in order of decreasing these values and start to plan measures for enterprises with the highest possible risk. The managerial decision results have to be carefully analyzed. Such analysis should determine the weak and strong points of the decisions taken and plans for their implementation, as well as additional opportunities and prospects that opens due to the changes.

Constantly updated data describing the working conditions and the consequences of their impact on the employees, as well as on the related mathematical and software are necessary conditions for the implementation of new risk management technology for occupational diseases and injuries.

The analysis of production risks using the developed algorithm on the example of enterprises of the coal industry shows that the risk of injury (estimated as the number of days of disability because of an accident) depends on possible value combinations of the specific weight of the causes and types of events that led to the accident. Maximum values of the number of disability days are observed in accidents characterized by the causes "disruptions in labor and production discipline" (these reasons have a maximum specific weight), events having the maximum and average specific weight ("Falling, collapse of objects, materials, rock, soil, etc.", "Other events", "Fall of the victim", "Action of moving, flying, rotating objects") . Such accidents are characterized a relatively large number of days of disability (15-50). The remaining combinations of the specific weight of the causes and types of events that resulted in an accident lead to comparatively mild injuries characterized by a small number of days of disability most often up to 10. At the same time, in machine-building workshops of machine-building enterprises, in repair workshops of any other manufacturing - production facilities where work is carried out and the high danger equipment is used one of the risk

sources of causing serious injuries is the work item - the processed workpiece.

Especially high risk have the processes of machining on lathes, where high speeds of rotation give a lot of kinetic energy. Processing becomes traumatic as a result of improper fixing, the loss of efficiency of the mechanism of fastening or even destruction of the workpiece under the influence of forces from the metalworking tools. The method of calculating the risk of fracture of the elements of the mechanisms of fastening of blanks is the same as that of other machines. The injury risk is largely due to the probability of destruction of the workpiece during its machining. The process has significant features and requires detailed analysis and on this basis the refinement of the forecasting technique. Such dangerous situations should be expected during the treatment of non-rigid parts such as thin-walled mufflers and cylinders (in engineering technology they are also called hollow cylinders) bushings and rings. Their fastening is accompanied by essential radial deformation. Such objects are widely used in various branches of mechanical engineering such as metalworking, transport, oil and gas extractive, energy etc. The spread and importance of such constructions as well as the complexity of their calculation is proved by the fact that special methods, analytical and mathematical models are created to determine their stress-strain state. They are singled out in separate sections of the machine part calculation guides. Low rigidity of such rings and cylinders in the radial direction necessitate special machine tool designs for fixing them during processing such as machine cartridges with wide jaw surfaces made to the workpiece base size, the cylinder and the hydroplastic cartridges, mandrels etc. [9, 10].

It is possible to propose the main directions of reducing personnel injuries risk caused by the destruction of non-rigid workpieces during its mechanical treatment based on analysis of the obtained results:

- narrow the range of normalized material strength due to increased technology stability. For example, due to the narrowing of the rated strength range by 14% (up to 207-229 MPa), it can be expected to reduce the risk of fracture damage from 0.64 to 0.29%, more than twice;

- stabilize and reduce the cutting power by reducing blunt tool effect (change the tool more often), reducing the feed s and f or the cutting depth t (reduce average cutting power). However, this direction is less effective because of significantly higher loss of productivity. It requires the introduction of an additional operation or workflow;

- use machine tools with reduced non-uniformity of fastening of non-rigid workpieces, for example with an increased number of cams, with elastic elements, etc. Traditional jaw or hydroplastic cartridges cannot be used due to insufficient base surface accuracy and increasing its accuracy requires an additional operation in the technological process of manufacturing the part.

It should be emphasized that proposed theoretical and methodological principles for predicting the risk of productive injuries not only give designers an instrument to meet the social standard requirements of production at the design stage but also expands scientific approaches to substantiate the effective production technology using rational and safe means and technological parameters. It should be noted that in order to increase the reliability of the proposed approaches, it is important to create a reliable database on the probabilistic characteristics of the construction materials and production conditions. That is, technological issues should be considered together with the work safety during the operation of equipment due to the peculiarities of the technological processes, the material properties and the factors affecting the workers.

The proposed algorithm for substantiating managerial decisions will allow receiving scientifically substantiated recommendations on planning measures aimed at achieving the accepted production risk level, to increase the level of on-the-fact justification of planning of occupational safety measures.

Research results implementation at the enterprises of the coal and mining industry will increase the safety of production through the control and analysis of the production environment state and the preparation of an optimal plan of occupational safety and health measures. In addition, level of occupational injuries and occupational disease will be reduced by reducing the level of harmfulness of working conditions.

Economic effect of reducing industrial risks. Planning work on occupational safety at enterprises provides development of such plans: long-term (for several years), medium-term (annual) and operational (quarterly, monthly, weekly). Long-term planning involves the most important, time-consuming and long-term measures. Their implementation requires the joint work of several divisions of the enterprise usually. The possibility of long-term measures plan implementing should be confirmed by a reasonable calculation of the necessary material and technical support and financial resources, identifying sources of financing. The main form of long-term planning of occupational safety work on is the comprehensive plan development of the enterprise to improve the state of occupational safety. Input data for the elaboration of long-term plan and comprehensive occupational safety and health measures are the results of passport-certification and attestation at workplaces and workshops, the results of studying the causes of injuries and target transitions, the state of occupational safety, materials for analyzing the implementation of previous plans, proposals workers, etc.

It is important to optimize the planning of occupational safety measures that makes it possible to meet these needs for a fixed amount of funds to obtain the maximum effect from measures in the form of reducing the level of injuries, diseases, reducing workplaces with harmful working conditions in market relation conditions. Methods for mathematical modeling and forecasting can be applied to optimize the planning of occupational safety and health measures.

Medium-term planning is carried out within the year by developing appropriate measures in the collective agreement section "Labor protection".

Operational planning is carried out basis on the control of the labor protection state in the structural units and the whole enterprise. The operational plan designed to solve everyday urgent tasks to eliminate identified shortcomings and take measures to eliminate the accident causes. Operational measures aimed at eliminating identified deficiencies indicate in the relevant enterprise orders or in the plan of measures approved in the established procedure.

One of the options for justifying the amount of financing for occupational safety and health measures is to use the average value of such expenses per one worker for Ukraine. For more precise defini-

tion of the funding amount estimates can be made for certain types of economic activity due to the costs per worker for each activity type.

Funding justification for preventive measures is carried out in two stages. The first stage, planned production costs are determined, based on assumption that labor costs can be group into permanent and variable. Expenditures on occupational safety measures are mainly one-time investments. They are planned for a certain period and no significant changes occur during this period. They can be attribute to permanent (conditionally permanent). Losses due to occupational accidents and occupational diseases are variable (conditionally variable) costs as the number of injuries and damage they follow tends to change with changes in production volumes and due to other circumstances. This assumption regarding the definition of the preventive measures cost allows us to use the method of analysis of break-even production for estimating the amount of financing.

The damage assessment from occupational injuries can be carried out by solving two problems.

The first task is to determine the the total amount of losses from occupational injuries accidents to the country as a whole, calculate the average losses value per accident; assess the trauma risk with regard to severity. The public management and oversight bodies require results of this task to realize the damage significance and needs for constant attention to the occupational injuries prevention.

The second task is to determine economic effect of the preventive measures implementation to stimulate the employer in terms of investment in occupational safety by assessing the damage from occupational injuries. The solution have be made due to the structure of losses caused by occupational injuries that must consider not only direct and obvious losses but indirect ones too.

That are not less than direct losses and significantly exceed them in some cases. Only account all losses from occupational injuries allows to get the realistic amount of enterprise losses (Table 2), which can be a significant incentive to strengthen prevention of injury.

The formula to determine economic effect estimation of algorithm implementation for substantiating management decisions on reducing production risks

$$E = \Delta E_{3n} + \Delta E_{Hn} + \Delta E_{\delta e} + \Delta E_{6n}, \quad (4)$$

ΔE_{3n} is the saving wages; ΔE_{Hn} is the economic effect of reducing the incapacity day number; $\Delta E_{\delta e}$ is the economic effect of reducing additional leave; ΔE_{p6n} is the economic effect of reducing payments in cases of worker death.

Table 2. Structure of enterprise losses from occupational injuries

Name of cost	Comment
Additional to the insurance payments to the victim	Additional payments in accordance with a collective or employment contract; Expenses related to family assistance
Compulsory payment of wages to employees involved in the liquidation of the consequences of an accident	Costs of accident investigation; Costs and financing for measures to prevent the repetition of such cases; Salary (bonus) for employees for the elimination of the accident consequences; Overtime extra payment associated the elimination of the accident consequences
Expenses for liquidation of the accident consequences	Cost of electric and other energy types spent on the elimination of the accident consequences; Cost of repairing machines, mechanisms, vehicles for the production restoration; Expenses for repair of production buildings and structures; Cost of new equipment purchasing
Enterprise losses as a result of the production process victim withdrawal	Victim salary for underexploited day when accident occurred; Additional payment the difference for victim transfer to a temporary less-paid job; Losses from reducing the victim productivity after returning to work; Outgoing assistance payment to victim in disability case
Cost of victim replacing	Costs for professional orientation and training new employee; Losses due to lower productivity new employee compared with victim

Formula to determine savings by implementation the optimal plan of action

$$\Delta E_{3n} = 3\Pi \cdot N \cdot \frac{\Delta k}{100}, \quad (5)$$

3Π is the average annual salary in harmful working areas; N is the average number of employees in the working areas that have improved labor conditions according to the measures results; Δk is change (percents) of allowances for harmful working conditions as a result occupational safety measures implementation.

Formula to calculate economic effect of reducing the number of days of non-workability

$$\Delta E_{un} = N_{\text{ohn}} \cdot C_{\text{zne}} \cdot \beta_{uy}, \quad (6)$$

ΔN_{ohn} is reducing the number of days of incapacity at the enterprise as a result of the implementation of occupational safety measures; C_{zne} is the average amount of reimbursement for one day of incapacity; β_{uy} is weighting factor which determines the proportion of incapacity days associated to harmful working conditions.

Formula calculate economic effect of reducing additional leave

$$\Delta E_{\text{de}} = C_{\text{dzn}} \cdot \sum M_i \cdot L_i, \quad (7)$$

M_i is number of employees per i -th type of work, L_i is reduction of additional leave due to improvement of working conditions for i -th type of work, C_{dzn} is average payment for one leave day;

Formula calculate economic effect of payments reduction in case of employee death

$$\Delta E_{\text{pbn}} = -\Delta N_c \cdot C_{\text{ce}}, \quad (8)$$

ΔN_c is the increase in the number of enterprise fatal accidents related to production, C_{ce} is the average amount of compensation for a fatal accident in the coal and mining industry.

The research propose approach to the estimation of the economic effect obtained as a result of reasonable planning and further implementation of preventive measures.

Conclusions

The research presents methodological principles of the production risk assessment.

The production risk analysis shows the injury risk level depends on possible combinations of the specific weight values of causes and types of events that led to an accident using the developed algorithm on the example of coal industry enterprises.

The impact on the injury risk is due to the technological process peculiarities in the metal processing at the machine-building enterprises.

The approach to the economic effect estimation obtained as a result of the justified planning and further implementation of preventive measures is proposed

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MANAGEMENT OF LAND RECLAMATION ON OPENCAST MINING

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Summary

Object of research. Development of mineral deposits in the open way leads to the considerable changes of ecological equilibrium and conditions of people activity around subsoil development. The negative influence of mineral deposits opencast mining is expressed in violation of land resources and the hydrological mode of the adjacent area, pollution of water, the soil and air, formation of external dumps and the developed space of pits. The specified negative consequences of opencast mining can be warned or lowered by mined-land reclamation during the field exploitation.

In this regard, land reclamation management on opencast mining of the republic, studying and justification of the land reclamation direction for concrete fields, their optimization and perfecting of flowsheet of the external dumps selective formation, are of great importance for an intensification of the mined territory reclamation on opencast mining.

Methodology of researches. When performing researches the complex method was used: generalization of earlier performed scientific works results; analysis of experience on land reclamation management perfecting.

Purpose and research problems. The purpose of researches is perfecting of land reclamation management due to establishment of a rational way of their restitution when conducting open mining operations.

For achievement of the goal, the following primal problems are solved:

Studying of open mining operations influence on the environment, those of and on land resources.

Studying of the recultivation direction of the lands mined- by open mining operations.

Development of recommendations about perfecting of land reclamation management in the conditions of technogenic pollution of environment at mineral deposits development.

Introduction

Development of mineral deposits in the open way is bound to violation of the considerable land resources during their exploitation. Therefore according to requirements of "About a subsoil and a subsoil management" legislations and "The Land Code" of the Republic of Kazakhstan subsoil users at mineral deposits development subsoil users are obliged to carry out [1,2]:

- mined-land reclamation, restitution of their fertility and other useful properties of the earth and its well-timed involvement in economic circulation;

- to restore the grounds and other natural objects mined- owing to carrying out operations on subsurface use to the state suitable for further use, according to the legislation of the Republic of Kazakhstan.

According to "The Ecological Code" of the Republic of Kazakhstan natural resource users when carrying out operations on subsurface use, exploration, construction and other works are obliged [3]:

- to contain the occupied land plots in the state suitable for their further use to its destination;

- to remove, keep and use a fertile layer of earth at work bound to the surface disturbance;

- to carry out land reclamation.

Expediency of the subsequent use of the mined-lands for needs of the national economy have to be established according to the republic legislation requirements for subsoil management on the basis of regional schemes of land regulation and recultivation, general plans of the territory building, results of engineering-geological researches in the mined-lands territory and technical and economic calculations.

In this regard perfecting of land reclamation management on account of studying of open mining operations interrelation with na-

ture, experience of the land reclamation rational direction justification at mineral deposits opencast mining, establishments of their restitution rational way for the purpose of use them during the operating mine enterprises work is of scientific and practical interest.

According to land balance as of November 1, 2017 in the republic are registered 245,4 thousand hectares of the mined-lands on which overburden and rocks dumps, tailings dams, ash dumps, coal pits and mine workings, oil fields and barns are placed. [4].

In all industrial regions, there are ecologically dangerous zones of influence: waste heaps, dumps, pits, boreholes, mining production wastage with a total area more than 60 thousand hectares, which soils constantly, become soiled.

Only as a result of the nonferrous metallurgy enterprises activity a wastage over 22 billion t, including about 4 billion t. of mining wastage, of toxiferous - over 1,1 billion t. wastage of enrichment and 105 million t. - wastage of metallurgical conversion are saved up.

The spaces occupied by nonferrous metallurgy waste ponds are about 15 thousand hectares, from them the rocks dumps occupy 8 thousand hectares, milltailings – about 6 thousand hectares and of steel works dumps – more than 500 hectares. The same order volumes of a wastage in ferrous metallurgy and chemical industry.

For the end of 2017 in the republic there are 248,3 thousand hectares of the lands mined during the process of the industrial facilities construction, the linear constructions and other enterprises when developing mineral deposits, their processing and conducting exploration works, from them 51 thousand hectares are abandoned and are subject of recultivation.

In the regional plan the greatest number of the mined-lands is in three areas, in Mangystau - 78,6 thousand hectares also are abandoned - 3,6 thousand hectares, in Karaganda – 45,3 thousand hectares and 10,6 thousand hectares respectively and in Kostanay – 37,8 thousand hectares and 13,7 thousand hectares respectively.

In total in the republic, 3346 enterprises and organizations having the mined-lands in the territory are registered. In reporting year in the republic 1,8 thousand hectares were mined, 0,6 thousand hectares are abandoned and 1,2 thousand hectares of the mined-lands are recultivated. The biggest square of the mined-lands was recultivated in the Aktyubinsk region - 1,0 thousand hectares.

With a comprehension of what land resources — is the main factor of economic wealth, social wellbeing of the country, the potential of national property the problem of their rational use and environmental protection increases.

The novelty of a subject consists in perfecting of technical and biological stages on well-timed land reclamation management at the mineral deposits opencast mining differing in collateral scheduling of mining technology and remediation operations.

Relevance of scientific decisions. Opencast mining of mineral deposits now is the largest source of lands violation and environment pollution. Therefore, the technical solutions justification and development directed to the mined-lands restitution is important for preservation of the mineral deposits development area ecology. In this regard perfecting of land reclamation management in the conditions of environmental technogenic pollution at mineral deposits development is relevant.

Research objective with research tasks. Mining-and-geological conditions of the field, the applied technology at its development, social-and-economic and climatic features of the development area, economic activity and the territory development prospects are the main criteria of the land reclamation directions choice when fields developing in the open way. The chosen direction of land reclamation has to provide problem solving of the region land resources rational and complex use, the harmonic landscapes creation answering to ecological, economic, esthetic-and-sanitary and hygienic requirements with the greatest effect and the least expenses. Therefore, when any field developing it is necessary to carry out the choice of the best way of the mined-lands well-timed restitution in the course of conducting open mining operations.

1. Open mining operations and surrounding medium

Opencast mining of mineral deposits now is the largest source of lands violation and environment pollution. Influence of technogenic landscapes on the biosphere and the pollutants distribution which are formed as a result of opencast minings and ore-processing plants activity causes the unpredictable effects rendering a surrounding me-

dium, on the soil condition, vegetation, representatives of fauna and human health.

It is established that the main environmental problem at coal mining increase is the person habitat deterioration because of landscapes change, an erosion process development, the air basin and water pollution, biological diversity impoverishment of the mining area. Environmental pollutant and ecological parameters change have the sluggish, accumulative effect of adverse effects for the person health, which shown in many decades [5]. Integral index of a of the population condition living in coal-mining areas is: increase in natural losses of the population, a high level of congenital anomalies, the raised hum of oncological diseases, the blood systems, nervous diseases and occupational diseases, a high specific gravity of the population groups, vulnerable to a surrounding medium influence. In this regard well-timed land reclamation is a necessary way of the destroyed ecosystems restitution, the conservation of biodiversity and increase in ecological capacity for improvement of the territory condition of the exploited fields' area.

As important priority is possible to recognize the mined-lands ecological restoration of the large mining enterprises and pits of popular minerals which activity in areas led to catastrophic distribution of landslides, a karst, a plane erosion, deflation, pollutants distribution.

At mineral deposits development the mining operations complete closed circuit has to include not only mining, but also the mined-lands restitution to optimum organized and ecologically balanced landscape. Realization of recultivation after the long-lived period of time after the end of mining operations in career is accompanied by considerably larger expenses, than in due time taken and realized measures in the course of mineral production and right after the end of a pit working off.

When fields open way development the condition of the biosphere following basic elements changes: water and air basin, earth, subsoil, plant and animal life [6]. Main types and results of impact of the mineral field development in the open way on a surrounding medium consist in following (fig. 1):

- formation of the considerable developed spaces in the course of opencast mining;

- a land relief change due to overburden rocks warehousing in external dumps;
- placement of minerals enrichment and processing wastage on the area of land allotment;
- change of hydrogeological and hydrological conditions near the field;
- air pollution by organized and unorganized emissions;
- deterioration of the area underground and surface water;
- change of plants growth of and animals dwelling conditions;
- decrease in efficiency of rural and forestry and also livestock production.

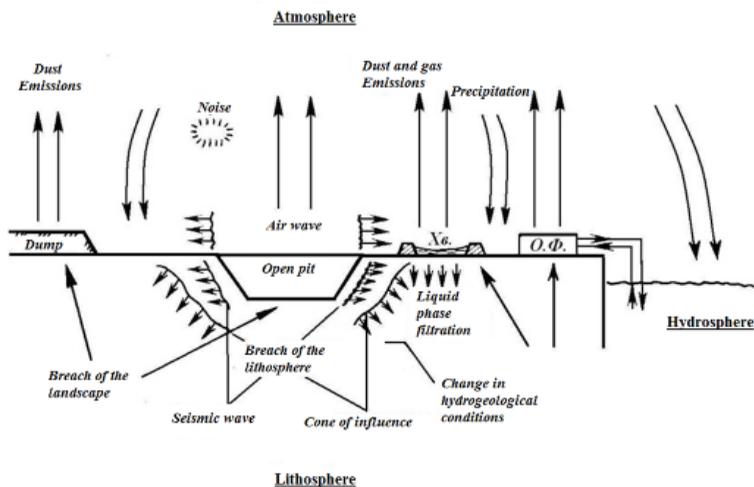


Fig. 1. The scheme of interaction of a pit with a surrounding medium

Studying of interaction of open mining operations with a surrounding medium shown on large number and variety types of exposures on an ecological condition of the developed field territory. Therefore, the researches of adverse environmental impacts regularity have to be directed to the following tasks solution with a goal of sustainable development of the subsoil exploration area:

- justification of impacts substance of the concrete developed field on a surrounding medium;

- development of a scientific basis of technological processes for the purpose of ensuring rational level of environmental impact;
- creation of scientific bases of land resources rational use and well-timed land reclamation;
- perfecting of optimization methods of open mining operations impact on a surrounding medium

Ensuring rational use of mineral resources in open way and environmental protections needs to be considered from the point of view of optimization of open mining operations technological processes affects the habitat condition. Then the concept of sustainable development of the area at fields exploitation to be logical transition of scientific knowledge greening and social-and-economic development. Studying of natural resources use and environment state violation as a result of subsoil development have to be directed to maintaining integrity of biological and physical natural systems of the mining area.

On the basis of studying of land reclamation experience on open-cast mining for minimization their negative impact on the environment and accelerations of restitution rates taking into account the accumulated experience of mineral deposits development abroad and in the republic is offered:

- to carry out the overburden rocks selection placement in a dump body according to their fitness with the rational technology solutions use reducing costs of external dumps recultivation [7];
- to arrange on well-timed land reclamation when mineral deposits developing in connection with increase in the sizes of abandoned lands in the republic on the basis of high standards application and the high-performance control system and also with use of advanced technologies experience in the world.

Use of the approved advanced technology in the course of conducting open mining operations the rational ways of technogenic mined-lands recultivation give the chance of well-timed restitution and preservation of the environment biodiversity at mineral deposits development.

2. Studying of a state and direction of land reclamation

At fields opencast mining there is man-made burden on a lithosphere, the atmosphere and the hydrosphere of the subsoil development area. The scale of open mining operations influence on the environment depends on climatic-and-production and technological features of the developed fields. At technological processes of overburden rocks stoping and ore extraction is necessary to provide use of the organizational and technical actions ensemble providing accessible extent of environment maintaining state around the operating mining enterprises by well-timed land reclamation in pits. Therefore studying of the mined-lands condition and acceptance of organizational and technical actions for their well-timed recultivation is a scientific and technical problem of fields' development in the open way.

The solution of the existing mined-lands problem on open mining operations can be divided into the following options:

- use of the mined-lands without realization of remediation works for various economic needs;
- carrying out recultivation in various directions;
- restitution of the mined massif and soils fertility to a natural state according to an arrangement of the developed field.

At mineral deposits opencast mining an essential shortcoming is their negative impact on a surrounding medium, to main types of influence are rated [8]: withdrawal of the considerable land acting as agricultural grounds and also being a habitat of various representatives of fauna; pollution of the air environment, soil and vegetable cover of adjacent territories; change of the territory relief, its hydrogeological conditions and nearby reservoirs pollution with sewage.

Impact of mining on a surrounding medium has multifactorial character, significantly altering upper lithosphere, the hydrosphere, the atmosphere, a soil cover and a natural biota [9]. When mineral raw materials extraction inevitably there is a technogenic violation of an upper lithosphere because of an objective achievement. The formed rocks dumps, which are stored in natural landscapes indefinitely, develop the fissile processes of chemical elements migration and permeates drains.

The negative impact of a pit on vegetation condition defined by the following factors: development of mining operations and increase of the mined-territories area, mass explosions and combustion gases when ore and overburden rocks transporting by potent dump trucks.

Valuation of environment state of the mining and processing works including a pit, external dumps of overburden rocks, the dressing-works and the tailings dam can form the further basis for rational decisions adoption on land reclamation technology.

On the basis of studying of a condition of lands violation and remediation works at mineral deposits opencast mining, for the purpose of the well-timed solution of the arising questions on environmental protection, regarding well-timed recultivation of the technogenic mined-lands at the operating mining enterprises, it is offered to use the following recommendations:

- maintaining environment state at the operating mining enterprises is reached at acceptance of organizational and technical actions for well-timed land reclamation;

- the long-term and permanent program of remediation actions at the mining enterprise and their well-timed realization promotes decrease of the open mining operations negative influences on surrounding medium.

On the basis of studying of experience of the choice of the rational direction of land reclamation, the geographical areas located in various physiographical regions, with inherent natural, mining-and-geological and mining conditions, the accepted following rational options of restitution of technogenic territories it is offered to use the following recommendations at the operating mining enterprises:

- subsoil users should observe the main requirements of the legislation of the Republic of Kazakhstan imposed to the user of nature when carrying out operations on subsurface use for the purpose of well-timed land reclamation to the state suitable for further use;

- the operating mining enterprises should make use of experience of rational direction justification of the land reclamation at mineral deposits opencast mining;

- at the choice of the recultivation direction the mined-land resources condition and ecologinomic feasibility of restitution, further target use according to territorial scheduling and town-planning zoning have to be considered;

- reduction of a flow diagram parameters of opencast mining dumps surface formation of slightly inclined fields in compliance to recultivation requirements increases the restored area of the agricultural direction;

- accounting of climatic conditions, the principles of mining recultivation of a terminating relief formation, technology of landings and quantity of the plants planted on one site allows to develop various schemes of recultivation;

- ecological safety of liquidating works and providing requirements of the nature protection legislation for lands recultivation is reached at follow-up of suitable supervision;

- measures for recultivation of the technologically disturbed lands should be taken during mining works and after mining operations in pit for reduction of the considerable costs of remediation works carrying out.

Thus, studying of the mined-lands condition and research of their recultivation possibility in the course of mining and acceptance of organizational and technical actions for the mined-territories restitution rational ways development promotes decrease the open mining operations negative impact on environment.

3. Management of land reclamation on opencast mining

Mineral deposits opencast mining is followed by the considerable violations of the Earth's surface and other components of a surrounding medium because of which there are changes in biological equilibrium and natural interaction around a subsoil development. Therefore, when mining it is necessary to pay special attention to conservation, rational justification of actions for technologically disturbed landscapes recultivation because of conducting open mining operations. Influence of fields' exploitation on a surrounding medium expressed in violation of lands, the hydrological mode of the adjacent area, pollution of the soil and air, formation of external dumps and the developed space of pits. In these conditions, prevention or decrease in the opencast mining negative consequences is possible when perfecting ways of recultivation management of technical and biological stages of the mined-lands during mineral deposits operation.

Management of land reclamation on opencast mining consists in the organization and scheduling of the mined-lands restitution in the course of the mineral deposit development. At the same time rational ways of the open mining operations negative consequences decrease on the environment surrounding the person by application of the remediation works modern ways at a subsoil development reached.

When mineral deposits developing land reclamation carried out sequentially in two stages: technical and biological according to requirements of the existing standards [10, 11].

The technical stage of land reclamation provides removal and application a fertile layer of soil, planning and formation of dumps slopes, installation of the hydraulic engineering and meliorative constructions and creation of necessary conditions for further use of reclaimed lands according to purpose or exercise of actions for soils fertility restitution.

At biological land reclamation for restitution of lost lands quality standards, directed to creation of conditions for soils ecological functions restitution and efficiency and ecosystems' specific variety are carried out agrotechnical, phytomeliorative also biological actions.

Biological land reclamation includes actions for restitution of the mined-lands economic and ecological value, their gardening, return to agricultural, forest or other use, creation of the landscape favorable for life and activity of the person. They directed to improvement of biochemical, agrophysical, agrochemical and other properties of the soil and creation of conditions for flora and fauna specific variety restitution.

When fields developing at a technical stage of land reclamation the following works interconnected among themselves are subject to management:

- implementation of the mining operations development in career and dump formations analysis;
- well-timed removal and warehousing of a fertile layer of soil from the area of the career field and dump;
- finding of rational option of a soil fertile layer temporary storage within land allotment;
- justification of the flow diagram of an external dump development and formation providing acceleration of the reclaimed surfaces preparation for the soil fertile layer application;

- establishment of rational option the soil fertile layer application on the reclaimed dump surface.

At the mining sinker system application land reclamation happens mostly after the field working off. Then there is a problem of this situation changing that developed at the mining enterprises, demanding searching of a land reclamation possibility in the course of the field development in the open way.

Based on technical and biological stages management ways studying the land reclamation offered to be carried out within the field exploitation period [12, 13]. Then by production of mining operations, the reclaimed areas appear in the course of the field development in the open way. The successful solution of an objective is possible at the stacking way allowing forming dump surfaces, for acceleration of remediation works on its disposed part.

Management of an external dozer dump formation for the purpose of recultivation acceleration provides disposing of potentially fertile rocks in a peripheral part of dump lifts, and in the dump body of rocks unsuitable for the recultivation purpose due to flow diagram of the overburden rocks selection placement (fig. 2).

At the same time, formation of whole dump carried out in the following sequence.

After dumping of a pioneer embankment the front of dump works on the first dump lift develops along border of dump claim from the right or left-hand flank.

A peripheral part of the first dump lift disposed by potentially fertile rocks. In process of the sufficient working platform emergence on the first dump lift disposing of a pioneer embankment of the second dump lift begins.

Stacking on the second dump lift will develop along its contour and slope part of a dump lift dispose with potentially fertile rocks. After advance of the dump works' front also potentially fertile rocks keep within on a surface of the second dump lift. Further simultaneous disposing of dump lifts with some advancing of the dump peripheral part carried out.

By the close of dump lifts disposing their peripheral parts and the level dispose rocks, suitable for recultivation, that will allow to accelerate recultivation of an external dump.

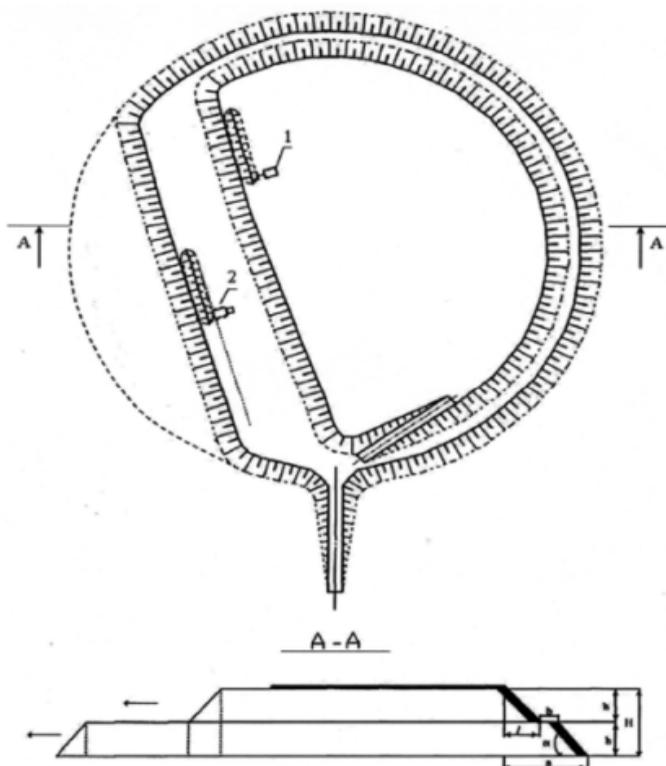


Fig. 2. Flow diagram of the selective formation of a double-deck external dozer dump: 1 - bulldozer; 2 - dump truck

Management of the potentially fertile rocks selective dumping by a peripheral part of dump lifts allows to accelerate recultivation of an external double-deck dump. When stacking the land use indexes improve due to decrease in lands violation intensity. Due to the selective formation of a slope part of dump lifts with potentially fertile rocks is offered to exclude slopes flattening that will allow to reduce mining and planning works.

The offered flow diagram at well-timed management of the double-deck external dump selective formation allows disposing dump lifts at the same time, and they in minimum terms reach design height. Further dump lifts are formed with an advance of the dumping front from right to left or from left to right with some advancing

on the periphery of dump claim. In all cases the advance of the front of dump works has to be parallel and equal for the purpose of the dump and remediation works normal organization.

Application of the operated overburden rocks selective placement in a dump body on fitness them for recultivation allows to accelerate remediation works and to reduce negative consequences of opencast mining on the environment. Exercise of well-timed land reclamation at mineral deposits opencast mining promotes ensuring ecological safety of technosphere.

Based on studying of land reclamation management when the concrete field developing for acceleration of the recovery works follows:

- during the field operation to define ways of recultivation management of the mined-lands technical and biological stages taking into account consequences of opencast mining;

- to carry out land reclamation technical and biological stages taking into account the existing best available technologies;

- on opencast mining for land reclamation management to define the works interconnected among themselves;

- for decrease in negative impact of open mining operations on a surrounding medium to carry out well-timed land reclamation;

- for the purpose of dumps surface recultivation acceleration to carry out the selective placement of overburden rocks, in a peripheral part of dump lifts dispose potentially fertile rocks, and in a dump body unsuitable rocks in the stacking period.

The well-timed decision-making by results of external dozer dumps recultivation management in the course of its dumping allows reducing the negative influence of mineral deposits opencast mining on rational use of land resources, the environment and people activity around a subsoil development.

At a mining stage of recultivation it is expedient to carry out planning of a dumps surface with application a fertile humus containing layer. At a biological stage of recultivation it is necessary to carry out the agrotechnical actions complex promoting increase in intensity of overgrowing processes of a dumps vegetation zone: long-term herbs seeding with mineral fertilizers and biostimulators use, landing of wood plants saplings of local and rogue flora (pine, poplar, maple, etc.).

Thus, based on studying of the creation principles of a simulated vegetable cover on the technologically disturbed by mining operations territories it is offered to make use of the available rational experience of restitution of the mined-lands on opencast mining of the republic:

- prediction of a state, definition of a recultivation opportunity and direction of the lands disturbed by mining operations promotes reasonable selection of plants species for creation of sustainable simulated phytocoenosis in the technogenesis conditions;

- the main efforts of the mining enterprises at subsoil operation have to go for natural resources rational use and decrease in negative impact on a surrounding medium;

- reasonable recultivation of the lands disturbed by mining operations occurs at the choice of the vegetation adapted for local climatic conditions and species of native flora;

- improvement of a condition of the operated fields area territory is reached at well-timed land reclamation for maintaining their biological diversity and increase in ecological capacity;

- carrying out the scale recultivation comparable to the area of the destroyed lands, and ecological restoration of lands of the available mining and processing works and local minerals pits will allow to stop transformations of the opencast mining area landscapes;

- ensuring high performance at land reclamation is reached when accounting feature of the environment, a social, economic and legal side of a question, responsibility of the mining branch enterprise and government of the country;

- the importation of organic matters from a wastage of agriculture and processing industry improves water and physical properties of pioneer soils, initiates structurization, provides plants with a mineral delivery elements and promotes restitution of the mined-lands biogeocenoses;

- acceleration of dumps overgrowing can be provided with a combination of natural and simulated forest recultivation by application on dump surface of soil layer and landing of a pine ordinary;

- land reclamation acceleration is possible at detailed studying of overgrowth processes of the mined-lands by means of remote sensing and ensuring results with data of field researches;

- overgrowth of dumps in climatic conditions of dry steppes is the long-lived process and therefore formation of a simulated vegetable cover is required by agrotechnical receptions;

- acceleration of dumps overgrowing process, formation of productive vegetation and increase in the mined-lands soils fertility are promoted by carrying out a complex of a technical and biological stage of recultivation.

Conclusions

Studying of open mining operations interaction with a surrounding medium show on large number and type variety of an impact on an ecological condition of the developed field territory. Therefore, researches of adverse environmental impacts regularity have to be directed to the following tasks solution with a sustainable development goal of the subsoil development area:

- justification of a impacts substance of the concrete developed field on a surrounding medium;

- development of the studying program and methods of influence by financial means on the subsoil user;

- creation of interaction model of opencast mining and surrounding medium;

- development of a scientific basis of technological processes for the purpose of ensuring rational level of environmental impact;

- creation of scientific bases of land resources rational use and well-timed land reclamation;

- development of the economic feasibility principles of the field development and nature protection effectiveness of actions;

- perfecting of methods of impact optimization of open mining operations on a surrounding medium.

Importance of studying of the choice of the rational direction of technologically disturbed recultivation on opencast mining according to their mining-and-geological and mining conditions, the production technology of mining operations and the field placement area is shown. The given experiences of the mined territory recultivation direction justification on the developed fields can be used at subsoil exploitation in the open way for a solution of the mined-lands restitution problem during conducting mining operations at various mining enterprises.

For remediation works management at open works is recommended to use the developed flow diagram of the selective formation of a double-deck external dump providing simultaneous dumping of dump lifts, allowing finishing dump surface recultivation with the end of dump works.

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CURRENT STATUS AND PROBLEMS OF NEW TECHNOLOGIES FOR COAL MINING IN THE WESTERN REGION UKRAINE

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Abstract

The section analyzes the current state of coal mining in Western Ukraine, as well as perspective methods for the development of thin and ultrathin coal seams, which is typical of the region. The main features of these methods are presented and the most promising ones are determined at the present time.

Introduction. Due to the situation in Ukraine (ATO in the eastern regions of Ukraine, where the vast majority of coal reserves of the country are concentrated), the question of promising methods for the development of thin and ultrathin layers of the Lviv-Volyn coal basin is undoubtedly relevant.

The purpose of this research is identifying promising practices and development of thin and ultrafine coal seams on the example of the Lviv-Volyn coal Basin.

To achieve the goal, the following tasks were set and solved:

- to carry out the analysis of the coal mining industry of Ukraine;
- to analyze the methods of coal mining that are used today in the country;
- to analyze the possibility of using promising methods for the development of coal seams at the mines of the Lviv-Volyn coal basin;
- to formulate conclusions.

1. Basic information about the Lviv-Volyn coal basin

Lviv-Volyn coal basin (LVCB) is located in northwestern Ukraine in the upper reaches of the Western Bug is the south-eastern part of the Lublin Basin in Poland. Its area - 1,400 square kilometers (nearly pulled meridionally 190 km with an average width of approximately 60 km). In the coal-bearing formations in the basin developed 199 coal seams and layers, including 99 seams, of which 30 - labor power (0,6 m) and 17 - industrial value.

Coal seams in basin belonging to the category of thin, at least - medium non-sustained, aged and relatively exposed. Most coal seams have a capacity of 0.2-0.4 m. Average thickness is working layers 0,66-1,5 m. Quite often there are coal seams capacity 1,55-1,9 m, sometimes - 2,1-2 76 m and very rare - 3,63-4,85 m.

By territorial origin, the geological structure and coal, the degree of industrial development basin is divided into three areas: Novovolynsky, Chervonohrad coal-industry and southwestern carboniferous.

Novovolynsky coal-industry region is sufficiently explored. Major coal reserves are concentrated in four operating mines: «Novovolynski» №№ 1, 4 (Buzhanska), 5 and 9, in the field of mine «Novovolynska» № 10 under construction since 1990, as well as the exploration areas for mining - Krechivska Verhnia, Porytska and Pivnichna.

Within Chervonograd coal-industry region of 70-80% of balance reserves of coal, most existing mines and almost all prepared for fur-

ther commercial development of the mine field. It posted 9 active mines, «Velykomostivska» «Bendyuzka», «Mezhyrichensky», «Vidrodzhennia», «Lisova», «Zarichna», «Nadiia», «Stepova» and «Chervonohradska» four back mine fields – «Chervonogradska» №№ 3, 4, 5, 6, two reserve blocks within the fields of mines «Zarichna» and «Chervonohradska» plot «Pivnichna Zabuzka» and detached Bug deposit with limited reserves of coal, which currently has no commercial value. Maximum coal concentrated in the southern area (Velykomostivska group of mines).

Southwestern carboniferous region occupies the rest of the basin. Within the area are explored Tyahlivske and Lubelskie deposits of coal. Now transferred to the industrial development of the field of mine «Tyahlivska» № 1 - the primary facility for coal in 1986 and «Lubelski» №№ 1,2. In other areas the district exploration work continues, albeit slowly.

In the peripheral part of the basin are promising for industrial coal seams search area Mezhyrichchya-Shidna, Mezhyrichchya-Pivdena, Bubnivska, Boyanetska and coal-bearing area of Kovel, Byshkivska and Kulykiv–Vynnyky within which predict 8-10 coal seams. Explored and mastered the industrial part of the Lviv-Volyn basin has an area of about 1,000 square kilometers.

With the discovery and exploration of deposits of Volyn and Mezhyrichensky (1948-1979) was built in the basin and have entered into service 21 coal mines. This was a period of intensive development of coal reserves. All existing mines (except for «Stepovoi») for a very short period reached and exceeded the majority and capacity.

However, even in the years 1975-1982, when production was maximum in the basin (13-14 million tons per year), coal in Western Ukraine was not enough and it additionally been imported from the Donbas and Dniprobassu in the amount of 10-12 million tons. General requirements, according to the Institute «UkrNDIproekt» made 22-23 million tons per year. With the decrease in coal consumption in the region (1982) significantly reduced its production, due to a decrease in overall production level, a decrease in capacity of mines and the lack of new mine construction. In 1993 in the basin, there were 18 mines with an annual capacity of 10,8 million tons. Well, 2010 - 14 with capacity of 4,65 million tons. Coal mining compared to 1989 decreased by 8,3 times and amounted to 1670 thousand tons. In re-

cent years, the state of the mining industry in the basin worse. On January 1, 2015 number of coal mines decreased to 13, and coal production for 2014 amounted to 1057 thousand tons.

Increased capacity of mines in Chervonograd and Novovolynsk coal-areas may be primarily due to the proven coal reserves and prepared for commercial development sites - such as mine fields «Chervonogradska» №№ 3, 4, back-explored areas for reconstruction and extension services active coal mines; redundant power pits «Zarichna», «Visean» and «Chervonogradska» reserve power remaining coal reserves closed mine «Chervonogradska» number 1 redundant power mine «Novovolynska» number 9, areas Krechivska Verkhnia, Pivnichna, Porytska. However, the possibility of filling the mine fund basin by commissioning backup objects is becoming becomes ghostly as policy Coal Industry of Ukraine is aimed at further mine closures 2014 closed mine «Visean» with redundant power and 2015 planned to close at least 2-3. With the commissioning of the mine «Novovolynska» № 10 with a design capacity of 900 thousand tons rise real opportunity to fill the power of the coal-mining area in which 9 coal mines currently has only 4 increases of coal reserves in the area about twice as adjusted calculations will facilitate their re-evaluation by the conditions approved for mines Chervonograd groups (minimum seam thickness 0,6 m by operating in the area 0,7 m, maximum ash content of coal 40%). In addition, with the assistance to the operation of off-balance sheet reserves of coal mines 13 lifetime can be extended to 10 years or more, and the amount of coal in the basin can be stored at 10 million tons.

An important factor is the maximum increase in coal extraction of coal reserves and protection of natural resources at the same time. It is known that the loss of coal during extraction is still significant and represent an average of 27.6 to 42.6%. To reduce the losses are introducing new enabling technologies working subsoil that best ensure the preservation of the earth's surface. An important element in the expansion of industrial prospects coal basin has the ability to attract deep horizons. However, the main development prospects of LVCB associated with carboniferous southwestern area that includes Tyahlivske, Lubelskie deposits and promising area Mezhyrichchya-Zahidna. Coal at the sites of the area with the highest quality, lowest ash and sulfur content and the best ability to enrichment and carboni-

zation. Reserves and resources of coal are estimated at 2 billion tons, almost double the remaining reserves of the industrial part of the basin.

Prospects for further development are inextricably linked with LVCB seams and carbonaceous rocks. Conducted in 2005-2014 years of research confirms prospects basin coal fields to identify industrial concentrations of methane (as an independent mineral resource and companion during industrial coal).

For component composition of gases in coal-bearing strata distinguish three zones: methane-nitrogen to a depth of 400 m, nitrogen-methane to a depth of 400-500 m and methane - less than 500 m. The methane gas zone dominated by methane and its homologues whose content ranges from 50,2 to 98,9%. In addition to methane, the gas mixture consists of nitrogen (0,21-46,5%), carbon dioxide (5,4%), oxygen (0,23-4,02%) and hydrogen (0,01-3,21 %), accompanied by a slight capable of migration component of helium (0,08-0,6%). Heavy hydrocarbons are especially significant with ethane content (0,076-0,46%), butane (0,396-0,834%), pentane (0,195-0,849%).

The coal seams and carbonaceous rocks of Volyn deposit located in the area and is non-methane and slightly gassed. In the south, south-west gas content increases, and at the Zabuzkiy and Mezhyrichensky deposits and operating mines are extreme explosion hazard level. In Tyahlivskiy field that has specific conditions of storage, gas-bearing coal seams and of carbonaceous rocks sharply, and the Lubelski, despite an increase in the depth of the carbonaceous thicker carbon again been active natural degassing, except the bottom of the cut coal-bearing strata, due to many natural geological factors.

In LVCB the most gas-bearing stratum is Tyahlivskiy deposits of coal, which has favorable conditions for the formation and accumulation of hydrocarbon gases, due to not only the depth of coal-bearing strata (528-1050 m), the degree of metamorphism and development of gas and impermeable mudrock horizons, but also the presence of regional top of the screen in the form of powerful (up to 650 m) dense limestone thicket of the upper chalk which is gas-tight in undisturbed condition. Almost all coal seams occur in the methane gas zone and are classified as high seam gas content. Major industrial gas-bearing coal seams reached 20-46,06 cubic meters per ton of dry ash-free matter [4-6].

However, over the last decade ingrained tendency to an unacceptable reduction in coal production, capacity utilization (54% of the project) and the number of mining companies. At the same time promising and proven reserves of coal in the bowels of the basin allow through the construction and commissioning of new mines to maintain and develop coal mining in a timely manner to fill the power to prevent a decrease coal output reached.

In addition to recovery and further exploration for coal, it is extremely important to conduct specialized work on methane in coal seams and carbonaceous rocks. In 1995 project offered by government order to search for gas deposits in coal-bearing carboniferous strata southwestern region, but due to lack of funding from the projected seven wells drilled, only one, which, incidentally, is very promising for gas saturation of carbonaceous rocks. In this regard it is necessary to actively attract foreign investors, particularly international company EurogasInc, which has considerable experience in the extraction of methane and since 2007 offers of study and experimental extraction of coal bed methane in Tyahlivskiy field.

2. Prospects for coal mining in Western Ukraine

For industrial development of this area was necessary to develop energy base. And this needed fuel resources. The hypothesis of the presence of coal among Ukrainian shield in Volyn was first put forward by Russian geologist M. Tetiaiev in 1912. Based on a detailed analysis of sediments and tectonic structures of European Russia and eastern Poland M. Tetiaiev not only predicted the existence of this basin, but scientifically grounded nature of its coal.

After 20 years, the hypothesis of M. Tetiaiev received confirmation and further development in the works Y. Samsonovycha. In 1931 near the city of Ostrog Y. Samsonovych discovered pebbles of carbonaceous rocks containing coal bottom fauna. The number and size of pebbles of coal were increased in the direction from east to west. Y. Samsonovych presence of fauna linked with similar deposits of coal.

Exploratory drilling began in 1938 within the Lviv province. Before the Second World War with 11 wells were completed 7. But no processing of the data obtained was not carried out. The published

material on these explorations for coal has reached only Y. Samsonovych short article, written in 1939.

In Soviet times, follow-up study of geological exploration in this area has received wide and systematic development. To view the state of geological exploration and processing of all materials on geology and minerals western regions of the USSR in late 1939 by the Committee of Geology at the Council of Commissars of the USSR created a special commission of geologists. This commission was collected and processed a wealth of factual material, which allowed the study prior to the 1940 master plan to make geological prospecting and exploration in Western Ukraine.

In 1940 for systematic geological exploration of coal was organized public trust «Lvivvuhlerozvidka» The war interrupted the scientific exploration and research work on the coal problem of western regions of the USSR.

Almost all wells remain incomplete, and major geological materials prepared for war during prospecting have been lost. Only in 1945 after the liberation of the territory from fascist invaders resumed geological exploration of coal. Based on a detailed study collected by state trust «Lvivvuhlerozvidka» geological materials was concluded on the feasibility of further prospecting for coal in the western regions of the USSR and identified areas where exploration should be carried out first.

In 1946-1947 state trust «Lvivvuhlerozvidka» significantly expanded area of scientific exploration for coal. Drilling was reaching not only in the Lviv region, but western districts of Volyn region of USSR and Belarus.

In July 1947, Vladimir-Volyn geological part of trust «Lvivvuhlerozvidka» found in the Volyn region industrial coal deposits.

In 1948 the Ministry of Coal Industry of the USSR for exploration in the North of prospective coal-bearing platform organized a special trust «Volynvuhlerozvidka» (Lutsk). It consisted of five exploration parties. Then opened the first coal deposits under Vladimir-Volyn. For the development of natural coal reserves in December 1949 was established trust «Zahidshahtobud»

It was planned soon in 1949 to find out another 10 mine fields in Volyn and Lviv. To accomplish this task trust «Volynvuhlerozvidka»

provided the necessary equipment and personnel from Donbass to help Volyn.

But success did not come immediately. During the detailed inspection found that coal seams northeast of Vladimir-Volyn unsuitable for use. Finding geologists conducted further to the south and southwest of Vladimir-Volyn, in the extreme south-west of Volyn region (Ivanychi and part of Vladimir-Volyn regions). The first good results given the well number 117 on the outskirts of vilaaage Buzhanka (now mine is number 4), which in October 1948 was discovered coal seam industrial power.

During the 1949-1950 were defined five fields for future mines. In subsequent years, geologists have completed reconnaissance of mine fields and found that total coal reserves Lviv-Volyn basin should reach 1.75 billion tons, of which about 23% in the territory of Volyn.

Within the Lviv-Volyn basin coal deposits found 4: Novovolinske, Zabuzke, Mezhyrichensky and Sokal. For the most part coal seams simple structure, but there are complex layers of two or three packs. Coal at depths of 315 to 535, almost as in the Donbass. The depth of coal increased in the south. According strike power changes sharply from 2.4 to 1 m, then less.

Coal in basin is basically of marks G and D. Novovolynsk coal deposits less metamorphosed. Scientist V. Ershov believes that within the Lviv-Volyn basin coal metamorphism on the rise due to the increased capacity of coal-bearing strata zone, i.e. a pattern as in the Donetsk Basin. Coal in basin is of good quality. It contains: 10-12% moisture, 29-45% in volatile combustible mass, 1.5-3.5% total sulfur. The calorific value of coal - 7700-8300 kcal/kg. Coal of Lviv-Volyn coal basin is used as energy fuel, but it is possible that coal western part of the basin can be used for carbonization.

Since July 1947 for 4 km from the city Vladimir-Volyn were found industrial coal seams. «This document was signed by head of trust «Lvivheolohorzvidka» by Vakurov. After a few days in the collections of regional radio was found tape recording, which reported that through perseverance of V. Shpakova in 1948 on 117 wells were found deposits of coal. And there was a question: «which of these documents you believe? » The best explain the matter in people who at the time worked: chief engineer «Volyneholohorz-

vidky» M. Struyeva and chief engineer Vladimir-Volyn exploration V. Shpatkova.

At the end of 1948 in Lutsk came first secretary of the country Khrushchev. He was instructed to report that industrial seams are found, and the message in 1947 was wrong. During this time, invested heavily, began to deliver mine building equipment, and coal was never found.

Soon appeared respectable commission. The fate of the Volyn basin was decided. It worked briefly, but quickly came to the conclusion that there are no seams of coal in Volyn.

The construction of the first stage of the industrial-cultural and welfare facilities, the Government has allocated 6.6 billion rubles, including 3,2 billion - in mine construction, 2 billion - surveillance for auxiliary enterprises, 1,4 billion - in housing and municipal construction.

Construction work unfolded, starting from 1950 in July this year on the outskirts of the village Dorogynychi laid the first Volyn mine capacity of 1000 tons of coal per day.

3. The volume of coal production and its reserves

Coal plays a leading role in global economic development, reducing poverty and providing basic needs of humanity as a solid fuel. Currently, the use of coal produced 29.6% of primary energy and 41% of electricity in the world [6, 10].

It is important to note that this coal will remain a major source of energy in all parts of the world, and this makes it necessary to maximize its usefulness to society while minimizing associated with its use of negative consequences. The coal industry, like any other extractive sector of the economy, affects the formation of the value of industrial production in the entire chain of creation - of transportation to the final implementation, therefore plays a significant role in shaping the competitive price advantages of products of national production in foreign markets.

In Ukraine, coal is the main energy source and plays a crucial role in ensuring the needs of metallurgical and chemical industries. However, the gradual exhaustion of coal deposits and the constant dete-

rioration of mining and geological conditions lead to increased costs of coal production and coal quality deterioration.

Coal reserves in Ukraine are concentrated mainly in three basins: Donetsk, Lviv-Volyn and Dnieper. In total coal reserves in Ukraine (117,1 billion tons) the high proportion belongs to the Donetsk basin - 87,0% (101,9 billion tons), Lviv-Volyn and Dnieper - respectively 2,0% (2,3 billion tons) and 3,5% (4.1 billion tons).

Lviv-Volyn coal basin located in Lviv and Volyn regions of Ukraine. It stretches from the north (from the city Ustilug in Volyn region) to the south (near to the city Velyki Mosty in Lviv region) at 125 km and from west to east at 60 km. The total basin area of about 10,000 square km. Total geological reserves of coal basin are estimated at 1.65 billion tons, including reserves of category A+B+C1 0,7 billion tons.

Terms of development Lviv-Volyn and Dnieper basin coal seams are more favorable. Maximum depth of mining in Lviv-Volyn basin is 550 m and capacity of coal seams - from 1 to 1,5 m. The risk of sudden coal and gas is almost absent. However, the ash content of coal produced (47,6%) is significantly higher than in the Donbass (36,2%) and also coal reserves are very limited (2,0% of total coal reserves of Ukraine).

Coal is humus: moisture content of 0,5-6%, ash 5-23% (preferably 7-12%), total sulfur 0,5-5,0%, calorific value of 32,6 - 35,3 MJ/kg (7800-8430 kcal/kg).

The amount of coal in the Lviv-Volyn basin is about 14 million tons per year. Some coal enriched and delivered to located in western Ukraine Burshtyn and Dobrotvorsku power plants. In areas created new coal mining town and village workers - Chervonograd, Novovolynsk, Sosnivka, Zhovtneve, Girnik and others [4].

Given the conditions of occurrence and characteristics of coal seams of the Lviv-Volyn coal basin, with modern logistics mining basin, significant reserves of coal are off-balance sheet, that is not economically feasible to develop in today's time.

Table 1 - Coal reserves of Lviv-Volyn basin against the background of total coal reserves Ukraine

Indexes	Lviv-Volyn basin	Common indicators for Ukraine	Percentage of the total, %
1	2	3	4
Industrial reserves of coal Cat. A + B + C1 billion tons	1,2	45,7	2,63
Developed and prepared for development of reserves, billion tons	0,7	23,3	3
The average power developed layers, m	1,24	1,18	-
Maximum depth development, m	550	1400	-
The minimum depth development, m	345	24	-
The average depth of the development, m	456	651	-
Production capacity, million tons	4,0	115,1	3,48
Coal mining, million tons	3,6	75,9	4,74
Ash content of coal mined%	47,6	36,0	-

Therefore, finding promising methods of coal development is very important in terms of future energy independence of Western Ukraine.

4. Review of possible technologies for the development of coal seams in the western region of Ukraine

4.1. Coal mining with harvesting combines

Mining harvesting combines - combined mining machine that simultaneously performs fracture reservoir minerals and reflected load mass on the conveyor.

Modern mining harvesting combines divided into:

- wide-hanging (working body width 1,0-1,8 m);
- narrow-hanging (working body width 1.0 m);
- flank;
- frontal;
- with unilateral and bilateral shuttle work scheme;

- with rope and chain system moving;
- with chainless system moving;
- with movement on the bottom of the formation;
- combine that works with a conveyor frame;
- with a drum, a disk, a corrugated, a drill, a screw conveyor and a combined working body.

Mainly used for removing harvesters on flat and inclined seams. This process involves the destruction of the reservoir and loading coal on the conveyor belt or metal sheets. There are wide-hanging and narrow-hanging removal. In the first case the width shattered and remove the strip more than 1 m. Between the processor and conveyor put two or three rows stands, so taking out a new band conveyor must first dismantle and then after the descent harvester mounted closer to the mining face. With narrow-hanging mining, the band-width is up to 1 m, so the conveyor can be moved to the mining face without dismantling. A type of narrow-hanging extraction is a plough system, in which the width of the capture does not exceed 0.2 m.

There are several schemes of the mutual arrangement of the combine and the blade conveyor relative to the mining face. The most common scheme, when the combine works from the conveyor frame located on the first track. Under this scheme works most narrow-hanging harvesters. In this case, provided good conditions for loading coal, it becomes possible to reduce the width of the bottomhole space. Quite often in the lower and upper parts of the longwall should be placed actuating heads and conveyor. In this case harvester cannot remove the layer in the final part of the longwall. So at the beginning and end of the longwall to arrange arrival combine niche.

The harvester can perform removal layer by one of two schemes:

- by shuttle scheme - removing a strip layer from the bottom up, and the other - from top to bottom:
- by unilateral scheme - removing only one direction - from the bottom up with idle race (downhill) and clean longwall.

Basic requirements for combines - providing mechanized break-age of coal any strength and toughness, full load of coal on the conveyor, high performance, ensuring the release of large classes of coal, the ability to remove the entire longwall (without additional installation of niches), low power consumption. Implementation of

most of these requirements depends on the combination of geological conditions and the type of executive body combine its design.

The most widely used and received the screw drum executive bodies. On executive agencies shall also function loading coal on the conveyor. Screw body performs this function. Left of the coal is loaded with additional mechanisms in the form of blades, retaining and loading panels.

Remove the charcoal harvesters steep fall below held up the one-way scheme. To increase the pressing mining face combine to prevent knocking and mount falling chunks of coal stope provide tilt 5 ... 10 ° to the fall line. Combine suspended on two ropes that through the blocks to the crane beam-catching winch installed on the airway. One safety rope, the other - provides supply combine harvester, so there no pressure part in combine harvester and it is more easy. Not required in these circumstances conveyor.

The advantages of using combines for coal are:

- providing mechanized breakage of coal of any strength and toughness;
- providing coal release large classes;
- the possibility of removing the entire of longwall;
- high performance;
- full load of coal on the conveyor;

The disadvantage of this technology is the difficulty of extraction operation, sufficient safe working conditions and use of equipment.

As an example, it is possible to consider and compare the technology of harvesting by combine harvesters with plough systems and to compare their features and the feasibility of using them on the mines of the Lviv-Volyn Basin.

4.3. Technology of coal mining by plough systems

Plough systems - one of the areas of advanced coal technologies. Unlike combine harvesting, the principle of shearing is used instead of the cutting principle, which greatly increases the quality of coal

Plough systems – narrow-hanging combined mining machine for long mining faces and designed for mechanized shearing (cutting) with plough and load minerals through its conveyor. Used for dredging coal seams flat and steep (up to 35 degree).

In the shallow layers plough systems include the following key components: 2 drives (upper and lower), traction body (chain), the executive body (plough), conveyor, the system of hydraulic jacks movable conveyor support beams for the directional movement of the drive station and adjust the position of installation in stope, power equipment, communication, signaling and dust suppression. In the plough systems for dredging coal seams steep (more than 35 degree), unlike faces flat seams, no belt [1, 3].

Classification of plough systems

Depending on the application conditions and the nature plough systems are divided:

- in the angle of the fall - the systems of flat seams (up to 35°), steep seams and universal systems for angle of the fall from 0° to 90°;
- the principle of destruction - the static and dynamic or active systems;
- at the speed of the executive body - the low-speed (up to 15 m/min) fast (15-60 m/min) and high speed (60 m/min) installation;
- by the executive body design - simple and combined with free and compulsory incisive turning heads with slip resistance and rolling resistance.

By type and nature of applied effort plough systems divided into two groups: static and dynamic. Dynamic special device for plough systems executive body during its movement provided by shock or vibration loads. These plough systems require much less energy to specific mass destruction because they are more advanced, but more complex to manufacture and use, have low reliability. Static planes more energy-intensive, but more reliable in operation, they are released commercially.

Technology of mining

There are two options for moving plough systems using hydraulic jacks in the composition section of powered support:

1. By continuously pressing of latticed stands, which is part of a plough, to mining face.
2. The delivery of latticed stands to the amount set step movement. This option (dosed extracting) is a promising development and can be implemented only in part of mechatronic plough systems. Its advantages:

- consistency of a given size chip h throughout the length of the machine and forming longwall straight mining face shape, which is especially important at high values of resistance to cutting seams and the presence solid rock layers;

- an opportunity to regulate the value of h , depending on conditions slot;

- eliminate bending of latticed stands therefore exclude jamming plough executive body and reducing the traction effort;

- a significant increase in performance and reliability in the excavation of coal;

- possibility of extending the scope of plough systems for layers of high strength.

Loading of coal on the conveyor by using shell and bottom blade and plough through self-loading conveyor in his movement, which is made by hydraulic jacks.

Plough cutting has been used successfully in the development of soft and hard, but brittle and fractured seams from side resistance not below average.

To develop the seam capacity of 0,24...0,45 m with side rocks above average strength are used scraper-plough systems. Vehicles as scrapers are metal boxes with cutters. They are attached to a chain that moves on a longwall along the bottom in a closed path.

The benefits of plough technology are:

- the constancy of the given size of the chip h throughout the machine length of the longwall;

- forming a rectilinear shape of mining face;

- raising performance and reliability in the excavation of coal;

- possibility of expansion of the scope of plough systems for layers of high strength.

The main disadvantage of coal seam development by plough technology is quite specific conditions and the feasibility of its application.

4.2. The development of deposits with a partial or complete change in the aggregate state of minerals

In recent years increasingly used underground mining with partial or complete change of the physical state of minerals using boreholes

(underground sublimation, dissolution underground, underground leaching, erosion, etc.). These methods are essentially combine the actual mining and mineral processing [1-3].

The main condition for the application of geotechnical methods is a real possibility and economic feasibility of transferring minerals under the influence of agents operating in the moving state. In addition, you must enable filing working agents to the surface interaction and minerals through drainage wells to the surface.

Due to the fact that coal is widely used in various industries and is a strategic raw material, the question of its production more feasible and environmentally acceptable method for efficient extraction of minerals without loss and preserving the inviolability of the crust.

These methods of coal mining in Ukraine, the use of which is growing, include a method of underground gasification.

This method is one of the more promising because coal is not required to produce under the ground, and raise it to the surface. However, this technology is not cheap. For example, electricity is produced from this coal is 10-20% more expensive than usual. However, the economic feasibility of gasification is still there, experts say, because this technology will have a few years to reduce the domestic demand for natural gas by 10%, while the increase in coal consumption by 10 million tons [11, 13, 16].

Underground gasification process involves burning carbonaceous rocks in the roof of seams and soles developed and unaccounted for in the balance sheet stocks rocks containing coal, the burning of which is further from the depths of producing energy.

The method of underground coal gasification (UCG) is the process of converting coal in place of its occurrence in the fuel gas.

UCG main stages:

- drilling wells in the ground coal seam;
- channels connecting this wells by channels;
- injection air in some wells or steam blowing oxygen;
- get gas from other wells.

Gas saturation occurs in the channel due to the chemical interaction of free and bound carbon and oxygen from thermal decomposition of coal.

Exit composition and calorific value gas obtained depends on the composition pumping element fed in wells of coal and its composi-

tion, geological conditions of occurrence of coal seams, its thickness and structure. Established that the calorific value of the gas in the air injection does not exceed $4,4 \text{ MJ/m}^3$.

In underground coal gasification process the main parameter is intensity of gasification process. It depends on several factors, most of which are determined empirically.

It is known that coal consists of organic combustible mass, mineral non-combustible mass and moisture. Characteristics of coal depend on the initial material that served for its formation, the conditions of accumulation, the chemistry of the environment of the formation of coal and the degree of metamorphism. The burning mass consists of carbon, hydrogen, sulfur, nitrogen and oxygen. Non-combustible mass - from ash, which includes silica, aluminum oxides, iron, calcium, magnesium.

The term «underground coal gasification» is meant the process of obtaining combustible gas from coal, and the term «underground gasifier» is part of a coal seam where gasification is carried out. The most important elements of the underground gas generator are the gasification channels formed along the stretch or fall of the formation. They interact with the oxygen supplied to the channels, with a solid phase (with coal and various chemical elements of the surrounding rocks). By entering the gas supply channel, oxygen is rapidly heated. Moving further, he reacts with carbon-carbon, forming oxide and carbon dioxide. The formed carbon dioxide, as well as the water vapor coming from the coal seam and the surrounding rocks, move further along the coal channel, washed off its heated surface and recovered by carbon. With further movement along the channel combustible gases heat the coal, resulting in a thermal decomposition of its combustible mass with the release of volatile particles that enter the gas stream. Further, this mixture of gases, which has a sufficiently high temperature, washes the rest of the channel surface, drying the coal. Thus, the process of gas formation in the gasification can be divided into four zones - oxidation (or combustion), recovery, thermal decomposition of coal, drying [18, 19, 22].

At the end of the combustion zone, the highest temperature is set, as most of the reactions occur here with the release of heat. In the recovery zone, all reactions occur with the absorption of heat, therefore the temperature in the channel drops sharply. At the exit of the

channel, the temperature varies greatly depending on its length and degree of filling of the fused space, but usually it does not occur below 100...150 °C. Simultaneously with the formation of gas in the channel, complex processes take place also in the surrounding coal massif. In parts of the coal massif, where the coal is heated to 900-1100°C, the combustible mass decomposes with the release of gas, which has a warmth of 4-4,5 thousand kcal/m³, and the formation of a solid residue - carbon. In the range of temperatures 700-800 °C there is an average temperature decomposition or medium-temperature carbonization, in which the gas is released with a heat of combustion of 5-6 thousands kcal/m³. At a temperature of 550-600 °C, the low-temperature decomposition of combustible mass of coal (or semi-carbonization) occurs with the formation of gases with a heat of combustion of 6-8 thousand kcal/m³ and solid residue - semi-carbon. As the gasification channels expand, the rocks that lie on the formation collapse, filling the fused space and reducing the free section of the channel. The collapse and melting of the rocks in the roof never lead to a complete blockage of the channel and the supplied blast has access to the reaction surface of it at any location of the channel in the plane of the formation [23].

In fig. 1 shows a change in gas composition along a horizontal channel of 100 m in length. Experiments were carried out on air blowing with the production of energy gas. As can be seen from Fig. 1, the energy gas of underground gasification contains combustible components - hydrogen, carbon dioxide and volatile products conventionally taken for methane.

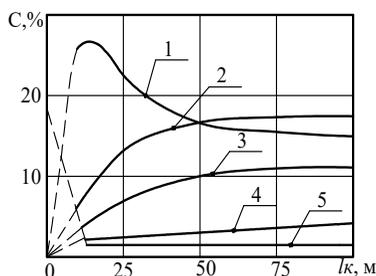


Fig. 1. Chart of the content change C: carbon (1), carbon monoxide (2), carbon dioxide (3), methane (4), carbon (5), along the length of l_k channel

In addition, it contains, in small amounts, hydrogen sulfide and non-limiting hydrocarbons. Non-combustible gases are represented by oxygen (up to 0.2%), carbon dioxide (up to 20-22%) and nitrogen. The concentration of the latter is particularly significant in the process of air-blowing and sharply reduced by enrichment of blast oxygen.

The process of underground coal gasification can be divided into three components: the reaction of the solid phase (carbon) with gaseous (oxygen, water vapor), the interaction of various components of gas in the gas environment, the thermal processing of combustible mass with the release of volatile substances.

On the nature and progress of the technological process of underground gasification is influenced by many factors that determine its two main aspects: the actual chemical process of gas formation and the hydrodynamic nature of the interaction of the blast with the reacting surface of the fuel. Of these, the most important are the intensity of blasting and concentration in it of oxygen, temperature in the channel of gasification, chemical composition of fuel, conditions of occurrence of layers, flood deposition of the deposit.

One of the necessary conditions for increasing the intensity of underground gasification process is to support high temperatures, which accelerates the rate of chemical interaction between the reactants (trapping the total gas production in the diffusion process area).

The intensity of blasting greatly influences the increase of diffusion velocity and helps to keep the total process in the diffusion region. However, experiments show that after a certain limit, further intensification of blasting leads to a deterioration in the quality of gas (the concentration of CO₂ and undisturbed vapor increases). This indicates the transition of the process from the diffusion region to the kinetic (more carbon dioxide and vapor is brought to the reaction surface), that is, each underground gas generator has its optimum intensity.

One of the easiest ways to raise the temperature in the gas supply channel, and, consequently, improving the quality of gas is to increase the concentration of oxygen in the oven. Underground gasification of coal in air blowing has the drawback that underground gas generators feed 79% of the ballast in the form of nitrogen, which has to be heated together with oxygen, then removed from the under-

ground gas generator along with the combustible components and sent to consumers. The transition to blast furnished with oxygen (steam-oxygen) is one way to significantly increase the heat of combustion of gas and the efficiency of the process, which can lead to a significant improvement in technical and economic performance.

An increase in pressure in an underground gas generator leads to an improvement in the quality of gas and a decrease in its humidity. This is due to the spin of water from the gas supply channel, as well as to the fact that the pressure is a function of the intensity of the flow of blast.

Increasing the ash content of coal causes a significant decrease in the heat of combustion of gas, lowering the quality of gas and reducing the output of gas from 1 kg of coal. There is also an optimum of moisture. When increasing the humidity of coal and surrounding rocks, as well as increasing the flow of water into the gasification channel, the content of combustible components in it decreases.

The capacity of the coal seam significantly affects the results of underground gasification. With its increase, the heat loss in the surrounding mountain range decreases.

With constant blasting and unchanged degree of coal gasification, increasing the length of the gasification channel leads to a decrease in the quality of gas. For example, at one of the underground gas generators near the Moscow station "Podzemgaz" with an increase in the distance from the well blast from 25 to 50 and 75 m, the lower value of the heat of combustion of gas decreased from 1025 to 870 and 750 kcal/m³, respectively. This reduction in the quality of gas is associated with a conversion reaction, which can be reduced by intensifying the process, increasing the amount of blasting or increasing the concentration of oxygen.

To ensure the satisfactory flow of the gasification process, it is necessary to arrange the channels in the coal seam. The process of burning in the coal seam of the channel by the combustion center moving toward the flow of blast or in the direction is called filtration failure of wells. In the first case, falsehood is called countercurrent, in the second one it is straight-line. An abrasive filtration malfunction is carried out as follows: a number of wells are drilled and cemented, only the lower part remains unplanned; further the annular space is tamped; then begin to squeeze out the moisture from the

formation. For this purpose, blasting in two, three or in all wells (depending on the presence of blast and the accepted order of fault). After pre-drying, the blasting is stopped in one of the wells (sparking), connected to the atmosphere and illuminates the coal seam. The development of combustion is provided by comparatively short-time blasting in a combustion well and its periodic discharge (combustion products are emitted into the atmosphere). As soon as stable coal combustion is achieved, gas is discharged from the incinerating well during the entire period of failure. Further combustion of coal is supported by oxygen blast that is injected into adjacent wells and burning, which is filtered towards the hearth. The final stage of failure for all coal is characterized by a sharp drop in pressure, rapid discharge of gases and an increase in their quality. Since then, the channel is considered ready for the gasification process. Filtration failure on new sites can be carried out in one, two, three or four directions simultaneously. In the presence of a fused space close to the borehole, it leads directly to it and the gases fuse are mixed with gasification. The rate of killing and the specific consumption of blasting influence the ash content of coal, its porosity and permeability, the nature of the soles and the roof of the formation, the intensity of blasting, the thickness of the formation and its watering, the distance between the wells, the composition of blasting. The filtration fault from the bore hole, located between the collapsing and gas-fired wells, is designed to inflate the blast for gasification, more advantageous than that of the gas-fired [1-3].

Thus, underground coal gasification is one of the most promising methods for obtaining energy from coal at the site of its occurrence, namely, its conversion into high-calorific gases, which are more calorie values than coal. The shortcomings of the UCG should include a relatively low degree of study and a significant cost of building a full-fledged production, and the benefits of the possibility, in the long run, to reduce the internal use of expensive natural gas, and the possibility of processing off-balance coal reserves. However, all this requires further research on state or regional support, since the experience of the experienced researchers is not sufficient for the wider application of UCG on an industrial scale.

Conclusions. Given the situation in the country, the development of coal seams in the Lviv-Volyn coal basin is the most promising.

Although coal reserves are not significant, compared to Donetsk or Dnipropetrovsk coal basins, however, they are able to meet the needs of consumers.

One of the most promising ways is the introduction and development of mining coal seams with the help of plough systems and more reliable maintenance and operation, and higher quality of coal produced by using the principle of shredding.

However, further scientific research on state or regional support may also have a real application of UCG within the West region on an industrial scale.

Consequently, the introduction of new technologies at the mines of the Lviv-Volyn coal basin will contribute to increased productivity, volumes of production, improvement of conditions and safety of work [1].

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THE PERSPECTIVE TECHNOLOGIES FOR THE PROCESSING OF FOSSIL FUELS

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Abstract

In the monograph chapter we will consider the scientific research on the creation of energy and resource-saving technologies for the processing of petroleum raw materials and coal. In the chapter there are presented two new promising technologies that were created and constantly are developing in East Ukrainian National University named V. Dahl. These technologies are known under the names: Aerosol nanocatalysis (AnC) and processing in a liquid high-temperature heat-carrier (LHC). The basis of AnC technology is the use of mechanical and chemical activation of catalyst particles in situ. It was noted that the catalyst concentration under AnC conditions is 1-5 g/m³ of the reactor. This will ensure that in industry the rate of chemical reaction is 10⁶ times less than the rate in processes using a heterogeneous catalyst on a carrier. LHC technology intensifies heat and mass transfer, which allows high-energy chemical reactions with improved technical and economic indicators.

Introduction

The development and competitiveness of Ukraine's fuel and energy and chemical industry shows widespread industrial use of domestic coal. Coal is the raw material for most chemical syntheses. It is believed that its reserves in the country are more than 400 years old. However, in complex coal processing there are a number of problems. One of these problems is the low efficiency of existing industrial and advanced coal conversion technologies. They are not competitors with synthesis gas technology by conversion of natural gas at the current price level. In the proposed technology of coal conversion to synthesis gas, high requirements are imposed on the quality of coal, oxygen and water vapor are used.

Most technologies are characterized by a low degree of decomposition of water vapor, raw material losses and a high content of carbon dioxide. Losses of raw materials are associated with the loss of coal from the reaction zone. In addition, a significant part of domestic coal is distinguished by high ash content, low caloric content and sulfur content. About 30% of the explored coal reserves are classified as "salty coals." They do not find industrial applications due to metal corrosion, slagging of boiler surfaces and emissions of acid gases requiring acidification.

To increase the efficiency of coal conversion technology in synthesis gas, it is proposed to realize the process by perspective technology. Such as aerosol nanocatalysis technology and technology in the melt of liquid high-temperature heat carrier.

The process of steam reforming of coal to produce synthesis gas in a catalyst aerosol was investigated.

The development of technologies for processing heavy oil fractions is one of the urgent tasks of science and industry. A positive solution to this issue will reduce the cost of production. For domestic refineries this will help to increase competitiveness in the world market. Currently, companies are usually focused on the purchase of imported catalytic processes for the processing of petroleum products or recycle oil residues by coking.

The processes of cracking hydrocarbon fractions of oil using aerosol nanocatalysis technology were considered.

A. THE NEW TECHNOLOGY OF APPLICATION PARTICLES OF CATALYST IN AEROSOL

The AnC technology is based on mechanochemical effects, which appear under constant mechanical action on a catalytically active substance. The catalytic system in the AnC technology consists of dispersing material and catalyst particles. It is known that in the process of continuous motion, the dispersing material undergoes constant impacts and abrasion. As a result, this leads to the following actions: mechanochemical activation of the catalyst; grinding to nanosize; changes in the thermodynamic potentials of substances; the appearance of surface defects.

In the theory and practice of AnC technology, an important factor is the theory of collisions, especially the moment of impact. It promotes the formation of nanoparticles. The characteristic features of nanoparticles is a reduction in the size of a solid to 100 nm or less. In this case, the phenomena of quantum-size effects, such as changes in the atomic-crystal structure and various physicochemical properties of the dispersed phase, are known.

The use of one catalytically active substance of aerosol allows to intensify chemical reactions. The mechanical action contributes to the support of the active state of the catalyst, which increases the reaction rate. It is noted that under mechanical action, the catalyst particles are destroyed in a collision with a solid surface. This phenomenon is called the free impact factor. Under its influence, the catalyst particles also decrease to the size of the aerosol in the reaction volume, that is, nanosize. The numerous studies have noted that the state of catalyst aerosol and the constant mechanical action also contribute to a decrease in deactivation of the catalyst.

The creation of structural defects and the active state of the particle surface affect the increase in reactivity.

It is known that shock mechanical actions and friction lead to the following:

- change in the thermodynamic potentials of substances;
- creation of surface structure defects;
- changes in the properties of the ground material.

As a result, it was found that in the reactor of aerosol nanocatalysis with continuous influence of mechanochemical activation of the catalyst chemical transformation of substances takes place.

The basic principles of aerosol nanocatalysis technology include the following:

a - refusal of the carrier. The catalytically active substance is used in the form of an aerosol and is not applied to a porous carrier.

b - application of mechanochemical activation of the catalytic system. This allows the dispersing material to also crush the catalyst particles.

It is noted that the mechanochemical interaction of the catalytic system significantly reduces the deactivation of the catalyst. Therefore, it is not necessary to frequently regenerate the catalyst.

The technology of aerosol nanocatalysis has been constantly researched and developed for more than 20 years. During this period, it was implemented in some types of reactors.

The first studies were carried out in a fluidized bed reactor. The technology was known as AnCFB – Aerosol nanoCatalysis with Fluidized Bed. At the same time, the mechanochemical interaction was effected by the fluidization effect. However, the study observed significant reagent costs and the need to support certain gas-dynamic regimes.

The next stage in the development of aerosol nanocatalysis technology was the use of a vibrating (vibro-impact) layer. The technology was called AnCVB - Aerosol nanoCatalysis with Vibrating Bed. It was noted in the reactor that the mechanochemical activation of the catalyst is due to reciprocating motions in the vertical state. It is noted that the productivity of the AnCVB reactor was higher than that of the AnCFB reactor. AnCVB reactor allows to control the kinetics of chemical processes. However, there are difficulties in scaling the reactor.

A new stage in the development of aerosol nanocatalysis technology was the use of a rotating reactor. The principle of its operation can be considered used in the industry ball mills. From the engineering point of view, they are simple and energy efficient machines. At this stage, the technology is called AnCRB – Aerosol Nanocatalysis in a Rotating Bed.

The rotating bed installation using the aerosol nanocatalysis technology is a new multifunctional development that can be applied in different fields of the gas and petrochemical industry.

A special principle of the aerosol nanocatalysis reactors is the unification of the grinding process and the chemical reaction.

The most common are grinding machines, which are used to produce a substance in a fine-dispersed state.

The process of steam conversion of coal in a reactor with a rotating bed using aerosol nanocatalysis technology

We will consider the research of the process of catalytic conversion of Ukrainian coal. The process was studied in a laboratory installation with a rotating bed of a catalytic system using aerosol nanocatalysis technology. A feature of the technology is a new way of using the catalyst. This method allows maintaining a constant concentration of the catalyst and its activity, reduces the concentration of the catalyst in the reactor.

The aerosol nanocatalysis technology has proved itself in chemical transformations of organic compounds, they are in the liquid and gaseous state. At this stage, we consider the field of research where the starting reagent is a solid. The process of steam coal conversion is one of the objects of research of this field. The studies use a solid feedstock and the process is carried out on a solid catalyst. This will expand knowledge in the field of solid-phase heterogeneous reactions. As a result, the aerosol nanocatalysis technology can be considered universal for chemical transformations.

At the end of the twentieth century, it was noted that an increase in energy consumption, the depletion of available deposits, the complexity of oil and gas production leads to an increase in the cost of raw materials. Therefore, the process of conversion of solid fossil fuels attracted the attention of science and industry. The use of artificial gases was considered to solve energy and raw materials problems.

This has served as the beginning for many companies of developing their own coal conversion technologies or improving existing technologies. In the world it is known that about 600 small coal conversion plants are operate.

In the industry, there are several technologies for obtaining synthesis gas. The most common are: steam methane conversion, partial

oxidation of methane, plasma gasification of waste and raw materials, gasification of coal. Everyone knows that the synthesis gas consists of a mixture of CO and H₂, is a multiprofile substance. This gas can be used as a raw material for most chemical reactions.

Synthesis gas is the main product for the following industries: ammonia from the nitrogen-hydrogen mixture, hydrocarbons, methanol, ethers and other products. The production of many products requires a certain ratio of H₂:CO. It is noted that from the synthesis gas it is possible to obtain compounds of different structure, depending on the process conditions. Carbon dioxide is constantly present in reaction products. It is separated and used as raw material for some syntheses.

The raw material for synthesis gas production can be any carbon-containing compound. The most common are methane or natural gas, liquid fractions of oil and coal. It is known that the main reaction of steam conversion of hydrocarbons takes place on a Ni/Al₂O₃ catalyst. The reaction is highly exothermic and the equilibrium shifts toward the reaction products with increasing temperature. Therefore, the process is carried out at 1073-1173 K and an excess of water vapor. At the same time, an exothermic reaction of carbon monoxide conversion takes place in parallel, which, with increasing temperature, shifts the equilibrium to the initial reagents, and the excess of water vapor increases CO₂ in reaction products.

At the refinery, hydrogen is a necessary source. It is obtained by separating the hydrogen per hydrocarbon fraction that is obtained after the reforming process. In the case of a lack of hydrogen, methane vapor conversion is additionally created by this method.

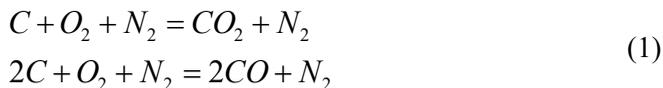
The transformation of coal into a mixture of gases is referred to the process of gasification of coal. Natural solid fuels differ in many ways, such as origin, composition, surface, dry coal mass structure, pore distribution, composition and catalytic properties of metal compounds and ash content. The speed of the conversion process is also determined by the following properties, such as temperature; pressure; heat and mass transfer processes that occur on the surface of solid fuel; diffusion factors.

The conversion process uses air, oxygen, water vapor, carbon dioxide and hydrogen, as well as mixtures of these compounds as gasifying agents. As a result, the following products are obtained: car-

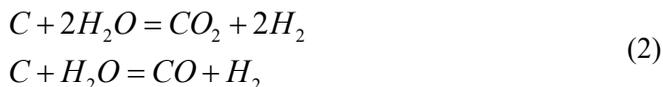
bon monoxide and carbon dioxide, hydrogen, a small amount of methane, steam and nitrogen (air gasification process).

The most well-known industrial processes developed for conversion of coal are the following

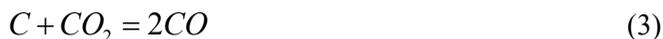
1. air conversion:



2. Steam conversion:



3. Carbon dioxide conversion:



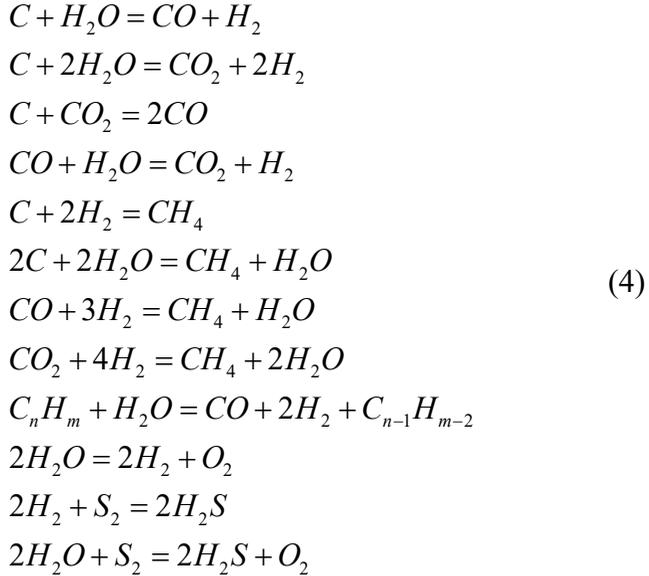
It is known that the important parameter of the synthesis gas production process is the CO: H₂ ratio. Most often, the industry uses the ratio of CO: H₂ from 1:1 to 1:3. This depends on the need to obtain a specific reaction products.

The most common way of obtaining synthesis gas is steam methane conversion. The process proceeds at 1073-1173 K and a pressure of 2-2.5 atm. The methane conversion process takes place in a reforming furnace on a Ni/Al₂O₃ catalyst, sometimes a Fe₃O₄/Cr₂O₃ catalyst is used. Note that an important factor here is the highly developed surface of the carrier. In spite of the peculiarity and wide application of this process, it has some drawbacks. These include:

- temperature difference across the height and intersection of the catalyst bed in the reforming furnace;
- the difference in the resistance of the catalyst bed in the different tubes of the furnace;
- destruction of the catalyst due to insufficient strength of the carriers.

The use of coal as a raw material for chemical and energy processes can lead to the development of the country's industry. Coal is one of the most widespread fossil resources of the country. Therefore, the creation of a coal processing plant in a product that is necessary for the chemical industry is one of the promising solutions.

The following main reactions are attributed to the chemical characterization of the conversion process of coal



It is also known that under the conditions of catalytic conversion, many reactions occur simultaneously.

Some reactions lead to the production of target products, and their small number.

Other reactions that lead to the creation of unwanted products, but more of them.

This process largely depends on the chemical composition of coal and the reaction temperature.

In Fig. 1 we presented a schematic diagram of a laboratory setup for studying the process of steam conversion of coal.

Water (stream A) is fed into the reactor (4) with a syringe dispenser (1).

The reactor is a cylindrical rotating apparatus, a catalytic system and a solid reactant are charged therein.

At the outlet of the reactor is a metal-fiber filter, which prevents the catalyst particles from carrying away from the reactor, and serves as a side wall for containing the dispersing material in the reactor.

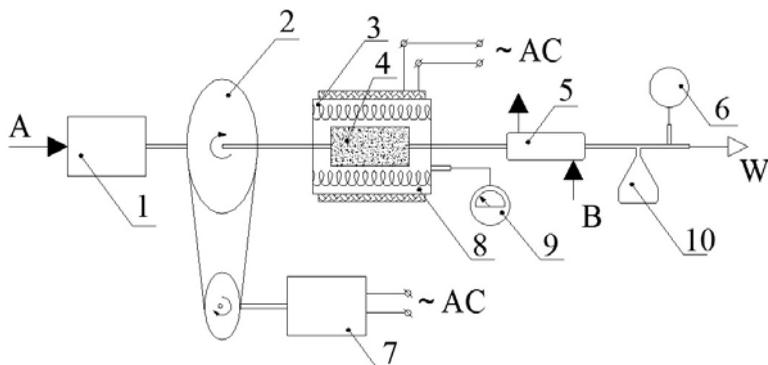


Fig. 1. Schematic diagram of the laboratory installation: 1 - feeder; 2 - transmission mechanism; 3 - the furnace; 4 - reactor; 6 - analytical control unit; 7 - the electric motor; 8 - heat insulation; 9 - thermocouple; 10 - condensate capacity. Flows: A - water (raw materials); W- gases of conversion

Heating is carried out by means of an electric heating coil (8). The reaction chamber is rotated by means of an electric motor (7) and a transmission mechanism (2).

The transmission mechanism is a device with a belt transmission.

The change in voltage makes it possible to regulate the rotational speed of the reactor and the temperature in the reactor. The reactor is located inside the heating furnace (3), in which the temperature is measured by a thermocouple.

To minimize heat loss to the environment, a layer of heat-insulating material is placed on top of the furnace.

The reaction effluent stream exits the heat exchanger (5), where the gaseous products are cooled (stream B). After the heat exchanger there is a condensate collection tank (10), a sampling point for analysis is also provided on this line (6).

The flow diagram of the catalytic system inside the reactor is best shown in Fig. 2.

Analytical control is conducted to determine the chemical composition of the reaction products obtained.

The received data are evaluated, analyzed and systematized. Based on the information received, it is possible to correct the experimental procedure.

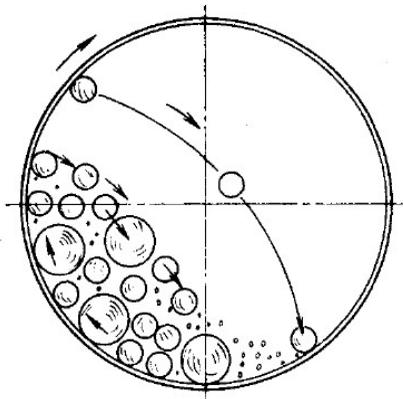


Fig. 2. Section of a reverse reaction chamber filled with a catalytic system consisting of a dispersing material (balls) and catalyst particles (points)

When setting the experiment, it must be taken into account that at the reaction temperature the chemical reaction passes between the steam and the coal. Also this process occurs on dust-like catalyst particles and also the process depends on the contact surface of the phases, the amount of water and temperature.

It is noted that during the conversion, two reactions can be observed, such as the interaction of water vapor with coal and with gas-like hydrocarbons, which are quickly obtained from coal. When using finely dispersed coal (less than 1.2-0.5 mm), the conversion of gases and carbon can take place practically simultaneously.

In the experiments, we studied coal from the town of Lisichansk. The composition of the coal was the following, % mass: C is 86; H is 4.5; N is 1.5; O is 3.1; S is 3.2; impurity is 1,7.

Preliminary, a prepared catalyst system and a certain mass of coal are loaded into the reactor. The preparation of the catalytic system is carried out according to the developed technique for the technology of aerosol nanocatalysis. The volume of the reactor was 90 ml. On the inner walls of the reactor are 3 blades. We investigated the crushed coal fraction with particles of 1,2-0,31 mm. For experiments, we loaded into the reactor coal with a mass of 19 g and 1 g. The density of the dust fraction of coal is 633 kg/m^3 .

The catalytic system consisted of a dispersing material (glass balls 0,8-1,2 mm in diameter) and a Cr_2O_3 catalyst. The initial parti-

cle size of the catalyst particles is about 200 μm . Under the mechanical action of the dispersing material, the catalyst particles are crushed to a size of 8-100 nm. This system occupies 30% of the volume of the reactor (in experiments with a mass of coal of 19 g) and 50% (in experiments with a mass of coal 1 g).

The process of coal conversion was carried out in two ways: without rotating the reactor and at a rotation speed of 1 to 7 Hz. It is noted that the rotation of the reactor ensures the creation and constant activation of the aerosol catalyst particles. The temperature of the process varied from 823 to 1023 K.

It is known that air for steam conversion of coal is an undesirable component. Therefore, before the experiment, the reactor is purged with nitrogen.

A feed rate for each experiment was set at a flow rate of 3.43 ml/min and 1.15 ml/min (0.2058 and 0.069 l/h, respectively).

Conversion gases were cooled in a refrigerator. Condensate was collected in a collection of condensate. It is known that conversion gases include water formed in the process and unreacted water. In practice, it was noted that it is very difficult to completely isolate water vapor from conversion gases, therefore, steam could partially be present in the analysis.

The selection of gases was further analyzed. The gas sample was taken to a sealed capacity of 20 ml.

Analytical control of the process was carried out using a gas chromatograph. Important indicators in the exhaust gases are the volume fraction of hydrogen and the volume fraction of carbon monoxide. Concentrations of organic substances (with the exception of CO and CO₂) are determined with an accuracy of more than 0.001% by volume, concentrations of H₂, CO, CO₂ – above 0.01% by vol.

In Fig. 3, the original form of the dispersing material can be observed.

Glass balls are a solid material with slight surface irregularities at the micro level. Therefore, before the experiment, they should be dusted with a catalyst under operating conditions. Dispersing material and a sample of the catalyst were loaded into a laboratory reactor. Further, the reactor rotates for a certain time at the operating temperature. Further, the catalyst system was discharged from the reactor and the non-sorbed amount of the catalyst was removed. The

process was repeated until the dispersing material reached a constant weight.

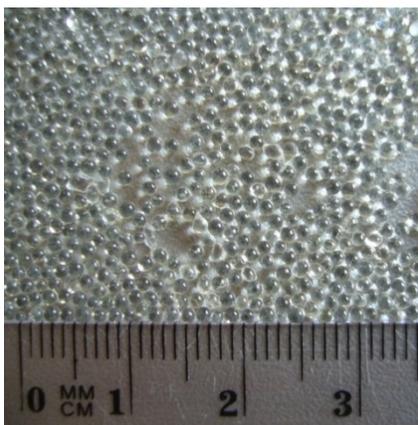


Fig. 3. General view of the dispersing material (glass beads)

Note that the process takes place on the aerosol particles of the catalyst additionally supplied to the reactor. We used in the experiment a mass of catalyst 0.001 g, which is 11.1 g/m^3 of the reaction volume.

This method of preparation of the catalytic system allows the experiment to be correctly set in the laboratory.

The research task was to obtain synthesis gas as the target product of the coal conversion process. The process had to be carried out under atmospheric pressure with high selectivity. The experiment was aimed at increasing the volume fraction of the product in the gas sample. However, it was noted chromatographically that, together with the target product ($\text{CO} + \text{H}_2$), also hydrocarbons and other substances are obtained.

According to the results obtained, it can be concluded that the composition of the conversion gases varies with different operating conditions of the aerosol nanocatalysis unit. Thus, the first task is to determine the optimum mode of operation of the aerosol nanocatalysis reactor and the range of variation by the control parameters.

It can be determined that the increase in carbon monoxide from the temperature is traditional for conversion processes. It is known that temperature is one of the factors that affect the composition of

synthesis gas. This dependence can help in determining the product and the needs of production.

In the process of research on the effect of temperature, two modes were modeled:

- with an excess of coal in the reactor ($C:H_2O = 5.5:1$). This mode leads the process to zero order by reaction and carbon (Table 1);
- with a shortage of coal to the reactor ($C:H_2O = 1:0.87$). This regime will allow studying and intensifying the process taking into account mechanochemical activation (Table 2).

The results of the studies showing the effect of temperature on the conversion process can be observed in Table 1 and Table 2.

Table 1

The composition of the conversion gases (coal mass in the reactor is 19 g, water flow is 3,43 ml/min)

Temperature, K	Composition of conversion gases,%by volume							CO:H ₂
	H ₂	CO	CO ₂	CH ₄	C ₂ H ₄	C ₂ H ₆	H ₂ S	
823	1,28	1,17	9,36	3,05	0,48	2,31	5,38	1:1,09
873	3,87	2,79	12,57	3,51	0,66	2,56	6,52	1:1,39
923	6,54	3,12	14,67	3,98	0,73	3,28	8,27	1:2,10
973	8,48	4,11	15,64	4,85	0,89	4,71	8,94	1:2,06
1023	11,73	5,74	15,58	5,22	1,97	4,98	9,79	1:2,22

If we consider Table 1 and Table 2, we see that the regime for studying the steam conversion of coal in the range from 823 to 1023 K contributes to the production of secondary products: carbon dioxide (about 9-18% by volume) and hydrogen sulfide (about 5-10% about.). It is noted that the yield of these products increases with increasing temperature.

It was determined that with increasing temperature, hydrogen productivity increased by 7 times, and hydrogen sulphide productivity was only 1.8 times (Table 1 and Table 2). From this it follows

Table 2

The composition of the conversion gases (coal mass in the reactor is 1 g, water flow is 1,15 ml/min)

Temperature, K	Composition of conversion gases,%by volume							CO:H ₂
	H ₂	CO	CO ₂	CH ₄	C ₂ H ₄	C ₂ H ₆	H ₂ S	
823	1.25	1.08	9.13	2.96	0.43	1.96	5.35	1:1.15
873	3.23	2.76	11.74	3.47	0.65	2.45	6.47	1:1.17
923	5.88	3.08	13.56	3.91	0.71	2.87	8.26	1:1.91
973	7.91	3.42	15.01	4.64	0.84	4.15	8.86	1:2.31
1023	10.67	4.28	15.07	5.10	1.95	4.94	9.71	1:2.34

that the conversion process is sensitive to the production of hydrogen in dependence on temperature.

The dependence of the composition of the conversion gases on temperature is shown in Fig. 4, Fig. 5 and Fig. 6 at varying initial parameters of the process (mass of coal, water flow).

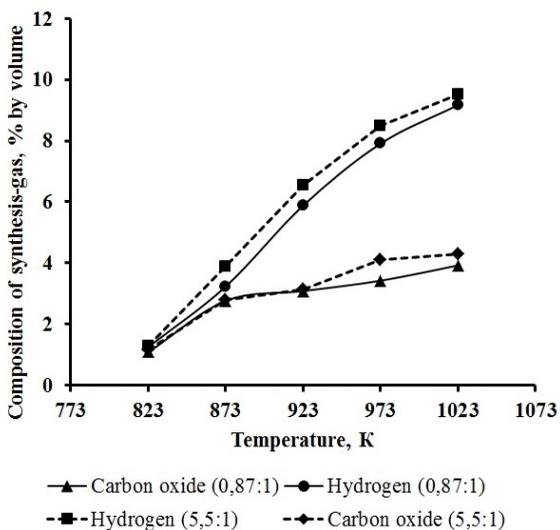


Fig. 4. Dependence of the yield of synthesis gas on temperature for various ratios (C:H₂O=0,87:1) and (C:H₂O=5,5:1)

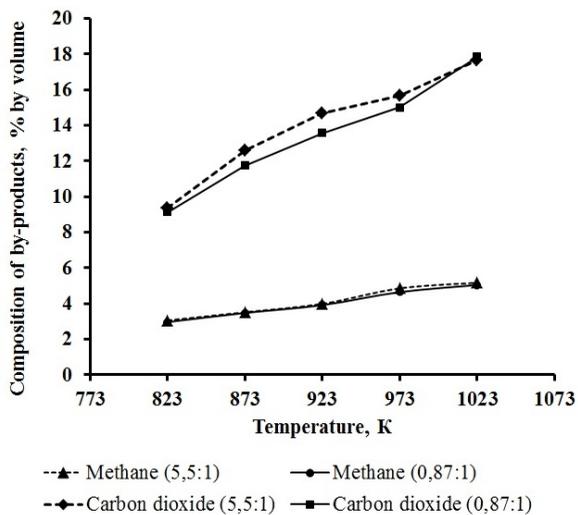


Fig. 5. Dependence of the yield of secondary products on temperature at different ratios of the initial reagent ($C:H_2O=0,87:1$) and ($C:H_2O = 5,5:1$)

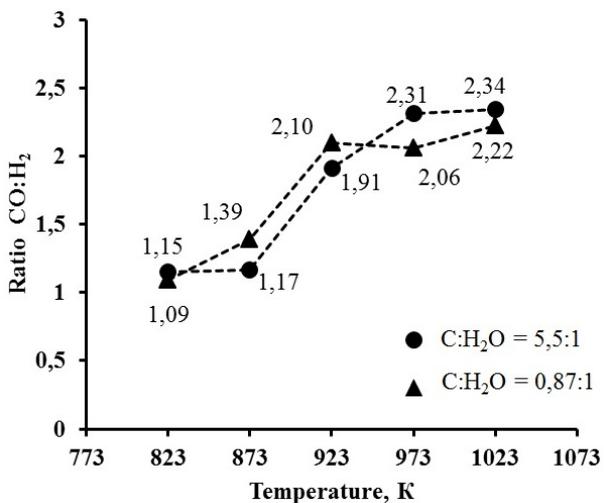


Fig. 6. Dependence of the change in the synthesis gas ($CO:H_2$) ratio on the conversion temperature

It was also noted that the yield of hydrogen increases with increasing temperature of 823-1023 K from 1,25% by volume. up to 10% by volume. (Fig. 4).

In Fig. 4 shows the influence of temperature on the yield of synthesis gas for a different ratio of the initial parameters (C:H₂O).

The second target component of the synthesis gas is carbon monoxide. At the same time, its productivity is noted to be increased 3.6 times with increasing temperature.

Some hydrocarbons in small quantities (methane, ethane, ethene) are noted as secondary products (Table 1, Table 2).

In Fig. 5 shows the effect of temperature on the yield of secondary products of the coal conversion process.

In Fig. 6 shows the dependence of the change in the ratio of synthesis gas (CO: H₂) on the temperature at various parameters of the initial reagents (coal mass and water flow).

Let us consider the process of conversion under the regime of studies with a carbon deficiency in the reactor (C:H₂O=0,87:1). At this we can observe two modes of temperature. These regimes are characterized by a practically stable ratio of synthesis gas (CO:H₂). It was noted that this ratio corresponds to 1.2 in the temperature range 823-873 K and the ratio is 2.3 in the temperature range 973-1023 K (Fig. 6).

The total yield of hydrogen H₂ and carbon monoxide CO during the conversion increases from 1,5 to 14,95% by volume in the temperature range from 823 to 1023 K.

When considering the process of conversion in excess carbon regime (C:H₂O=5,5:1), it was noted that the practically stable ratio of synthesis gas (CO:H₂) at the level of 2,1-2,2 at temperatures of 923-1023 K.

The results of the study show that the yield of synthesis gas (H₂ and CO) (Table 1, Table 2, Fig. 4) can be explained by the relatively low reaction temperature for this process. Usually the process of steam conversion of coal is carried out at temperatures of 1273-1373K. Our technology of aerosol catalysis can reduce the temperature by almost 623-723 K. This is a feature and advantage of carrying out the process of steam coal conversion under the conditions of an aerosol catalyst.

The results of studies on the effect of reactor rotation speed on the conversion process are arrived at in Table 3 and Table 4.

Table 3

The composition of the conversion gases (the ratio of the initial reagents C:H₂O=5,5:1, water flow rate 3,43 ml/min, temperature 1023 K)

Rotational speed, Hz	Composition of conversion gases,% by volume							CO:H ₂
	H ₂	CO	CO ₂	CH ₄	C ₂ H ₄	C ₂ H ₆	H ₂ S	
0	3,11	2,62	9,27	3,57	0,76	2,62	6,23	1:1,19
1	4,56	3,37	12,43	3,95	1,24	3,44	7,47	1:1,35
2	10,67	5,35	14,52	4,88	1,84	4,75	8,63	1:1,99
3	11,73	5,74	15,58	5,22	1,97	4,98	9,79	1:2,04
4	10,32	4,91	14,11	4,72	1,71	4,27	8,30	1:2,10
5	8,27	4,22	13,78	4,47	1,44	3,95	7,97	1:1,96
6	6,32	3,53	13,17	4,22	1,27	3,71	7,72	1:1,79
7	5,89	3,36	12,75	4,03	1,19	3,56	7,60	1:1,75

Table 4

The composition of the conversion gases (the ratio of the initial reagents C:H₂O = 1:0.87, water flow rate 1.15 ml / min, temperature 1023 K)

Rotational speed, Hz	Composition of conversion gases,% by volume							CO:H ₂
	H ₂	CO	CO ₂	CH ₄	C ₂ H ₄	C ₂ H ₆	H ₂ S	
0	2,91	2,24	9,09	3,34	0,72	2,54	6,12	1:1,30
1	4,22	3,01	11,61	3,82	1,02	3,19	7,28	1:1,40
2	8,94	3,72	13,45	4,51	1,78	4,35	8,37	1:2,40
3	10,67	4,28	15,07	5,10	1,95	4,94	9,71	1:2,49
4	8,60	3,65	13,02	4,49	1,58	3,98	7,86	1:2,36
5	7,03	3,34	12,71	4,31	1,34	3,66	7,75	1:2,10
6	6,10	3,08	12,42	4,06	1,23	3,47	7,51	1:1,98
7	5,38	2,87	12,07	3,91	1,08	3,39	7,44	1:1,87

Further, we consider the dependence of the composition of the conversion gases and the ratio of $\text{CO}:\text{H}_2$ on the rotational speed of the reactor. The results will also be considered under two regimes of the ratios of the initial reagents ($\text{C}:\text{H}_2\text{O}$), which are presented in Fig. 7.

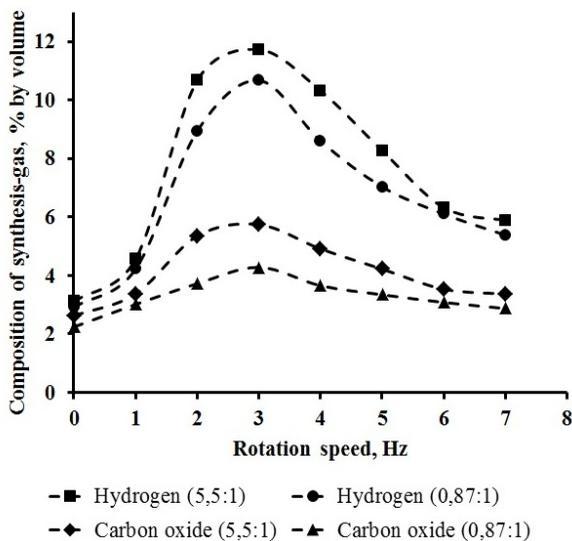


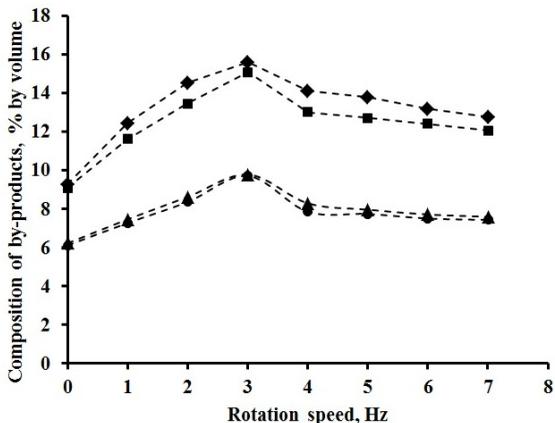
Fig. 7. Dependence of the yield of synthesis gas on the rotation speed for different ratios of the initial reagents ($\text{C}:\text{H}_2\text{O}=0,87:1$) and ($\text{C}:\text{H}_2\text{O}=5,5:1$)

It is determined that the rotation speed exhibits a special effect on the yield of synthesis gas. It was noted that at a rotation speed of 3 Hz we get the maximum amount of the target product both with excess coal and with its lack.

In Fig. 8 we can observe the influence of the reactor rotation speed on the yield of secondary products (carbon dioxide and hydrogen sulfide).

We can observe in Fig. 8, that the maximum yield of reaction products occurs at a rotational speed of 3 Hz.

In Fig. 9, the dependence of the change in the synthesis gas ratio ($\text{CO}:\text{H}_2$) on the rotation speed for different ratios of the initial reagents is considered.



-▲- Hydrogen sulfide (5,5:1) -●- Hydrogen sulfide (0,87:1)
 -◆- Carbon dioxide (5,5:1) -■- Carbon dioxide (0,87:1)

Fig. 8. Dependence of the yield of secondary products on the rotation speed for different ratios of the initial reagents ($C:H_2O=0,87:1$) and ($C:H_2O=5.5:1$)

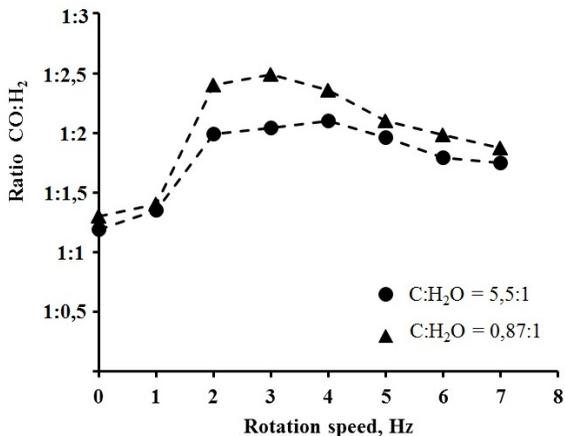


Fig. 9. Dependence of the change in the synthesis gas ($CO:H_2$) ratio on the rotation speed

It follows from the experiments that the rate of rotation of the reactor is one of the factors that affect the composition of the synthesis gas and allows its variation.

It is noted that at a rotation speed of 1 Hz we obtain the synthesis gas ratio ($CO:H_2=1:1$). Such a ratio is possible for the production of

esters. At a rotation speed of more than 5 Hz, we get the synthesis gas ratio ($\text{CO}:\text{H}_2=1:2$). A similar ratio can be used to produce alcohols. At a rotation speed of 2-4 Hz, we obtain the synthesis gas ratio ($\text{CO}:\text{H}_2=1:3$). This ratio can be used for the production of hydrocarbons. This result can be used even to produce the gasoline fraction by the Fischer-Tropsch method using the aerosol nanocatalysis technology of the vibrating bed.

An experiment conducted without rotating the reactor showed a low yield of the conversion products. This confirms that the rotation of the reactor is able to intensify the conversion process. Due to mechanical actions, the number of collisions of the catalyst with themolecules of the reagents increases. The known fact that the rotation of the reactor not only increases the efficiency of catalyst activation, but also mixes the coal dust. This allows for further grinding of the coal particles to a dust state.

From Table 3 and Table 4 it can be seen that by changing the intensity of mechanochemical activation from 1 to 7 Hz, the composition of the conversion gases can be controlled. It is noted that the yield of the conversion products increases with the growth rate of the reactor to 3 Hz, a further increase gives a decrease in the yield of the products. This fact can be explained as follows. With a further increase in the rotation speed, the effect of the catalytic system oppression to the walls of the reactor increases. Therefore, the growth of the rotation speed loses its meaning. This effect is related to the center force.

The results of the studies show that the greatest yield of the target products is observed at 3 Hz. In Fig. 8 that the yield of hydrogen at 1 Hz was 4,56%, and at 3 Hz it increased to 11,73%. That is, it grew 2,6 times. Similarly, the output of CO also behaves. At 1 Hz, its yield was 3,37%, and at 3 Hz it increased to 5,74% (increases by 70,33%).

With a further increase in the intensity of mechanochemical activation, we see that the expected decrease: hydrogen yield to 5.89% and carbon monoxide to 3,36% (Table 3). That is, the decrease is 49,79% and 41,46%, respectively. A similar effect is observed in a regime with a lack of coal (Table 4). It follows that the process is more likely to be carried out at a reactor rotation speed of 2 to 4 Hz (the optimum is 3 Hz).

It is known that the target products are produced together with the secondary products: hydrogen sulphide, methane, carbon monoxide and in small amounts: ethane and ethylene (Table 3 and Table 4). It was noted that the largest amounts of H_2S and CO_2 were detected at a rotation speed of 3 Hz, both in the regime of investigation with an excess of coal and in a regime with a lack of coal (Fig. 8). It is known that the target products are produced together with the secondary products: hydrogen sulphide, methane, carbon monoxide and in small amounts: ethane and ethylene (Table 3 and Table 4). It was noted that the largest amounts of H_2S and CO_2 were detected at a rotation speed of 3 Hz, both in the regime of investigation with an excess of coal and in a regime with a lack of coal (Fig. 8).

The composition of the conversion gases (Table 3, Table 4) is explained by the conditions of the process and the composition of the feedstock. The yield of hydrogen sulphide can be explained by the level of sulfur in the samples of coal. However, it should be noted that with an increase in the intensity of mechanochemical activation from 1 to 3 Hz, the yield of hydrogen increases faster than hydrogen sulfide. Perhaps this is due to the chemistry of the process. The peculiarity is that the formation of hydrogen increases with increasing intensity of mechanochemical activation.

Also in Table 3 and Table 4 it can be noted that the difference between the yields of products with different ratios of the initial reagents is explained by the influence of the molar ratio of raw materials to the choice of the course of the reactions.

It was interesting for us to consider the influence of the synthesis gas ratio ($CO: H_2$) in regimes with a different ratio of the initial reagents ($C:H_2O=0.87: 1$ and $C: H_2O=5,5: 1$). At the same time, a regime of intensity of mechanochemical activation was detected, where the practical stability of the ratio of the target products ($CO: H_2$) was noted (Fig. 9). It was noted that in the 2-4 Hz range the synthesis gas ratio ($CO: H_2$) is 1:1.99 – 1:2.10 in the regime of investigation with excess coal (Table 3).

Considering the results obtained, the ratio of synthesis gas ($CO: H_2=1: 1.99-1:2,10$) in the regime of studies with excess carbon (Table 3) can be interfaced with the process of obtaining methanol or other alcohols. In this industrial process the ratio of $CO:H_2\approx 1:2$ is used. The same ratio is used for the production of oxyfluoride prod-

ucts. Synthesis gas ratio $\text{CO:H}_2=1:1.19$, obtained in excess carbon regime (Table 3), is used in industry to produce esters (1:1-1:1,2).

It is noted that the total yield of H_2 and CO increases from 7.93 to 17,47% by volume. when the reactor rotation speed varies from 1 to 3 Hz in the regime with an excess of coal. It was found out that in a regime with a lack of coal, the total yield of H_2 and CO is found to be from 7,23 to 14,95% by volume. It turns out that when designing industrial production of methanol, you can orientate yourself by the ratio of the produced synthesis gas to CO:H_2 (1:1,99-1:2,10) and the total yield of H_2 and CO is 17.47% by volume. This is possible at a rotation speed of 3 Hz and in a regime with an excess of carbon.

Our studies of the Fischer-Tropsch process for the production of hydrocarbons using the aerosol nanocatalysis technology in a vibrating layer in 1 atm have shown that the optimum modes are the synthesis gas ratios: $\text{CO:H}_2 \approx 1:3$ and 6 Hz; $\text{CO:H}_2 \approx 1:2$ and 4 Hz. From this it follows that obtaining such a ratio is possible by steam conversion of coal in the aerosol of the catalyst in a rotating reactor in the ratio of the feedstock $\text{C:H}_2\text{O} \approx 0.87:1$ by 1 atm and 2-4 Hz (Fig. 9).

The results of the studies show that the composition of the conversion gases and the CO:H_2 synthesis gas ratios can be controlled by varying the temperature and the rotational speed of the reactor. Thus, by changing the intensity of mechanochemical activation, it is possible to obtain product ratios at 1 atm, depending on the needs of a particular production.

The results of studies of the process of steam coal conversion showed that under laboratory conditions it is possible to achieve several optimal regimes that are acceptable for further industrial products.

After analyzing and discussing the obtained research results, optimal regimes for specific industrial processes were identified. The following modes are noted. A regime with an excess of carbon, a temperature of 973-1023 K, a rotation speed of 2-4 Hz, yields a syngas ratio of $\text{CO:H}_2=1:1,99$ and $\text{CO:H}_2=1:2,10$, which can be used to produce alcohols, specifically methanol. A regime with an excess of carbon, a temperature of 873-1023 K, a rotation speed of up to 1 Hz, produces a synthesis gas ratio $\text{CO:H}_2 = 1:1,19$ in industry can be used in the preparation of esters (1:1-1:1.2).

The results show that it is possible to efficiently carry out the process of steam reforming of coal under the conditions of the technology of aerosol nanocatalysis in a rotating reactor.

Obviously, this process is complex and the technology of aerosol nanocatalysis has specific control parameters. This affects the way the process is implemented. Namely, the chemical transformation of the solid reactant and water vapor occurs on the solid surface of the catalyst nanoparticles.

An analogue of this process can be considered the process of steam methane conversion. It proceeds at 1073–1173 K and 2–2.5 atm. At the same time, steam conversion of coal under conditions of catalyst aerosol stably proceeds at 973–1023 K and 1 atm. It is also possible to control using a large number of process control parameters, for example, the rotation speed of the reactor. Such a solution can give widespread use of technology.

Thermocatalytic destructive transformations of heavy petroleum fractions in the vibro-reactor of aerosol nanocatalysis

A prospective process is the purification of fuel oil. It is the remainder of oil products after atmospheric distillation of oil. Purification of fuel oil occurs by its separation under vacuum with further thermocatalytic cracking of vacuum gas oil.

The use of the AnC technology with the vibrating bed (AnCVB-aerosol nanocatalysis with vibrating bed) for the processing of petroleum products shows that, compared with the catalysis on carriers, the reaction rate is 10^4 - 10^6 times the catalyst weight. This entails, respectively, a reduction in its concentration to 0.3-5 g/m³ of the reactor and also the possibility of lowering the temperature. Also in the technology AnCVB, new control parameters appear that allow controlling the activity of the catalyst. Such as frequency and amplitude of oscillations and others.

The processes of thermal and catalytic cracking of vacuum gas oil were carried out in a laboratory setup (Fig. 10). Kinetic studies were performed on this flow-type installation with a reactor operating mode that is close to the ideal mixing mode.

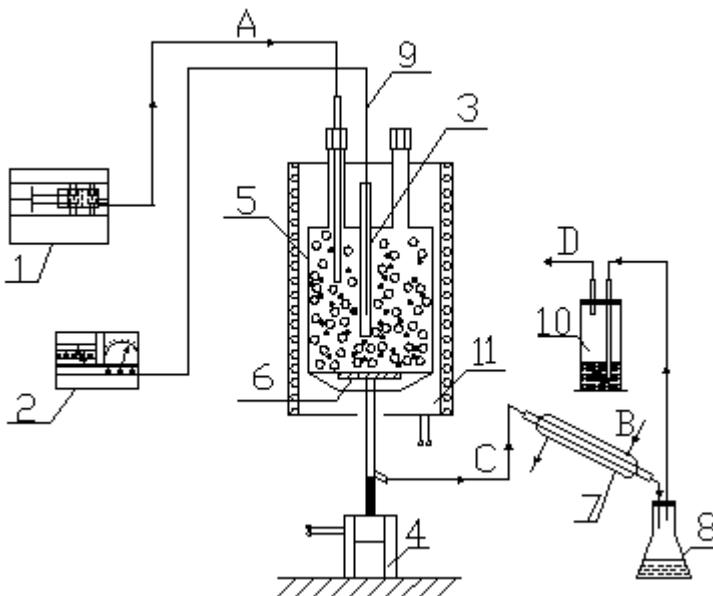


Fig. 10. Schematic diagram of a laboratory unit for processing hydrocarbons using AnCVB technology: 1 - syringe dispenser; 2 - control unit; 3 - thermocouple pocket; 4 - vibration control; 5 - reactor; 6 - metal-fiber filter; 7 - refrigerator; 8 - collection; 9 - thermocouple, 10 - bubbler; 11 - furnace.

Streams: A- fuel oil; B - water for cooling; C- cracking products; D - gases

Raw materials (fuel oil) syringe dispenser (1) is fed into the reactor (5), heated by a furnace (11). Cracking reactions take place in the reactor. The temperature in the reaction zone is measured using a thermocouple (9) and maintained by the control unit (2). In order for the catalyst not to be carried away from the reaction zone, a metal filter filter (6) is provided. After the reactor, the products enter the refrigerator (7), the cooled product enters the collection (8), and the cracking gases enter the bubbler (10). The reactor performs a reciprocating motion using a vibrating device (4), the oscillation frequency is set and controlled using the control unit (2).

Mechanochemical activation of the catalytic system is carried out by controlled mechanical vibration of the reactor. Gaseous reaction products were analyzed by chromatography. The obtained results of the research allowed to make a method of their mathematical proc-

essing, to find out the peculiarities of the kinetic parameters of the process for calculating the volume of industrial reactors.

Thermal cracking was investigated for comparative analysis. For catalytic cracking used known catalysts and their components. Such as, zeolite NaX, Al₂O₃, industrial dispersed catalyst Nexus - 345p (Lisichansk) and others. Note that some of the experiments were carried out with a small degree of conversion of raw materials (up to 10%). This allows us to obtain kinetic equations, especially with specific parameters of the technology of aerosol nanocatalysis. These parameters include the oscillation frequency of the catalytic system f and the concentration of the catalyst C_{cat} . The experimental conditions and the composition of the reaction products are presented in Table 5 and Table 6. The best experimental results will be highlighted in bold in the tables.

Table 5

The thermal cracking of vacuum gas oil (raw material consumption 1,1 ml/min)

№	t , K	X , %	τ , sec	composition of reaction products, % mass.			r , $\frac{kg}{m^3 \cdot h}$	k_{eff} , sec^{-1}	E , kJ/mol
				gases	gasoline fraction	diesel fuel			
1	743-823				50-55			0,001-0,07	225-235
2	773	5,5	5,9	20,0	48,3	29,2	79	0,008	170±1
3	773	5,1	4,8	18,4	49,7	29,4	73	0,010	5
4	773	6,8	4,8	18,5	47,8	31,2	98	0,015	

t - temperature; X - degree of transformation; r - cracking rate; k_{eff} - the effective reaction rate constant; E - the activation energy

Thermal cracking studies were carried out at 773 K and several modes. Line 2 shows the process mode in an empty reactor; line 3, the reactor was filled with 50% pure glass beads; in line 4, the glass beads were dusted with a catalyst. The degree of conversion (wt%) varied from 5,5 to 6,8. At the same time, the yield of the gasoline fraction was up to 49,7% by weight, and the amount of light oil products was about 79,1% by weight. It was noted that at 723 K no thermal cracking was detected.

Table 6

The catalytic cracking of vacuum gas oil using AnCVB technology

№	experiment conditions				X, % mass.	composition of reaction products, % mass.	
	t, K	V, ml/min	f, Hz	C _{cat} , $\frac{g}{m^3_{r.vol.}}$		gasoline fraction	diesel fuel
Catalyst zeolite NaX							
1	350	1,1	4,5	5,0	3,3	52,2	33,2
2	400	1,1	4,5	5,0	8,5	49,4	28,1
3	450	1,1	4,5	5,0	37,7	37,3	22,2
4	500	1,1	4,5	5,0	89,7	34,6	26,3
Catalyst Al ₂ O ₃							
5	460	1,1	4,5	5,0	4,9	44,7	14,6
6	500	1,1	4,5	5,0	12,8	35,2	14,1
7	540	1,1	4,5	5,0	18,8	39,9	17,6
8	600	1,1	4,5	5,0	25,2	37,7	16,7
Catalyst Nexus-345p and its components							
9	500	1,1	4,5	1,0	4,3	49,4	32,7
10	500	1,1	4,5	2,0	5,4	52,8	40,2
11	600	1,1	4,5	2,0	30,1	42,0	31,1
12	550	1,1	4,5	2,0	9,4	51,1	32,3
13	550	1,1	4,5	2,0	10,8	53,1	34,0
14	630	4,0	4,5	2,0	40,0	55,0	30,5
15	630	2,0	4,5	2,0	89,1	51,8	23,0
16	570	0,4	4,5	2,0	86,0	50,4	22,5
17	570	0,34	4,5	2,0	86,8	46,1	26,0

t – temperature; V - raw material consumption; f - frequency; C_{cat} - concentration of catalyst; X - degree of transformation.

The catalytic cracking studies were started with a NaX catalyst. Its concentration in the reactor was maintained at 5 g/m³ of the reactor, the consumption of raw materials and temperatures are the same as in the thermal process. In line 4 it is noted that when using vibration and at 773 K, the degree of conversion of raw materials increased to 89% by weight, the yield of gasoline decreased to 34,6% by weight, and the amount of light oil products was 60,7% by weight. As a result of the research, the lower temperature limit of the course of the catalytic process was determined. It was 623 K (line 1). The degree of conversion of raw materials amounted to 3.3% by

mass, the yield of gasoline was 52,2% by mass, the yield of light products was 85,4% by mass. It was found that when the NaX catalyst is used and the same degrees of transformation, the temperature is reduced by 423 K.

Investigations of the cracking process on the Al_2O_3 catalyst showed low catalytic activity (lines 5-8). It was noted that the cracking reaction occurs at 733 K (line 5). This temperature is lower by 323 K than in thermal cracking and catalytic in industry. However, the yield of gasoline and diesel fuel is much lower than for thermal cracking and other catalysts. Investigations of the cracking process on the Al_2O_3 catalyst showed low catalytic activity (lines 5-8). It was noted that the cracking reaction occurs at 733 K (line 5). This temperature is lower by 323 K than in thermal cracking and catalytic in industry. However, the yield of gasoline and diesel fuel is much lower than for thermal cracking and other catalysts.

The following studies were performed on a Nexus-345p catalyst (lines 9-13). The best yield of the gasoline fraction was obtained at 773 K and it amounted to 52,8% of the mass. and the amount of light amounted to 93,2% of the mass. (line 10), while the degree of conversion of raw materials amounted to 5,4% of the mass. This output of gasoline and the amount of light oil is higher than on the catalyst NaX. This shows the greater selectivity of the Nexus-345p catalyst. In lines 12-13, a catalytic cracking study was conducted on the components of the Nexus-345p catalyst. In line 12, the experiment was carried out on a catalyst residue that did not dissolve in HNO_3 (possibly SiO_2). In line 13, the experiment was carried out on a catalyst residue, which was formed after evaporation of a part of the catalyst dissolved in HNO_3 (possibly Al_2O_3). The results of the research (lines 12 and 13) show that the gasoline yield is 51.1% of the mass. and 53,3% of the mass., and the amount of light oil 83.4% of the mass. and 87,1% of the mass. respectively. As you can see, part of the catalyst (line 13) exhibits high catalytic activity, which is higher than the chemically pure sample (lines 5-8). However, the best performance shows dispersed catalyst Nexus-345p.

Lines 14-17 were obtained at high degrees of conversion of raw materials. This showed a new kind of experiments with an industrial Nexus- 345p catalyst.

The greatest degree of conversion of raw materials in a laboratory mixing reactor was achieved by 86% by weight. (line 16). The reaction temperature was 843 K. This is the average temperature in an industrial lift reactor. As a result, the output of gasoline was 50,4% by weight, and the diesel fuel was 22,5% by weight. on raw materials. At the same time, the amount of light oil products was 72,5% by weight, and the selectivity for light oil products was 84,8% of the mass. This is more than in industry. Note that these results were obtained in one pass in the mixing reactor. It is known that in the industrial plant G-43-107M / 1 in the lift-reactor, a conversion degree of 88% by weight, a gasoline yield of 50% by weight, a yield of diesel fuel of 15% by weight is obtained. At the same time, the amount of light oil products was 65% by weight. and their selectivity is 73,9%.

The high results of the experiment can be explained by the high selectivity of catalysis and the decrease in the contact time by almost 2 times.

The results of processing the experimental data and their kinetic characteristics are presented in Table 7.

According to the experimental data, the coefficients of the kinetic equation were determined as follows

$$r = k_{eff} \cdot C_{C_3H_{12}} \cdot f^n \cdot C_{cat}^m \cdot B^d, \quad (5)$$

$$k = \frac{k_{eff}}{k_{vibration}}, \quad (6)$$

k - is the reaction rate constant according to the Arrhenius equation for determining the influence of temperature;

k_B - is the reaction rate constant, which determines the influence of vibration. $k_{vibration} = f^n \cdot C_{cat}^m \cdot B^d$ (7)

f^n is the coefficient of influence of the vibration frequency of the catalytic system on the reaction rate;

C_{cat}^m is the coefficient of influence of the aerosol concentration of the catalyst on the reaction rate;

B^d is the coefficient that determines the unknown vibration parameters;

note that for the cracking process on a zeolite NaX catalyst, the rate constant at 773 K was $0,47 \text{ sec}^{-1}$ (line 4 Table 7). The rate constant for thermal cracking is $0,01 \text{ sec}^{-1}$ (line 3 Table 5). Thus, the reaction rate in the catalytic process using AnCVB technology is 50 times higher, the thermal process.

Table 7

Catalytic cracking of vacuum gas oil using AnCVB technology (calculation of kinetic parameters)

№	τ , sec	Yield, % wt.		Cracking rate		k_{eff} sec ⁻¹	E kJ/mol
		Gases	Gasoline + Diesel	$\frac{kg}{m^3_{r.vol.} \cdot h}$	$\frac{kg}{kg_{cat} \cdot h}$		
1	2	4	5	6	7	8	9
catalyst zeolite NaX							
1	7,0	12,6	85,4	47	9500	0,005	71±10
2	6,2	20,0	77,5	122	24500	0,014	
3	5,5	38,0	59,5	541	108000	0,086	
4	4,8	36,6	60,7	1288	257600	0,474	
catalyst Al ₂ O ₃							
5	5,5	38,5	59,3	70,6	14100	0,009	82±10
6	4,8	49,3	49,2	183,8	36700	0,029	
7	4,2	30,1	57,4	269,9	54000	0,050	
8	3,7	33,1	54,4	361,8	72400	0,078	
catalyst Nexus-345p and its components							
9	4,8	15,4	82,1	62	61700	0,009	86±12
10	4,8	4,5	93,0	78	38700	0,012	
11	3,4	26,4	71,1	432	216200	0,105	
12	4,1	15,1	83,4	135	67500	0,024	
13	4,1	10,5	87,1	155	77600	0,028	
14	0,1	11,0	85,5	2015,2	1007000	4,1	
15	0,2	11,7	74,8	2242,0	1120100	4,4	
16	1,0	10,6	72,9	434,1	217000	0,8	
17	1,2	13,3	68,1	372,0	186000	0,8	

The mathematical description of the cracking process on the zeolitic NaX catalyst (conversion to 30%) kinetics is represented by equation (6) with a deviation of 10%

$$r = k_{\text{eff}} \cdot f^{-0.91} \cdot C_{\text{cat}}^{0.3} \cdot (1 - X_0) \quad (8)$$

X_0 - degree of conversion of vacuum gas oil.

As a result of the experiment, the rate constants were determined, which made it possible to determine the activation energy. The catalytic cracking energy was 71 kJ/mol.

The thermal cracking energy was 170 kJ/mol. However, according to the literature, it is 225-235 kJ/mol.

One of the principles of the action of the catalyst is a decrease in the activation energy.

It was experimentally reported that the cracking reaction rate on the Nexus-345p catalyst at 773 K is 78 kg/m³ of the reactor per hour, and the rate on the NaX zeolite catalyst is 1288 g/m³ of the reactor per hour.

However, it was noted that the yield of gasoline and light petroleum products on the NaX zeolite catalyst was 34,6% and 60,9%.

This is significantly less and is probably associated with low selectivity. The activation energy was 86 kJ/mol.

The activation energy of the catalytic cracking process on the Al₂O₃ catalyst was 82 kJ/mol.

This is lower than in the thermal process. As a result, it is seen that in most experiments the reaction rate is higher than in thermal cracking.

Table 8 shows a comparative analysis of the catalytic cracking process using AnCVB technology on a Nexus-345p catalyst with an industrial catalytic cracking process.

As can be seen, the output of gasoline remains practically unchanged.

The amount of catalyst in the reaction volume is reduced from 300-700 kg/m³ (according to the regulations) to 5·10⁻³ kg/m³ (according to the AnCVB experiment).

The catalyst supply during operation decreases from 0.545 kg/ton of raw material to less than 0,04 kg/ton.

It is known that at a large research facility, the catalyst recovery rate is more than 99%.

Table 8

Comparative analysis of petroleum cracking technologies

Options	Technology				
	Thermo cracking	Catalytic cracking		AnCVB в peakropи	
		G-43-107M/1	Literature	mixing	displacement
productivity, thousand tons per year		2000		2000	2000
1. temperature, K					
in the reactor	823	798		843	930
in the regenerator	-	913		no regenerator	
2. catalyst composition		Nexus-345p	*	Nexus-345p	
grain size, m		$5 \cdot 10^{-5}$		$(8 \cdot 100) \cdot 10^{-9}$	
surface, m ² /g		150–400		30–360	
pore radius, Å		5–30		no pores	
heat resistance		850–900		more 2000	
deactivation time, sec		1–3		there is	no deactivation
3. k , sec ⁻¹	0,01			0,80	4,41
4. yield of gasoline, % wt.	50-55	50,0	54,8 %vol,	50,4	51,8
5. volume of reactor, m ³		950		420	85
volume of regenerator, m ³		1800		is absent	
one-time catalyst loading, tons		350		less $7 \cdot 10^{-4}$	
Catalyst feed, kg / ton of raw material		0,545	0,575	-	
recycling	obligatory			without recycling	

Composition of Nexus-345p - (Na₂O-0.2%, Al₂O₃-47%, SiO₂-52.8%);

* - aluminosilicate + 10% calcium faujasite

Continuous mechanochemical activation of the catalyst in situ makes it difficult to deposit coke on its surface and coagulation process. This allows in the industrial process to maintain high continuous activity unlimited for a long time. However, it is known that in traditional processes the catalyst loses activity after 1-3 seconds.

The volume of the mixing reactor in AnCVB technology is reduced by 2-10 times in comparison with the traditional industrial

process. Taking into account the regenerator in the industrial process, the volume decreases almost 20 times. This allows you to significantly reduce capital costs.

The results obtained indicate that it is necessary to continue scientific research. It follows that the subsequent tasks should take into account the consumption of raw materials, the cost of the target products, the amount of coke and the supply to the reaction zone of the thermal energy necessary for carrying out endothermic reactions of cracking.

For comparison of some quality indicators of gasoline and diesel fuel, experiments were performed with a maximum conversion in a laboratory mixing reactor at 843 K (Table 6 and 7, line 16). Further, the gasoline fraction and diesel fuel were examined for the content of olefins and aromatic compounds.

The indicators were given in Table 9.

Table 9

Indicators of the quality of petroleum products, which were obtained by catalytic cracking using AnCVB technology on the Nexus-345p catalyst

Indicator	gasoline	diesel fuel	Values by State Standard and Technical Indicator*
Bromine number	23.4	-	not standardized
Iodine number	not standardized	0,5	5–6
Olefin content, % wt.	12.1	0,3	not standardized
Aromatic content, % wt.	32.1 (is determined)	46,0	not standardized
The content of benzene, % wt.	2.1	not standardized	before 5%
Octane number, research method	103		catalytic cracking - 83,5-91,6, thermo cracking 67,0-76,1

The content of benzene in the product obtained does not exceed 2.1%. This is better than the requirements for modern fuels, such as the Super 98 (State Standard R 51105-97). According to the normative indicators, the obtained oil products meet the requirements for

motor fuels. It is known that the benzene content is used for gasoline and the iodine number is used for diesel fuel. It should be noted that these characteristics were obtained in a laboratory mixing reactor on a dispersed industrial catalyst. For the industrial process, a reactor with a mode close to displacement should be used. The choice of the optimum catalytic system and reactor should allow to improve the yield of gasoline and its quality indicators. The resulting diesel fuel can be used as a component of commercial diesel fuel.

Summary

The actual use of aerosol nanocatalysis is that a new method of obtaining synthesis gas and processing petroleum products is proposed.

The technology of aerosol nanocatalysis will solve the problems that are encountered in industrial technologies. Such as methane vapor conversion technology and vacuum gas oil processing technology.

The use of aerosol nanocatalysis technology can open up new and effective prospects for the development of the chemical and petrochemical industry in Ukraine.

The technology allows the use of available raw materials, to simplify the technological scheme and conditions of the process, to simplify and reduce the concentration of the catalyst.

This allows to maintain a uniform reaction rate and, accordingly, to reduce the catalyst concentration in the reactor up to 10^6 times.

The study of the process of steam reforming of coal using the technology of aerosol nanocatalysis in a rotating reactor will allow to solve the problem of industrial synthesis gas production.

As it turned out, it is possible to obtain a ratio of conversion products by changing the intensity of mechanochemical activation and depending on the needs of a particular production.

The use of only the active part of the aerosol of the catalyst in the reactor makes it possible to remove the mechanical and thermal limitations that are associated with its use.

A. THE NEW TECHNOLOGY OF APPLICATION OF THE HEAT-CARRIER IN THE MELT

The technology in the melt of liquid high-temperature heat carrier will solve the following issues:

- increase the operating temperature to 1300 K and more;
- increase heat and mass transfer;
- increase the conversion of raw materials and oxidizer;
- reduce carbon dioxide in the synthesis gas;
- remove slag in liquid form with utilization of its heat;
- to obtain a slag with a carbon content of less than 1%;
- organize the processing of slag casting into marketable products or building materials.

The offered technologies of coal conversion are realized in melts of metals, their salts and slag at the experimental level.

The lack of technological data for obtaining synthesis gas by conversion of coal in melts inhibits the effective implementation of this process. Therefore, the creation of a new technological scheme for coal conversion in the melt of a liquid high-temperature heat carrier to produce synthesis gas requires additional studies. They are related to the search for optimal parameters of the process, the choice of equipment, the creation of a mathematical model.

The process of coal conversion in the melt of the heat carrier to produce thermal energy

The idea of technology research is the creation of a low-cost technology for producing synthesis gas from coal. It is proposed to solve the following tasks:

- failure of the reactor to combine the reaction of conversion and oxidation;
- flow of the process in the melt of a liquid high-temperature heat carrier;
- separation of the conversion and oxidation zone.

This will eliminate the consumption of oxygen and steam, replacing them with industrial water and air. The application of the melt provides energy supply. This occurs by the circulation of the melt between the conversion (I) and oxidation (II) zones. Allows to intensify the conditions of heat and mass transfer with reagents and facilitate its removal.

The new technology allows to exclude energy consumption from external sources. They are only needed during the start-up period. The source of raw materials and energy is only coal processed in the reactor. In industrial realization, it is proposed to use molten slag of processed coal as a liquid high-temperature heat carrier. If it is necessary to reduce the melting point, it is possible to add additives to the melt such as fluxes.

A schematic diagram of the new technology for the heat of carrier melt is presented in Fig. 11.

Thermodynamic calculations show that the highest concentration of synthesis gas can be ensured separately by carrying out the conversion and oxidation reaction in the reactor in separate zones. In this case, the heat of the endothermic reaction of coal conversion by water is provided by oxidation of a part of the coal (carbon residue)

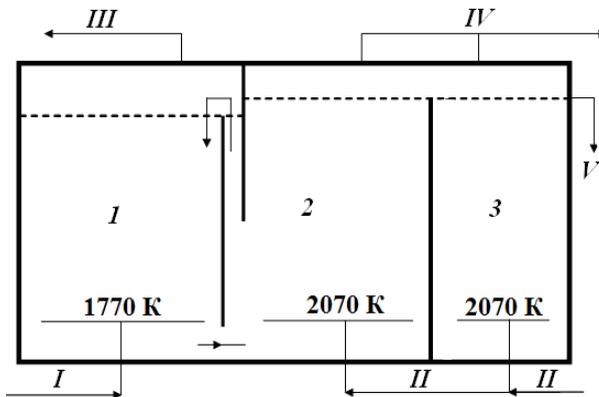
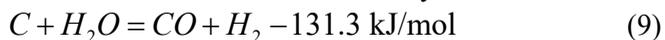


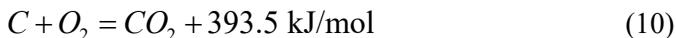
Fig. 11. Scheme of the reaction unit of technology in the melt for production of synthesis gas, *I-III* - three reaction zones of the reactor: *I* - conversion zone; *2* - oxidation zone; *3* - additional oxidation zone; *I* - Water, coal, CaCO_3 ; *II* - Air; *III* - Synthesis gas; *IV* - Oxidation products; *V* - Slag

by air. Conversion and oxidation zones are separated only by the gas phase in order to ensure explosion safety and have a melt of a liquid high-temperature heat carrier circulating between them.

the endothermic reaction of coal conversion by water



the oxidation of a part of the coal by air



To obtain the basic kinetic regularities of the coal conversion process, a flow-through method was used.

The laboratory installation (Fig. 12) includes a quartz reactor or a reactor of steel X23D18 (1) of bubble type.

The reactor was placed inside the furnace (2). The temperature in the furnace was maintained at 1273-1373 K with an accuracy of ± 20 K. It was measured with its calibrated platinum-rhodium thermocouple to the reactor by an electromechanical syringe dispenser (12), or

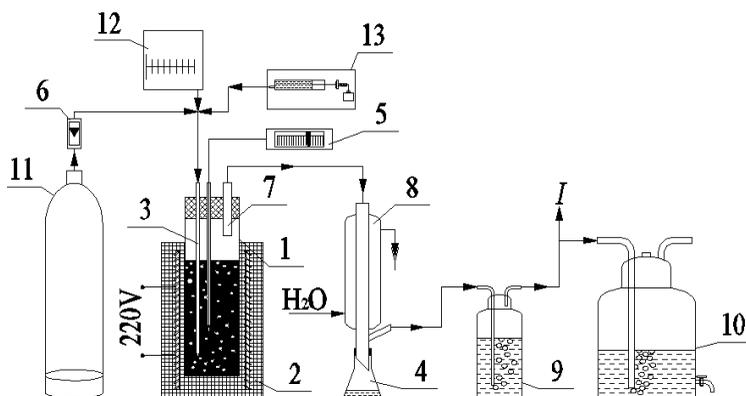


Fig. 12. Diagram of a laboratory installation for the conversion of carbonaceous materials in a melt: 1 - reactor of quartz or heat-resistant steel; 2 - electric furnace; 3, 7 - quartz tubes; 4 - condensate collector; 5 - thermocouple with potentiometer; 6 - rotameter; 8 - refrigerator; 9 - Drexel's bottle; 10 - the vessel of Mariott; 11 - a bottle with nitrogen or air; 12 - syringe water dispenser; 13 - pneumatic feeder of solid raw materials; *I* - gas analysis through an evaporator (not shown in the diagram)

The introduction connected to a potentiometer (5). The water was supplied directly of gaseous reactants into the reaction zone was carried out from cylinders (11) with nitrogen, air and carbon dioxide. The flow rate of gases was regulated and measured by means of rotameters (6). Coal was fed into the reactor by a pneumatic dispenser (13). The collection system for liquid and gaseous reaction products consisted of a condenser (8), a condensate receiver (4), a Drexel bottle (9), and a Mariott vessel (10). The volume of gas formed was determined by the amount of brine expelled from the vessel of Mariott.

During the experimental studies of coal conversion and oxidation, sodium chloride was chosen as the liquid high-temperature heat carrier. Its use makes it possible to simulate the processing of "salty coals." A sample of crystalline sodium chloride (State Standard 13830-97) was charged into the reactor preheated to the operating temperature (1100-1353 K). The main characteristics of NaCl are as follows: melting point $1073,8 \pm 0,5$ K; boiling point 1686 K; the density of the liquid is 1100 K = 1.56 g/cm^3 . The salt melts and boils without decomposition. When the melt temperature reaches ≥ 1100 K, it is considered prepared for the experiment.

The monograph presents the results of studies of the oxidation of the carbon residue. A mixture of crystalline sodium chloride and coal was charged into the reactor, preheated to the operating temperature (1100-1373 K). At the same time degassing and pyrolysis of coal gases took place, and a carbon residue remained in the melt. Preliminary removal of hydrocarbon gases allows one to study the oxidation of only carbon. Oxidation of coal is the slowest stage. When the melt homogeneity was reached (temperature more or equal 1100 K), the reaction system was purged with nitrogen to completely remove the volatile components, then an oxidant such as water or air was supplied.

Analytical determination of the content of gaseous reaction products was carried out with continuous gas analyzers and gas chromatographs.

The physical and chemical properties of the melt were determined by chemical methods of analysis of substances. The temperature was recorded with a chromel-alumel or platinum-rhodium thermocouple.

For the experiments, we used coals with particle sizes less 0,3 mm, their composition is shown in Table 10.

The most reactive substances of coals are concentrated in volatile components.

When coal enters the high temperature zone, two types of reactions can occur:

- degassing and separate conversion;
- oxidation of the gas and solid phases, accompanied by heat transfer.

Table 10

Composition of the tested coals

Coal	Wetness, W ^P	Volatiles, V ^g	Ash, A ^P	Combustible mass					Ash composition		
				C	H	N	O	S	SiO ₂	Fe ₂ O ₃	Na ₂ O
mass. %											
Gasous	5,9	41,3	7,2	81,0	5,7	2,0	11,0	0,3	47,3	4,2	0,4
Anthracite type ASh	8,0	4,0	28,0	93,0	1,8	1,0	3,0	1,7	52,0	15,0	1,5
Anthracite Donetsk	10,0	7,0	20,0	70,0	4,3	-	-	-	8,0	40,0	4,0
Coal	7,5	22,8	12,0	86,0	4,5	1,5	3,1	3,2	-	-	-
Salted coal	7,3	28,7	15,4	77,6	4,7	5,6	6,5	5,6	29,8	31,8	15,0
Coke	3,4	4,0	2,0	95,5	0,5	1,2	1,8	1,0	-	-	-

The processes are limited by reactions with a solid phase represented by carbon.

Excess carbon was maintained in the reaction zone (melt) to study the rate of the coal conversion reaction and the degree of its conversion to synthesis gas.

The investigated coal has a different composition (Table 11) and the amount of volatile components.

When oxidized in a melt, they have a large surface and a high rate of chemical transformations.

To exclude the influence of volatile components on the process of conversion of the solid phase (coal) in the study, the coal was previously degassed.

This allowed to obtain data for comparing the conversion of different coals.

Table 11

The composition of the coal conversion gas in water in NaCl melt (coal fraction less or equal 0,3 mm, $T=1253$ K, melt height 110 mm, water flow 7 ml/h, water injection point depth 55 mm, coal concentration in the melt 0,078 g coal per g melt, $\tau=0,3$ sec)

Se- ries*		Composition of synthesis gas, vol. %				$\sum CO+2CO_2$	H_2/CO	$\frac{H_2+2CH_4}{CO+2CO_2}$
		H ₂	CO	CH ₄	CO ₂			
1	2	3	4	5	6	7	8	9
		Gaseous (Kuzbass, Siberian), ash content of 7,2 wt. %						
1		72,0	19,4	0,3	8,3	36,0	3,7	2,0
2		74,0	17,5	0,4	8,1	33,7	4,2	2,2
		Coal (Lisichansk sh.Melnikova), ash content of 12.0 wt. %						
1	Young coals	72,8	14,9	0,3	12,0	38,9	4,9	1,9
2		72,5	13,9	0,3	13,3	40,5	5,2	1,8
		Salty coal (Dnepropetrovsk), ash content of 15.4 wt. %						
1		73,9	19,5	1,4	5,2	29,9	3,8	2,6
2		74,5	17,2	1,0	7,3	31,8	4,3	2,4
		Anthracite (Donetsk), ash content of 20.0 wt. %						
1	Mature coals	75,6	16,0	1,0	7,5	31,0	4,7	2,5
2		75,4	15,3	1,4	8,0	30,3	4,9	2,5
		Anthracite type ASH (Rovenky), ash content 28.0 wt. %						
1		75,4	11,8	1,1	11,8	35,4	6,4	2,2
2		76,0	10,6	1,4	12,1	34,7	7,2	2,3

* - data are presented only for two series, but not less than seven series for each coal

The process of conversion of pre-degassed coals of different degree of maturity and content of mineral components was studied. Analysis of technological operating modes in the solid-liquid-melt system showed that the use of bubbling in a reactor with a diameter of 31 mm at

a gas velocity at the injection point of 20 m/sec excludes entrainment by gaseous products. Removal from the reactor eliminates melt, ash, coal and carbon. The system studied was "degassed coal - evaporating water - sodium chloride melt". The conditions and experimental data of the water conversion process are given in Table 11.

One of the important parameters characterizing the conversion process is the composition of the produced synthesis gas and the H_2 per CO ratio in it. When the coal is converted by water, the theoretical H_2 per CO ratio is ~ 1 . As a result of the conversion of the coals of various deposits in the NaCl melt, a synthesis gas with a H_2 per CO ratio (Table 11, column 8) is obtained from 3,7 to 7,2. which is much higher than the stoichiometric one.

It is known that working with the carbon residue excludes the appearance of hydrogen contained in the volatile components of the initial coal. However, the data characterizing the ash content of coal and columns 7 or 8 and column 9 are not correlated (Table 11). Note that an exact conclusion can not be drawn, since the high ratio of H_2 per CO and ΣH_2 per ΣO depends only on the ash content of the coal (Table 11) and changes almost in 4 times (from 7,2 to 28,0 mass%).

The experimental data in Table 11 are compared with the important properties of coals, such as the content of volatile substances and ash content. The influence of these parameters on the gaseous reaction products is arbitrary. Volatile components are pre-removed and do not affect the composition of the gas phase. The degassing process changes the porosity and internal surface of the coals, and this should increase the speed of the conversion process. A slight change in the composition of the conversion products was noted, namely, the CO content increases, the amount of H_2 , CO_2 , and CH_4 decreases. It is known that with preliminary thermodesorption of volatile gases, an increase in the internal surface of the coal should increase the adsorption of oxygen and the chemical reaction with the formation of CO and CO_2 .

The effect of ash on the composition of the reaction products is of an opposite nature, namely, an increase in the content of H_2 , CO_2 and CH_4 is observed, and CO decreases. It should be noted that H_2 and O_2 are formed during the decomposition of water, respectively, the formation of H_2 and CO with CO_2 should change synchronously.

However, the results obtained do not explain the high ratio of H₂ per CO much more 1.

Ukrainian scientists of the Institute of Physical Organic Chemistry and Coal Chemistry of the National Academy of Sciences of Ukraine have obtained the results of the process of conversion of salted coals with an increased ratio of H₂ per CO to 10. The studies were carried out in a flow-through unit with a fluidized bed reactor with a diameter of 40 mm and a fuel consumption of 24-29 g/min. Steam-air conversion of salted coals of the Novomoskovsk deposit of Ukraine (pressure 1.1 MPa, temperature 1173-1223 K) was performed to obtain an energy gas with H₂ per CO equal to 0.4 and 0.7. The heat of combustion of the produced gases is 4,4-4,6 MJ/m³. The second series of experiments with coals of Ukraine was carried out at atmospheric pressure (base of Institute of Chemistry of Natural Organic Raw Materials SB RAS, Krasnoyarsk) using a steam per oxygen mixture of 2.7 to 30.9, at 933-1068 K in a fluidized bed reactor. The H₂ per CO ratio increased from 3.7 to 10.1. These results are consistent with the data in Table. 11. However, there is no explanation for the reasons for the increased H₂ per CO ratio. It is assumed that this is due to the catalytic action of alkali metals present in the coal composition.

Investigation of the effect on the conversion by water of the particle sizes of the coal particles made with the carbon residue of anthracite is presented in Table 12.

Table 12

Conversion of anthracite type ASh of different fractional composition (temperature 1233 K, initial coal concentration 0,05 g carbon per g melt, water flow 0,1 g/min)

Fraction of anthracite mm	Synthesis gas composition					H ₂ /CO	$\frac{H_2+2CH_4}{CO+2CO_2}$
	H ₂	CO	CH ₄	CO ₂	CO+CO ₂		
	volume%						
1	2	3	4	5	6	7	8
0,05	74,8	16,2	0,3	8,7	24,9	4,6	2,3
1,2-1,5	74,5	14,3	0,5	10,7	25,1	5,2	2,1
1,5-2	78,1	10,5	0,0	11,4	21,9	7,4	2,3
2-2,5	81,6	8,4	1,4	8,7	17,1	9,7	3,3

An increase in the fraction leads to an increase in the hydrogen content and a decrease in the concentration of carbon monoxide in the synthesis gas. It is noted that with increasing particle diameter, the carbon surface decreases and, accordingly, its oxidation rate with water vapor. It was found that when using an anthracite fraction more than 2 mm, the amount of carbon dioxide is reduced. It was found that the H₂ per CO ratio increases by more than 2 times when using a coal fraction of 2-2,5 mm. The ratio ΣH per ΣO when using the coal fraction to 1,5 mm remains constant. With further increase in anthracite particles (fractions 2-2,5 mm), the ratio ΣH per ΣO increases by more than 60%.

The effect of the fractional composition of anthracite type ASh in the conversion process on the degree of water transformation is shown in Fig. 13. The following anthracite fractions were used in the study: 50 μm, 1,2-1,5 mm, 1,5-2 mm, 2-2,5 mm. It is noted that an increase in the size of the fraction with the same residence time of the raw material leads to a decrease in the degree of water conversion (Fig. 13). This is explained by the decrease in the surface of carbon

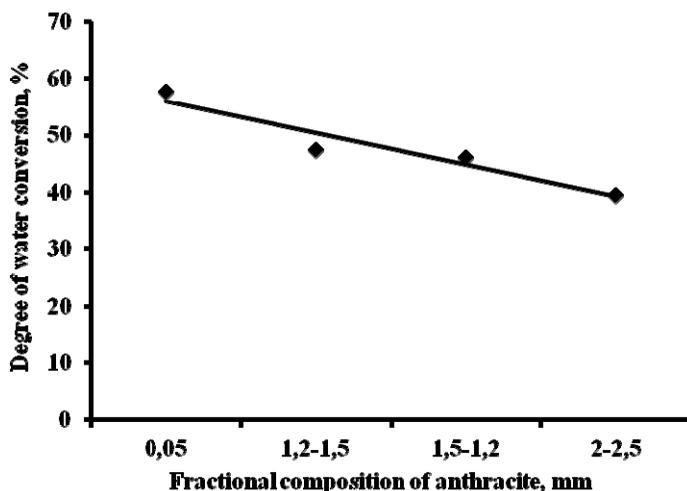


Fig. 13. Effect of the degree of water conversion from the fractional composition of anthracite (temperature 1233 K, initial concentration of coal 0,05 g carbon per g melt, water flow 0,1 g/min)

in the melt. It was found that the change in the degree of water conversion during the conversion of ASh type anthracite of different fractional composition has a linear character.

The experimental data (Table 12, Fig. 13) are described by the equation of the rate of conversion of anthracite (1) with an error of up to 7%

$$W_C = k \cdot C_{H_2O}^m \cdot C_c^n \quad (11)$$

where $k=62,5$ for anthracite with a particle size of 0,05-2,5 mm.

Dusty solid fuel (fraction not more than 0,3 mm) should be used in the process of coal conversion in the melt. This will ensure a high conversion rate and a complete conversion of coal to carbon oxides.

The aqueous solution of the cooled melt has a pH ~13, and the condensate of the gas phase has a pH ~(1-2). This is consistent with the literature data on salty coals and is explained by the catalysis of alkali metal chlorides.

The results of the studies (Table 13) established important regularities for the coal conversion process. The proposed assumptions on the effect of ash components on the H₂ per CO ratio were not confirmed by the results of Tables 13 and 10. The effect of ash and volatile components of coal on the yield of synthesis gas was noted. At the same time, the ash content decreases, and the volatile components increase the reaction rate.

It is noted that an increase in water consumption by 22 times increases the height of bubbling of gases above the point of input of raw materials by 2 times, also reduces the contact time (Table 13, column 3) and the degree of water transformation. This contributes to an increase in the yield of synthesis gas (Table 13, column 11), and H₂ per CO is practically increases in 2 times. It was found that the height of bubbling of gases above the point of input of raw materials is considered an important control parameter for technology in the melt.

The balance from the experimental data (Table 13) shows that the carbon residue varies according to individual dependence.

Table 13

Conversion of carbon residue of coal from different deposits in NaCl melt (fraction up to 0,3 mm, $T=1250$ K, melt height 110 mm, water injection point depth 55 mm, coal concentration in the melt 0,078 g carbon per g melt, melt volume 50 ml, water is introduced through the quartz tube with a diameter of 2,5 mm)

№	type of coal	water consumption g/h	contact time sec	height of bubbling mm	Synthesis gas composition				H ₂ /CO	gas outlet		Q _{burn} SG, (calculation) MJ/m ³
					H ₂	CO	CH ₄	CO ₂		H ₂	CO	
					volume%					l/h		
					5	6	7	8		9	10	
1	Cassious	2,8	0,317	116,9	71,1	20,6	0,6	5,7	3,5	3,2	4,5	10,7
2		6,6	0,306	119,1	72,0	19,4	0,3	8,3	3,7	7,0	9,7	10,3
3		66,4	0,272	165,0	76,4	9,5	0,2	13,8	8,0	28,3	37,0	9,5
4	Coal	2,8	0,317	116,9	72,7	20,4	0,2	6,7	3,6	3,1	4,3	10,5
5		6,6	0,306	119,1	72,8	14,9	0,3	12,0	4,9	6,2	8,5	9,8
6		66,4	0,272	165,0	76,6	9,0	0,1	14,3	8,5	24,9	32,5	9,4
7	Salty coal	2,8	0,317	116,9	71,9	23,4	1,2	3,4	3,1	2,9	4,0	11,2
8		6,6	0,306	119,1	73,9	19,5	1,4	5,2	3,8	6,6	8,9	11,0
9		66,4	0,272	165,0	77,9	9,2	0,3	12,7	8,5	27,3	35	9,7
10	Anthracite *	6,6	0,306	119,1	75,6	16,0	1,0	7,5	4,7	5,1	6,8	10,5
11		27,1	0,286	142,3	75,9	12,3	1,0	10,9	6,2	13,1	17,2	10,1
12		66,4	0,272	165,0	75,0	10,5	0,7	13,8	7,1	18,9	25,2	9,7
13		6,6	0,306	119,1	75,4	11,8	1,1	11,8	6,4	4,3	5,7	10,0
14		27,1	0,286	142,3	76,4	8,6	0,8	14,2	8,9	10,0	13,1	9,6
15	66,4	0,272	165,0	77,4	7,3	0,6	14,7	10,6	14,9	19,3	9,5	

* - line 10-12 is sample 1; line 13-15 is sample 2

Q_{burn} SG - Lower heat of synthesis gas

The amount of hydrogen in the melt introduced by the water flow rate of 2,76 g/h practically does not affect its content in the synthesis gas. In this case, the difference in oxygen is more than 50%. With increasing water flow, this discrepancy decreases. Some of the oxy-

gen in the water remains in the form of by-products in the melt. This shows the independence of the direction of reactions in hydrogen and oxygen. Carbon residue of coal is more active than coal anthracite. There, in the process of coal degassing, pores are released and their surface increases.

The process of conversion of the carbon residue of anthracite type AH fractions from 0,05 to 2,5 mm with water was carried out at a temperature of 1230 K. The flow rate of steam 0,1 g/min. It is determined that an increase in the coal fraction leads to an increase in the ratio of H₂ per CO from 6 to 9. Thermal power plants use coal with a dispersion of 50 μm. For the technology with melt, fractions up to 0,3 mm are expedient.

The effect of the carbon concentration in the melt (Fig. 14) on the conversion of the carbon residue of anthracite ASh type with water was studied.

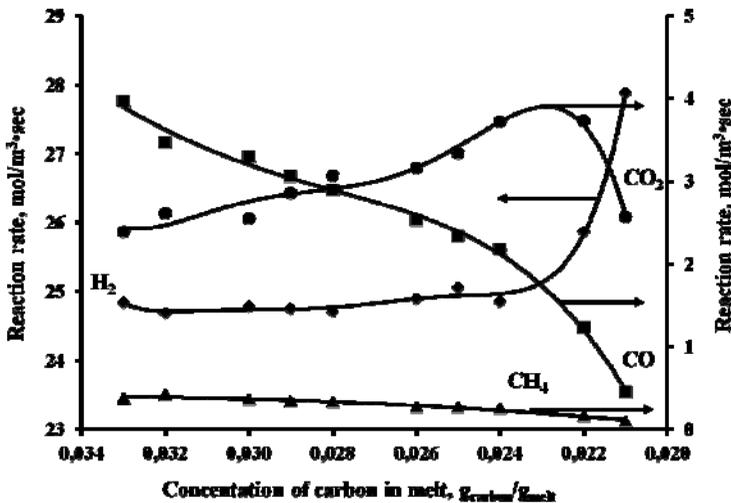


Fig. 14. Dependence of the reaction rate of the conversion of the carbon residue of anthracite (screen 2) with water on the concentration of carbon in the melt (water flow rate = 6,6 g/h, T=1270 K, coal fraction diameter 50 μm, melt height 90 mm, reagent injection height 35 mm)

During the reaction with an excess of carbon (C), the C/H₂O and C/Ap (Ap - Ash content) ratios decrease, which introduces changes

in the composition of reaction products and process indices. An analysis of the experimental data showed that when the concentration of carbon (C) decreases to 0,023 g of carbon per g of the melt, the change in the gaseous products of the reaction occurs practically linearly, and the H₂/CO ratio increases from 6,7 to 11,5. This can be explained by the interaction of water with reduced ash metals. The lower limit of stable conversion is 0,023 g carbon per g melt. It is noted that when the concentration of carbon decreases, the ratio of C/H₂O does not exceed 2 g of carbon per g of water and a sharp decrease in the amount of converted carbon occurs.

Investigations were carried out to determine the activation energy of the process of coal conversion by water in the interval of coal concentrations above and below 0,023 g carbon per g melt. This value is 100 kJ/mol with coal concentration more than 0,023 g carbon per g of melt and 78 kJ/mol at coal concentration less than 0,023 g carbon per g melt.

The rate of the process of coal conversion by water in the melt can be described by the dependence

$$W_C = k_0 \cdot C_{H_2O}^m \cdot C_C^n \cdot e^{\frac{-E_A}{R \cdot T}} \quad (12)$$

where $k_0=1.2 \cdot 10^6$, $E_A=100$ kJ/mol for coal concentration more than 0,023 g carbon per g melt;

$k_0=1,9 \cdot 10^5$, $E_A=78$ kJ/mol for the coal concentration of less than 0.023 g carbon per g melt.

The studies of the regularities of oxidation of the carbon residue of coal in the melt of sodium chloride were carried out.

The work is aimed at energy supply of the conversion stage. During the oxidation, anthracite (Donetsk) and coke were used.

The influence of hydrodynamic conditions, carbon concentration and temperature on the composition of oxidation products in the melt was studied.

The results of these studies are presented in Fig. 15.

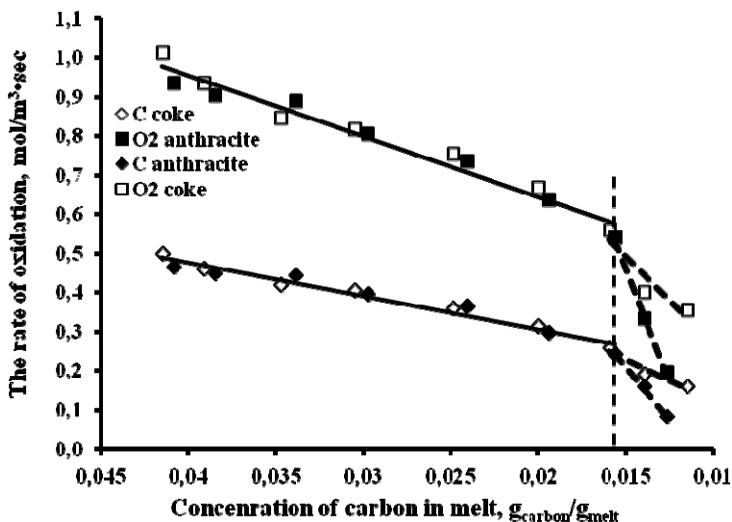


Fig. 15. The rate of oxidation of the carbon residue of coke and anthracite by carbon and oxygen. (air flow 18 l/h, $T = 1250$ K, fraction diameter 0.3 mm, melt height 65 mm, height of reagent injection 55 mm)

The nature of the change in the reaction rate of oxidation shows that at a carbon concentration of more than 0.016 g carbon / g melt, the rate is fairly stable and has a practically linear dependence on the carbon content in the melt. These dependences are almost identical in form for anthracite and coke. This is typical for a process in which the course of a chemical reaction is not limited by the mass transfer stage from volume to the interface. At a carbon concentration of less than 0.016 g carbon / g melt, the velocities for carbon and oxygen differ in coke and anthracite. At the same time, the rate of oxidation decreases sharply. Thus, the process at a concentration of C_C of more than 0.016 g of carbon / g of the melt first proceeds in a region close to the kinetic region, and then goes over into a diffusion one. In this regard, in the reactor we exclude zone 3 named additional oxidation. This allows us to keep in zone 2 a high reaction rate and heat release.

Summary

It is noted that the proposed technology of synthesis gas in the melt heat carrier is fundamentally different from the known

technologies (Lurgi, Winkler, Koppers-Totzek, Tehaco). These differences are as follows:

1 - refusal from the combined reactor, with the coal-vapor-oxygen feedstock flow;

2 - use of a reactor with a single circulating melt heat carrier;

3 - separate zones for the conversion of coal with technical water and the oxidation zone for a part of carbon to supply the process with oxygen in the air.

When comparing the technical and economic indicators of the process of coal conversion with water in the molten slag with existing technologies (Koppers-Totzek and others) allows the following:

- to increase the specific capacity of the reactor by coal 2 times;

- decreases the volume of the reactor almost 2 times;

- to increase the calorific content of the produced synthesis gas by 10% (up to 11.7 MJ/m^3) due to the almost complete absence of CO_2 conversion in gas products;

- to ensure the maximum degree of conversion of carbon 99%;

- reduce the residence time in the reactor 2 times;

- in existing technologies, 50–900 kg of water vapor and 230-640 kg of oxygen are consumed to obtain 1 thousand m^3 of synthesis gas, however, the proposed technology requires 226 kg of unprepared water of any quality.

The technology of coal conversion in slag melt eliminates the capital and energy stages, such as air separation for oxygen production, steam production and water treatment. This allows to reduce capital and operating costs by ~ 40% compared to existing synthesis gas technologies from coal and natural gas.

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A NOTE ON THE APPLICATION OF THE DISTINCT ELEMENT METHOD (DEM) TO GEOMECHANICS

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Abstract

The chapter presents some applications of programs based on the distinct element method. Conclusions resulting from the comparison of own, laboratory and analytical tests with numerical tests are presented. There are two extremely different examples. Research on the behavior of rock samples under of uniaxial compression and tension conditions and rock mass in the vicinity of a longwall work.

Keywords: uniaxial tension test, uniaxial compression test, longwall face, behaviour of joined rock masses, discontinues of rocks, numerical simulation, distinct element method, DEM, PFC2D code, UDEC code, PFC3D

1. Introduction

Rocks are, by their very nature, mostly discontinuous, heterogeneous, anisotropic and not only elastic medium. Describing materials with such complicated properties using mathematical formulas is difficult, sometimes impossible. Simplifications are used to solve many engineering problems and treat rocks as continuous, homogeneous, isotropic and elastic centers. Assumption of simplifications might be sufficient in many cases. However, accurate analysis and description of phenomena occurring in rocks and rock masses requires taking into consideration the real structure of rocks.

Generally, rocks are built of mineral grains glued with bonds of significantly lower strength. Rock material seen in micro scale is often cracked, with defects occurring in it. In the macro scale there are local and regional discontinuities seen, e.g. faults.

These features of rock material limit use of computational programs based on solutions of continuum mechanics. Of course, there are packages of programs based, e.g. on the finite element or finite difference method, that make it possible to model phenomena occurring in rocks and rock masses. However, sometimes it is necessary to consider the fact that rocks are discontinuous materials.

The fundamentals of the Distinct Element Method (DEM) were developed by Cundall (1971). Initially the method was used to solve tasks of rock mechanics and soil mechanics (Cundall and Strack, 1979). The basics of the method were described more precisely by Cundall (1988), Hart et al. (1988), Cundall and Hart (1993), Hart (1993) and in manuals of programs based on the DEM method: UDEC, PFC, 3DEC and PFC3D (Itasca, 1994).

Generally, the DEM method assumes that polygonal particles are to be deformed. The *grains* interaction is treated as a dynamic process of material states, affected by changes of internal forces. Contact forces, displacements of distinct element aggregates and their deformations depend on displacements of individual particles. Mass forces, motion of walls and particles cause displacement. The intensity of these phenomena depends on physical properties of the DEM continuum.

Models of polygonal particles (e.g. UDEC and 3DEC programs) more correspond to the real structure of minerals, however, modeling bonds and reactions between spherical particles (e.g. PFC2D and PFC3D programs) is easier and enable to construct models with significantly many more particles.

The UDEC code was described many times, also by the authors themselves (Itasca, 1989). Generally, according to the UDEC code, models are built of polygons - distinct elements of possibly diverse shape and size. They can be stiff or deformable when divided into finite elements. The vertexes of the distinct elements can be rounded to optimize the detection of contacts as they move.

UDEC has been applied many times for solving problems of geomechanics and geoen지니어ing so far. Numerical simulations were used, among others, for: uniaxial compression of anisotropic rocks (Kwaśniewski and Tomiczek, 1998), testing stability of the rock mass in the vicinity of the underground hockey stadium in Gjøvik in Norway (Barton et al. 1999), testing stability of Nishida bridge in Japan (Jiang and Esaki, 2002), modelling of a field explosion test (Chen, Zhao and Zhou, 2010) and basis of masonry analysis (Lemos, 2016) (Fig. 1 and 2).

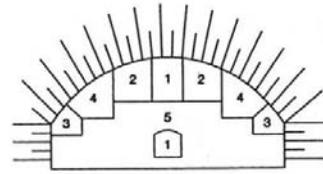


Fig. 1. Underground hockey stadium in Gjøvik (Norway; Barton et al., 1999)

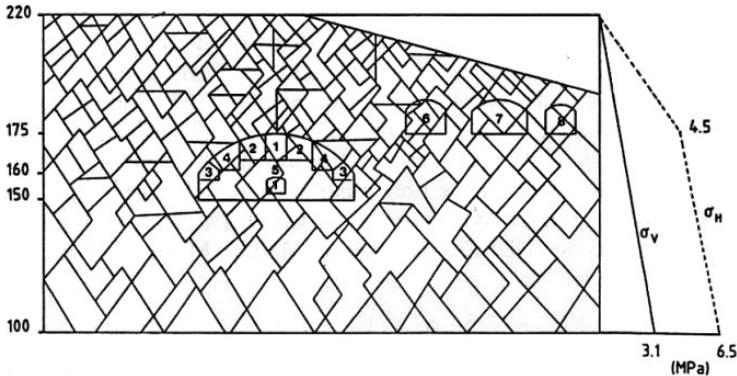


Fig. 2. Nishida Bridge (Japan; Jiang and Esaki, 2002)

The PFC2D Itasca C.G. code assumes circular shape of particles. The assumptions adopted by PFC2D is that it is a suitable tool for researching behaviour of cohesive, granular and loose materials with a granular structure. Mostly rocks are the materials made of bonded grains.

Features of the PFC2D code allow describing quantities characterizing the damage process of rock material and also enable dynamic observation of the phenomenon of rock material failure in the micro scale.

The first attempts of modelling various geomechanical phenomena using the PFC2D code as a tool began in the 90s of the last century. Simulated, among others: behaviour of rock blocks (Guest and Cundall, 1994), phenomenon of rock bursting (Cundall et al., 1995), behaviour of loose materials under the influence of gravitational forces (Lorig et al., 1995), explosive phenomenon destruction of rocks as a result of the combined phenomenon of breakout and rock-burst (Potyondy et al., 1996), the compressibility effect of the chalk under uniaxial compression (Itasca, 1998), the phenomenon of rock failure around a tunnel (Cundall et al., 1996), numerically studied behaviour of rocks in the pre- and postcritical state under triaxial compression conditions (Potyondy et al., 1996), the possibility of using PFC2D in geomechanics (Czene and Havel, 1999), the phenomenon of grain compaction of sandstone samples (Holt et al., 2000) and stability of the dog heading (Kidybiński, 2008).

2. Examples of application of the distinct element method in geomechanics

Based on our own research, two very different applications of DEM in geomechanics are presented. The first example is the simulation of a uniaxial compression and tensile test of rock samples, and the other is a simulation of rock mass behaviour in the immediate vicinity of a longwall excavation face exploited with a fall of roof layers.

2.1. Simulation of rock sample behaviour under uniaxial compression and tension

Simulations of strength tests using the distinct element method in the Department of Geomechanics and Underground Construction began in the 90 s of the last century. At the beginning, these were simple models of rock samples made of a dozen or so elements. Uniaxial compression tests were then taken. (Kwaśniewski, 1994).

After the appearance of the PFC2D code, more advanced simulations were started (Tomiczek, 1999). It was attempted to obtain, by means of numerical simulations, the same shape of stress-strain characteristics as obtained in laboratory tests.

The result of these studies were the simulations of uniaxial compression of rock samples, including *Jastrzębie* sandstone. A summary of these tests was presented at the Gelsenkirchen symposium on modelling using the PFC code (Tomiczek, 2002).

Numerical simulations of the uniaxial compression tests were then carried out on samples with dimensions of 42×84 mm (diameter × height).

The cylindrical sample model for compression tests was made of 4267 particles with a diameter of 0,25 to 0,75 mm. Particles were not bonded into aggregates. The volume density of *rock* was equal to 2,500 kg/m³ and its porosity was 0,05.

The particles were bonded with each other by a *cement* - about 9500 parallel bonds; you can imagine them as springs with some constant normal and tangent stiffness.

Figure 3*b* compares stress-strain characteristics obtained on the basis of a laboratory test (sample 220F.1.1., dashed lines) and numerical simulation (continuous lines). Very similar peak values of uniaxial compression strength were obtained, which amounted to approximately 137 MPa (laboratory tests) and 140 MPa (numerical simulation), respectively. Very small differences occurred in the values of total axial strain ε_z . The strains were 0,51% and 0,47%, respectively. However, large differences, up to 46% in comparison to laboratory tests, occurred in the amount of lateral strains $\varepsilon_{x,y}$; $\varepsilon_{x,y}$ were 0,37% and 0,68%, respectively. It reflected in the value of volumetric strains ε_V . Similar behaviour of the numerical model was observed by Holt et al. (2000). However, Holt stated that the three-dimensional version of the code (PFC3D) better reflect behaviour of real materials.

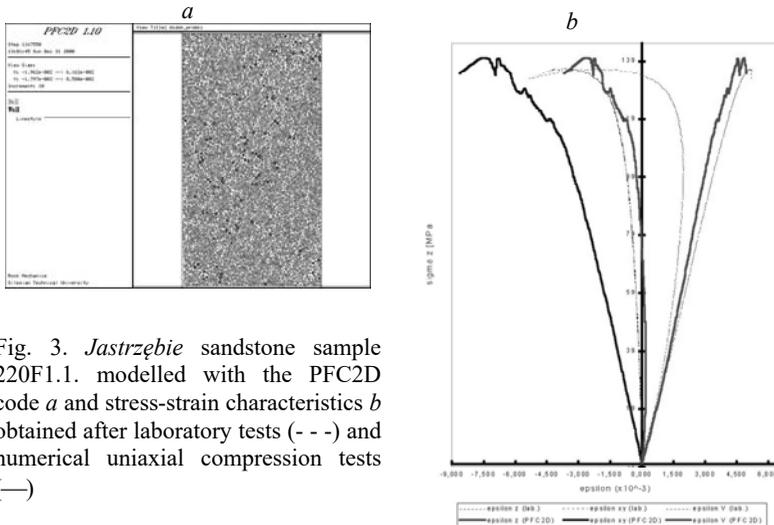


Fig. 3. *Jastrzębie* sandstone sample 220F1.1. modelled with the PFC2D code *a* and stress-strain characteristics *b* obtained after laboratory tests (---) and numerical uniaxial compression tests (—)

Because the subject of the research conducted by the author was the rocks behaviour in the field of tensile stresses, the next stage of the research were simulations of direct tensile tests using the PFC2D code.

This time, it was decided to simulate uniaxial compression and tension tests of *Strzelin* granite samples. The *Strzelin* granite featured low deformability and high strength in comparison to the tested *Jastrzębie* sandstone (Tomiczek, 2006).

The tests of uniaxial compression of the *Strzelin* SN-02 granite sample were carried out on two-dimensional models with a height of 84mm and a diameter of 42 mm. Numerical models were built of 603 grains with a diameter from 1,00 mm to about 1,50 mm bonded by parallel bonds in over 1200 contact points (Fig. 4). The particles were diameters almost twice larger than the diameters of models for the *Jastrzębie* sandstone. Research conducted by Potyondy and Cundall proved that such a change in particles size cut down the time of simulation and had a small influence on the values of linear strain modulus E_l and values of uniaxial compression strength σ_C (Tabl. 1).

Tabl. 1 - Influence of the particles size of the rock sample model (63,41×131,7 mm) on the values of the axial linear strain modulus E_l and the ultimate uniaxial compression strength σ_C (Potyondy, Cundall, unpublished)

Diameter of the particles D_{sr} , mm	Linear axial strains modulus E_l , GPa	Ultimate uniaxial compression strength σ_C , MPa
2,87	68,3	186,8
1,44	68,8	184,4
0,72	70,9	199,1
0,36	71,5	194,8

Tabl. 2. Basic properties of the *Strzelin* granite sample model

Diameter and height of the sample, $d \times h$, mm	42,0×84,0
Diameters of particles, mm	1,00
r_{max}/r_{min} ratio	1,50
Bulk density, ρ , kg/m ³	2600
Particles deformability modulus, $E_{c\,md}$, GPa	50
Parallel bonds deformability modulus, $E_{c\,pb}$, GPa	30
Tensile strength of bonds, σ_n , MPa	160
Shear strength of bonds, σ_s , MPa	300

Job Title: Granit "Strzelin"

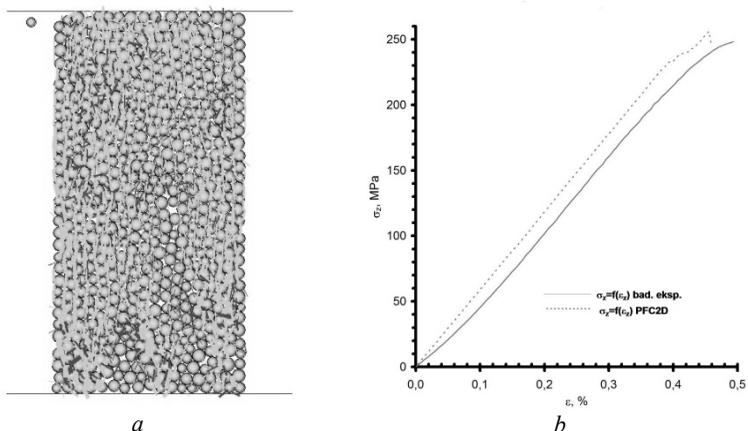


Fig. 4. The numerical model of the *Strzelin* granite sample before the simulation of the uniaxial compression test *a* and stress - strain characteristics obtained on the basis of laboratory uniaxial compression test (—) and numerical simulation (- - -) *b*

The particles interacted with each other in accordance with the non-linear Hertz-Mindlin law. The moduli of particles E_{cmd} and parallel bonds deformability E_{cpb} were equal to 50 and 30GPa, respectively. Particles were not bonded into aggregates. The coefficient of external friction of particles was 0,7 and the bulk density of the material - 2600kg/m³.

Tab. 2 - Values of material constants of *Strzelin* granite calculated on the basis of simulation and laboratory uniaxial compression tests

		Model of rock sample	Rock sample
(Ultimate) uniaxial compression strength	σ_C MPa	256,02	248,14
Axial strain at failure	ε_z^F %	0,459	0,493
Secant axial strain modulus at the stress ratio $\sigma_z = 0.5\sigma_C$	E_{s50} GPa	58,2	51,7
Linear axial strain modulus	E_1 GPa	59,3	56,1

On the basis of numerical simulations, similar uniaxial compression strength values σ_C were obtained - similar to those determined on the basis of laboratory tests. Differences between σ_C values did not exceed 4 %. Small differences also occurred in the values of axial strains at the failure; they were less than 7%. The differences of values of the secant E_{s50} and the linear E_1 axial strain moduli, determined on the basis of numerical simulations and laboratory tests, were also relatively small; they did not exceed 9%.

The $\sigma_z=f(\varepsilon_z)$ characteristics determined on the basis of numerical tests were of a quasi-linear shape. In the case of some of the numerical simulations, the laying down part of the $\sigma_z=f(\varepsilon_z)$ characteristic can be treated as the part that predicts an increase in the rate of deformation and fracture of the rock sample. At the same time, the crown of the characteristic $\sigma_z=f(\varepsilon_z)$ at low ratio of compressive stresses σ_z/σ_C seems impossible.

Numerical simulations of direct tensile tests were carried out on two-dimensional models of *Strzelin 2* granite with a height of 168 mm and a diameter of 42 mm (Fig. 5a). The total height of the numerical model of the sample together with the top and bottom grips

was higher, equal to 228 mm. The models were built of approximately 1,600 particles with diameters from, approximately 1,00 mm to 1,50 mm bonded by parallel bonds in approximately 4,200 contact points.

The values of constants describing properties of particles and bonds were the same as in the case of uniaxial compression tests. For the purpose of better compatibility of the stress σ_z - strain ε_z characteristics, the strength values of parallel bonds in the normal and tangential direction were changed; they were equal to 43 MPa.

Top and bottom grips were modelled by grouping particles in the lower and upper part of the model (*group*). To measure stresses σ_z three measuring areas were created - circles with diameters corresponding to the sample diameter, in the lower, middle and upper part of the model. The centres of the upper and lower measuring circles were located at points lying on the lines of contact between the sample and the handles (Fig. 5b).

Numerical models of samples were subjected to brittle tensile macro cracking in quasi-planes lying quasi-perpendicular to the direction of the load. These planes were most often located near to upper or lower grips (see Fig. 5c).

As a result of numerical simulations, ultimate values of uniaxial tensile strength σ_T were similar to those determined by laboratory tests; they were respectively equal to 12,78 and 11,46 MPa (Tabl. 3). Practically the same values of axial strain at failure were obtained F_{ε_z} . There were differences in the values of the secant axial modulus E_{s50} ; they reached 33%.

The $\sigma_z=f(\varepsilon_z)$ characteristics obtained on the basis of laboratory tests were of an extremely nonlinear character (Tomiczek, 2006). It was not possible to calculate the linear axial modulus E_l for rocks subjected to direct tensile tests. The values of the secant axial strain modulus at failure E_{s100} for the numerical and laboratory samples were calculated. These values, equal to 28,9 and 33,0 GPa respectively, were similar; the difference between them did not exceed 13%.

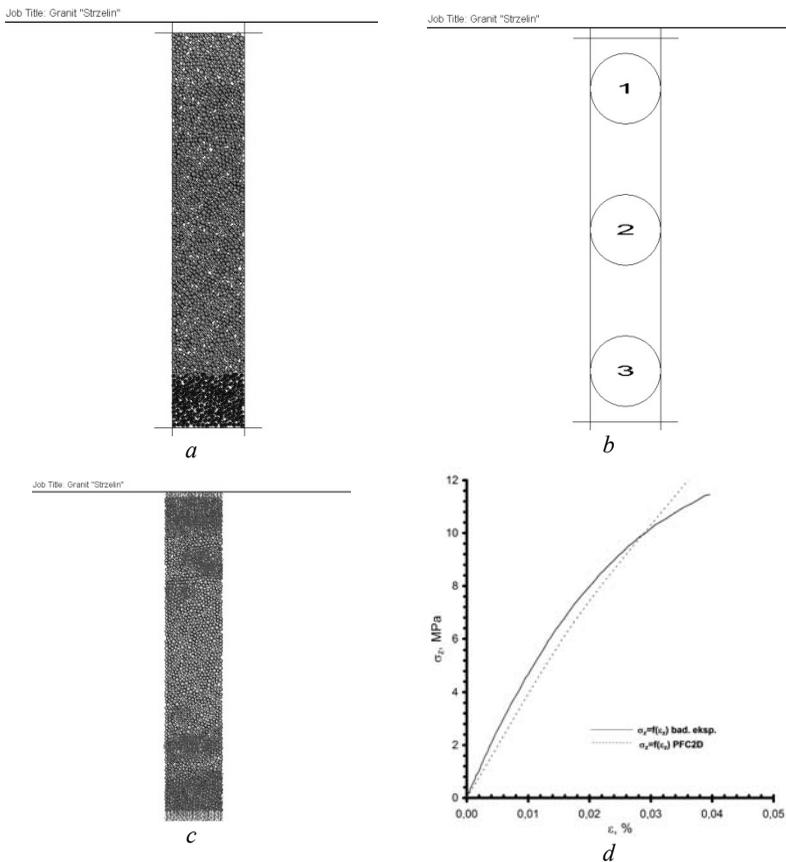


Fig. 5. Two-dimensional model of the *Strzelin* granite glued to the upper and lower grip *a*, location of the measurement circles on the sample *b*, displacement vectors *c* and stress-strain characteristics obtained after laboratory tests (—) and numerical simulations of uniaxial tension test (---)

There were different shapes of the stress characteristics σ_z - strain ϵ_z determined on the basis of numerical simulations and experimental tests (Fig. 5*d*). The characteristics drawn on the basis of numerical simulations of tensile tests were of a quasi-linear shape, whereas those marked on the basis of experimental tests - remarkably non-linear.

Tabl. 3 - Values of material constants of *Strzelin* granite calculated on the basis of numerical simulation and laboratory uniaxial tensile tests

Constant		Model of rock sample	Rock sample
(Ultimate) Uniaxial tension strength	σ_T MPa	12,78	11,46
Axial strain at failure	$F \varepsilon_z$ %	0,0388	0,0396
Secant modulus at the stress ratio $\sigma_z = 0.5\sigma_T$	$E_{s,50}$ GPa	30,4	44,9
Secant modulus at the stress ratio $\sigma_z = \sigma_T$	$E_{s,100}$ GPa	28,9	33,0

Generally, when studying the characteristics of normal stress σ_z - axial strain ε_z , it was found that with this two-dimensional version of the code, σ_T and $F\varepsilon_z$ values determined on the basis of experimental tests might be set as matching to those that had been obtained while testing based on numerical simulations. However, the shape of these characteristics was slightly different. The σ_z - ε_z characteristics determined on the basis of numerical simulations were quasi-linear which distinguished it highly from non-linear characteristics obtained while laboratory testing.

2.2. Numerical simulation of jointed rock mass behaviour near a longwall face

The numerical model was built using the UDEC v.4.0 code. The model's shield dimensions were of 200×100 m ($w \times h$). Above the coal bed, with a thickness of $h_w=2,5$ m were modelled 5 rock layers in the roof with thicknesses: $h_s=2,5$ m, 3,0 m, 17.5m, 20.0m and 30,0 m. In the floor there were two rock layers with thicknesses $h_{sp}=5$ 0 m and 20,0 m.

The exploitation was simulated at the distance from $L_s=10,0$ m to $L_s=80,0$ m, in 10 m steps.

All layers the characteristics of Carboniferous rocks and the Coulomb-Mohr strength criterion were assigned (Tabl. 4).

The lateral edges of the model were free to move along the vertical axis. Points on the bottom edge could not move along the vertical nor horizontal axis.

Tabl. 4 - Basic properties of rocks and bonds

Lp	Rock/bond/support	Parameter		Mean value
1	Sandstones (roof)	Bulk density	ρ , kg/m ³	2700
		Bulk modulus	K , MPa	5800
		Shear modulus	G , MPa	6300
2	Coal	Bulk density	ρ , kg/m ³	1700
		Bulk modulus	K , MPa	1600
		Shear modulus	G , MPa	500
3	Sandstones (floor)	Bulk density	ρ , kg/m ³	2800
		Bulk modulus	K , MPa	6000
		Shear modulus	G , MPa	6500
4	Bonds of the joints	Normal stiffness	k_n , MPa	250-1100
		Tangent stiffness	k_s , MPa	100-450
		Angle of friction	φ , °	9-17
5	Hydraulic mechanical roof support	Maximum load	p_m , MN	10

It was assumed that the roof of the bed was placed at a depth of $z=-660$ m and a vertical component σ_z equal to 16 MPa was applied. The value of σ_z featured the depth of the bed (660 m).

In the model, the assumption that the weakness planes - cracks with an opening (width) of $d_s=0,0$ m were vertically at an angle $\delta=90^\circ$ to rock layers and horizontally $\delta=0^\circ$, separating individual layers, was taken. The distance between vertical cracks d_z was different: for the direct roof with thickness $m_{strb}=(2,5+3,0)$ m and $d_z=1,0$ m and $d_z=2,0$ m, for the fundamental roof $m_{strz}=17,5$ m and $d_z=4,0$ m and for the remaining roof layers with total thickness $m_{str}=(20,0+30,0)$ m - $d_z=8,0$ m and $d_z=16,0$ m (Fig. 6b).

The wall face was outcropped on the length of 1.0m, but on the next 4.0m the roof was supported by elements simulating the mechanized hydraulic support and outcropped on the next 5.0m in the caving part (Fig. 6b).

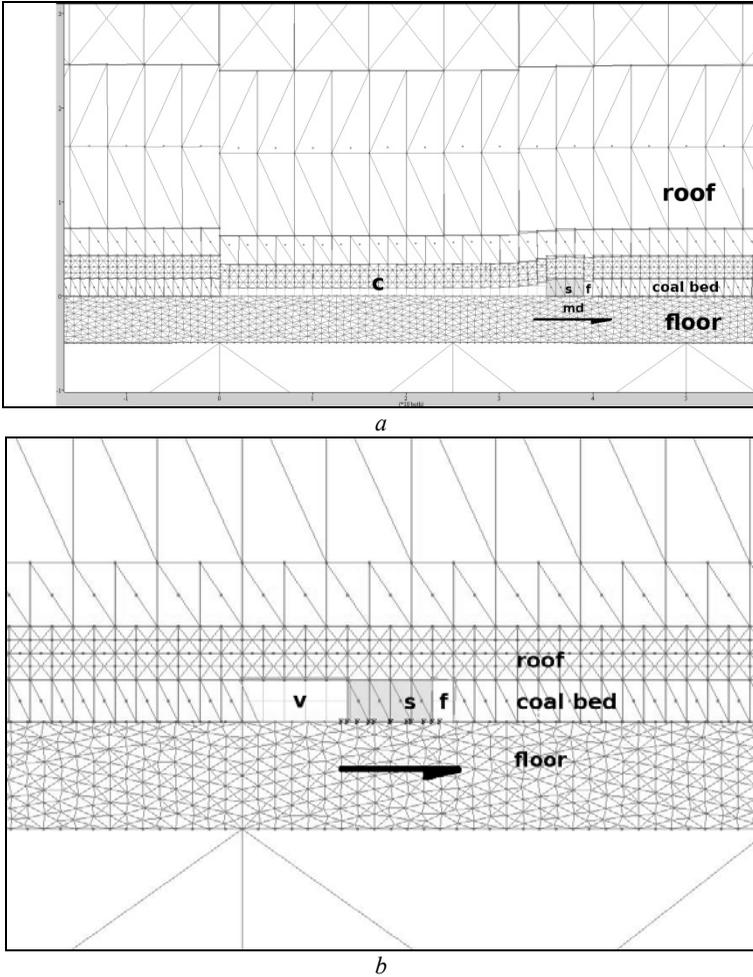
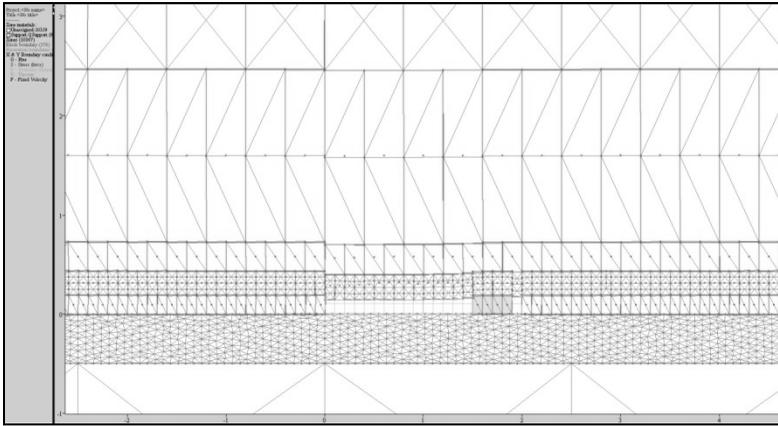
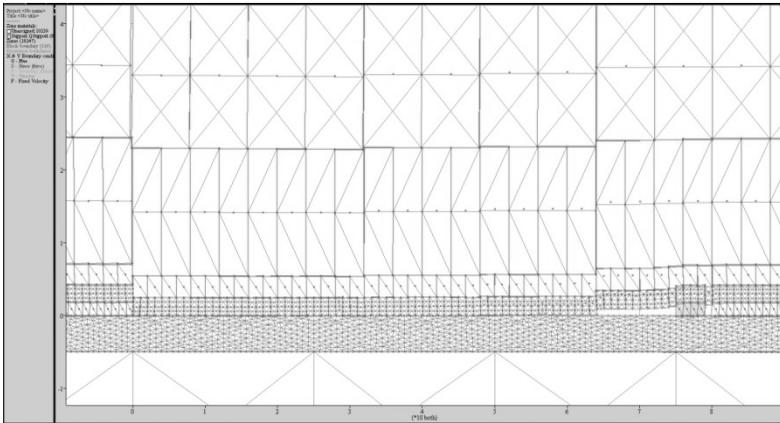


Fig. 6. Model with layers and deformable distinct elements zonation *a* and the immediate vicinity of a longwall face *b*; *f* – longwall face, *s* – mechanical hydraulic support; *md* – mining direction; *c* – cavity; *v* – void cavity

Eight stages of the longwall mining were modelled, each of them had a length of 10m; total longwall advance was $L_s=80$ m. Fig. 7 and 8 show the longwall face vicinity views after the end of mining at the distance of 20 and 80 m.

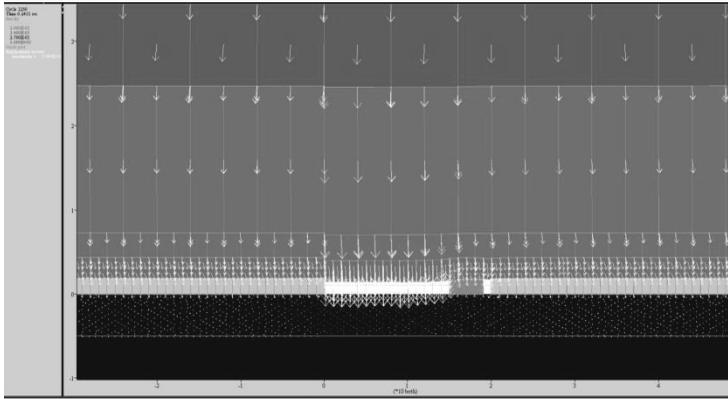


a

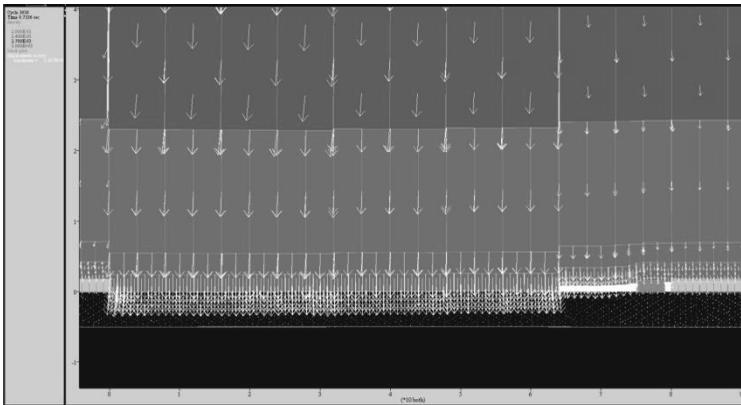


b

Fig. 7. Model after longwall mining the bed on the length $L_s=20$ m -*a* and $L_s=80$ m *b*



a



b

Fig. 8. Vectors of vertical displacement λ_z of blocks after longwall minings of the bed were of $L_s=20$ m - *a* and and $L_s=80$ m - *b*

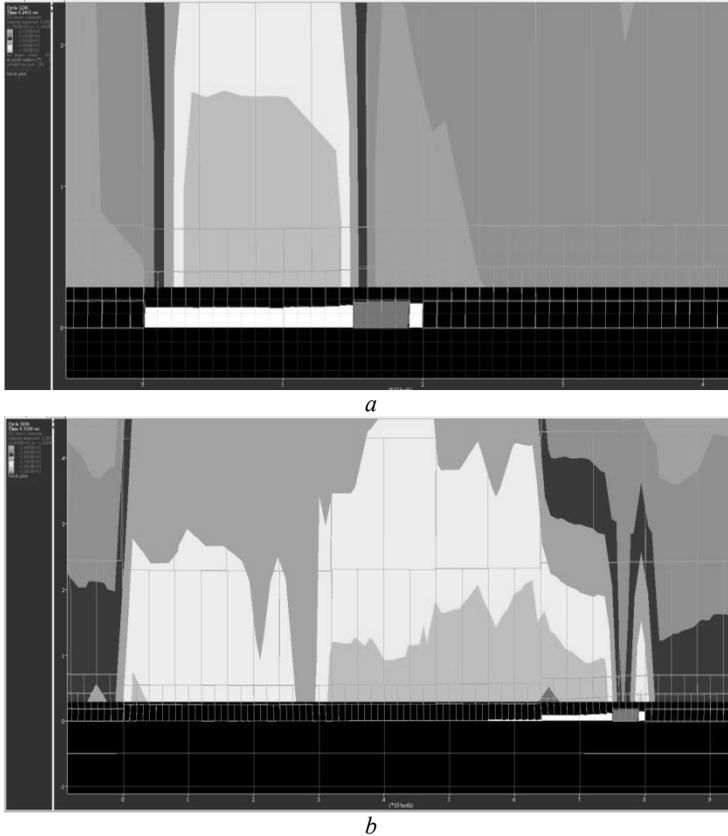


Fig. 9. Vertical stresses σ_z after the longwall minings of the bed were of $L_s=20$ m - *a* and $L_s=80$ m - *b*

Figures 7÷9 present nearby views of longwall mining face after 20m and 80m, i.e. after the 2nd and 8th stage of mining.

After the 2nd stage, the vertical displacements of blocks in the caving and the unfilled part of the caving *void* were clearly visible.

The bold lines at the block edges indicate shear stresses. As the longwall mining progressed, the blocks fell to the caving until the compressed zone was formed.

Maps of vectors distributions of blocks displacements λ_z are shown in Fig. 8. In the second stage, the largest block displacements were 0,6 m in the caving and grew up to 2,4 m in the 8th stage

($L_s=80$ m). In the last stage, the blocks filled the caving cavity. The values of displacement vectors for blocks indicated their separation from the body of rocks and the displacement to the caving.

Fig. 9. presents distributions of vertical stresses σ_z in floor layers. In the UDEC code, the calculated values of stresses were correlated with the shape and size of distinct elements (blocks) that built the model.

Therefore, the shape of stress zones is characterized by a certain irregularity.

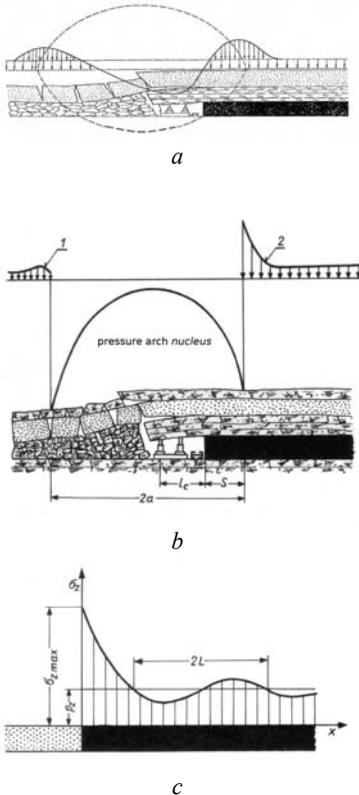


Fig. 10. Distribution of stresses in the vicinity of a longwall excavation according to the theory of pressure arch according to Majcherczyk et al. (a, 2006), Kłeczek (b, 1994) and the theory of pressure waves according to Kłeczek (c, 1994) after: Fayol (1885), Protodiakonov (1912), Budryk (1933), Spruth (1951), Sałustowicz (1950); 1-stress in abandoned workings, 2-oversupport stress in longwall face, l_c -distance between the longwall face and the support, S -range of stress vault, $2a$ -vault width, σ_{max} -maximum stress (exploitation pressure), p_z -vertical stress (primeval), L -pressure wave length

The distribution of stresses is commented for the 8th, final stage of longwall mining ($L_s=80$ m, Fig. 9b). The mechanized hydraulic support is marked in blue, and the void in the front of the wall in white. At a distance of about 3m in front of the longwall face, the

values of vertical stresses σ_z reached about 19MPa. In the longwall face, stress values σ_z decreased to 14MPa.

Above the mechanized hydraulic support, the stress values σ_z rose to around 18MPa and then again decreased to 14MPa directly behind the housing and in the caving. Stresses increased to 16MPa in the compressed caving and reached $(18 \div 19)$ MPa after this zone.

By comparing qualitatively the distribution of stresses determined using the UDEC code (Fig. 9) with selected analytical solutions (Fig. 10), many similarities can be noticed.

These are, among others:

- stress zone over the unexplored part of the bed, where the stress values are close to the *primeval* ones;
- zone of increased stresses in front of the longwall face;
- zone of reduced stresses over the rear part of the mechanized hydraulic support and in the caving;
- increase the value of stresses in the zone of a sealed caving;
- stress zone over the compressed caving, where the stress values are close to the *primeval* ones.

Both, those similarities and the received values of stresses and displacements obtained by means of numerical simulations, allow to assume that the UDEC code is a useful tool for solving problems of stress distributions in joined materials.

4. Summary

Two different programs (PFC2D, UDEC) based on the distinct element method (DEM) were used to solve completely diverse problems of geomechanics and rock mechanics. The first problem was simulation of uniaxial compression and tension of cylindrical rock samples and the second one was to simulate behaviour of the jointed rock mass in the vicinity of a longwall face.

Generally, in the first, PFC2D code, models were made of circular particles, in the second - UDEC - of polygons. Different strength and deformation properties could be assigned to distinct elements and their aggregates.

Both, in case of laboratory tests and the rock masses modelling, satisfactory simulation results were obtained.

In the first case, the stress-axial strain characteristics for the uniaxial compression and tension tests of numerical and laboratory tests were very consistent. Initial test results also indicated compatibility of the stress-lateral deformation characteristics using the 3-dimensional version of PFC3D.

Similarly, in the case of modelling the rock mass behaviour using the UDEC program, taking into account own experience and literature sources as well, proper visualisation of the rock mass behaviour was obtained.

A kind of problem is time-consuming nature of calculations when trying to build complex numerical models consisting of several or several hundred thousand distinct elements.

Certainly both of these programs enable to solve issues of rock and rock mass mechanics.

They enable to conduct numerical simulations for educational purposes and advanced research in areas that require building models of discontinuous and inhomogeneous materials.

Currently, further numerical research is being conducted using programs based on two- and three-dimensional DEM solutions, including, i.e. for solving tasks: testing the dilatancy effect in uniaxial compression tests, simulating the Brazilian and bending tests and the influence of discontinuities on the stability of a rock masses.

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RESOURCE-SAVING TECHNOLOGY OF MAGNETITE QUARZITE UNDERGROUND MINING

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Abstract

The need to involve in the underground extraction the magnetite quartzite underground deposits, which lie in the fields of Kryvbas mines, in order to expand the raw material base of underground mines and reduce the intensity of the development of high-grade ore, is an actual problem.

The carried-out technical and economic analysis of surface-chamber system of development with ore breaking and vibrorelease showed that the technology of magnetite quartzites underground production, which is now applied on Ordzhonikidze mine is characterized by low technical and economic indicators in comparison with similar technology on the basis of dump techniques.

For change patterns establishment of ore extraction indicators from thickness of the cave floor pillar and distance between loading arrivals during the application of the block trench bottom and load-haul-dumpers, the laboratory researches which allowed to establish the floor pillars optimum parameters and the trench bottom design were conducted.

As a result of laboratory studies the regularities of change of indicators of losses and contamination of ore, which allowed to justify the size of the structural elements of trench bottoms blocks was established.

The passport of superficially chamber system of development of thick deposits of magnetite quartzites using load-haul-dumpers, which should be used in the design of underground mining of magnetite quartzite deposits at existing Kryvbas mines is developed.

The developed of high-performance surface-chamber system of development of steeply dipping magnetite quartzites thick deposits with drill carriages and load-haul-dumpers will allow to improve the technical and economic indicators of system in 1, 5-2 times.

Keywords: magnetite quartzites, block parameters, trench bottom, delivery orts,

breakage, loading, ore delivery, ore recovery indicators, equivalent materials, losses, ore contamination.

Actuality of the problem. The problem of expanding the mines resource base and the rational complex use of underground Kryvbas ore resources, which owns the developed infrastructure, established mining household and qualified staff engineers and technical workers, causes the necessity of attraction of magnetite quartzite to development, reserves of which are billions of tons. This will greatly expanding the raw material base of existing mines, reduces the intensity of underground mining of high grade iron ore and increase the lifetime of the mine, as well as playing an important role in the problem solution of complex use of iron ore deposits in the Kryvyi Rih basin. The reserves of magnetite quartzites located on the upper horizons of the operating mines can be fulfilled in the next years at implementation of the minimum reconstruction of main mining developments and cameras on the fulfilled horizons using the existing hoisting units.

Experience of Ordzhonikidze mine has confirmed that the development of magnetite quartzite, located on the upper horizons is possible with a minimum costs on lifting, pumping, ventilation and transportation. But it must be based on high-technology cleaning recess, created in accordance with modern global trends in the development of strong and persistent ores. Therefore, the development and introduction of new technological schemes and high performance systems of magnetite quartzite underground development based on the use of load-hould dumpers is an actual problem, which is of practical importance.

Scientific works of G.M. Malakhov, Yu.P Kaplenko, M.B. Fedko, B.I. Rimarchuk, E.G. Logachev, M.I. Stupnik, V.O. Kalinichenko, V. V. Tsarikovsky, and also mining engineers - production workers O.S. Kolodeznev, T.I. Karamanits, V.V. Peregudov, V.P. Protasov, S.S. Bashtanenko, etc. are devoted to a problem of underground mining of magnetite quartzites in Krivbass. They made the foundation of the theory and practice of ferriferous quartzites development on the operating mines of the basin.

The technical and economic analysis of the applied system of development. Currently, underground mining of magnetite quartzite in

Krivbass by surface-camera system is carried out only at the mine of Ordzhonikidze, which develops on the horizon 527 m of steeply dipping (60-65 °) thick (120-270 m) deposit of magnetite quartzites " Youzhny " of 1050 m long.

The floor pillar and bottom collapse – by fans of deep boreholes, and the pillar – by vertical concentrated charges (VCC). Ore release is processed by vibration installations VDPU-4TM.

For a technical and economic assessment of surface-camera system of development let's give the technological and technical indicators, which were received during the block mining (+22)(+34):

the costs of preparatory workings - 2,18 m/1000 tonnes;

the costs of rifled workings - 1,15 m/1000 tonnes;

ores yield of 1 m of the borehole - 13 tonnes/m;

the cost of explosives on the breaking of ore - 0.508 kg/tonne;

the cost of explosives for secondary crushing - 0.167 kg/tonne;

electricity consumption - 6,5 kW h/t;

VDPU-4TM performance- 500 t/shift;

the performance of one miner by development system - 51 tonnes/shift.

losses of magnetite quartzites during mining: cameras - 4%; "triangle" of the lying part - 36%; floor pillar - 42%; pillar - 46%;

contamination of magnetite quartzites during mining: cameras - 4%; "triangle" of the lying part - 14%; floor pillar - 17%; pillar - 18%.

Analysis of technical and economic indicators of the block mining (+22)÷(+34) horizon. 527 m by surface-chamber system of development with ore breakage by deep boreholes and ore vibrorelease compared with indicators of similar development system, but with the use of load-hould mining dumpers at foreign mines, showed such shortcomings of development system applied at Ordzhonikidze mine:

very complex structure of the block bottom with the ore vibration release with not enough effective ventilation of workplaces;

danger of works at elimination of jams of ore in ore chutes;

big expenses of preparatory and cut developments (3,33 m/1000 ton) compared with systems which apply the load-hould equipment (1,6-1,8 m/1000 ton):

explosives significant costs on the cutting and secondary crushing of ore (0.675 kg) compared with systems that use the load-hould

dumpers (0,450-500 kg / t);

low productivity of vibrorelease and delivery of ore (450 - 500 ton / shift);

low productivity of the drilling foreman on the NKR-100M machine (50 - 60 m/shift) compared with load-hould drilling rigs (90-110 m/shift);

low productivity of one miner on system (50-51 ton/shift) in comparison with systems which apply load-hould dumpers (70-80 ton/shift):

cost value of production of 1 ton of magnetite quartzites in 1, 5-2 times higher compared with systems using load-hould dumpers.

So, the carried-out technical and economic analysis of surface chamber system of development with ore breakage by vertical fans of boreholes and ore vibrorelease allows to draw such conclusion.

The technology of underground production of magnetite quartzites applied now on mine of Ordzhonikidze is characterized by low technical and economic indicators compared with technology on the basis of load-hould boring and delivery equipment.

For the purpose of efficiency increase of magnetite quartzites underground production technology in Krivbass it is necessary to develop and enter the systems of development with use of high-performance load-hould mining dumpers.

Establishment of trench bottom optimum parameters. Floor pillar processing and pillar with the surface-chamber system of development, as mentioned above, it is characterized by significant losses and blockage of ore.

In order to establish the laws of the ore extraction indicators changes from the cave floor pillar thickness and the distance between the loading drives when applying the block trench bottom and load-hould dumpers the laboratory tests, which allow to optimize the floor pillar settings and trench bottom construction were conducted.

Laboratory tests were made on stationary model with the front glass wall constructed in scale 1:100. The bottom of model imitated the trench bottom of the camera 40 m wide and 15 m high, prepared with a bilateral arrangement of loading drives from delivery orts.

As magnetite quartzites of the cave floor pillar the crushed magnetite ore with fineness of 2-3 mm with a volume weight of 2,3 t/m³ was used, and the cave waste rocks, which covered the floor pillar,

were provided by the crushed gray granite with fineness of 3-4 mm.

Horizontal contact "ore -gangue" was created by use of the crushed chalk to the sizes of 0,05-0, 1 mm.

Edge ore release from model on a bottom of the loading drives, which located at distance 10, 12, 14 cm was carried out by doses of 250 g.

The ore release mode – is uniform and consecutive. Release and delivery of ore from model were simulated by the load-hould dumper of firm " Atlas Copco" of EST-3,5 with a loading capacity of 6000 kg with a standard ladle spaciousness by 3 m³. On the basis of the received indicators the dependences of losses and a contamination of the released ore from distance between loading drives are established at a different floor pillar thickness (fig. 1).

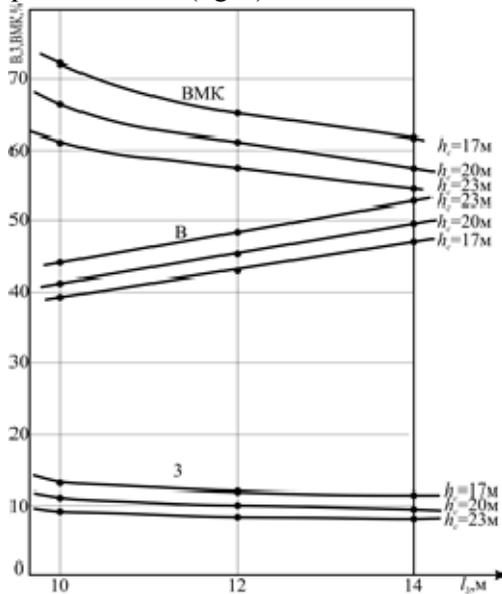


Fig. 1. Dependences graphs of losses In , a contamination Z and recovery of the BMK magnetite quartzites when developing by surface chamber system from thickness of a floor pillar of h_c and distance between loading drives of l_3

Dependency graphs analysis showed that at the same distance between the loading drives with increasing distance between the loading drives with the same floor pillar thickness the ore losses increase

with an increase of floor pillar thickness. Ore losses by increasing the distance between the loading drives with the same floor pillar thickness also increased. This is because the thicker floor pillar and the greater the distance between the loading drives, the larger will be the ridges between the exhaust ore workings at the bottom of the trench.

The contamination of released ore at an equal distance between the loading drives decreases with increasing the floor pillar thickness. This is because the smaller the floor pillar thickness, the greater the accuracy of the waste rock displacement to the ore during release. As we can see the regularities of changes of the released ore contamination values has an opposite character to change the quantities of ore losses. The established change patterns of losses indicators determined as a result of laboratory researches and ore contamination allowed to prove the sizes of constructive elements of the blocks trench bottoms. The optimum size of the trench bottom in specie should be considered: the height of the bottom - 15 meters, the distance between the delivery orts - 20 m, distance between the loading arrivals - 12 m, the distance between the trench and the delivery orts - 10 m.

Development of high-performance surface-chamber development system of magnetite quartzites thick deposits using load-hould mining dumpers.

In the design of the surface-camera system, the following block design parameters are accepted:

camera width behind extension of a deposit- 40 m;

camera height- 50 m;

width of interchamber pillars- 20 m;

thickness of the trench bottom- 15 m;

floor pillar thickness to the level of the retractable horizon above the placed floor of-15 m;

floor pillar thickness considering the cameras bottom part of the abandoned floor - 20-25 m.

Considering the patterns of change in ore extraction indicators at distances between loading drives of 10, 12 and 14 m (see. Fig. 1), as well as requirements of durability ensuring and saving of loading and delivery workings of block trench bottom, the reasonable distance between the loading drives is 12 m.

According to reasonable parameters of the block and constructive

elements of the bottom of the camera the following sizes are established:

distance between delivery orts-	20 m;
distance between the delivery and boring orts-	10 m;
distance between boring orts-	20 g.

The functional workings cross sections for operation of load-haul mining dumpers in them, considering dimensions of load-haul mining dumpers and safety requirements was determined. In development system designing such cross-sectional dimensions of the main workings was dopted:

delivery ort -	3,6×3,8 m
loading drive -	3,8×3,8 m
boring ort-	4×4 m
delivery strike of the main horizon	3,8×3,0.

Development of the recommended design of superficially chamber system using load-haul-dumpers is based on the following assumptions:

camera is placed with the long side crosswise to extension of a deposit;

the block bottom – is trench (fig. 2);

ore recovery – is edge on loading drives;

loading and delivery of ore is carried out by load-haul-dumpers NDM TORO 400 E of Sandvik firm which has big productivity compared with EST-3,5 of firm "Atlas Copco" (fig. 3);

drilling of deep boreholes is carried out by "Sandvik" DL 410-10 or "Sandvik" DL 421-15 drilling rigs;

magnetite quartzites breaking is carried out by vertical fans of deep boreholes from subfloor boring orts;

form of a cleaning stope – is stepped, with an advancing of an upper subfloor in relation to lower;

drilling of a floor pillar is carried out from developments of the bottom of the fulfilled floor blocks.

Calculations of the BPR parameters are executed according to the Instruction of NDGRI [15]. With a diameter of deep boreholes of 110 mm of LNO - 2,65 m, distance between boreholes in a fan - 3,2 m.

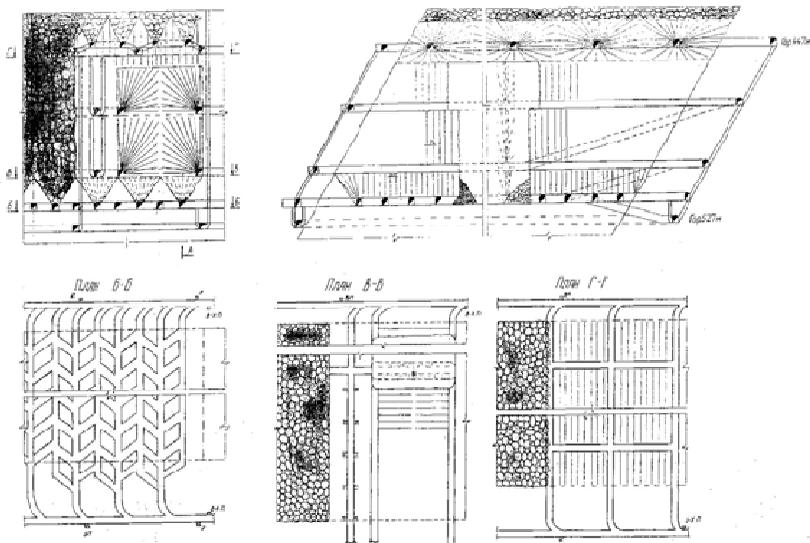


Fig. 4. Surface and chamber system of development of magnetite quartzites thick deposits using modern load-haul mining dumpers

The main calculation technical and economic indicators of the developed system

Chamber reserves of the block, thous. tones	2448
Total length of preparatory developments, m	2925
Total length of cut developments, m	1500
Specific expenses preparatory developments, m/1000 ton	1,19
Specific expenses of cut developments, m/1000 ton	0,61
Total length of boreholes on the block, m	126 648
Recovery of magnetite quartzites from 1 m boreholes, ton	17
Specific expenses of explosive, kg/ton	0,480
Productivity of the master of the Sandvik DL 421-15 drilling rig, m/shift	90-110
Productivity of the driver of a load-haul-dumper, TORO 400E at delivery distance in the ore chute of 120-150 m, t/shift	1000-1200
Productivity of one miner on system of development, t/shift	76
Cost value of 1 ton of magnetite quartzites, UAH/ton	115
Total losses of magnetite quartzites, %	37
General contamination, %	13.

On the basis of the offered technology the passport of surface and chamber system of development of magnetite quartzites powerful deposits using dump techniques which should be used at design of underground mining of magnetite quartzites deposits on the Krivbass operating mines is developed.

Conclusions. Expansion of a raw materials source of underground Krivbass for the purpose of increase in term of iron ore mines existence and reduction prevention of commercial ores production in case of attracting to magnetite quartzites underground production, which lie on the upper horizons in fields of the operating mines, which have sufficient lifting opportunities, the developed infrastructure and the qualified mining personnel.

The development technology of a deposit "Youzhny magnetite", which is currently applied at the Ordzhonikidze mine is still uniform mine of magnetite quartzites underground production in Krivbass and characterized by low technical and economic indicators and insufficient level of safety on release and delivery of ore vibroinstallations in comparison with the advanced foreign mines.

In order to improve the efficiency of ore underground production technology the high-performance surface and chamber system of development with the block trench bottom and with the ore delivery by load-haul-dumpers which is characterized by high technical and economic rates was developed.

Implementation in practice of Krivbass mines operation of the recommended technology of magnetite quartzites underground production will allow to increase the work productivity of one miner by the system of development by 1,5-1,7 times, to reduce costs of preparatory and cut developments for 1000 ton of stocks in 1,8-2 times, the explosives costs of ore secondary crushing in 1,2-1,3 times and to reduce the cost value of 1 ton magnetite quartzites production by 1,5-1,75 times.

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**NUCLEAR-GEOPHYSICAL TECHNOLOGIES
OF “ON-LINE” CONTROL OF THE CHEMICAL
COMPOSITION OF COPPER-CONTAINING
POLYMETALLIC ORES**

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Objective. Developing a unified highly effective on-line control system over the chemical composition of copper-containing polymetallic ores at the mining and processing enterprises of Kazakhmys Holding LLC, which is oriented not only to the profiling (copper) element, but also to the accompanying (silver, cadmium, molybdenum) elements.

Methodology. The basic method of the research is X-ray fluorescent (RFM). This method is considered the most common method of nuclear geophysics in mining enterprises of non-ferrous metallurgy in Kazakhstan. There have been used present day nuclear-geophysical technologies (NGPT), as well as the equipment for "on-line" testing and analyzing ores, products of ore processing, developed in Kazakhstan.

Results. NGPT complex for testing and analyzing ores has been developed and adapted for mining and geological conditions of underground mines, concentrating mills and copper smelteries that allow controlling and managing their quality at different stages of exploration, extraction and processing by content of basic accompanying (silver, cadmium, molybdenum) elements. The bases of the complex are energy dispersive X-ray fluorescent (EDXRF) spectrometers manufactured in Kazakhstan: portable RLP-12RI and RPP-12T, laboratory RLP-21T and stationary conveyor type RLP-21T. The complex provides an effective "on-line" control of the chemical composition of the ores when testing the breakage faces, the bulk of the

mined rock mass, the ore on the belt of the conveyor of the reinforcing factory, mine geological and factory technological samples.

Scientific novelty. The limits of practical application of PPM at the stages of mining and processing operations have been extended. It has been proved that the RFM provides an effective management of the ores quality for all industrial components, including light and associated elements. For the first time it was shown that: geological sampling at mines and control of the chemical composition of ore entering the concentrating factories of “Kazakhmys Holding” LLC can be fully transferred to the NGPM "on-line" ore testing; effective "on-line" control of the silver and cadmium content is practically realized in the case of the contents of these elements in ores from 1 + ppm (including the size of ores on the conveyor belt - 300mm).

Practical relevance. NGPT allow organizing effective on-line control of the chemical composition of ores in the chain: the mine- the quarry- concentrating mill at the “Kazakhmys Holding” LLC. New samples of nuclear-geophysical equipment are introduced into production and are widely used.

Introduction

“Kazakhmys Holding” (Kazakhmys Holding) LLC is the largest copper producer in Kazakhstan. The company includes 13 underground and open pit mines, five concentrators, two copper smelters, two coal mines, a copper wire rod plant, Karagandinskaya GRES, Zhezkazgan and Balkhash Heating Power Stations, an impressive fleet of railway cars (gondolas, dumpcars, tanks for transportation of technical black acid).

The company does everything possible to not only gain a foothold in the top ten world copper producers, but also to increase its assets. The company's shares are listed on the London, Hong Kong and Kazakhstani stock exchanges.

The subject of this work is "on-line" control of the chemical composition of ores at the stages of the mining and, in part, the concentration processing of the company. Determination of the contents of elements in ores is the task of mine testing (mining) and testing of Technical Control Department at concentrating plants (concentration processing). The ore testing operations are an obligatory element for assessing the investment attractiveness of deposits and the operational management of the mining process in order to ensure the release of ore with a planned metal content.

From the point of view of mining, it is important to have not only accurate and maximally complete information on the elemental

composition and content of the main, accompanying and harmful elements (from the point of view of ecology, concentration and metallurgical treatment) in ores along the entire technological chain: exploration, mining and preparatory work (associated mining), purification works (main production), ore stores, ore supplied to the concentrator, but also a significant evidence base to reasonably defend the quality of the ore supplied while distributing the drain metal of the processing factory at the end of the calendar month.

At the mining enterprises of the Zhezkazgan production site, this task was accomplished: the quality of ore in the mines and quarry is controlled on-line by portable EDXRF spectrometers RPP-12, RPP-12R and RPP-12T (19 brigades of X-ray radiometric testing of faces) EDXRF RLP-21T; At Zhezkazgan concentrating factories ZHOF-1 and ZHOF-2, the quality of the ore supplied is controlled by four EDXRF ore monitoring stations (RCS) of the RLP-21T at the input conveyors and EDXRF spectrometers RLP-21T in laboratories. Quality control of ore is carried out both on the basic balance elements of copper, lead and zinc, and on the accompanying balance elements, silver and cadmium [1-5].

EDXRF spectrometers RPP-12T and RLP-21T were used at the mining enterprises of the Karaganda and Balkhash production sites until recently, EDXRF spectrometers RLP-21T were used at the Balkhash, Karagaily and Nurkazgan concentrators. That is, the quality control system was not fully deployed: the EDXRF RKS RLP-21T was not installed at the inlet conveyors of the concentrator factories, the EDXRF spectrometers RPL-12T were not used in mines and quarries, allowing on-line monitoring of the contents silver, cadmium and molybdenum.

The real work is devoted to the completion of the on-line system for controlling the quality of ores at the mining and processing enterprises of the Karaganda and Balkhash regions to the finished form.

The main emphasis in the studies was made on ore control stations:

- two RCS were planned to be installed on heavy belt conveyors No. 2 and No. 2A of Balkhash CP;
- one RKS - on the conveyor belt No. 4 of the Karagaylinsky Concentration Plant;

- one RKS - on the main belt conveyor of the Nurkazgan-underground mine.

The new research cycle is a logical continuation of Zhezkazgan studies, but with much more stringent production tasks: the ore size class is the same (-300 mm), but the ore to the concentrating plants does not come from the same deposits (Zhezkazgan and Zhaman-Aibat - similar deposits of cuprous sandstones), but from diverse deposits:

- sulfide gold-copper-porphyry deposit in Nurkazgan (Cu, Au, Ag, Mo, Se, S);

- stratiform pyrite-copper-lead-zinc deposits of Kusmurn (Cu, Zn, Pb, Au, Ag, Cd, Se, Te, S) and Akbastau (Cu, Zn, Pb, Au, Ag, Cd, Se, S, Te);

- gold-pyrite-copper-lead-zinc deposit in Abyz (Pb, Zn, Cu, Au, Ag, S, Se, Te, Cd, In, Hg);

- Sayak group of copper-skarn deposits (Cu, Mo, Fe, Au, Ag, Bi, Te, Se, Re);

- copper-porphyry Shatyrkol deposit (Cu, Mo, Au, Ag, Te, Se, U).

The ores of these deposits are characterized by a large scale of the contents of the main and accompanying components, low silver content: 1+ ppm (in the Zhezkazgan and Zhaman-Aibat fields, the average silver content is around 15 ppm), a large number of technological varieties. These ores, of course, are a very difficult object for the introduction of NGPM ore testing based on the X-ray fluorescent method (in particular, this applies to ore monitoring stations).

For today in the world non-ferrous metallurgy there are no examples of effective solution of the problem of "on-line" control of ores of class of size - 300 mm and silver and cadmium content from 1+ ppm by X-ray fluorescent method.

The Balkhash concentrating mill (BCM) receives ore from the Konyrat mines, Sayak (Sayak-1 and Tastau mines), Shatyrkol, Nurkazgan, Akzhal, and also the slag from the Balkhash copper smelter.

The Karagailinsky concentrating mill (KCM) receives ore from the Akbastau and Abyz mines.

The Nurkazgan concentrating mill (NCM) receives ore from the Nurkazgan underground mine.

On-line monitoring of the chemical composition of ores of the type RLP-21T at the input conveyors ZHOF-1 and ZHOF-2, the QC departments on the crushers of large crushing type 900/160 (ZHOF-1) and 1500/1800 (ZHOF-2) were abolished. A similar task is posed for BCM and KCM.

At a number of underground mines of the company (Nurkazgan, Zhomart) extracted ore is transported by means of the main belt conveyors. There is still no effective control over the chemical composition of ores on these conveyors. The launch of the RCC on the main belt conveyor of the Nurkazgan-underground mine is the first attempt to cover the effective "on-line" control of this type of ore. Examples of successful solution of the task in the world practice do not exist.

In work [1] there was a question about tests of portable EDXRF spectrometer RPP-12T on mines of Zhezkazgan production site. When introducing the spectrometer into production, we focus on three circumstances: firstly, the RDO at silver mines is the most urgent production task; secondly, in the world market of portable EDXRF spectrometers there are no devices adapted to testing high (4m and higher) faces; thirdly, the average silver content in the ores is at the level of 15 ppm, which (with exposure of measurements at one point of 10 seconds) requires a high level of methodological and mathematical support in the software package to ensure high accuracy of the determined silver content (for example: $15,8 \pm 1,4$ ppm).

In addition to those specified above, the tasks of this work are:

- practical introduction of the RPP-12T spectrometer into the system of geophysical maintenance of underground mining at the mines of the Zhezkazgan production site and at the Zhomart mine;
- practical introduction of the spectrometer RPP-12T at the mining enterprises of the Karaganda and Balkhash production sites.

As a result of the introduction of the RPP-12T spectrometer at the mining enterprises of Kazakhmys Holding LLC, the issue of organizing on-line control of the contents of silver, cadmium, molybdenum, selenium and a number of other elements in ores will be resolved.

The task of increasing the safety of on-line quality control of ores along the walls of underground mine workings remains extremely

urgent. This task is being solved by replacing the EDXRF spectrometer RFP-12 with EDXRF spectrometers of the new generation RPP-12R and PIII-12T.

The work objective

Carrying out a cycle of methodical research and hardware development to create and implement effective on-line system for controlling the chemical composition and quality management of metal-containing polymetallic ores at the stages of mining and, in part, concentrating operations of Kazakhmys Holding LLC based on the most modern hardware, methodological and mathematical support. At the same time, "on-line" control should be conducted not only on the content of the profile (copper) industrial component, but also on all balance components, including the accompanying (silver, in the first place). An important goal is to increase the safety of on-line quality control of ore testing on the walls of underground excavations.

Methodology of studies

The bulk of methodological research and hardware development for the practical implementation of the on-line system for testing ores on heavy belt conveyors of concentrating mills was carried out in Zhezkazgan [1].

Subsequent methodological studies and instrumental developments were aimed at adapting the Zhezkazgan developments to the specificity of the elemental and chemical composition of the ores of the Karaganda and Balkhash fields, developed by the mining enterprises of Kazakhmys Holding LLC.

A series of studies related to the introduction of the on-line method of testing ore on the walls of mine workings and the copper, lead, zinc, silver and cadmium that was sold on the portable EDXRF spectrometer RPP-12T was also implemented in the practice of geophysical maintenance of mining operations and was executed in mines of Zhezkazgan production site.

The research method is X-ray radiometric (X-ray fluorescence) method of testing and analysis of ores, which proved the right for priority use in mining enterprises of Kazakhmys Holding LLC for 40 years.

The equipment is modern nuclear-geophysical equipment manufactured in Kazakhstan ("Aspap Geo" LLC, Alma-Ata is the only producer of EDXRF spectrometers in the Kazakhstan market):

- energy-dispersive X-ray fluorescent (EDXRF) portable spectrometer RPP-12T (assay of ore on the walls of mine workings for 34 elements, including silver); The photo of the spectrometer is given in Fig. 2 and Fig. 3;

- EDXRF ore monitoring station of the type RLP-21T (assay of ore ores on the conveyor belt of the concentrating mill and the main belt conveyor of the underground mine for 6 elements: copper, lead, zinc, silver, cadmium and iron (BCM, KCM) and copper, lead, zinc, silver molybdenum and iron (Nurkazgan-underground mine), photo RCS RLP-21T is given in Figures 1 and 2.

The main components of RKS RLP-21T:

- fan - EBM-PAPST 4414ML;
- X-ray tube - VF-50J / W / S;
- high-voltage power supply - uX50P50 / XCC;
- semiconductor detector - XR-100SDD X-Ray Detector;
- ultrasonic distance sensor - MaxBotix MB7067;
- thermoelectric module - Laird Technologies AA-150-24-44-00-XX.



Front view



Power supply unit

Fig. 1 – RCS RLP-21T



Fig. 2 –View of the probing part RCS RLP-21T

The key elements of the equipment used in the studies:

- silicon drift detector (SDD) with internal collimator and digital signal processor with resolution of $MnK\alpha$ (5,9 keV) 145 eV, high integrated load (more than 100 kHz) and high peak-to-background ratio;

- 50 W X-ray tube with a face-to-face radiation output; combined secondary targets and optimal geometric conditions of measurements (high light-gathering power and sensitivity for elements from Al to U provided for measurements in the air);

- software that allows: to accurately determine the function of the detector response and the spectral composition of the exciting radiation; to reconstruct the spectrum of secondary radiation using the method of least squares and taking into account the dependence of the relative intensities of the characteristic lines on the real composition; to ensure accurate determination of the true intensities of the analytical lines of the elements;

- taking into account matrix effects using fundamental algorithms (including scattered radiation) to compensate for changes in geometric measurement conditions with variations in the real composition and density of the analyzed ore samples;

- high-speed electronics.

For the RCS on the BFU and the Nurkazgan underground mine,

The main factor significantly complicating the use of the X-ray fluorescence method for "on-line" testing of ores on conveyor belts is high lumpiness of ore (class -300 mm). Accounting for the effect of the ore size on the sampling results was carried out using the same

algorithms as the ZHOF-1 and ZHOF-2. At KCM ore size was much smaller (class - 50 mm).

Of the extremely complex analytical solutions for the launch of the RCS on the BCM, KCM and the Nurkazgan-underground mine, the most difficult task was to solve the Balkhash CM. The reason: it was necessary to test in the course of the shift in the on-line mode, both heterogeneous objects - ore deposits, and actually homogeneous objects - dump slag copper smelting plant. The ores are represented by the whole palette of copper contents: rich (Shatyrkol), medium (Sayak-1, Tastau, Nurkazgan), poor (Konyrat) and squalid (Akzhal). In addition to the ore, a dump slag with a very complex element for the X-ray fluorescent method, such as Cu = 1,13%, Zn = 5,91%, Pb = 0,63%, Fe = 46,78%, is supplied to the processing.

To more rigorous production tasks, it was necessary to adapt the apparatus and methodological fragments of the RCS-RLP-21T. And it was done - in all four new RKS-type RLP-21T were installed: more powerful X-ray tubes; silicon drift detectors (SDD) of larger area; the most modern high-speed electronics; upgraded to new, tough analytical software package tasks. As a result of this modernization, the RKS RLP-21T is able to provide a representative on-line testing of ores with low levels of silver, cadmium and molybdenum.

In the RCS RLP-21T intended for the BCM, it was necessary to abandon the unified calibration of the RLP-21T spectrometer and move on to object-based gradings. The procedure for selecting the desired calibration for the processing of secondary spectra is made automatically, depending on the contents of the main elements (as well as iron) and records in the weighted invoices. In the remaining two sets of RKS RLP-21T, the methodology of conducting RROs has been applied, which made it possible to implement the principle that the developers and suppliers of RLP-21 and RLP-21T spectrometers are guided by Aspaz Geo LLC: different RFO facilities, different types of ore, one calibration.

For the convenience of checking the correct operation of the RCS and reducing (up to 3 min) the time for stopping the conveyor to perform this procedure, an artificial test sample is put into the RKS package RLP-21T, which is put on the windows of the X-ray tube and the SDD detector on the end part of the RKS casing and is held

by magnets. The content of elements in the control sample: Cu - 1,38%, Ag - 12,0 ppm, Zn - 0,05%, Pb - 0,2%, Cd - 1,8 ppm, Fe - 4,65%.

The technology of testing the ores was also preserved: the exposure of a single measurement was 1 second; the contents of copper, lead and zinc are given out as an average of 20 single measurements; the content of silver, cadmium and molybdenum - as an average of 40 individual measurements. Only in the Karagailinskaya CM the contents of the elements were given out at five-minute intervals.

Before installation on the conveyors all RKS passed the obligatory stage of bench research. The objects of the research were sets of calibration specially prepared samples of ores from each deposit with known chemical analyzes of all six elements. Each set included three types of samples: powders, a fraction after a roller crusher, a fraction after a jaw crusher. After the suspension of each RCS directly on the conveyors, the whole cycle of studies on the samples was repeated, but taking into account the limitations on the time of stopping the conveyors for research.

In parallel with these studies, the Department of Automated Control Systems was tested software for the systems "RKS-Client BOF", "RKS-Client COF" and "RKS-Client mine Nurkazgan" for recording data on the content of elements in on-line mode, consolidating these data with data on the reception of ore on the railway scales of BCM and KCM and weights on the main pipeline of the Nurkazgan mine, as well as data storage. The system provides access to reports on the work of the RCS to all interested specialists of the corporation.

The portable EDXRF spectrometer RPP-12T in the basic version does not fully correspond to the specific features of the RRA faces on the walls of the mine workings (Figure 3A) of the Zhezkazgan area mines.

It required a major upgrade of the sensor of the device in order to protect the thin beryllium windows of the SDD detector and the X-ray tube from the abrasive surface of the ore. The following parts were added: protective ring; legs-holders of the ring; the assembly of the rod fastening to the sensor, a set of 2-3 rods. Battery power sensor was installed in the first rod.

The upgraded mine version of the sensor of the RPP-12T spectrometer is shown in Fig. 3B.

It should immediately be emphasized that no wearable spectrometer presented in the world market of EDXRF equipment can provide such a level of protection. As an example, the comparison of the probe part of the spectrometer RPP-12T and the probe part of the NITON XL3 spectrometer. The sensor of the spectrometer RPP-12T has much better protection and, therefore, is more reliable and durable in operation. In addition, the sensor's viewing area is increased to 4-5 cm². This is more than the spectrometers presented on the world market.

Briefly about the characteristics of the RPP-12T: a silicon drift detector (SDD) with an area of 25 mm² with thermal cooling and an energy resolution of 140 eV along the 5.9-kV line; device for fixing rods; X-ray tube 50 kV, 4 W; a wireless (bluetooth) scheme for transmitting the signal from the sensor to the instrument; Samsung smartphone with shockproof case; 34 elements: Cu, Zn, Pb, Ag, Cd, As, Se, Ba, Fe, Mo, Mn, Ti, V, Cr, Co, K, Ca, Ni, Ga, Br, Rb, Sr, Zr, Y, In, Pd, Nb, Sn, Sb, Te, Bi, W, Th, U; the surface area of the sampling object is 4-5 cm²; exponent of measurement at one point - from 10 sec.



A. RPP-12T (basic version)



B. RPP-12T (Mining type version)

Fig.3 – EDXRF spectrometer RPP-12T



A. RPP-12T



B. NITON XL3

Fig. 4 – Probing parts of the devices RPP-12T and NITON XL3

The research results

The spectrometer RPP-12T has one more important advantage: the device of registration and processing is the usual smartphone of the latest generation with the Android operating system and impact-resistant casing. This innovation provides high speed, software flexibility, the possibility of voice control of the device, as well as additional possibilities for documenting the results of sampling (photographing the face, determining the coordinates, operative data transfer in the presence of a network). Competitors use portable pocket personal computers, which are much more cumbersome and less productive.

1. RKS RLP-21T on the conveyors of the BCM. At the BCM RKS RLP-21T are installed on the input belt conveyors No. 2 and No. 2A. RKSs were put into operation at the BCM on May 4, 2018 (Fig. 5).



Fig. 5 – RCS RLP-21T on the conveyors №2 и №2A BCM

The results of the RKS RLP-21T operation at the BCM are given in Table 1.

Table 1 - Comparison table of average monthly copper content in the Balkhash Concentration Mill (GK - main building, CCD - crusher of a large crushing body)

Month 2018	Copper content, %		
	Draining GK BCM	RCS	CCD (probe of the QC department)
May	0,85	0,85	0,86
June	0,93	0,93	0,92
July	0,93	0,95	stopped
August	0,92	0,95	stopped

Since July 2018, the point of carload testing of QC department on the CCD 1500/180 crusher has been reduced. As the set of statistical material is being refined, the algorithms for calculating the contents of some ore suppliers are being refined.

Attention should be paid to the fact that during 4,5 months of operation, the maximum silver content recorded by the RCS in one train was 11,5 ppm (Tastau) and 12,3 ppm (dump slag), and the minimum - 1,9 ppm (Kounrad). This is much lower than the level of silver content in ores entering the ZHOF-1 and ZHOF-2. Thus, for the first time in the world practice, EDXRF RKS was able to take such low silver content on ores with a size of - 300 mm.

2. RKS RLP-21T on the conveyor of KCM. RCS RLP-21T is installed on the conveyor №4. The RCS was put into operation at the KCM on July 27, 2018 (Fig. 6). From the dust of the RCS, the RLP-21T was protected by a device in the form of a house. The measurements are made with a discreteness interval of 5 minutes.

The silver content recorded in the RCS in one five-minute measurement was: 19,6 ppm (maximum) and 7,8 ppm (minimum). This is another evidence of the uniqueness of the methodological and mathematical fragments of the RCS RLP-21T.

3. RKS RLP-21T on the main belt conveyor of the Nurkazgan-underground mine. RKS RLP-21T on the mainline belt conveyor of the Nurkazgan-underground mine was put into operation on June 14, 2018 (Fig. 7).



Fig. 6 – RCS RLP-21T on the conveyor of №4 KCM



Fig. 7. – RCS on the conveyor in Nurkazgan underground mine

In contrast to the RCS installed at the BCM and KCM, there were two features in the Nurkazgan underground mine: first, the ore of the

deposit is very poor in silver (average deposit content of 2,9 ppm); secondly, molybdenum is present in the ores, the average content of which in the contours of the balance ores is 140 ppm, in contours of off-balance ores - 81 ppm. There is no information in the literature on successful x-ray fluorescence testing of molybdenum ores on a conveyor belt. In Nurkazgan, the molybdenum content should be determined in the ore with the size of -300 mm.

The interval of discrete output of contents of elements is 5 minutes.

The silver content recorded in the RCS in one five-minute measurement was: 6,5 ppm (maximum) and 1,1 ppm (minimum), molybdenum: 1135 ppm (maximum) and 16 ppm (minimal).

Thus, a unique result has been achieved: nowhere before EDXRF RKS with high accuracy did not determine so low the content of silver and molybdenum in ore of a size of -300 mm on the conveyor belt.

4. PPD faces for silver. As a result of the studies, five portable EDXRF spectrometers RPL-12T were put into permanent operation at the mines of the Zhezkazgan production site (one of them at the Zhomart mine) and one RPT-12T were put into operation at the Karaganda (Belousovsky underground mine) and Balkhash (mine Sayak) production sites.

Thus, for the first time in the practice of geophysical maintenance of mining operations, RRA for silver (and cadmium) of high (4-5 m) faces were realized. At that, the content of silver and cadmium was effectively determined, starting from 1+ ppm.

At the moment, the manufacturer of the spectrometer RPP-12T includes 2-3 meter long rods. This makes it possible to test the faces with a height of up to 4-5 m. For the mining and geological conditions of the Zhezkazgan and Zhomart mines, this is not sufficient. It is possible to work with a large number of rods, but for this it is necessary to equip the crews of the RRA faces with physically strong operators on the sensor, minimize the impact of the sensor on the wall of the mine workings, and exclude the possibility of the sensor falling onto the mine floor.

The REA face-down process with the RPP-12T spectrometer is shown in Fig. 8A. In Fig. 8B shows the process of the RPO faces

with a RPP-12R spectrometer (with a radioactive source of plutonium-238 and a SDD detector). It can be seen that the height of the bottom hole PPB with the RPP-12R spectrometer is much larger than with the RPP-12T spectrometer. Nevertheless, in both pictures the operator with the remote (smartphone) is behind the operator on the sensor, farther from the breasts chest and is in safer conditions. The sensor and the instrument panel are not connected by cable, which also increases the safety of the RRA of the face: in case of a dangerous situation, each operator can leave the RRA site independently.



A. RPP-12T



B. RPP-12R

Fig. 8 – RRO of the stope with devices RPP-12T and RPP-12R

Conclusions

The results of the aggregate of scientific, methodical and mathematical research, based on the latest hardware, are expressed as follows:

1. Nuclear-geophysical technologies (NGPT) were developed on-line for controlling the chemical composition of copper-containing polymetallic ores of a very complex composition, covering the mining (in fact, completely), concentrating (partially)

redistribution of the Kazakh non-ferrous metallurgy flagship of “Kazakhmys Holding” LLC based on X-ray radiometric X-ray fluorescence) method.

2. In practice, it is possible to determine the contents of all the main and almost all associated ore components. Thus, all conditions have been created for controlling the quality of ores in terms of the contents of the main and associated ore components (silver, in the first place). The limits of detection of associated ore components correspond to the tasks of ore quality management.

3. For the first time in the non-ferrous metallurgy in Kazakhstan, it is possible to obtain not only accurate and maximally complete information about the elemental composition and content of the main, accompanying and harmful (from the point of view of ecology, concentrating and metallurgical treatment) elements in ores along the entire technological chain: exploration, mining and preparatory work (associated extraction), purification works (main production), ore stores, ore supplied to the concentrating mill, but also a weighty evidence base for the reasoned shaping the interests of mines and quarries in the distribution of the drainage of concentrating factories after the expiration of a calendar month.

4. The level of management of mining processes at the stage of mining is raised to silver.

This is done for the first time. The task of "on-line" quality control of ores and products of their processing by the content of silver is completely solved at the stages of mining and processing (partially) redistribution. At the underground Nurkazgan mine the task of "on-line" quality control of ores on the content of molybdenum in them was also solved. No one did before these studies on molybdenum on the belt conveyor in the "on-line" mode.

5. The optimal analytical complex of Kazakhstan-made equipment has been selected for the "on-line" chemical composition control developed by the NGPT. These are EDXRF spectrometers: portable RPP-12, RPP-12T, RPP-12R, laboratory RLP-21T, for ore-controlling stations RLP-21T.

These spectrometers are based on an innovative ideology: deposits are different, technological grades of different ores, different processed products - calibration of spectrometers is one.

6. Four ore-monitoring stations RLP-21T were put into operation: two on the Balkhash CM (heavy belt conveyors No. 2 and No. 2A), one on the Karagaily CM (belt conveyor No. 4) - PPO ores on Cu, Pb, Zn, Ag, Cd, Fe and one on the main belt conveyor of the Nurkazgan-underground mine - RRA ores on Cu, Pb, Zn, Ag, Mo, Fe. The problem of "on-line" determination of the contents of the main (Cu, Pb, Zn) and, most importantly, the accompanying (Ag, Cd, Mo) elements at low (1 + ppm) silver, cadmium and 15 + ppm molybdenum ore - 300mm.

7. 8 wearable spectrometers RPP-12T (5 at the Zhezkazgan production site, one at the Karaganda and Balkhash production sites) were put into operation, which allow carrying out the RRA of the faces at silver to the height of the faces up to 4-5 m. Silver at the faces of this height was not determined earlier in Kazakhstan, and not only in Kazakhstan,.

8. The commissioning of EDXRF spectrometers RPP-12T and RPP-12R significantly increased the safety of the RRA process.

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ESTIMATION OF CONTENT OF QUALITY INDEXES OF MINERALS IN ARRAY OF ROGITINUMS OF MAGNETITE AND IN STREAM OF IRON-ORE MASS

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Abstract

Considered basis of the surveyor providing of management content of quality indexes of minerals in the array of Rogitinum of magnetite and in iron-ore streams. For the different stages of the surveyor, providing of management content of quality indexes of minerals used primary signs that got as a result of the surveyor-geological monitoring, office computations of scales 1:500–1:5000 mountain works, mining holes and assay of content of indexes. Analysed forming of content of quality indexes of minerals in the stream of iron-ore mass from the array of balance-industrial supplies that belong to one class, but have different charts of assay of content of indexes, the absolutely identical and alike charts of assay of signs have enterprises that for classifications attribute to the different classes.

Determining the amount of minerals in the stream of iron-ore mass executed by means of weighing, account, measuring, surveys and mountain graphic surveyor documentation of different scales. Statistical analysis and control of content of quality indexes of minerals in the array of Rogitinum of magnetite and in the stream of iron-ore mass, exposure of actual oscillation of descriptions and creation there is an actual task on this basis of rational chart of prognostication of by volume of-quality indexes of minerals. Offered rational chart of collection of information about content of quality indexes of minerals in the array of Rogitinum of magnetite and in the stream of iron-ore mass in those points, where transformation of by volume of-quality indexes of minerals took place, and for enterprises with the linear models of forming of content of quality indexes of minerals in the stream of iron-ore mass the charts of assay of signs are recommended where measuring of descriptions is envisaged on an entrance and exit of system.

The designs of content of quality indexes executed by means of vector-content of quality indexes for the decision of practical tasks, that plugs in consideration each of consumer properties. Study is undertaken in relation to the components of minerals in the array of Rogitinum of magnetite and in the stream of iron-ore mass.

The constituents of signs forming of content of quality indexes of minerals differentiated on the stages in the stream of iron-ore mass taking into account the features of different periods of planning of mountain works and booty of balance-industrial supplies. The complex sign of content of quality indexes of minerals in the array of Rogitinum of magnetite and in the stream of iron-ore mass allows in one estimation to take into account the different groups of indexes of setting, technologicalness, static and dynamic descriptions of exactness, reliability and stabilities.

Entry. Productive work of every extractive unit at the booty of ferrous quartzites arrive at an open method, if certain accordance sticks to between the different project technological types of mountain works. Planning of development of mountain works in the process of exploitation of balance-industrial supplies of areas of array of hard minerals of deposit is the important stage in the decision of questions of technology of mountain production that provides plenitude of mastering of balance supplies of bowels of the earth [1].

At the annual planning of development of mountain works go into detail and specify perspective plans, and also decide concrete technological questions: establishment of volumes of pre-production mining and threaded works taking into account norms on the degree of preparedness of the prepared and ready to the booty balance-industrial supplies exposed, and also task on the volume of commodity products; set experience works that is sent to the improvement of booty of balance-industrial supplies from the bowels of the earth; determine the rational amount of simultaneously working extractive units with the aim of providing of necessary amount and quality of commodity products; set the optimal loading, fold the calendar graphic arts of booty of balance-industrial supplies of ferrous quartzites on every extractive unit and determine terms their redemption. Provision of every extractive power-shovel the industrially-balance supplies prepared to the booty with the different degree of preparedness to the booty, and quarry on the whole, depends on a time domain between loosening of array of ferrous quartzites. Effective work of quarry will be in that case, when time domains between the mass loosening of array of balance-industrial supplies and loosening of array of ferrous quartzites in coalfaces gather, then, when time of mass explosion coincides in all extractive coalfaces. An optimal time domain between the mass loosening of array of balance-industrial supplies in iron-ore careers is in limits from two to three weeks [3–5].

An aim of work is development of methodology of setting of norms of ready of the booty of balance-industrial supplies. For the achievement of the aim such tasks are untied: it is an analysis of present methods of setting of norms of ready to boot of balance-industrial supplies; it is an improvement of existent methodologies of setting of norms of the balance-industrial supplies prepared to the

booty; it is establishment of norms of the balance-industrial supplies prepared to the booty.

An idea of work is an analysis and determination of methods of calculation of optimal of the balance-industrial supplies prepared to the booty for development of economy of ore-mining enterprises and indexes of plenitude of the use of resources of bowels of the earth at present labour and material sources.

A research object is the balance-industrial supplies of ferrous quartzites prepared to the booty.

The article of research is methodology of setting of norms of ready to the booty of balance-industrial supplies.

The system of receipt of primary information is at the surveyor providing of management content of quality indexes of minerals in an array.

Basis of the surveyor providing of management content of quality indexes of minerals in the stream of iron-ore mass is information about a volume and standards of minerals in the array of Rogitiums of magnetite and in iron-ore streams.

For the different stages of the surveyor providing of management content of quality indexes of minerals used primary signs that is got as a result of the surveyor-geological monitoring, to documentation of scales 1:500–1:5000 mountain making, mining holes and charts of assay of indexes. Determining the amount of minerals in the stream of iron-ore mass executed by means of weighing, account, measuring, surveys and mountain graphic surveyor-geological documentation of corresponding scale. The objects of mountain graphic surveyor information are areas of ore bodies and beds deposits of balance-industrial supplies, that is exposed by the mountain making and mining holes. On results documentation studied the structure of areas of ore body and bed put the deposits of Rogitiums of magnetite, feature of morphology and structure [1–5].

A basic method of estimation of content of quality indexes of minerals is an assay of signs of indexes chemical and mineral component minerals and containing breeds, фізико-механічних and technological properties. On the different stages of secret service, booty of balance-industrial supplies, assay it is carried out in mining holes and mountain making. In the process of exploitation executed the assay of signs of indexes of array of Rogitiums of magnetite (in

the mountain making and blastholes) and in the stream of iron-ore mass (in transport and capacity elements).

Minerals were subject a commodity assay in the stream of iron-ore mass, that shipped to the consumer on the exception of content of quality indexes of the iron related to magnetite, Fe_{mg} .

At determination of content of quality indexes of useful components used chemical and mineralogical analyses and geophysical methods of express-analysis. A capture of basic data is about the amount of balance-industrial supplies and content of quality indexes of minerals in a stream in the stream of iron-ore mass, carried out in the process of receipt of mountain graphic surveyor-geological information, documentation and assay of signs of indexes at the industrial and operating secret service detailed, directly during exploitation of areas of ore body and bed of deposit of balance-industrial supplies and assay of the prepared products.

Totality of all processes of receipt of primary mountain graphic surveyor information in scales 1:500–1:5000 there is realization of functions of the surveyor providing of management – measuring and determination of location of points of assay of signs of indexes and estimation of amount of minerals in the array of Rogitinums of magnetite and in the stream of iron-ore mass.

Amount of obtained and the shipped minerals determined gravimetric and statistical methods, surveyor providing of works at monitoring and stowage of mountain graphic surveyor documentation and determination of volumes of mine-out space or on compositions of averaging of content of quality indexes of minerals. Weighing of trolleys with minerals executed on mine, quarry and mine scales that are on operating horizons, in around barrel court and on compositions of averaging of content of quality indexes of minerals. In default of executed a statistical account trolleys with minerals, coming from a carrying capacity, degree of filling, coefficient of loosening of mountain mass. The methods of determination of volumes of the obtained balance-industrial supplies and bits and pieces of minerals on compositions of усреднения of content of quality indexes of minerals executed on the basis of the surveyor measuring, surveys and mountain graphic surveyor documentation [3–5].

Secret service of areas of ore body and bed of deposit of balance-industrial supplies was subdivided into detailed, industrial and

operating. The detailed secret service is conducted to exploitation of areas of ore body and bed of deposit of Rogitiums of magnetite by geological exploration organization. The closeness of reconnaissance network was determined by complication of geological structure of areas of ore body and bed of deposit of balance-industrial supplies, majority from that is difficult (**II** and **III** of group for classifications of the State committee of supplies). The detailed secret service was carried out by the ore-bore systems with detailed that does not exceed the category of **B**. Information was used for the current planning of mountain works and content of quality indexes of minerals in in the array of Rogitiums of magnetite and in the stream of iron-ore mass and at the perspective planning of booty of balance-industrial supplies.

Industrial supplementary exploration conducted on areas ore bodies and beds of deposit of Rogitiums of magnetite, applying the boring and the ore-boring systems of secret service for networks and lines. At the irregular location of making on the areas of ore bodies and beds of deposit of balance-industrial supplies found out on categories **B**, **C₁** and **C₂**, and for the separate districts of Krivbass on categories **A**, **B** and **C₁**. Distance between makings to one direction consistently twice condensed in transition from subzero to the higher categories reconversion. An iron-ore zone was tested on all power. Length of tests hesitated from 0,1 to 3 m. conducted Operating secret service the mountain, boring systems irregularly, for networks and lines at distance between making, that answers the maximal closeness of industrial secret service and length of tests presents about 1 m in middle.

A chemical assay on the ore-minig enterprises of Krivbass is complemented by geophysical. On the stage of industrial secret service distance between making approximately answers the sizes of operating blocks or proceeding units. Operating secret service was carried out on more thick network, so that distances between reconnaissance cuts far fewer sizes of operating blocks and answers the parameters of structural elements of proceeding unit.

These assays on these stages of secret service provided information for the perspective and current planning of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass.

The structure of the system and methodology of operating assay was determined by changeability of standards and properties of balance-industrial supplies of hard minerals, complication of technology and organization of process of booty, by the requirements of consumers to content of quality indexes of the iron related to magnetite, Fe_{mg} . The assays of signs of indexes of minerals conducted in the array of balance-industrial supplies and in the stream of iron-ore mass. The points of assay are transport and capacity elements of technological chain. Information about content of quality indexes of minerals in the stream of iron-ore mass on all stages, where her transformation was is the ideal chart of assay, however on enterprises such chart of assay fully is not realized. A rational chart, leaning against a limit number of points of assay, gives necessary and sufficient information for the effective surveyor providing of management content of quality indexes of minerals in the array of Rogitinums of magnetite and in a stream in the stream of iron-ore mass on all stages, where her transformation was is the ideal chart of assay, however on enterprises such chart of assay fully is not realized. A rational chart, leaning against a limit number of points of assay, gives necessary and sufficient information for the effective surveyor providing of management content of quality indexes of minerals in the array of Rogitinums of magnetite and in the stream of iron-ore mass.

Existing on careers and mines of Krivbass the system of assay of signs of indexes of minerals in the array of Rogitinums of magnetite and in the stream of iron-ore mass is oriented to the receipt of information about content of quality indexes of minerals of streams of iron-ore mass from the array of Rogitinums of magnetite of coal-faces, blocks, areas, quarries, mines, shipped on the exception of content of quality indexes of the iron related to magnetite Fe_{mg} .

About content of quality indexes of minerals in the stream of iron-ore mass from the array of Rogitinums of magnetite, coalfaces information was obtained by the assay of signs of indexes of ore array (mining holes and making), iron-ore mass in invasions, boxhole (or at producing from boxhole), flitting transport.

The points of assay of sectional and district streams of iron-ore mass are invasions and transport vessels. Content of quality signs of minerals in the stream of iron-ore mass from the array of Rogitinums

of magnetite of quarries and mines was determined by the assay of signs of indexes of iron-ore mass in transport vessels before getting up or then in bunkers. The assays of the shipped minerals in the stream of iron-ore mass executed on compositions averaging of content of quality indexes of minerals and in transport capacities. Minerals in the stream of iron-ore mass tested on a thundershower the classifiers of ore mining and processing factory and on conveyers after growing shallow. Operating on careers and mines of the system of assay of signs of indexes does not depend on complication of processes of forming of content of quality indexes of minerals in the stream of iron-ore mass and does not answer the task of optimal informative result of processes of the surveyor providing of management content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass.

By a main defect them there is an incommunication with complication of processes of forming of streams of iron-ore mass from the array of Rogitiums of magnetite, that represented the models of content of quality indexes of minerals in the stream of iron-ore mass. A rational chart envisages collection of information about content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass in those points, where transformation of by volume of-quality indexes of minerals took place. For enterprises with the linear models of forming of content of quality indexes of minerals in the stream of iron-ore mass recommended the simple charts of assay of signs of indexes that envisaged measuring of descriptions on an entrance and exit of the system.

At presence of local into complex or intercomplex complications set the additional points of assay of signs of indexes of minerals in the stream of iron-ore mass. Enterprises with the consilient or different models of forming of content of quality indexes of minerals in the stream of iron-ore mass have these assays of signs of indexes on an entrance and exit of the system, and also in those points, where single streams meet or a general stream goes away on single. In points assays controlled the results of local transformations of content of quality indexes of minerals in the stream of iron-ore mass.

On enterprises with the combined models of content of quality indexes of minerals in the stream of iron-ore mass of chart of assay is

difficult. There is a necessity to envisage control of content of quality indexes of minerals in iron-ore mass in those points, where streams meet, go away or yield to local transformation of content of quality indexes of minerals in a stream iron-ore mass the concrete structure of chart was chosen in accordance with the features of model of enterprise. At the observance of the considered requirements of chart of assay of signs of indexes does not provide necessary information the system of the surveyor providing of management content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass, as a number of levels limit. In this connection the task of statistical analysis and control of content of quality indexes of minerals becomes actual in the array of Rogitiums of magnetite and in the stream of iron-ore mass, exposure of actual oscillation of descriptions and creation on this basis of rational chart of prognostication of by volume of-quality indexes useful minerals.

Structure, base, statistical and dynamic signs of content of quality indexes of minerals.

The surveyor providing of management content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass of ore-mining enterprises contains establishment and forming of optimal structure of indexes of content of quality indexes of minerals in the stream of iron-ore mass by a systematic and purposeful study and influence on terms, factors and parameters of secret service of areas of ore body and bed of deposit, booty of balance-industrial supply and exception content quality index iron, related to magnetite, Fe_{mg} in iron-ore mass [8,11].

Content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass, them quality indexes description a multidimensional vector with the components of C_1, C_2, \dots, C_K , that influence on motion results of technological processes of exception of content of quality indexes of the iron related to magnetite, Fe_{M_2} in iron-ore mass. Design of content of quality indexes of vector-content quality indexes plugs all consumer properties in consideration, but for the decision of practical tasks the account of possible consumer properties is unacceptable and researches conducted in relation to any component of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass [9,10].

An ore mining and processing factory or metallurgical plant is interested by those properties of content of quality indexes of minerals, that determine the nomenclature of eventual products and parameters of process of exception of content of quality indexes expressed by single indexes, rarer – group. At the surveyor providing of management content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass, that is sent to providing of requirements of exception of content of quality indexes of the iron related to magnetite, Fe_{mg} used the single signs of content of quality indexes of minerals.

In accordance with a theory [1,6], the system of signs of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass reflects properties and specific of products in relation to the certain modes of production and terms of consumption. The constituents of signs forming of content of quality indexes of minerals differentiated on the stages in the stream of iron-ore mass from taking into account the features of different periods of planning. Being based thereon, examined systematization of indexes of content of quality indexes of minerals in the stream of iron-ore mass for the use of them in a theory and practice of the surveyor providing of management content of quality indexes of minerals in the array of Rogitiums of magnetite.

Content of quality indexes of minerals in the stream of iron-ore mass in the process of the creation exists in forms that transformed consistently one in other at forming of iron-ore stream. The different forms of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass described different indexes that differ in the quality indexes of static objects (minerals are in balance-industrial supplies) from the quality indexes of dynamic objects (minerals from the array of Rogitiums of magnetite loosening, obtained, and shipped). Today the component assays of signs of indexes are not reasonable for description of forms of existence of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass.

In relation to properties of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass, coming from an aim, estimation of assay of signs of indexes and terms of exception of

content of quality indexes of iron related to magnetite, Fe_{mg} in iron-ore mass, distinguished groups: setting, technological, transportable, maintenance, exactness, reliability and stability. The indexes of setting of minerals play a leading role at the estimation of level of signs of indexes of minerals included in the criterion of optimization of process of the surveyor providing of management content of quality indexes of minerals in the array of Rogitinums of magnetite and in the stream of iron-ore mass. To the indexes, setting took basic and concomitant minerals or connections.

The technologicalness characterizes efficiency of exception of minerals at enriching and metallurgical redistribution of content of quality indexes of the iron related to magnetite, Fe_{mg} . To them took content of harmful admixtures, oxidized phases, durability, granulometric composition of minerals, grain-size distribution, humidity and other. Characterized the capacity of minerals the indexes of transportability for moving transport vehicles. In this group enters: granulometric composition of minerals in the stream of iron-ore mass, humidity, adherence and solidifying. To the indexes adherence of maintenance take oxidization of minerals and inclination them to solidifying.

Characterized the indexes of exactness, reliability and stability with the set probability an error, authenticity and changeability (in time or in space) of values of the enumerated indexes of substance. To it group standard deviation, error of middle, dispersion, coefficient of variation, scope and other, enters. Without establishment of these indexes estimation of substance indexes of setting, technologicalness and loses definiteness.

At the estimation of content of quality indexes of minerals in the array of Rogitinums of magnetite and in the stream of iron-ore mass, as well as any industrial products, the measured indexes compared the assay of signs of indexes of minerals with base. Base is content of quality indexes of minerals in the array of Rogitinums of magnetite and in the stream of iron-ore mass of some эталона, normative or plan index [1,7].

The choice of the system of base assay of signs of indexes of minerals depends on the aim of estimation, form of existence of content of quality indexes of minerals, phase and period of the surveyor providing of management content of quality indexes of

minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass. For the estimation of assay of signs of indexes of minerals in the stream of iron-ore mass as base used industrial standards that present by a soba totality of requirements to content of quality indexes of minerals in the bowels of the earth, mining-and-geological (industrially-balance supplies, system of development) and other terms of development. Numeral these are the maximum values of taken for standard parameters that establishment for the areas of ore body and bed of deposit of Rogitiums of magnetite.

The observance of standards allows to divide the supplies of minerals by folk-economic value on balance and balanced. Composition of standard indexes, what applicable for the concrete areas of ore body and bed of deposit, depend on the type of minerals, features of method of his development (exposed, preparation, ready to taking out, unindignant, indignation, passive and active). In accordance with materials of inspection, the basic index of standards is minimum industrial content of quality indexes of useful components in a block, that is calculated and will be used on the areas of ore body and bed of deposit of Rogitiums of magnetite.

For formation of balance-industrial supplies the value of side content of useful components was taken in a test. All other indexes of standards used as base. Requirements to content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass of preferentially. Such indexes are: it is side content of quality indexes useful components in a test for forming supplies; it is minimum industrial content of quality indexes of useful components in making, that was formed; are requirements to the selection of types and sorts of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass; it is a possible coefficient of ore-bearingness; contain minimum quality indexes of passing components.

Researchers [1,7,11] mark, that standards, what stated for the areas of ore body and bed of deposit of balance-industrial supplies, on the whole enumerate in 5-15, not fully answer the task of the optimal use to content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass.

On the stage of project of development it is conditioned by that geological standards do not take into account the features of

mastering of areas of ore body and bed of deposit and order of working off the supplies of different content of quality indexes of minerals, and on the stage of exploitation the set standards that used as base indexes at the estimation of assay of signs of indexes of minerals in the stream of iron-ore mass. In works [1,7,11], reasonably constituents of maximum indexes of content of quality indexes of minerals are in the array of Rogitinums of magnetite (operating standards) on mines. Basic setting of that – to set in the concrete mining and geological conditions developments are a standard of industrial supplies of separate areas of ore body and bed of deposit of Rogitinums of magnetite and standard of iron-ore stream on the different levels of his forming.

Nomenclature of maximum indexes of content of quality indexes of minerals in the array of Rogitinums of magnetite and in the stream of iron-ore mass (operating standards), from that it is recommended as base at an estimation assays of signs of indexes of level of content of quality indexes of minerals in the stream of iron-ore mass following:

a - minimum industrial content of quality indexes of useful components at the balance-industrial supplies of виймальної unit (to the block) prepared to taking out - $C_{m.in}$;

б - side content of quality indexes of useful components on the contour of balance-industrial supplies of виймальної unit - $C_{б.in}$;

в - minimum industrial content of quality indexes of useful components in the stream of iron-ore mass is $C_{m.p}$, for the division of loosening minerals in the stream of iron-ore mass on a standard, for the exception of content of quality indexes of the iron related to magnetite, Fe_{mg} , and unstandard, that left in the array of Rogitinums of magnetite or transported in a dump;

г - minimum-normative content of quality indexes of useful components in the array of Rogitinums of magnetite and in the stream of iron-ore mass for planning period (average annual, middle quartal, average monthly) - $C_{n.p}$.

First two indexes of "a" and "б" - base for determination of level of content of quality indexes of minerals in the stream of iron-ore mass in within the limits of units, and two other - "в" and "г" estimation of level of content of quality indexes of minerals on the stages of forming and different periods of the surveyor providing of

management content of quality indexes of minerals in the array of Rogitinums of magnetite and in the stream of iron-ore mass.

By base indexes for determination of level of quality indexes of the prepared products of quarries and mines – content of quality indexes of minerals in the stream of commodity iron-ore mass is requirements of standards and technical requirements.

As marked [16,17], standardization of content of quality indexes of minerals in the array of Rogitinums of magnetite and in the stream of iron-ore mass is at low level that is determined by complication and unicity of geological terms of areas of ore body and bed of deposit of Rogitinums of magnetite (especially content of quality indexes of minerals in the stream of iron-ore mass).

In the technical requirements of ore-mining enterprises (given on 6 careers and 8 mines of Krivbass) the next maximum indexes of content of quality indexes of minerals are envisaged in the array of Rogitinums of magnetite and in the stream of iron-ore mass, that is today taken for basic: normal-planning content of quality indexes of valuable useful components on all inspected careers and mines; content of brack of quality indexes of minerals; legitimate values of humidity and granulometric composition of minerals in the stream of iron-ore mass; contain possible harmful admixtures, additions, oxidized phase et al. Operating on mines and careers of Krivbass the system of base signs of content of quality indexes of minerals in the stream of iron-ore mass plugs only the requirements of geological standards in the quality indexes of minerals in the balance supplies of bowels of the earth and requirement of technical requirements to the minerals in commodity iron-ore mass.

A process of creation of content of quality indexes of minerals is in the stream of iron-ore mass both on phases and periods of the surveyor providing of management and on the forms of existence out of control, as management criteria, base indexes of content of quality signs are abscent. Rational system of base indexes, that provides the effective surveyor providing of management content of quality indexes of minerals in the array of Rogitinums of magnetite and in the stream of iron-ore mass, except the requirements of geological standards and technical requirements plugs the maximum operating signs of content of quality indexes of minerals in the stream of iron-ore mass. Minimum industrial and side content of quality indexes of

components in releasable unit determines the level of content of quality indexes of minerals in the array of Rogitiums of magnetite at the current and perspective planning of mountain works. By means of minimum-industrial and planning contents of quality indexes of components in the array of Rogitiums of magnetite and in the stream of iron-ore mass estimated the level of quality indexes loosening, shipped and закладованих of minerals for different phases and management periods.

The lack of the existent system of base indexes is absence in her structure of indexes of exactness in the system of base signs causes the necessity of receipt of them reliability and stability and for the actually measured sizes. Forming of content of quality indexes of minerals in the stream of iron-ore mass that presents by a soba from the mathematical point of view casual process, on the separate stages of process, that answer the certain forms of existence of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass. Description statistical distribution casual sizes – measuring quality indexes of descriptions of minerals in the stream of iron-ore mass.

An estimation of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass is estimation of parameters of distribution verification of accordance of empiric distributions is preceded that to the theoretical models of content of quality indexes of minerals in the stream of iron-ore mass.

Undertaken studies [12,15,17], all variety of content of quality indexes of minerals in the stream of iron-ore mass is erected to three basic theoretical models of distribution of content of quality indexes of minerals in an array Rogitiums of magnetite and in the stream of iron-ore mass there is an estimation of parameters of distribution verification of accordance of empiric distributions is preceded that to the theoretical models of content of quality indexes of minerals in the stream of iron-ore mass is erected to three basic theoretical models of distribution of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass – normal, logarithmic normal (lognormal) and reflected lognormal (Fig. 1, table 1). The choice of these models is comfortable that all statistical criteria and tables are built for the normal law of distribution of casual sizes. Verification of accordance of empiric

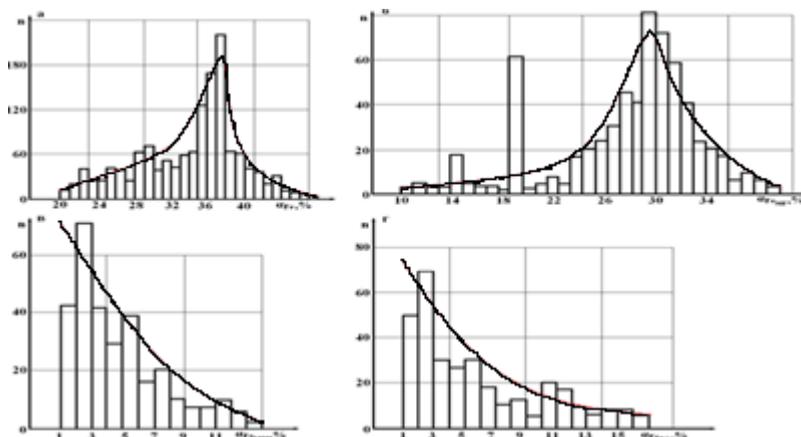


Fig. 1. Content of quality indexes of Rogitunums of IV of area of quarry of "ПівдГЗК" and is iron a common; δ – is the iron related to magnetite, Fe_{mg} ; $\theta-$ in is an anhydroferrite; z - carbonate silicate

distributions to these models was conducted by means of comparison of estimations to asymmetry A also excess of S with basic errors, and for the criterion of accordance χ was used control of the got conclusions 2 of Pierson [7,13,14].

For homogeneous totalities for known formulas the selective estimations of statistical parameters of distribution of indexes χ of functions of $\ln\chi$ and $\ln(c-\chi)$ are calculated: position of center of distribution (AV), description of dispersion (dispersion, standard deviation, standard error of middle, coefficient of variation, asymmetry and excess).

As the convincing, reasonable, undisplaced and effective estimation of center of empiric distribution (at нерівноточних supervisions) sizes are accepted middle self-weighted arithmetic for normal distribution and maximally plausible estimation middle self-weighted arithmetic for asymmetric distributions (lognormal and reflected lognormal).

The considered indexes are attributed to statistical descriptions of oscillation of content of quality indexes of minerals in the balance-industrial supplies of bowels of the earth or iron-ore streams that is describe content of quality indexes of minerals in in the balance-industrial supplies of bowels of the earth or iron-ore streams that is describe content of quality indexes of minerals in the stream of iron-

Table 1 - Statistical characteristics of the content of qualitative indices of minerals in an array of magnetite cornices and in the flow of iron ore by the levels of formation of iron ore masses at the Kryvybas mining enterprises

Enterprise (mine, quarry)	Levels of formation of content of qualitative indices of minerals in a stream of iron-ore mass from an array of magnetite cornices					
	coalface		mine, quarry		Mining or concentrating factory	
	Coefficient of variation, V , %	Kind of model	Coefficient of variation, V , %	Kind of model	Coefficient of variation, V , %	Kind of model
Quarry ПрАТ «ІнГЗК»	18,4	L	12,7	1- L	19,4	N
Quarry ПрАТ «ПвдГЗК»	25,5	1- L	26,4	N	25,9	N
Quarry № 2-bis, ПрАТ «НкГЗК» «ArcelorMittal Kryviy Rih»	17,8	L	16,3	1- L	18,8	N
Головатський quarry ПрАТ «ДГЗК»	24,1	1- L	27,8	N	25,7	N
Ганнівський quarry ПрАТ «ПвнГЗК»	18,7	1- L	17,6	N	17,3	N
Гернівський quarry ПрАТ «ПвнГЗК»	21,4	1- L	20,3	N	21,5	N
«Mining control department under the underground mining method on mine rights» ПрАТ «ArcelorMittal Kryviy Rih»	41,7	L	20,2	N	22,6	N
Міне «Жовтнева» ПрАТ «КЗРК»	21,3	N	22,5	N	23,4	N
Міне «Орджонікідзе» ПрАТ «ПГЗК»	21,8	1- L	24,1	N	21,7	N
Міне «Батьківщина» ПрАТ «КЗРК»	34,3	L	23,5	N	26,6	N
Міне «ім. Фрунзе» ПрАТ «КЗРК»	43,7	N	26,5	N	21,5	N
ПрАТ «ЕВРАЗ «Суша Балка»	23,5	L	22,3	N	28,1	N
Міне «Гернівська» ПрАТ «КЗРК»	17,9	1- L	18,2	N	15,6	N
Міне «Гвардійська» ПрАТ «КЗРК»	16,6	N	16,7	1- L	16,2	N

Note. Types of models: N – normal, L – lognormal, 1- L – reflected lognormal

ore mass. The process of his forming is one-sided – from the point of view of dispersion of descriptions of content of quality indexes of minerals in the stream of iron-ore mass in the fixed-static states of iron-ore stream in relation to the center of distribution.

Dynamic indexes gave complete description to content of quality indexes of minerals in an iron-ore stream, as reflect temporal changeability of content of quality indexes of minerals in the stream of iron-ore mass on all interval of iron-ore stream or in separate temporal intervals. Examining an area as industrial supplies for that the temporal sequence of loosening of minerals is set, as an initial iron-ore stream of Rogitiums of magnetite. Spatial changeability of minerals in the balance supplies of bowels of the earth on certain directions characterize the same dynamic indexes.

Oscillation of content of quality indexes of minerals in the stream of iron-ore mass (in relation to some component of X) presented by the function of $X(t)$ of temporal or spatial changeable t . An estimation of dynamic signs of content of quality indexes of minerals in the stream of iron-ore mass is being of statistical descriptions of casual function of $X(t)$. Non-stationary casual sequences over are brought to stationary by deduction of linear тренда from the initial row of values. The estimation of structure of changeability of casual sequence of dynamic row of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass is certain statistical descriptions: the expected value, dispersion and autocorrelation function [15-18]

$$\tilde{M}(X) = \frac{1}{n} \sum_{i=1}^n X(t_i), \quad (1)$$

$$D(X) = \frac{1}{n-1} \sum_{i=1}^n [X(t_i) - \tilde{M}(X)]^2, \quad (2)$$

$$\tilde{K}_x(h_m) = \frac{1}{n-m} [X(t_i) - \tilde{M}(X)] [X(t_{i+m}) - \tilde{M}(X)], \quad (3)$$

where $h_m = t_{i+m} - t_i$

An autocorrelation function characterizes the degree of dependence of values of casual function in cuts that is taken to different t , that gives the evident picture of that, how dependence between the members of dynamic row of content of quality indexes of minerals in the stream of iron-ore mass diminishes with an

increase to distance or temporal interval between them. For the considered class of mining-and-geological tasks express the autocorrelation function of $K_x(h)$ экспонентною dependence [1,18]

$$\tilde{K}_x(h) = \sigma_x^2 e^{-\frac{|h|}{h_0}}, \quad (4)$$

where σ_{2x} is dispersion; h_0 is an interval of correlation.

A maximal interval of correlation of h_{max} is that time domain, for what chart of estimation of autocorrelation function (correlogram) will enter the area of permissible errors, id est $|K(h_{max})| \leq \delta$. In this consideration for δ the area \pm of $2\sigma_r$ is accepted. In accordance with formulas (1)–(3) on results the discrete assay of content of quality indexes of minerals in the stream of iron-ore mass built an experimental autocorrelation function that was then smoothed out on a least-squares method. The type of autocorrelation function, value of coefficient of correlation of r_{kk} and size of maximal interval of correlation of h_{max} allowed to estimate character of changeability of dynamic row of content of quality indexes of minerals in the stream of iron-ore mass. In works [1,7] changeabilities of content of quality indexes of minerals are investigational in balance supplies and iron-ore streams of Rogitiums of magnetite. Paid attention to the spectrology of dynamic rows of content of quality indexes of minerals in the stream of iron-ore mass, but spectral the closeness of $S_x(\omega)$ is related transformations of Fourier to the autocorrelation function to correlations

$$S_x(\omega) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} e^{-j\omega h} K_x(h) dh = \frac{1}{\pi} \int_0^{\infty} K_x(h) \cos \omega h dh. \quad (5)$$

For the casual process of $X(t)$, that has a function of kind (4), have

$$S_x(\omega) = \frac{\sigma_x^2 h_0}{\pi(1 + h_0^2 \omega^2)}. \quad (6)$$

The spectral going near research of parameters of averaging of content of quality indexes of minerals in the stream of iron-ore mass on careers is successfully used in [2]. Limit nature of range of frequencies that present the process of vibrations of content of quality indexes of minerals in the stream of iron-ore mass allows for the areas of ore bodies and beds of deposit to find the spectral closeness of $S(v)$ and determine numerical descriptions of vibrations: standard deviation σ and midfrequency of vibrations after formulas

$$\sigma = \sqrt{\int_{\nu_1}^{\nu_2} S(\nu) d\nu}, \quad (7)$$

$$\bar{\nu} = \frac{\int_{\nu_1}^{\nu_2} \nu S(\nu) d\nu}{\int_{\nu_1}^{\nu_2} S(\nu) d\nu}. \quad (8)$$

In the spectral closeness of spectrum and autocorrelation function used mountain graphic surveyor information about statistical properties of spatial and temporal changeable dynamic rows of content of quality indexes of minerals in the stream of iron-ore mass. Each of them was got by means of transformation to Fourier and knowledge of cross-correlation function of process of equivalent spectrum. Autocorrelative function was used for the building model of dynamic row and for prognostication of content of quality indexes of minerals. Set physical sense of harmonious constituents of dynamic row of content of quality indexes of minerals in the stream of iron-ore mass. At prognostication of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass used cross-correlation approach.

A process of forming of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass is the casual function of time, that on an eventual interval has it is certain number of rejections, minimums and maximums, with a different value that exceeds level of technological norms or technical requirements on the booty of Rogitiums of magnetite (pic. 2).

A rejection of casual function of $C(t)$ for this level ν is graphic arts of this function after a horizontal line, that falls behind from the axis of C in the distance ν . In the theory of casual functions an analysis of rejections of temporal process is from normative levels it is known as a "task about extrass". The general view of her decision is considered in [6]. For a normal process simple calculation formulas are got, what suitable for determination of parameters of rejections of dynamic rows

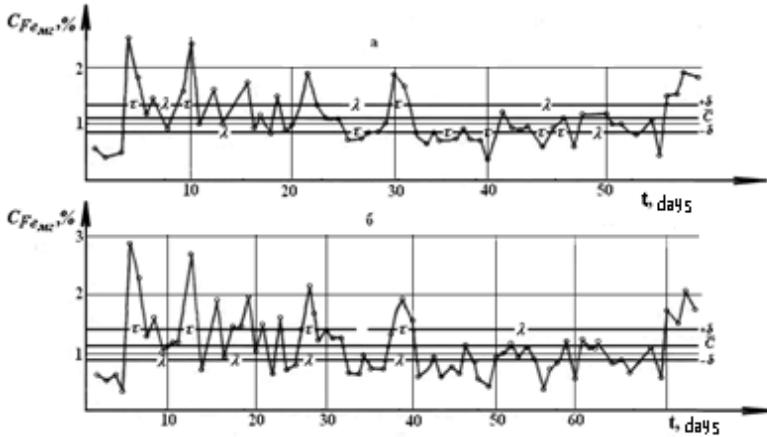


Fig. 2. Dynamic range of contents of qualitative indices of minerals (random function) $C(t)$ and parameters (τ, λ) , which characterize its deviation from the normal level $\pm \delta$ (a, b – respectively, the content of qualitative mineral indicators in the flow and commodity iron ore mass)

of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass. Speed of changeability of ordinate of casual function v and ordinate of casual function of C for the same moment of time are uncorrelated and independent by casual sizes for a normal stationary casual process. The two-dimensional closeness of probability of $f(C, v)$ distribution equals the product of normal consistence distribution for C and v

$$f(C, v) = \frac{1}{\sigma_C \sqrt{2\pi}} e^{-\frac{(C-\bar{C})^2}{2\sigma_C^2}} \frac{1}{\sigma_v \sqrt{2\pi}} e^{-\frac{v^2}{2\sigma_v^2}} \quad (9)$$

where dispersion of speed of changeability of ordinate of casual function equals the value of cross-correlation function of speed in a zero

$$\sigma_v^2 = -\frac{d^2}{d\tau^2} K(\tau) |_{\tau=0}, \quad (10)$$

and the expected value $v(t)$ as a result of stationarity of casual process equals a zero. Probability of that a rejection takes place in the infinitesimal span of time of dt , located near-by the point of t , numeral answers the middle number of rejections in time of size of C unit higher level δ and determined after a formula

$$P(\delta) = n_{\delta} = \frac{\sigma_v}{2\pi\sigma_c} e^{-\frac{(\delta-\bar{C})^2}{2\sigma_c^2}} . \quad (11)$$

Middle duration of rejection was determined from expression

$$\bar{\tau}_{\delta} = \pi \frac{\sigma_c}{\sigma_v} e^{\frac{(\delta-\bar{C})^2}{2\sigma_c^2}} \left[1 - \Phi\left(\frac{\delta-\bar{C}}{\sigma_c}\right) \right] , \quad (12)$$

where $\Phi\left(\frac{\delta-\bar{C}}{\sigma_c}\right)$ – integral function of Laplace.

Estimated a middle interval an analogical method between rejections λ_{δ} . Examining a rejection for a "zero level", when $\delta=C$, a formula (12) assumes a simplified view

$$\bar{\tau} = \pi \frac{\sigma_c}{\sigma_v} . \quad (13)$$

The calculated value is necessary \bar{n}_{δ} be doubled, if scope of vibrations of parameter limit symmetrically both from above, and from below by the size $\Delta_c = |\delta - \bar{C}|$. Knowing the AV number of rejections for period of T and middle duration of one rejection $\bar{\tau}_{\delta}$, determined mean time of stay of casual function of dynamic row of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass outside the set level (general duration of rejections) $\bar{t}_{\delta} = \bar{\tau}_{\delta} \cdot \bar{n}_{\delta}$. Sizes $\bar{\tau}_{\delta}$ i \bar{n}_{δ} and proportional to the period of T , and middle duration $\bar{\tau}_{\delta}$ of one rejection does not depend on a period T .

Nomenclature of signs of content of quality indexes of minerals. The nomenclature of signs of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass includes middle for a substance descriptions of setting, technology, maintenance and transportability. Paid attention to consideration of indexes of setting, that express content of quality indexes of minerals in the stream of iron-ore mass, metals and their connections (oxides), and also static and dynamic indexes of exactness, reliability and stabilities, that characterizes the degree of dispersion, spatial or temporal changeability of values of content of substance of quality indexes. The estimation of signs is got on the

basis of treatment of these points of assay of content of quality indexes of minerals in the balance supplies of bowels of the earth and in an iron-ore stream. Research of level and stability of content of quality indexes of minerals in the stream of iron-ore mass is executed at base, static and dynamic balance-industrial supplies of substance (groups of indexes of exactness, reliability and stability).

The nomenclature of indexes is differentiated on the stages and management periods, on the forms of existence of content of quality indexes of minerals in the stream of iron-ore mass. Offered system of indexes of content of quality indexes of minerals in the stream of iron-ore mass and statistical description of content of quality indexes of minerals in the stream of iron-ore mass for on the гірничовидобувних enterprises of Krivbass it is driven the levels of forming of streams of iron-ore mass to the table. 2.

For the estimation of level and oscillation of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass from data of the detailed secret service in the complement of base indexes of standards possible deviations are included maximum from the rationed sizes.

The statistical signs of oscillation of content of quality indexes are used for comparison of content of quality indexes of minerals in the stream of iron-ore mass in the different objects of balance-industrial supplies (bed, ore body, area, block, test). On the stage of exploitation next to static the dynamic signs of oscillation of content of quality indexes of minerals are used in the stream of iron-ore mass is an interval of correlation, indexes of rejections of values for the set norms. Corresponding limits are included in the complement of maximum operating signs of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass (operating standards) as for pseudo dynamic (content of quality indexes useful minerals in array of Rogitiums of magnetite on directions of working), offso for the veritable dynamic rows of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass (quality indexes of loosen, obtained and warehoused minerals from the stream of iron-ore mass).

To enter the analogical quality indexes of *требє* in the complement of standards and technical requirements. Differentiated

Table 2 - System of indications of the content of quality indicators of minerals in the flow of iron ore

Forms of content of qualitative indicators	Selective Indicators			Basic Indicators		
	assignment	accuracy, reliability, stability		assignment	accuracy, reliability, stability	
		statistical	dynamic		statistical	dynamic
Development of sections of the ore body and deposits of magnetite corneas						
Content of qualitative indices of minerals in balance-industrial subsoil reserves; pseudodynamic series	The average content of the qualitative indices of minerals in the extracting unit \bar{C}_g Content of qualitative indices of minerals in the contour of the extracting unit C_k	Standard deviation $\pm S_g$; coefficient of variation V_g ; asymmetry A_g ; excess E_g Standard deviation $\pm S_g$	Deviation: – average \bar{T}_g ; – duration \bar{T}_g ; – total duration of deviations \bar{T}_g	Minimum industrial content of qualitative indices of minerals in the ore array of the extracting unit C_{ak} On-board content of the qualitative indices of minerals on the contour of the extracting unit C_{gn} Minimum industrial content of qualitative indices of minerals in the flow of iron ore – in a dose C_{uo} – for the planned period C_n	Limit values: - $\Delta_{ug}, V_{gk}, A_{gk}, E_{gk}$ Extremely permissible deviation $-A_{gk}$ Extremely permissible deviation $-A_{go}$ Limit values: $\Delta_{un}, V_{gn}, A_{gn}, E_{gn}$	Limit values $\bar{T}_{g,n}; \bar{T}_{g,n}; \bar{T}_{g,n}$
Content of qualitative indices of minerals in loose, extracted, constituting iron ore mass; dynamic series	Average content of qualitative indices of minerals in the flow of iron ore; – in a dose \bar{C}_d – for the planned period \bar{C}_n	Standard deviation $\pm S_n$; coefficient of variation V_n ; asymmetry A_n ; excess E_n	Deviation: – average \bar{T}_n ; – duration \bar{T}_n ; – total duration of deviations \bar{T}_n	Regulatory content of the extracting unit C_{en} Minimum industrial content of qualitative indices of minerals in the flow of iron ore – in a dose C_{uo} – for the planned period C_{un}	Limit values: Extremely permissible deviation $-A_{en}$ Limit values: $\Delta_{un}, V_{gn}, A_{gn}, E_{gn}$	Limit values $\bar{T}_{g,n}; \bar{T}_{g,n}; \bar{T}_{g,n}$
Removal of the content of qualitative indices of iron associated with magnetite, $F_{e_{agg}}$ in iron ore mass						
Content of qualitative indices of minerals in commodity iron ore mass (dynamic range)	Average content of qualitative indices of minerals in an array of ferruginous quartzites (for the planned period) \bar{C}_m	Standard deviation $\pm S_m$; coefficient of variation V_m ; asymmetry A_m ; excess E_m	Deviation: – average \bar{T}_m ; – duration \bar{T}_m ; – total duration of deviations \bar{T}_m	Regulatory content of qualitative indices of minerals in commodity iron ore (for the planned period) C_{nm}	Limit values: $\Delta_{um}, V_{gm}, A_{gm}, E_{gm}$	Limit values $\bar{T}_{g,m}; \bar{T}_{g,m}; \bar{T}_{g,m}$

estimation of level and stability of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass by means of single indexes effective not enough.

At comparison of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass on different enterprises estimation of затруднена. In such situation the complex methods of estimation of content of quality indexes of minerals are used in the stream of iron-ore mass. Complex index of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass determined after a formula

$$Q = \sum_{j=1}^m b_j \sum_{i=1}^{n_j} q_{ij} a_{ij} ; \quad \sum a_{ij} = \sum b_j = 1 , \quad (14)$$

where q_{ij} - is a single sign of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass of j - group that is conditioned by attitude of actual index toward base; n_j – is an amount of single indexes in j group; a_{ij} – is ponderability of i -to of single content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass in j group; m – is an amount of groups of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass; b_j – is ponderability in j group of indexes of minerals in the stream of iron-ore.

The complex sign of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass allows in one estimation to take into account the different groups of indexes of setting, technologicalness, static and dynamic descriptions of exactness, reliability and stability. Ponderability of single indexes in a group and ponderability of every group of indexes are set by statistical and heuristic methods. The use of complex sign of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass results in erroneous conclusions, if it is unsatisfactorily appraised to ponderability of single signs of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass and their groups. Accepting equivalent all groups and indexes that is included

in the estimation of oscillation of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass expression (14) simplified and it is presented as a product of relative sizes of single signs of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass. Determination of ponderability of indexes or simplification of expression (14) it is set after the detailed study on every quarry and mine of character of oscillation of content of quality indexes of minerals in the stream of iron-ore mass and the educed role of every group of indexes in a general estimation.

Depending on the put aim separate groups of indexes are setting, static or dynamic descriptions of stability of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass – will be excluded from an estimation. Weight of corresponding content of quality indexes of minerals in the stream of iron-ore mass and groups for comparison of different enterprises is accepted by identical, as a sum of bar of single signs of content of quality indexes of minerals in the stream of iron-ore mass and separate groups is taken for unit.

Size of complex sign of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass at near accordance of values of parameters of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass aspires base to unit. In this relation consider an estimation (14) the complex sign of evenness of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass.

A volume and sign of statistical researches of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass depend on the put tasks and group of complication of enterprise. Limit to the study of simple objects the analysis of functions of distribution of indexes and estimation of descriptions of substance and statistical of oscillation of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass, and for difficult objects are dynamic vibrations of content of quality indexes of minerals.

Comparisons of different enterprises and different levels of forming of streams of iron-ore mass conducted by means of complex

sign of content of quality indexes of minerals in the stream of iron-ore mass, that characterize accordance of actual values of single indexes normatively-base. The amount of levels of statistical analysis, estimation and control of content of quality indexes of minerals determines complication of charts of forming of streams of iron-ore mass and content of quality indexes of minerals in the stream of iron-ore mass. On mining enterprises with the difficult charts of forming of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass statistical studies are undertaken on all levels, where got at an assay the dynamic row of content of quality indexes of descriptions of minerals in the stream of iron-ore mass.

Certain connection of statistical complication of quality structure of coalfaces with the type of minerals in the stream of iron-ore mass or type of deposit, bed, ore body or areas of balance-industrial supplies educing is not succeeded. In separate cases on a career or mine one component can have high vibrations of content of quality indexes of minerals, and in other – subzero.

At level career and mines distribution of content of quality indexes useful to the component (content of quality indexes of the iron related to magnetite, Fe_{mg}) submits to the same laws, but there are cases, when on a career and mine different components have the different appearances of distribution. Vibrations after the coefficient of variation on the whole below, than at previous level of iron-ore stream. Distribution of content of quality indexes useful to the component (content of quality indexes of the iron related to magnetite, Fe_{mg}) in the minerals of commodity iron-ore mass that supply with on crush or ore mining and processing factory, submits only to the normal and lognormal laws. Thus, as well as on the previous levels of forming of iron-ore stream different constituents on a career and mine have the different appearances of models of distribution of content of quality indexes of minerals in the stream of iron-ore mass. Characteristically, that in minerals and in commodity iron-ore mass statistical vibrations of content of quality indexes of useful component, judging on a coefficient there are variations, below, than in loosen and the obtained balance-industrial supplies. On most quarries and mines size of coefficient of variation less than 40 %. The study of type of functions of distribution and statistical

parameters gives information about changeability of level and stability of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass in the process of forming of commodity products of mining enterprise.

Increase of stability of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass in the process of her forming on careers and mines expresses reduction of values of coefficient of variation and accompanied by transformation of asymmetric distributions of content of quality indexes of minerals in more symmetric even in normal. In the array of Rogitiums of magnetite and in the stream of iron-ore mass only for quality indexes useful to the component, that it is used as a criterion of content management of quality indexes of minerals in the stream of iron-ore mass.

Implications

1. Statistical control as a function of the surveyor providing of management content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass consists in a decision-making about the process of forming of content of quality indexes of minerals state in the stream of iron-ore mass and necessity of influence in case of his discord on the basis of statistical analysis and estimation of sample data. A volume and sign of statistical researches of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass depend on the put tasks and group of complication of enterprise.

2. Limit to the study of simple objects the analysis of functions of distribution of indexes and estimation of descriptions of substance and statistical of oscillation of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass, and for difficult objects are dynamic vibrations of content of quality indexes of minerals. In the rational statistical checking system on every stage of forming of single and incorporated iron-ore streams in accordance with requirements envisage control of content of quality indexes of minerals in the array of Rogitiums of magnetite and in the stream of iron-ore mass.

3. Control methods on ore-mining enterprises and levels are different, depending on changeability of level and stability of content

of quality indexes of minerals in the array of Rogitinum of magnetite, in the stream of iron-ore mass and volume of information. The complex sign of content of quality indexes of minerals in the array of Rogitinum of magnetite and in the stream of iron-ore mass allows in one estimation to take into account the different groups of indexes of setting, technologicalness, static and dynamic descriptions of exactness, reliability and stability.

4. The use of complex sign of content of quality indexes of minerals results in erroneous conclusions, if it is unsatisfactorily appraised to ponderability of single signs of content of quality indexes of minerals in the array of Rogitinum of magnetite, in the stream of iron-ore mass and their groups. Size of complex sign of content of quality indexes of minerals at near accordance by the base value of parameters of content of quality indexes of minerals in the array of Rogitinum of magnetite and in the stream of iron-ore mass aspires to unit.

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ANALYSIS OF THE EXISTENT TECHNOLOGIES OF AMBER MINING

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Abstract

The features of amber deposits, description of amber as a mineral, methods and technologies of amber mining are analysed. The features of hydromechanical method of amber mining from sandy beds are investigated. It is conducted various technologies of mining for amber mining. Technical equipment for mining, flow-sheets and calculation methods, are analysed. The methods of calculation, offered by the known scientists and specialists of leading institutes in industry of mining and technologies of hydromechanisation, are analysed.

Introduction

The object of researches is a process of extraction of amber by the hydromechanical method of amber mining from sandy beds.

The existent technical equipment for hydromechanical process of amber mining not fully meet the requirements, namely, technologies do not guarantee plenitude of taking out useful to the component from containing rocks and not always effectively use a working liquid.

For today the amber mining requires the newest technologies and improvement of technical and technological equipment for intensification the mining process, at that the higher productivity and efficiency, and also diminishing of negative ecological influence to the environment. Most rational is implementation of hydromechanical method of amber mining, that does not require realization of expensive geological survey and recultivation, characterized by minimum capital and operating costs, and has a prospect of improvement by the management of emerging of amber speed from sandy beds by the change of air flow and frequency of oscillation of working organ.

1. Characteristics of amber and its beds

1.1. Characteristics of amber beds

In the world amber meets on the seacoast of the Baltic sea in the countries of the Baltic States, Poland, Germany, Denmark, Sweden, Belarus. Larger deposit to this time was Primorske (Palnnikenske) in the Kaliningrad area of Russia.

The known deposits in Seashore (Russia), Italy, Poland, Myanmar, Canada, the USA, Dominican Republic, Mexico, but 90% of world supply of amber is obtained in the Kaliningrad area (Russia).

Rock that contain amber bed on a different depth: than farther from the Baltic sea, that deeper. Therefore exactly on the coast of the Baltic sea - from the island of Rugen to Western Dvina - since olden times obtained amber. Layers that contain amber are subjacent the Baltic sea level, and a surf often washes the pieces of amber from them, throwing out them ashore.

Erosions and changes, and also further glaciers, spread amber on large distances. Secondary accumulations of amber, found in Poland, Germany, Denmark, Belarus and Ukraine.

To the sedimentations of paleogene the Klesiv deposit of amber only in Ukraine is related. Based on data of Ukrainian geologist V.Panchenko, it is in the zone of framing of proterozoic crystalline rocks of north-western part of the Ukrainian shield of sediment formations of paleogene. A mineral deposit consists of a few areas, two of them is open careers 472 and 43 (Large Pugach). This area is accommodated in 1-4 kilometres to north west from the station of Klesiv. Productive horizon of deposit consists of three sandy layers, made differently granular quartz sands, that is differently enriched by a clay substance, organic material and amber. An understratum is sporadically enriched by a glauconite, from what a amber containing rocks acquires a blue tint. The pieces of amber arrive to a size of 10 cm. From data of V. Panchenko and O. Tkachuk, content of amber in a deposit - from 15 to 310 and even 1000 g/m³, middle are 50 g/m³. Distribution of amber is uneven, maximal is in basis of layer.

The considerable beds of valuable amber are found out in Ukraine. There are about six percents of world supply of amber is in the Rivne region. Extractive works are presently conducted on Klesiv deposit (Sarny district) and on the areas of Volodymyrets (village Beregnitsya) and Dubrovitsa (village Vilne) districts. Total supplies of amber are estimated in 100 thousand tons, that mainly bed in sandy and sand-clay soils on a depth a to 15 m and is sufficient for research and implementation of new technologies.

1.2. Physical, mechanical and chemical properties of amber

Amber is high molecular connection of organic acids, that contains on the average to a 79 % of carbon; to 10,5% of hydrogen; to 10,5% of oxygen. Its formula is C₁₀H₁₆O. There is a 81 g of carbon; 7,3 g of hydrogen; 6,34 g of oxygen, a bit sulphur, nitrogen and mineral substances in 100 g of amber. In the process of oxidization (weathering) content of oxygen grows in amber, and content of other components diminishes. In amber as admixtures (from tracks to 3%) found out 24 chemical elements (Y, V, Mn, Cu, Ti, Zr, Al, Si, Mg, Ca, Fe, Nb, P, Pb, Zn, Cr, Ba, Co, Na, Sr, Sn, Mo, Yb). 17 of them it is found in low-laying area amber of Klesiv deposit, 12 - in amber of the Beach area of the Primorske deposit, 11 and 13 - accordingly in amber of Kurshska braid and Prykarpattya. The least amount of

chemical elements is contained in transparent amber. This mineral can have white, greenish, blue, red, yellow, but typical are orange and golden varieties. A mineral is amorphous, soft (hardness is 2,2-2,5 points by a Mohs scale), viscid, easily polished. Density: 1,05-1,096 g/cm³. At a temperature of 150 °C amber grows soft, at 300 °C it melts. It burns easily, giving out a resinous smell. A mineral owns dielectric and heatproof properties, in the wild meets as grains and pieces of size from 1 to 10-20 cm and larger, however finding pieces weighing to 10 kg. A form of pieces can be any: drops, icicles, influxes of various wrong forms, porous slabs.

Content of succinic acid in Baltic amber hesitates from 3 to 8%. Depending on the type of amber it is distributed on different ways. In transparent amber of succinic acid contained from 3,2 to 4,5%, in Bastardo - from 4,0 to 6,2%, in bone amber - from 5,5 to 7,8%, in the oxidized crust - 8,2%. It is continued to study composition and structure of amber. Its volatile part (about 10% masses) is known for a long time. Its aromatic connections of terpenes with 10 atoms of carbon and sesquiterpenes with 15 atoms of carbon in a molecule. As mass spectrometric researches showed, more than 40 connections enter in the complement of amber. Many of them are not known yet. In a pure form abietic acid and her isomers are abstracted from amber. They fold soluble in organic solvents part (20-25%) of Baltic amber. Remain of amber, insoluble in none of the known solvents. The IR spectrometry showed that « succinite » contained lactone groups, id est shows by itself difficult ether. In addition, in amber constantly there are succinic acid (about 4%) and admixtures of salts (mainly amber sour) of potassium, calcium, natrium, iron (to 1%). Thus, amber consists of three groups of connections : volatile terpenes and sesquiterpenes; soluble organic acids; insoluble polyesters of these acids with alcohols that formed of the same acids.

Rivne amber differs in the chemical composition. It is most saturated by admixtures and includes 18 chemical elements. Except, silicon, magnesium, iron, calcium, that being almost in all deposits, such are added as lead, zirconium and to 3,19% sulphur. Ash-content of Ukrainian amber - 8,7%. It influences on quality and color of hardening resin. Amber is a mineral of class of organic compounds, resin of conifers mainly period of paleogene. Composition of amber : volatile aromatic oil, two soluble factions of resin, succinic acid and

90% of insoluble fractions. Amber is an amorphous polymer, has an enormous amount of colors, gives a specific IR spectrum (within the limits of $700...1900\text{ cm}^{-1}$) that distinguishes amber from other alike resins. Temperature of melting is $t=365...390\text{ }^{\circ}\text{C}$. Specific weight is $1000...1100\text{ kg/m}^3$ (there are 970 kg/m^3 in the Baltic, and in Prykarpattya are 1220 kg/m^3). Well yields to tooling. Does not dissolve in water (partly in an alcohol - 20...25%, in ether - 18...23%, in chloroform - to 20%), but can swell and increase in a volume to 8% at the protracted stay in water. Fully disintegrates in the hot concentrated nitric acid, it is possible to soften at $t=100\text{ }^{\circ}\text{C}$.

2. A review and analysis of existent methods and technologies of amber mining

Analysing literary sources we set that on the present tense of getting amber from sandy deposits mainly comes true by two methods: mechanical and hydraulic.

The problems of amber mining engaged in Lustyk M., Korniyenko V., Kononenko E., Mishin Yu. and other.

A mechanical method include mechanical development of array of soil in an open quarry or under earth. Getting of amber by this method that is used on Klesiv deposit and includes: opening of productive layer of soil, excavating, transporting of rocks from the place of development to the crash, where it takes place dissociating of amber from a rock by washing, recultivation.

The lacks of such method are large running and economic expenses, bearing-out of rocks on a surface and negative ecological influence to the environment. In addition, this method becomes antiquated, a productive equipment is used small and the severe losses of minerals are marked.

Hydraulic method is carried out by blurring the productive soil layer with high-pressure jets and outlet amber to the surface of the deposit by hydraulic flows

According to the researches of M. Lustyuk the method of the downhole hydraulic mining includes opening of productive horizon holes by the contoured of mining chamber, strengthening them, establishment in them of hydraulic mining equipment with a giveout device, connection between mining holes, cut productive horizon and

filling of cutting crack by water, destruction of rocks of productive horizon in a cutting crack, hydroerosion of rocks in the flooded coal-face and raising the pulp on a surface on a mining hole by self fusion due to the permanent entering of liquid working zone in the center of mining chamber.

In private artels the amber mining comes true exactly by a hydraulic method with the low level of mechanization and severe losses of amber through imperfection of mining technology of minerals from sandy deposits.

However all of them are accompanied by the bearing-out of mineral soil on the surface of deposit, does not provide the complete exception of amber from deposits, energy-capacious, and change of structure of soils, formation of emptinesses and accordingly render considerable negative man-caused ecological influence to the environment.

On Klesiv deposit in the Rivne region the amber mining is carried out by an open quarry method. Amber beds in sandy soil. Depth of bedding - to 15 m. Near a deposit is granite quarry with the considerable supply of water. A deposit is located not far away from roads and electric system.

In the Baltic States and Kaliningrad area of Russian Federation for amber mining use a quarry method, with mining by hydraulic dredgers and with the use of hydromonitors. For today the known hydraulic method that is accompanied by beginning to swing of liquid in a amber containing array with next pumping out of the ground pulp on the surface of deposit.

Melnikov N., Arens V., Cherney E., Malanchuk Z. consider that founding results of exploration of deposits for the using of hydraulic technology. A task is taken only to clarification of separate mining-and-geological indexes on the basis of laboratory researches of physics and mechanical properties of minerals and applying rocks.

Considerable payment in the decision of problem of co-operation of stream and mountain range was brought in by the works of M. Lavrentyev, B. Voycekhovskiy, Y. Kuzmich, A. Atanov, B. Teodorovich, A. Zhuravskiy, R. Nikonov, V. Muchnik, N. Cyapko, V. Poturaev, A. Bulat, V. Nadutiy, B. Bluss, Z. Malanchuk, V. Korniienko. According to data, presented in researches, established that researchers have absent an only idea in relation to the theory of

hydraulic destruction and there is an enormous amount of hypotheses, factors, that influence on a process destructions the values of that and their specific gravity mainly are not studied, incorporated by a group. Not enough there are the considered questions of process control of hydraulic mining and documentation of chambers of taking out on this stage.

3. Analysis of features of hydraulic mining of amber

Modern development of mountain production status in industry of development of ore and not ore minerals in the Rivne-Volyn region is characterized by the presence of far industrially meaningful deposits that is not brought over to development in connection with impossibility of their exploitation by traditional methods, because of difficult terms of geohydrology with the high standing of subsoil waters and bogginess. Exploitation of such deposits a traditional underground method is ineffective and expensive.

Hydraulic mining is effectively for such deposits of minerals, that comes true by means of hydraulic energy, that is used for destruction of mountain rocks, delivery of the destroyed rocks on the map of alluvium or to the mining hole and raising of them on a surface. The hydraulic mining is one of geotechnological methods of mining. Essence of hydraulic mining consists in bringing minerals over in place of bedding in the movable state by hydromechanical influence, and delivery them as a slurry on the map of alluvium or on the surface of mining hole.

Complication and plenty of technological processes of mining and specific of exploitation of deposits specify on a study and development of geotechnological methods which must be systematized. According to data of Z. Malanchuk, E. Cherney, systematization it is expedient to carry out by the essence of process that is the basis of mining technology. On this sign distinguish the methods based on chemical processes, methods based on physical processes, and combined methods.

The choice of method of mining is determined by geotechnological properties of minerals (ability of minerals under act of working agents to accept the movable state) and physics geological surroundings that together with geological and geohydrology terms represents

description of properties of mountain rocks and saturate them fluids (porosity, permeability, cracking, content of minerals, salt content).

The main condition of using geotechnological methods are the real possibility and financial viability of translation of minerals under act of working agents to the movable state. Except it, it is necessary to provide possibility of serve of working agents to the surface of co-operation and taking of minerals through mining holes on a surface.

A lot of researchers engaged in experimental researches of fluidizing of sandy soils, in particular N. Maslov. Theoretical and experimental researches executed also by O. Vlasov, G. Lyakhov, N. Dmytriev, V. Bilokopytov, A. Aronov and others.

Researching the influence of oscillation technique on the ground environment engaged by A. Bulat, V. Poturaev, V. Franchuk, V. Nadutiy, Ye. Lapshin, K. Sofiytskiy, A. Zorin, L. Vasilyev, V. Lenda, A. Uchitel, L. Vaysberg, I. Blekhman, L. Levenson, I. Goncharevich, P. Pilov, E. Nepomnyaschiy, E. Nazymko, A. Bondarenko and others.

The hydromechanical method of getting up amber to the surface of sandy deposit is worked In the National university of water and environmental engineering (NUWEE).

Essence of these method consists in that an array is saturated by water and activates by mechanical excitation to formation of continuous suspension layer of such density, at that there is expulsive force that lifts amber on the surface of deposit. There is an array to the complete loss of connections between particles by a mechanical action, at presence of water in the array. freeing of amber and achievement of the suspension state of environment with a closeness, what anymore from specific attractive of amber power, that allows last to emerge on the surface of deposit due to Archimedes force.

The process of fluidizing of soil takes place as follows. In a amber containing array bars submerge an oscillation method with bi-conical vibroemitters at a simultaneous serve through them water and air in the array of soil. An array is set vibroemitters in fluctuating motion, the zone of the continuous boiling of soil appears here. Amber moves away from an array and under the action of expulsive force emerges on a surface. Suspension of environment allows vibrodevice to freely move.

The use of vibromachine for the amber mining from deposits al-

lows to attain the exception of amber from a deposit, to increase the labour productivity, decrease power-hungryness and negative man-caused ecological influence on an environment.

For the increase of volumes of mining at the decline of prime price industry requires introduction of modern technologies in the amber mining. The amber mining with heavy tolls requires a lot of money and time an out-of-date method on a mining and processing of considerable volumes of soil for the receipt of amber.

Thus, for today the amber mining requires new technologies and development of facilities for intensification of process of exception, at that a high yield and efficiency are arrived at, and also negative ecological influence diminishes on an environment.

4. Analysis of technical and technological features of amber mining

4.1 Mechanical method of amber mining

In Rivne-Volyn region amber is in sands, so getting it from sandy deposits mainly comes true by two methods: mechanical and hydraulic.

A mechanical method includes for itself mechanical development of soil array by an open quarry (Figure 1). Getting of amber with this method includes: opening of productive layer of soil, excavation, transporting of rocks from the place of mining to the crash, where it takes place dissociating of amber from a rocks by washing, recultivation.

The mechanical amber mining comes true as follows. After opening of productive layer of soil, a power-shovel plased the obtained rocks in a cone to the dump on an overhead ground. The cone of rocks is washed out by a hydromonitor, and well-educated pulp enters suction dredger setting. The large pieces of amber are withdrawn in a career by hunting of them by hand. Farther a suction dredger pumps over pulp from career on the knot of enriching. A pumping-over of pulp is a not only transport but also important technological operation. A more than 90 % of pulp hatches from a process and retires in tail dumps. Then material acts on enriching in drum separators and assorted on screens.

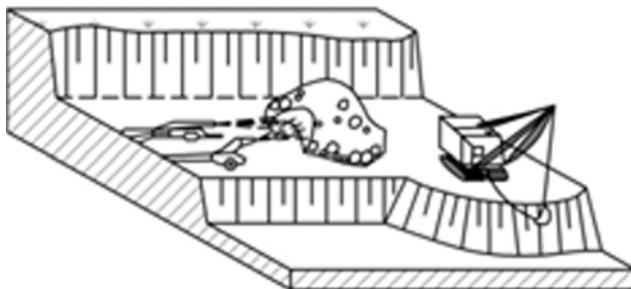


Fig. 1. Mechanical method of amber mining

The lacks of such method are heavy operating and economic tolls, bearing-out of rocks on a surface and negative ecological influence on an environment, and considerable losses of fine-grained amber.

4.2. Hydraulic method of amber mining

A hydraulic method comes true washing out of productive layer of soil by high-pressure jets and bearing-out of amber on the surface of deposit by hydraulic streams.

This method is used on areas where it is impossible to apply a mechanical method, id est there is the high standing of subsoil waters, protected territories, deep bedding of amber, or its localization in the determined locations.

The method of the downhole hydraulic mining (Figure 2) will be realized as follows. In a deposit contoured of mining chamber bore peripheral mining holes deeper level of productive horizon with a diameter sufficient for placing in them of hydraulic equipment. In a center of mining chambers bore an additional outlet mining hole with a diameter that would provide the free passing of amber with maximal diameter. Mining holes are planted around by casing pipes to the limit of productive horizon. Then in peripheral mining holes place a hydraulic mining equipment that includes a hydromonitor and outlet device.

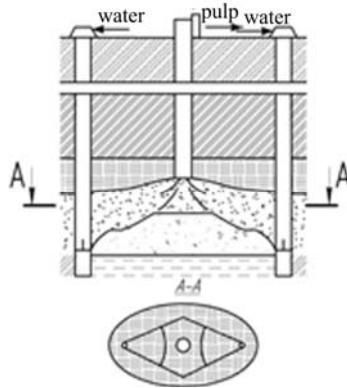


Fig. 2. Blurring of the next fall layer of productive horizon

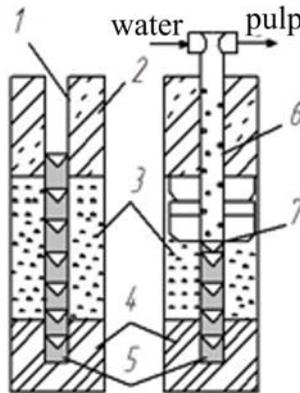


Fig. 3. A method of exception of the amber through the mining holes

A hydromonitor is setting on a level of laying rocks, that wash out, forming on a limit with productive horizon horizontal cutting crack. By rotation of hydromonitor in a horizontal plane form the within the limits of mining chamber the sector of washing away. For diminishing to time of forming of cutting crack washing away is conducted in dried in a coalface. At an exception pulps on a surface use a outlet device.

After formation of cutting crack a hydromonitor is plased on the level of the first cutting layer of productive horizon. Form a cutting crack hydromonitors with direct lop-sided to additional outlet mining hole, and the bottom butt end of casing pipes is lifted to the over-

head point by the roofs of the first cut layer. In the process of forming of sloping cutting crack horizon is filled by water to the level of outlet will build on. On a measure, deepening of sloping cutting crack takes place collapse of layer of productive horizon in mine-out space of cutting crack. After connection of cutting crack with the overhead butt end of casing pipes getting up of pulp is stopped and begin washing away in the coalface of the caused to fall layer. Disintegration of particles of rocks and amber are thus provided freely from connections with the array of soil. Clay fraction passes to pulp the closeness of that arrives at $1,2 \text{ g/cm}^3$. Sand falls out in sediment, as more heavy fraction. As, specific gravity of amber makes $1,00-1,11 \text{ g/cm}^3$, then he due to expulsive force and force of stream of pulp rises to the bottom butt end of casing pipes. After washing away of the first caused to fall layer of productive horizon a hydromonitor is moved on the level of the second layer, and casing pipes lift the roofs of the second cut layer to the overhead point, form a cutting crack and wash out the second productive horizon. Operations repeat to complete development of all productive horizon.

Another ways of downhole amber mining are known, for example, with the use of mixtures of different viscosity. So, to the prepared mining hole 1 a viscid non-freezing liquid is given 5, that forms with the ground array 2 pulps 3 and due to the difference of closeness, more heavy factions go down downward mining holes 4, and more easy - dart out together with the ground array pumps 7, that pump out pulp 6, on the surface of deposit (Figure 3). This method is used for getting of materials from the frozen soils, and also for sorting of minerals of different closeness.

The considered methods have a substantial defect, so as all of them are accompanied by the bearing-out of mineral soil on the surface of deposit, does not provide the complete exception of amber from deposits, energy capacious, result in the change of structure of soils, formation of emptinesses and accordingly render considerable negative ecological influence on an environment.

4.3. Hydromechanical method of amber mining

The hydromechanical method of getting up amber to the surface of sandy deposit is worked In the National university of water and environmental engineering (NUWEE).

Essence of this method consists in that the array, saturated by water activates by mechanical excitation (vibroexcitation) to formation of continuous suspension layer of such closeness, at that there is expulsive force that lifts amber on the surface of deposit. It is by a mechanical action at presence of in the array of water take him to the complete loss of connections between particles, freeing of amber and achievement of the suspension state an environment with a closeness, what anymore from specific attractive of amber power, that allows last to emerge on the surface of deposit due to Archimedes force.

A method will be realized as follows: barbells as pipes, from that water is given and on that the envisaged causative vibroagents, submerge with oscillation method to the amber containing array. Thus an array is saturated by water and causative vibroagents set in fluctuating motion. Amber rids of connections with an environment and emerges on a surface. Realization of method at a complete exception from the deposit of amber allows to eliminate a mineral rock yield on the surface of deposit, and that and decrease negative technogenic influence on an environment, to promote the labour productivity with diminishing of general economic charges.

A vibrohydraulic intensifier for the amber mining from sandy deposits (Figure 4) includes causative agent of vibrations 3 and set about on vertical bars 4 (what are executed by hollow one) biconical vibroemitters 5. On the ends of bars 4 cone tips are set 6. a vibrohydraulic intensifier is fastened on a hanging equipment 2, that is fastened to the working equipment of tractor 1.

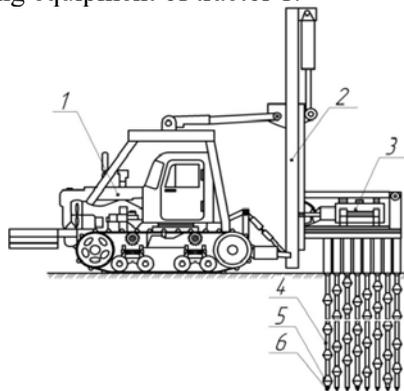


Fig. 4. Vibrohydraulic intensifier with an underlying working hardware

The process of fluidizing of soil takes place as follows. In a chamber containing array bars submerge an oscillation method 4 with bi-conical vibroemitters 5 at a simultaneous serve through them and cone tips 6 in the array of water. Array by vibroemitters 5 set in fluctuating motion, the zone of the continuous boiling of soil appears here. Chamber moves away from an array and under the action of explosive force emerges on a surface. Cone tips 6 destroy the understrata of soil, creating round itself a suspension environment that allows to move to the vibrodevice in any longitudinal direction.

Thus, the use of vibrohydraulic intensifier for the chamber mining from deposits comparatively with known another ways (mechanical and hydraulic) has certain advantages, so as allows to attain the high exception of chamber from a deposit, to increase the labour productivity, decrease power consumption and negative ecological influence on an environment.

4.4. Directions of development of technology of exception of chamber are from sandy deposits

The analysis of the researches testifies that the study of question of development of technologies of hydraulic mining engaged by the wide circle of researchers. The difference in the conditions of bedding and composition of minerals did not allow at researches to do universal quantitative conclusions. For the grant of practical value to the quantitative decisions, physical assumptions that are the basis of analysis must, in order of the accepted sizes, comport with natural terms. Absence swims out from here, in a necessary volume, complex researches of choice and comparative estimation of the systems of assay and development on the basis of scientific methods. In addition, the variety of deposits of minerals, stage of its industrial mastering and condition of exploitation is determined necessity of not only scientific ground of the use of the systems but also determination of them techno-economical indexes on the basis of that a choice and comparative estimation come true. In this connection, basic elements in the geotechnological system are the exposed places bedding of minerals, that open access of working agents to the bed, and minerals on a surface.

Thus, the geotechnological methods of mining it follows to exam-

ine not as competitive with traditional, but as complementary them. These methods it is expedient to apply on unprofitable deposits for the underground and open methods of mining: on large deposits comparatively poor ores; where a considerable economic effect can be got due to the scale of production; on low-powered beds and minerals shown of rich ores, on deposits exhaust traditional methods, for the exception of useful components from left pillars and off-balance ores; on the dumps of off-balance ores and milltailings of put the and operating up shutters from the amber mining in the Rivne-Volyn region.

Most perspective for development of beds of amber in the conditions of the Rivne-Volyn region there are results of research of V. Korniienko, that offered technology of hydromechanical exception of amber and technical equipments for it. So for determination of charges of liquid and air in a sandy array the next formulas are offered

$$Q_w = \frac{ABv}{1+e} \left(\frac{(\rho_{sk}(1+W) - \rho_{env}(1+e))}{\rho_{env} - \rho_w} \right), \quad (1)$$

$$Q_a = \frac{n_1 ABv(\rho_w - \rho_{en}) + \frac{ABv}{1+e} (\rho_{sk}(1+W) - \rho_{env}(1+e))}{\rho_{env}}, \quad (2)$$

where v - it is speed of deepening of unit, m/h;

e - coefficient of porosity;

W - humidity of soil;

ρ_{sk} - density to the skeleton of soil, kg/m³;

ρ_w - density of water, kg/m³;

ρ_{env} - density of environment, kg/m³;

ρ_a - density of air kg/m³;

n_1 - porosity of environment in the natural state;

A, B - width, length of array of soil that hesitates, m.

Consumption of water and air, straight proportional to the volume of working array, speed of deepening, closeness of environment, porosity and humidity of environment follows from formulas (1) and (2), but the volumes of consumption of water and air depend yet and on duration of treatment of array, id est from correlation of depth of treatment and speed of emerging of amber from sandy beds

$$E = (C_w Q_w + C_a Q_a) \eta \eta' \frac{H}{v} + 2(C_w Q_w + C_a Q_a) \eta \eta' \frac{H}{v} + C_0 \frac{A}{v_0} (\eta - 1)(\eta' - 1), \quad (3)$$

$$\eta = \frac{L}{A}, \quad (4)$$

$$\eta' = \frac{L'}{B}, \quad (5)$$

where E - charges for working mine, UAH;

C_w - cost of supply of water, UAH/m³;

C_a - cost of supply of air, UAH/m³;

H - depth of bedding of amber, m;

v - speed of emerging of amber, m/s;

C_0 - cost of moving of setting on a new places of mining, UAH /s;

v_0 - speed of moving of setting on a new places of booty, m/s.

In equalization (3) for research of influence the speed of amber moving to losses at working mine its worth to separate members that depend on different factors

$$E = E_v + E_0, \quad (6)$$

$$E_v = \frac{(Q_w + Q_a) \eta \eta' H}{v}, \quad (7)$$

$$E_0 = 2(C_w Q_w + C_a Q_a) \eta \eta' \frac{H}{v} + C_0 \frac{A}{v_0} (\eta - 1)(\eta' - 1), \quad (8)$$

where E_v - losses, that depend on speed of amber moving, UAH;

E_0 - losses, that does not depend on speed of amber moving, UAH.

By means of (6) it is not difficult to estimate the relative increase of losses for working mine, in case of amber moving not with maximally possible speed (Fig. 5)

$$\varepsilon = 100 \frac{E - E_m}{E}, \quad (9)$$

$$\varepsilon = 1 - \frac{v}{v_{\max}}, \quad (10)$$

where ε - a relative increase of losses for working mine, in case of amber moving not with maximally possible speed %;

E - losses for working mine of amber moving not with maximally possible speed, UAH

E_m - losses for working mine of amber moving with maximally possible speed, UAH;

v_{\max} - maximally possible speed of amber moving, m/s.

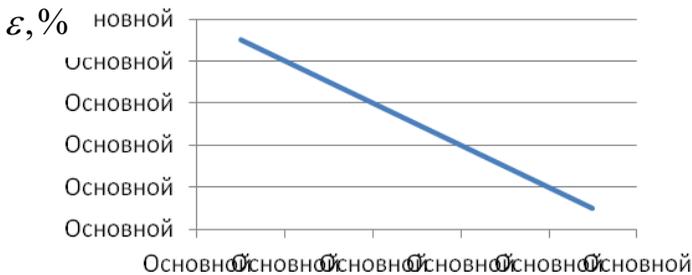


Fig. 5. Relative increase of losses for working mine, in case of amber moving not with maximally possible speed

From Fig. 5 evidently, that speed of amber moving substantially influences on losses at working mine. Dependence of speed of amber moving investigational not sufficiently, but some from results specify on existence of a maximum of this size depending on the expense of air and frequency of oscillation of working organ. But these results, specify only on possibility of existence of extremum in case of one deposit, and does not allow to define neither maximally possible speed of emerging of amber, nor expense of air, that provides her nor to ground these parameters for other deposits.

The using of vibrohydraulic method of amber mining from amber containing sands allows to attain complete exception of amber from a deposit, to increase the labour productivity, decrease power-consumption and negative man-caused ecological influence on an environment.

The process of exception of amber with using the technology of hydromechanical mining is presented on Figure 6. The exception of amber takes place after the next stages:

- raising of amber on a surface with the vibrohydraulic intensifier by means of vibration, feeding of water and air;
- collection of raised up amber and loading it on a transport vehicle by means of loading technique (loader, power-shovel, drag-shovel);
- transporting of the collected amber to the line of enriching and sorting;
- enriching and sorting of the got mass (dissociating of amber is from sand and sorting by the size).

Essence of the offered scheme consists in that an array is saturated by water and activates by mechanical excitation (vibroexcitation) to formation of continuous suspension layer of such closeness, at that there is expulsive force that rising amber on the surface of deposit.

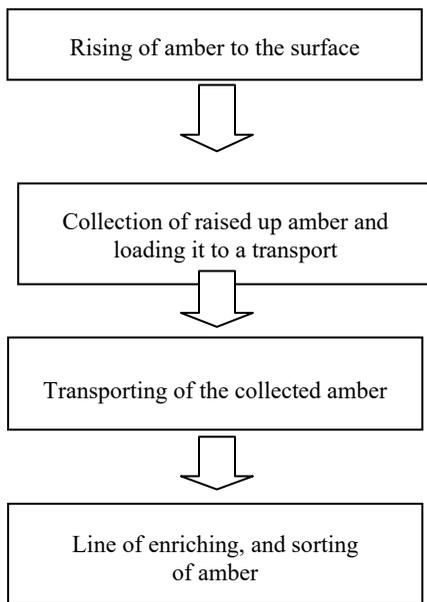


Fig. 6. Scheme of hydromechanical exception of amber

The process of fluidizing of soil takes place as follows. In a amber contained array bars submerge an oscillation method at a simultaneous serve through them in the array of water and air. An array to the vibrations of bars is set in fluctuating motion, the zone of the continuous boiling of soil appears here. Amber moves away from an array and under the action of expulsive force emerges on a surface. For intensification of process of fluidizing of soil the serve of air is included. Adjusting of frequency, amplitude of vibrations and force comes true by the change of frequency of rotation of drive shaft. Creation of closeness of environment for the receipt of terms of emerging of amber at full pelt depends on the serve of gas-liquid mixture, parameters of vibrations, geometrical parameters of setting and her weight. The serve of water influences on duration of dilution of environment.

Moving of setting is possible at moving of working equipment on a deposit. At this bar remain in a sandy array, developing areas round itself, or taken out by cathead from an array and moved on a new area for a mining.

At application of cathead on the wheeled motion it follows to use the coupled undercarriages in an order to increase the area of pressure of wheels on a surface. Practice showed also, that effectively to apply a working equipment on caterpillar motion in difficult communicating, water-wet and boggy localities. Namely such climate is observed on north territory of the Rivne region, where a amber mining is.

Duration of work of setting on one area is folded since a necessity on deepening, emerging of amber and taking out of bars from an array. At the conducted experimental researches the rational parameters of dominant factors of amber mining are got from amber containing sands: frequency of vibrations of causative vibroagent 26-36 Hertz; a closeness of the rarefied amber consist environment is 1670-1750 kg/m³; expense of water in the array of 0,01-0,02 m³/h and serve of air of 0,004-0,006 m³/h, here speed of raising of amber arrives at a 0,09 - 0,12 m/s. with efficiency of exception of amber to 95 %. Here duration of deepening on a depth a 2 m will lay down within the limits of 1 minute, 2 minutes works and 1 minute on extraction, thus on all process it is needed not more than 5 min After it

setting is transported on other area, but thus, that the zones of work of setting intersected or touched.

After working off the area of deposit by means of hydromechanical method collection of heaved up on a surface amber is conducted with the epiphase of sand by means of power-shovel or loader, and loading of the collected mass on a tipper. The collected mass is transported a tipper to the bunker of line of enriching and sorting, where separating of amber originates from bits and pieces of sandy environment and sorting of him after the classes of sizes.

Conclusions

Thus, the existent for today technical equipments of realization of process of hydromechanical amber mining suit not in a complete measure, namely, the worked out technologies do not guarantee plenitude of taking out useful to the component from containing rocks and not always effectively use a working liquid. Part of factors of technology of гідромеханічного booty remained out of eyeshot many researchers, although efficiency of work of hydromechanical extractive options and economy of resources (energy, water, amount obtained useful to the component) depend on them.

Thus, the use of technology of hydromechanical exception for the amber mining from deposits allows to attain a to 95 % exception of amber from a deposit, to increase the labour productivity, decrease power-consumption and negative influence on an environment. The use of the offered flowsheet allows after completion the amber mining from the bowels of the earth of Earth to continue to use these areas on purpose without realization of recultivation.

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CONSIDERING EXCESSIVE ROCK PRESSURE BY USING VARIOUS FAILURE CRITERIA

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Abstract

The research aims to determine the way criteria of rock strength and stability are modified in presence of excessive pressure in pore liquids and to assess the impact of pore pressure on the critical height of the vertical slope by analyzing solutions of classical problems in soil mechanics.

The research methods include theoretical studies of geomechanical processes by means of analytical mathematical methods.

The obtained results include modifications of the known Mohr-Coulomb, Bieniawski, Hoek-Brown and Shashenko failure criteria determining rock strength

with due regard to excessive pore fluid pressure. The critical height of the vertical slope and active and passive stresses of saturated and unsaturated rocks are compared. The given results enable natural generalization for rocks in which there is some pore gas under excessive pressure.

The scientific novelty of the research includes modifications of the Mohr-Coulomb, Bieniawskii, Hoek-Brown and Shashenko failure criteria enabling consideration of impacts of excessive pore fluid pressure on rock strength and stability.

Practical significance of the research involves predicting the failure of rock in mine workings composed of water-bearing strata and support structures.

Keywords: failure criterion, rock, saturation, elasticity, cohesion, internal friction.

Introduction. At present, there are many various failure criteria used in rock and soil mechanics among which the Mohr-Coulomb criterion, the Bieniawskiy criterion, the Hoek-Brown criterion and the Shashenko criterion are the most widespread [1-5]. There are also combined criteria considering several mechanisms of destruction like strains and shears.

Each of them is aimed at describing unsaturated materials except for the Mohr-Coulomb failure criterion which uses the internal friction angle φ and specific cohesion c as failure characteristics. It is not clear how one should calculate strength and stability of saturated rocks using conventional strength characteristics R_c and R_p which are uniaxial compressive and tensile strengths correspondingly. This research deals with this issue.

It should be noted that the authors do not make a distinction between ‘soils’ and ‘rocks’ as “in terms of construction, a soil is any rock used in construction as a foundation, the environment in which a building is built and a material for constructing”.

The research aims to determine the way the failure criteria (the Mohr-Coulomb criterion, the Bieniawski criterion, the Hoek-Brown criterion and the Shashenko criterion) are modified in presence of excessive pore fluid pressure to evaluate the impact of pore pressure on the critical height of the vertical slope and that of the active and passive stress on protecting structures by analyzing solutions of classical problems in soil mechanics. The task has been set to obtain modifications of failure criteria enabling the authors to consider impacts of excessive pore fluid pressure on rock failure and stability.

Materials and methods. The research task is formulated in the following way:

1. There are known strength characteristics of a soil or rock (the specific cohesion c and the internal friction angle φ) or the uniaxial compressive R_c and tensile R_p strengths.
2. The specific weight of a soil (rock) γ is known.
3. The pore fluid pressure P is known.
4. The failure criterion of unsaturated rocks is known.
5. The known failure criterion is to be modified for saturated rocks.

Part 1. Let us first consider the Mohr-Coulomb one-dimensional failure criterion [4]

$$\tau \leq (\sigma - P) \cdot \operatorname{tg}(\varphi) + c, \quad (1)$$

where σ is shear stress; τ is the same normal one.

It should be noted that in soil and rock mechanics, compressive normal stresses should be considered as plus signed and strain normal stresses should be considered as minus signed.

Besides, it is worth noting that according to the Mohr-Coulomb failure criterion and under other equal conditions, a soil, rock and coal are destroyed if the maximum and minimum normal stresses σ_1 and σ_3 reach some critical combination. In these conditions, the principal normal stress σ_2 does not practically affect failure.

In order to reduce the one-dimensional condition of Mohr-Coulomb (1) to the three-dimensional case with principal normal stresses σ_1 and σ_3 according to data provided by V.A. Florin and other authors, we assume (1)

$$\left. \begin{aligned} \tau &= \tau_m \cdot \cos(\varphi); \\ \sigma &= \sigma_m - \tau_m \cdot \sin(\varphi); \end{aligned} \right\},$$

$$\left. \begin{aligned} \tau_m &= \frac{\sigma_1 - \sigma_3}{2}; \\ \sigma_m &= \frac{\sigma_1 + \sigma_3}{2}. \end{aligned} \right\}. \quad (2)$$

We have

$$\left. \begin{aligned} \frac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3 - 2 \cdot P + 2 \cdot c \cdot ctg(\varphi)} &\leq \sin(\varphi); \\ \sigma_1 + \sigma_3 - 2 \cdot P + 2 \cdot c \cdot ctg(\varphi) &\geq 0; \\ \sigma_1 &\geq \sigma_2 \geq \sigma_3. \end{aligned} \right\}, \quad (3)$$

Analysis of (3) enables the following conclusions

1. This expression differs from the known failure condition of Mohr-Coulomb [1, 4, 5] and the ratios presented below (5) in terms of the summand “ P ” present in the denominator, i.e. pore pressure which is minus signed.

2. With pore pressure increased and the denominator of positive value (3), the left side of the equation increases. Thus, in this case, soil (rock) strength decreases.

3. When values of pore pressure P are considerable and the condition is observed

$$\sigma_1 + \sigma_3 - 2 \cdot P + 2 \cdot c \cdot ctg(\varphi) < 0, \quad (4)$$

the failure condition (3) passes to the overcritical region and does not have any physical sense.

4. If in (3) pore pressure is assumed equal to zero, we reach the accepted recording of the Mohr-Coulomb failure condition

$$\left. \begin{aligned} \frac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3 + 2 \cdot c \cdot ctg(\varphi)} &\leq \sin(\varphi); \\ \sigma_1 &\geq \sigma_2 \geq \sigma_3. \end{aligned} \right\}. \quad (5)$$

Thus, the well-known recording of the Mohr-Coulomb failure condition (5) is a special case of the obtained solution (3).

5. If in (3) we change the sign of pore pressure P (i.e. not to force fluid or gas into the foundation, but to withdraw them) the foundation will be consolidated.

Let us compare failure conditions (3) and (5).

We divide the upper equity (5) by the upper equality (3) term by term.

Considering the fact that the left and right sides of (3) and (5) are greater than zero, we have

$$\psi = \frac{\sigma_1 + \sigma_3 - 2 \cdot P + 2 \cdot c \cdot \text{ctg}(\varphi)}{\sigma_1 + \sigma_3 + 2 \cdot c \cdot \text{ctg}(\varphi)} \leq 1. \quad (6)$$

Next let us assume in (6)

$$\chi = \frac{2 \cdot P}{\sigma_1 + \sigma_3 + 2 \cdot c \cdot \text{ctg}(\varphi)} \quad (7)$$

Considering inequality (7), the second condition (3) and inequality (6) will look like

$$\left. \begin{aligned} \psi &= 1 - \chi \leq 1; \\ 0 &\leq \chi \leq 1. \end{aligned} \right\} \quad (8)$$

Thus, the range of definition of the dimensionless number χ includes all positive numbers within the interval $\chi \in (0,1)$, the range of definition of the function ψ is within the interval $\psi \in (0,1)$. It allows us to conclude that with any value of pore pressure in saturated rocks (soils) their strength will be smaller than that in the unsaturated ones.

It should be noted that equality (3) can be also obtained in a simpler way on the basis of the following ideas:

Let us consider some elementary volume of a soil (rock), to which the principal stresses σ_1 , σ_2 and σ_3 are applied outside.

Pore fluid/gas pressure equal to P (called neutral in soil mechanics) acts inside a sample.

According to Pascal's law, the pressure acts in all directions and its values are equal in all directions as well.

Besides, as indicated by the Terzaghi's saturation capacity principle, the soil (rock) skeleton is under the effective pressure equal to the difference of principal stresses and the pore pressure P

$$\left. \begin{aligned}
& \left| \begin{array}{ccc} \sigma_{1,\varphi} & 0 & 0 \\ 0 & \sigma_{2,\varphi} & 0 \\ 0 & 0 & \sigma_{3,\varphi} \end{array} \right| = \\
& = \left| \begin{array}{ccc} \sigma_1 & 0 & 0 \\ 0 & \sigma_2 & 0 \\ 0 & 0 & \sigma_3 \end{array} \right| - \left| \begin{array}{ccc} P & 0 & 0 \\ 0 & P & 0 \\ 0 & 0 & P \end{array} \right| = \\
& = \left| \begin{array}{ccc} \sigma_1 - P & 0 & 0 \\ 0 & \sigma_2 - P & 0 \\ 0 & 0 & \sigma_3 - P \end{array} \right| ; \\
& \left. \begin{aligned}
& \sigma_1 \geq \sigma_2 \geq \sigma_3; \\
& \sigma_{1,\varphi} \geq \sigma_{2,\varphi} \geq \sigma_{3,\varphi}; \\
& \sigma_1 - P \geq \sigma_2 - P \geq \sigma_3 - P.
\end{aligned} \right\} \quad (9)
\end{aligned}$$

where $\sigma_{i,\varphi}$ is an effective value of the principal stresses.

To receive the final solution of the problem, we replace the principal stresses σ_i with their effective values $\sigma_{i,\varphi}$. In this way, we receive the ratios obtained earlier (3).

It is worth noting that the same failure condition (3) for saturated soils (rocks) was obtained in different ways. It indicates accuracy of the result obtained.

Strength characteristics c (specific cohesion) and φ (the internal friction angle) are typically used in predicting soil failure [1, 4].

The uniaxial compressive R_c and tensile R_p strengths are used as strength characteristics in rock mechanics [5].

According to data presented in “Basic principles of soil mechanics” by V.A. Florin and [5], there are such ratios between uniaxial compressive R_c and tensile R_r strengths as well as between trigonometric functions of the internal friction angle of rock and its specific cohesion

$$\left. \begin{aligned} c &= \frac{1}{2} \cdot \sqrt{R_c \cdot R_r}; \\ \sin(\varphi) &= \frac{R_c - R_r}{R_c + R_r}; \\ \cos(\varphi) &= \frac{2 \cdot \sqrt{R_c \cdot R_r}}{R_c + R_r}; \\ \operatorname{tg}(\varphi) &= \frac{\sin(\varphi)}{\cos(\varphi)} = \frac{R_c - R_r}{2 \cdot \sqrt{R_c \cdot R_r}}; \\ \operatorname{ctg}(\varphi) &= \frac{\cos(\varphi)}{\sin(\varphi)} = \frac{2 \cdot \sqrt{R_c \cdot R_r}}{R_c - R_r}. \end{aligned} \right\} \quad (10)$$

We put ratios (10) into the obtained equality (3) and considering $\xi = R_r/R_c$ we will find

$$\left. \begin{aligned} \xi &= \frac{R_r}{R_c}; \\ \frac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3 - 2 \cdot P + 2 \cdot R_c} &\leq \frac{1 - \xi}{1 + \xi}; \\ \sigma_1 + \sigma_3 - 2 \cdot P + 2 \cdot R_c \cdot \frac{\xi}{1 - \xi} &\geq 0; \\ \sigma_1 &\geq \sigma_2 \geq \sigma_3. \end{aligned} \right\} \quad (11)$$

Obtained conditions (11) are another form of recording the Mohr-Coulomb failure condition received earlier for saturated soils (3) in which some other material constants R_c and R_r , are used instead of strength material constants c and φ .

Then, we find the variation range of the parameter $\xi = R_r/R_c$.

According to current ideas of rock strength, the internal friction angle takes values of $\varphi \in (0 \dots 45^\circ)$ and, that is why, the tangent of the internal friction angle varies within $\operatorname{tg}(\varphi) \in (0 \dots 1^\circ)$.

From (10) we have $\operatorname{tg}(\varphi) = \frac{R_c - R_r}{2 \cdot \sqrt{R_c \cdot R_r}} = \frac{1 - \xi}{2 \cdot \sqrt{\xi}}$, so the parameter

$\xi = R_r/R_c$ has a variation range of $\xi \in (1, \dots, 3 - 2 \cdot \sqrt{2})$

Part 2. The Bieniawski failure criterion for the three-dimensional

case looks like [1, 3, 6]

$$\left. \begin{aligned} \sigma_1 &\leq A \cdot (R_c)^{0,25} \cdot (\sigma_3)^{0,75} + R_c; \\ \sigma_1 &\geq \sigma_2 \geq \sigma_3. \end{aligned} \right\} \quad (12)$$

where $A \in (0 \dots 20)$ is an empirical constant.

To consider the influence of pore fluid pressure P on rock failure, we use inequality (12) and ratios (9). Thus, we have

$$\left. \begin{aligned} \sigma_1 &\leq A \cdot (R_c)^{0,25} \cdot (\sigma_3 - P)^{0,75} + R_c + P; \\ \sigma_1 &\geq \sigma_2 \geq \sigma_3. \end{aligned} \right\} \quad (13)$$

Analysis of the inequality (13) enables the following conclusions:

1. If pore pressure exceeds the principal stress σ_3 (i.e. $P > \sigma_3$), the principal stress σ_1 is a complex number and has no physical sense.

2. If the empirical constant A is equal to zero, we have the inequality $\sigma_1 \leq R_c + P$ suggesting that with the increased pore pressure P we observe the increased breaking stress σ_1 as well. In other words, the higher the pressure, the greater the rock strength.

This fact does not correspond to modern ideas of behaviour of saturated rocks under load.

For further analysis of the Bieniawski failure criterion, we reduce (12) and (13) to the dimensionless form

$$\left. \begin{aligned} \bar{\sigma}_1 &\leq A \cdot (\bar{\sigma}_3)^{0,75} + 1; \\ \bar{\sigma}_{1,\beta} &\leq A \cdot (\bar{\sigma}_3 - \bar{P})^{0,75} + 1 + \bar{P}; \\ \bar{\sigma}_1^* &\leq \frac{A \cdot (\bar{\sigma}_3 - \bar{P})^{0,75} + 1 + \bar{P}}{A \cdot (\bar{\sigma}_3)^{0,75} + 1}; \\ \bar{\sigma}_1 &= \frac{\sigma_1}{R_c}; \quad \bar{\sigma}_3 = \frac{\sigma_3}{R_c}; \quad \bar{P} = \frac{P}{R_c}; \\ \bar{\sigma}_1 &\geq \bar{\sigma}_2 \geq \bar{\sigma}_3. \end{aligned} \right\} \quad (14)$$

where $\bar{\sigma}_1$ is the principal stress σ_1 related to the uniaxial com-

pressive strength R_c in unsaturated rock; $\bar{\sigma}_{1,\epsilon}$ is the same one in saturated rock; $\bar{\sigma}_3$ is the principal stress σ_3 related to the uniaxial compressive strength R_c ; the same principal stress σ_3 ; \bar{P} is the same pore pressure; $\sigma_1^* = \bar{\sigma}_{1,\epsilon} / \bar{\sigma}_1$.

The former upper inequality (14) is obtained by normalizing the Bieniawski criterion for unsaturated rocks (inequality (12)), the latter is obtained by normalizing the Bieniawski criterion for saturated rocks (inequality (13)).

For some series of parameters of A and $\bar{\sigma}_3$ there are built dependencies of critical dimensionless stress σ_1^* on dimensionless pore fluid pressure \bar{P} (Fig. 1-3), where Series 1 is $\bar{P} \neq 0$ and A=0; Series 2 is $\bar{P} \neq 0$ and A=1-10; Series 3 is $\bar{P} \neq 0$ and A=1; Series 4 is $\bar{P} \neq 0$ and A=5; Series 5 is $\bar{P} \neq 0$ and A=10; Series 6 is $\bar{P} \neq 0$ and A=15; Series 7 is $\bar{P} \neq 0$ and A=20.

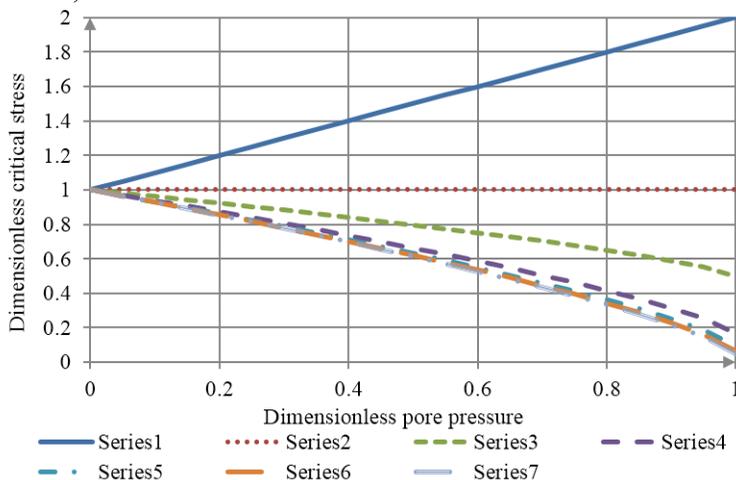


Fig. 1. Dependency of relative breaking stress on dimensionless pore pressure (according to the Bieniawski criterion)

Notes to Fig.1:

1. The relative pressure calculated by $\bar{P} = P / R_c$ is plotted X-direction.
2. The relative pressure calculated by $\sigma_1 \cdot \sigma_{1,\epsilon} / \sigma_1$ is plotted Y-direction.

direction.

3. The ratio between the principal stresses is $\sigma_3 = \sigma_1$.

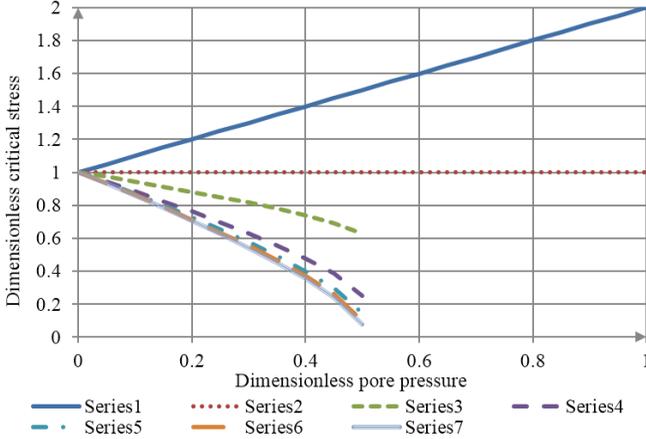


Fig. 2. Dependency of the relative breaking stress on the dimensionless pore pressure (according to the Bieniawski criterion)

Notes to Fig.2:

1. The X- and Y-axes are similar to Fig.1.
2. The ratio between the principal stresses is $\sigma_3 = \sigma_1/2$.

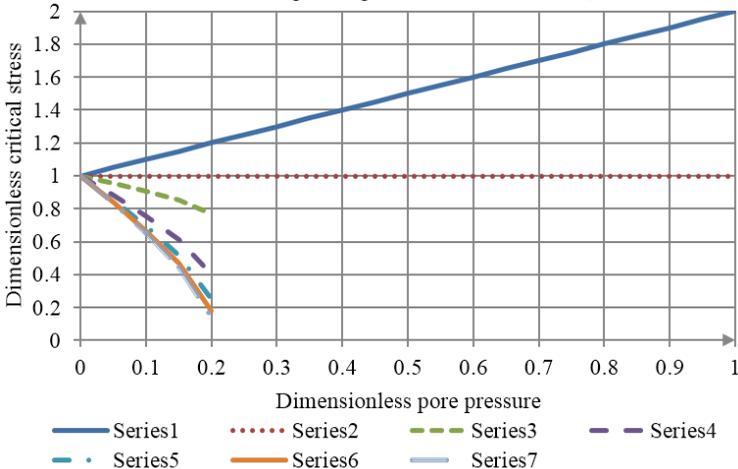


Fig. 3. Dependency of the relative breaking stress on the dimensionless pore pressure (according to the Bieniawski criterion)

Notes to Fig.3:

1. The X - and Y -axes are similar to Fig.1.
 2. The ratio between the principal stresses is $\sigma_3=\sigma_1/5$.
- The curves in Figures 1-3 let us conclude the following:

1. The greater the pore fluid pressure, the smaller stress σ_1 should be applied to rock deformation.

2. The smaller the ratio of the principal stresses σ_3/σ_1 , the smaller range of pore fluid pressures can be related to the Bieniawski formula.

3. The greater the empirical constant A , the greater the slope ratio of the curve “relative principal stress $\bar{\sigma}_1$ – dimensionless pore pressure \bar{P} ”.

4. If the empiric factor A is equal to zero, the rock strength rises along with the increased pore pressure. This fact contradicts experiment data and modern ideas of rock behaviour under load.

The conclusions obtained indicate that modification of the Bieniawski failure criterion is suitable for forecasting failures of saturated rocks in a limited range of pore fluid pressures and a limited variation range of the empirical factor A .

Part 3. The Hoek-Brown failure criterion for soils and rocks of undisturbed structure in the three-dimensional case looks like [1, 3, 6]

$$\left. \begin{aligned} \sigma_1 &\leq \sigma_3 + R_c \cdot \sqrt{m \cdot \frac{\sigma_3}{R_c} + 1}; \\ \sigma_1 &\geq \sigma_2 \geq \sigma_3. \end{aligned} \right\}, \quad (15)$$

where $m \in (0...33)$ is an empirical constant.

It should be also taken into account that in ratios (15) tensile stresses should be taken minus signed, the compressive ones should be taken plus signed.

To consider the impact of the pore fluid pressure on the rock strength, we use inequality (15) and ratio (9). We have

$$\left. \begin{aligned} \sigma_1 &\leq \sigma_3 + R_c \cdot \sqrt{m \cdot \frac{\sigma_3 - P}{R_c} + 1}; \\ \sigma_1 &\geq \sigma_2 \geq \sigma_3. \end{aligned} \right\}, \quad (16)$$

Analysis of inequality (16) enables the following conclusions:

1. With the empiric factor equal to zero, rock strength does not depend on pore fluid pressure. This behaviour under load is characteristic for perfect plastic media.

2. While performing the inequality

$$P > \sigma_3 + \frac{R_c}{m}, \quad (17)$$

the principal stress σ_1 becomes a complex number, that is why, inequality (16) loses its physical sense.

For further analysis of the Hoek-Brown failure criterion, we reduce (15) and (16) to the dimensionless form. We have

$$\left. \begin{aligned} \bar{\sigma}_1 &\leq \bar{\sigma}_3 + \sqrt{m \cdot \bar{\sigma}_3 + 1}; \\ \bar{\sigma}_{1,e} &\leq \bar{\sigma}_3 + \sqrt{m \cdot (\bar{\sigma}_3 - \bar{P}) + 1}; \\ \sigma_1^* &= \frac{\bar{\sigma}_{1,e}}{\bar{\sigma}_1} \leq \frac{\bar{\sigma}_3 + \sqrt{m \cdot (\bar{\sigma}_3 - \bar{P}) + 1}}{\bar{\sigma}_3 + \sqrt{m \cdot \bar{\sigma}_3 + 1}}; \\ \bar{\sigma}_1 &= \frac{\sigma_1}{R_c}; \quad \bar{\sigma}_3 = \frac{\sigma_3}{R_c}; \quad \bar{P} = \frac{P}{R_c}; \\ \bar{\sigma}_1 &\geq \bar{\sigma}_2 \geq \bar{\sigma}_3. \end{aligned} \right\}. \quad (18)$$

where $\bar{\sigma}_1$ is the principal stress σ_1 related to the uniaxial compressive strength R_c in unsaturated rocks; $\bar{\sigma}_{1,e}$ is the same one in saturated rocks; $\bar{\sigma}_3$ is the principal stress σ_3 related to the uniaxial

compressive stress R_c ; the same principal stress σ_3 ; \bar{P} is the same pore pressure; $\sigma_1^* = \bar{\sigma}_{1.e} / \bar{\sigma}_1$.

The former upper inequality (18) is obtained by normalizing the Hoek-Brown criterion for unsaturated rocks (inequality 15), the latter is obtained by normalizing the Hoek-Brown criterion for saturated rocks (inequality 16).

For some series of parameters of m and $\bar{\sigma}_3$ there are built dependencies of the critical dimensionless stress σ_1^* on the dimensionless pore fluid pressure \bar{P} (Fig. 4-6), where Series 1 is the empirical factor $m=0$;

Series 2 is the same one for $m=1$;

Series 3 is the same one for $m=5$;

Series 4 is the same one for $m=10$;

Series 5 is the same one for $m=15$;

Series 6 is the same one for $m=20$; Series 7 is the same one for $m=33$.

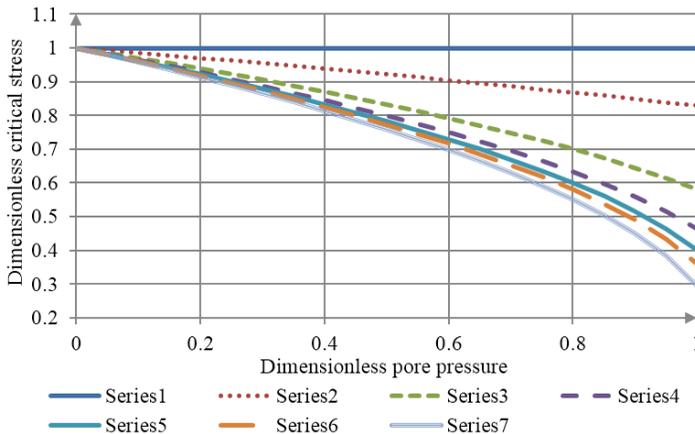


Fig. 4. Dependency of the relative breaking stress on the dimensionless pore pressure (according to the Hoek-Brown failure criterion)

Notes to Fig. 4: The axes and ratios are similar to Fig.1.

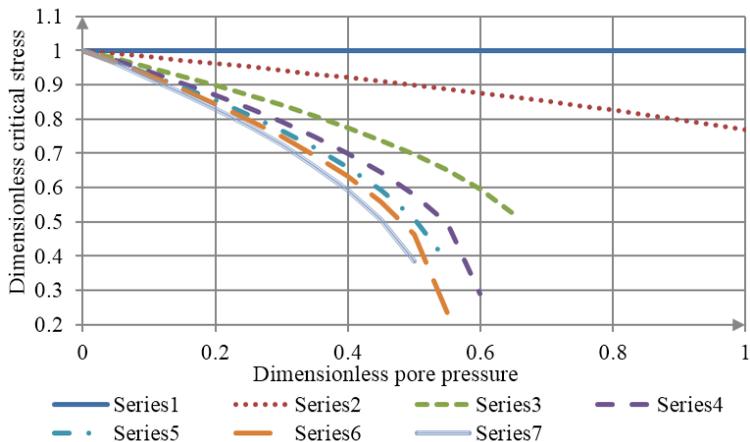


Fig. 5. Dependency of the relative breaking stress on the dimensionless pore pressure (according to the Hoek-Brown failure criterion)

Notes to Fig. 5: The axes and ratios are similar to Fig.2.

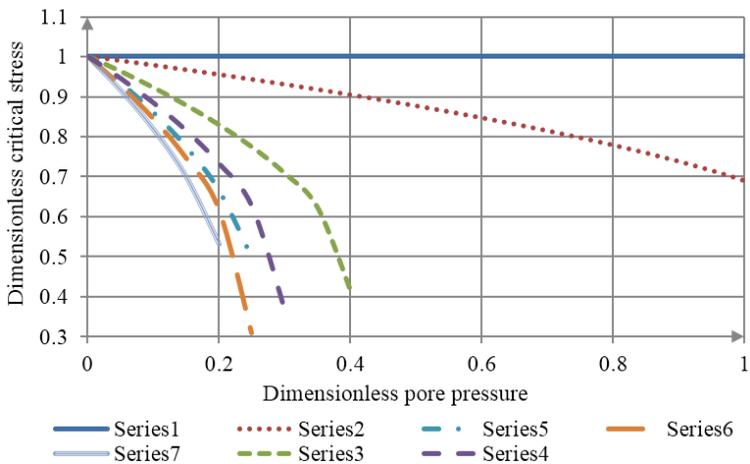


Fig. 6. Dependency of the relative breaking stress on the dimensionless pore pressure (according to the Hoek-Brown failure criterion)

Notes to Fig. 6: The axes and ratios are similar to Fig. 3.

The curves in Fig. 4-6 enable the following conclusions:

1. The greater the pore fluid pressure, the smaller stress σ_1 should

be applied to rock deformation.

2. The smaller the ratio of the principal stresses σ_3/σ_1 and the greater the empirical factor m are, the smaller range of pore fluid pressures can be related to the Hoek-Brown formula.

3. The greater the empirical constant m , the greater the slope ratio of the curve “relative principal stress $\bar{\sigma}_1$ – dimensionless pore pressure \bar{P} ”.

The conclusions obtained indicate that modification of the Hoek-Brown failure criterion is suitable for forecasting failures of saturated rocks in a limited range of pore fluid pressures and a limited variation range of the empirical factor m .

Part 4. The Shashenko failure criterion for soils and rocks of undisturbed structure in the three-dimensional case looks like [1, 2, 3, 6]

$$\left. \begin{aligned} & (\psi - 1) \cdot (\sigma_1 + \sigma_3) + \\ & + \sqrt{\left[(1 - \psi)^2 \cdot (\sigma_1 + \sigma_3)^2 + \right.} \\ & \quad \left. + 4 \cdot \psi \cdot (\sigma_1 - \sigma_3)^2 \right]} - \\ & - 2 \cdot \psi \cdot R_c \leq 0; \\ & \psi = \frac{R_r}{R_c}; \\ & \sigma_1 \geq \sigma_2 \geq \sigma_3. \end{aligned} \right\} \cdot \quad (19)$$

Ratios (19) result in

$$\left. \begin{aligned} & \sigma_1 \leq \sigma_3 + (1 - \psi) \cdot \frac{R_c}{2} - \\ & - \frac{R_c}{2} \cdot \sqrt{\left[8 \cdot \frac{\sigma_3}{R_c} \cdot (1 - \psi) + \right.} \\ & \quad \left. + (1 + \psi)^2 \right]} ; \\ & \psi = \frac{R_r}{R_c}; \\ & \sigma_1 \geq \sigma_2 \geq \sigma_3. \end{aligned} \right\} \cdot \quad (20)$$

To consider the impact of the pore fluid pressure \bar{P} on the rock failure, we use inequality (20) and ratios (9). We have

$$\left. \begin{aligned} \sigma_1 &\leq \sigma_3 + (1-\psi) \cdot \frac{R_c}{2} - \\ &-\frac{R_c}{2} \cdot \sqrt{\left[8 \cdot \frac{(\sigma_3 - P)}{R_c} \cdot (1-\psi) + \right. \\ &\quad \left. + (1+\psi)^2 \right]}; \\ \psi &= \frac{R_f}{R_c}; \\ \sigma_1 &\geq \sigma_2 \geq \sigma_3. \end{aligned} \right\}. \quad (21)$$

Analysis of inequality (20) enables the following conclusions:

1. With the dimensionless factor ψ equal to one, ratios (21) look like

$$\left. \begin{aligned} \sigma_1 &\leq \sigma_3 \pm R_c; \\ \psi &= 1; \\ \sigma_1 &\geq \sigma_2 \geq \sigma_3. \end{aligned} \right\}. \quad (22)$$

In this case, rock failure does not depend on pore fluid pressure. This rock behaviour under load corresponds to perfect plastic media.

2. In performing the inequality

$$P > \sigma_3 + \frac{R_c}{8} \cdot \frac{(1+\psi)^2}{1-\psi}, \quad (23)$$

the principal stress σ_1 becomes a complex number, that is why, inequality (21) loses its physical sense.

For further analysis of the Shashenko failure criterion, we reduce (20) and (21) to the dimensionless form. We have

$$\left. \begin{aligned}
& \bar{\sigma}_1 \leq \bar{\sigma}_3 + (1-\psi) \cdot \frac{1}{2} - \\
& - \frac{1}{2} \cdot \sqrt{\left[\begin{array}{l} 8 \cdot \bar{\sigma}_3 \cdot (1-\psi) + \\ + (1+\psi)^2 \end{array} \right]}; \\
& \bar{\sigma}_{1,6} \leq \bar{\sigma}_3 + (1-\psi) \cdot \frac{1}{2} - \\
& - \frac{1}{2} \cdot \sqrt{\left[\begin{array}{l} 8 \cdot (\bar{\sigma}_3 - \bar{P}) \cdot (1-\psi) + \\ + (1+\psi)^2 \end{array} \right]};
\end{aligned} \right\}$$

$$\sigma_1^* \leq \frac{\left\{ \begin{array}{l} 2 \cdot \bar{\sigma}_3 + 1 - \psi - \\ - \sqrt{\left[\begin{array}{l} 8 \cdot (\bar{\sigma}_3 - \bar{P}) \cdot (1-\psi) + \\ + (1+\psi)^2 \end{array} \right]} \end{array} \right\}}{\left\{ \begin{array}{l} 2 \cdot \bar{\sigma}_3 + 1 - \psi - \\ - \sqrt{\left[\begin{array}{l} 8 \cdot \bar{\sigma}_3 \cdot (1-\psi) + \\ + (1+\psi)^2 \end{array} \right]} \end{array} \right\}};$$

$$\psi = \frac{R_r}{R_c};$$

$$\bar{\sigma}_1 = \frac{\sigma_1}{R_c}; \quad \bar{\sigma}_3 = \frac{\sigma_3}{R_c}; \quad \bar{P} = \frac{P}{R_c};$$

$$\bar{\sigma}_1 \geq \bar{\sigma}_2 \geq \bar{\sigma}_3. \quad (24)$$

For some series of parameters of $\psi=R_r/R_c$ and $\bar{\sigma}_3$ there are built dependencies of the critical dimensionless stress σ_1^* on the dimensionless pore fluid pressure \bar{P} (Fig. 7-9), where Series 1 is =0; Series 2 is the same one for $\psi=0,2$; Series 3 is the same one for $\psi=0,4$; Series 4 is the same one for $\psi=0,6$; Series 5 is the same one for $\psi=0,8$; Series 6 is the same one for $\psi=1,0$.

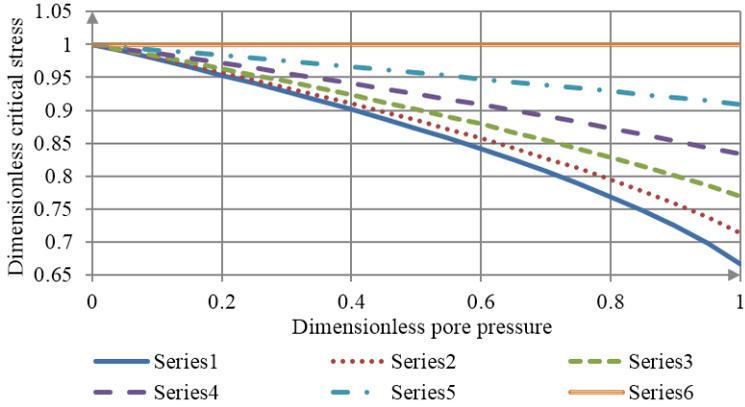


Fig. 7. Dependency of the relative breaking stress on the dimensionless pore pressure (according to the Shashenko failure criterion)

Notes to Fig. 7: The axes and ratios are similar to Fig.1.

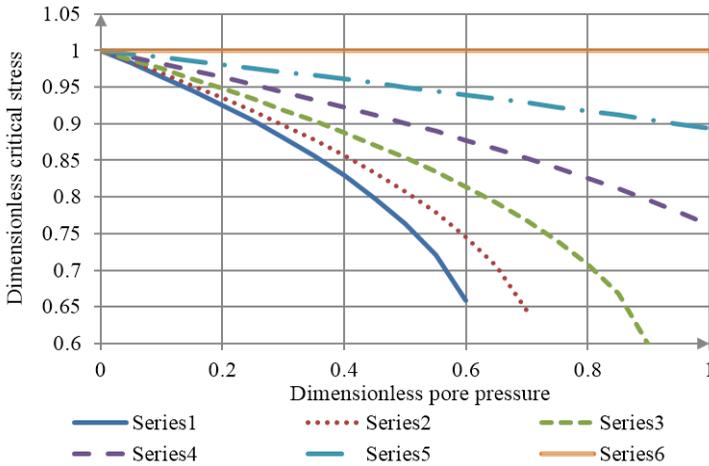


Fig. 8. Dependency of the relative breaking stress on the dimensionless pore pressure (according to the Shashenko failure criterion)

Notes to Fig. 8: The axes and ratios are similar to Fig.2.

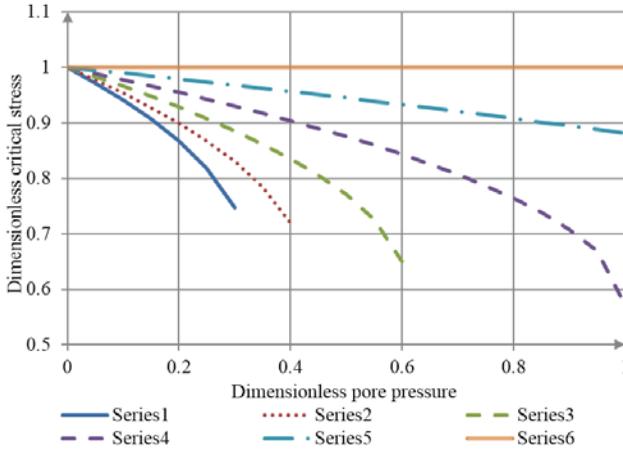


Fig. 9. Dependency of the relative breaking stress on the dimensionless pore pressure (according to the Shashenko failure criterion)

Notes to Fig. 9: The axes and ratios are similar to Fig.3.

The curves in Fig. 7-9 enable the following conclusions:

1. The greater the pore fluid pressure is, the smaller stress σ_1 should be applied to rock deformation.
2. The smaller the ratio of the principal stresses σ_3 / σ_1 and the parameter $\psi = R_r / R_c$ are, the smaller range of pore fluid pressures can be related to the Shashenko formula.

The conclusion drawn indicates that modification of the Shashenko failure criterion is suitable for predicting failures of saturated rocks in a limited range of pore fluid pressures and a limited variation range of the parameter $\psi = R_r / R_c$.

Conclusions

1. The Mohr-Coulomb, Bieniawski, Hoek-Brown and Shashenko failure criteria resulted in new failure criteria for saturated rocks with excessive pore fluid pressure.
2. The results allow of natural generalization for rocks under stress in the pore gas and water-gas mixture.
3. It is indicated that the obtained failure criteria have some physical sense in a limited range of pored fluid/gas pressures and a limited range of combinations of the normal principal stresses.

4. The numerical experiment establishes that excessive pore fluid/gas pressure results in reduction of rock strength:

- according to modification of the Mohr-Coulomb three-dimensional failure criterion - by 0-100%;
- according to modification of the Bieniawski three-dimensional failure criterion - by 0-90%;
- according to modification of the Hoek-Brown three-dimensional failure criterion - by 0-70%;
- according to modification of the Shashenko three-dimensional failure criterion - by 0-60%;

5. The obtained results can be applied to forecasting strength, stability and bearing capacity of saturated soils and rocks including solving such problems as stability of slopes and mine workings, definition of active stress on protecting structures.

In general, a conclusion can be drawn that all suggested criteria of rock failure have their own application range for solving the problems of strength, stability and bearing capacity of saturated soils and rocks. Meanwhile, these ranges should be defined in the course of further research and experiments.

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PROBLEMS AND PROSPECTS OF LITHIUM PRODUCTION TECHNOLOGY IN UKRAINE

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Abstract

Purpose. A method to intensify leaching process by means of shock-vibrating mineral activation has been developed. Possibility of selective dissolution of various components in terms of grinding mode variation has been demonstrated.

Methods. Systematic approach is proposed to study regularities of postmagmatic formations and to develop further classification scheme to identify geological and structural regularities and genetic peculiarities of ore field formations.

Findings. It has been demonstrated that despite the detailed examination of Archean formations within the Ukrainian Shield, a problem of complex comprehensive study of their postmagmatic formations (pegmatites, hydrothermal-metasomatic formations) is still topical. Details of the essential problems of geological and structural regularities of the formations and location of the formation fields, i.e. their interaction, have not been completely explained yet. That is a considerable gap for further studies since the mentioned geological factors are the basis for further research while substantiating predictions on geological exploration for the deposits of rare metals, gold, uranium and other metallic minerals. The idea is proposed concerning the fact that pegmatites, metasomatites, and hydrothermal veins as well as the zones of those complexes are basic for a series of rare-metal elements; in terms

of certain elements, those are the only localizers of commercial concentrations where, according to statistic data, Precambrian blocks include from 73 to 92% of all the Li, Rb, Cs, Be, Ta, U, Au reserves concentrated within those formations.

Practical implications. Experimental data confirms the fact that there is practically linear dependence between a change in lattice parameter and floatation properties of mineral particles. Thus, changes in lattice parameters helps consider the deviation of surface properties of natural materials comparing to purely chemical compounds.

Keywords: lithium ores, natural minerals, mechanical activation, vibro-impact mill

Introduction

Nowadays, there are two commercial types of lithium ores in the worlds: endogenous (associated to granite-pegmatite complexes) and exogenous (associated to brines and their salts) ones. All the lithium deposits are complex (Cs, Ta, Nb, Be, Sn, Rb) where lithium is rarely of principle value (Table 1).

Table 1– Basic genetic types of lithium deposits

Genetic type	Rocks enclosing mineralization,	Commercial type	Mineral ore type	Average Li ₂ O content in ore, mineralization scale	Mineralization distribution	Accompanying minerals	Examples of the deposits, the ones under development are underlined
Granite pegmatite lithium							
Pegmatite	Gabbroic anorthosites, para- and ortho- amphibolites, crystalline schist, marmorized limestones, greenschist formations	Li-silicate; Ta-Be-Li-oxide-silicate	Li-silicate; Ta-Be-Li-oxide-silicate	0,7-1,5; up to very coarse	Uniform and nonuniform	Ta, Nb, Be, Sn, Rb in pegmatites	Zavitinsk (Russia), Kings Mountain, North and South Carolina (USA), La Corn, Cat Lake, La Croix (Canada), deposits of Eastern Afganistan

Granite pegmatites rare-metal (complex)							
Pegmatite	Para-ortho- amphibolites, crystalline schist and greisses	and Li-silicate; phosphate; Li-Cs-silicate; Ta-Cs-Li-oxide-silicate	Spidumene; Petalite; Eucryptite; Amblygonite; Pollucite - lepidolite; Tantalite-pollucite-lepidolite	0,6-0,9; coarse	Nonuniform, often zonal	Nb, Sn, Ga, Cs, Li, Rb	Voronji in Tundry, (Russia), Bikita (Zimbabwe). Bernic Lake (Canada), Black Hills (USA) (cglimmerites)
Stanniferous zinnwaldite greisens							
Greisen	Granites, porphyres, quartz porphyre, sand-shale formations	Sn-Li-oxide-silicate	Quartz-zinnwaldite and topaz-quartz-zinnwaldite with cassiterite and struverite	0,4-0,8; fine to medium	Nonuniform	Sn, Nb, Be, Rb and Cs	Cinovec (Check Republic)

Li_2O content in the pegmatite deposits being developed is 0,3-3,0% with minimum economic value depending upon mineral and technological indices from 0,5%. Average Li_2O content in lithium-bearing brines is within the range of <0,01-0,5%; it is characterized by large deposits with the reserves being more than 200 thousand tons of lithium [1]. Top suppliers of lithium (per year) are as follows: Chile – from 5 thousand tons (lithium-bearing brine); Canada, China, Russia, Australia, and the USA (pegmatites) - from 15 thousand tons in total.

Table 2 shows the largest lithium deposits in the world. Hydro-metallurgical processing of ores and concentrates is based upon the selective dissolution of minerals in water solutions of chemical agents to extract the required components from the solution. That method is applied to extract metals and eliminate harmful impurities of raw material which is rather hard to be prepared mechanically.

Table 2 – Largest lithium deposits

Deposit, country	Lithium concentrators	Reserves, thousand tons Li ₂ O	Li ₂ O content, %	Other useful components
Rare-earth granite pegmatite				
Manono-Kitotolo, Zair	Spodumene	320	-	Ta, Nb, Sn
Kings Mountain, USA	Spodumene	360	1,5	Be
Bernic Lake, Canada	Spodumene Petalite Lepidolite	65	3,0	Ta, Cs, Be, Rb
Greenbushes, Australia	Spodumene	570	2,9 (up to 4,0 within a rich zone)	Sn, Nb, Ta
Bikita, Zimbabwe	Petalite Spodumene Amblygonite	30	3,0	Sn, Be, Cs, Ta

In terms of hydrometallurgical methods of ore processing, preparation products are enough to grind up to partial mineral release, i.e. aggregates do not prevent dissolution while leaching; however, dissolution rate of fine-grained material increases owing to the active surface formation.

As it is known, natural minerals contain various impurities and have structural defects resulting in the fact that one and the same variety of the mineral extracted from different deposits, has dissimilar surface properties. Thus, numerous ores do not have sufficient reacting capability during the processes of chemical preparation. Owing to that, it is required to apply additional physical and chemical methods to effect minerals for their transformation into activated state.

Configuration of electronic orbits with the available valency bonds plays rather important role in dissolution process. It is known that electronic orbits have diverse configuration in space along with their moving away from atomic nucleus. Changes in behaviour of the ground mineral will depend either upon the impurity character or upon defects of crystalline lattice since any disturbance of a strict lattice periodicity always influences free energy of a crystal as well as the state of chemical bond [1, 2].

Mechanical activation of minerals, when the developed activity will depend upon the intensity and duration of grinding, is one of the methods to develop and accumulate structural defects [3].

Since shock-vibrating mineral loading results in the formation of super-reacting surface with numerous active centers and volumetric ionization, it is possible to suppose that shock-vibrating mineral activation is one of the methods to intensify leaching processes [10].

Purpose. Objective of the paper is to demonstrate a method of intensification of hydrometallurgical ore processing, in particular, leaching process, owing to the application of shock-vibrating mineral activation comparing to the available methods.

Formulating the problem. Basic methods and techniques to obtain metallic lithium from ores of various genesis have been characterized. Efficiency of hydrometallurgical ore processing in terms of its shock-vibrating activation has been substantiated. The consumer properties of the raw materials were assessed by studying their phase composition, physico-chemical and physico-mechanical properties, and their compliance with the technical specifications for the further processing of the products obtained.

Mineral and raw material base of Ukraine. Territory of Ukraine is characterized by principally complex deposits of lithium ores. All the previously known deposits and ore occurrences are associated to rare-metal granite-pegmatite complexes of Archaean-Proterozoic age and rarely with greisens of joint areas of the Ukrainian Shield. Hydrothermal-metasomatic formations (silicate-carbonate rocks), being described well in the Middle Pobuzhzhia [2], can be considered as the ones belonging to a new poorly studied type. Deposits of rare-earth pegmatites Krutaia Balka and Shevchenkovskoie are preliminarily explored and estimated in Pryazovia megablock. Such deposits as Polokhovskoie, Stankovatskoie, Nadiia and several ore occurrences within granite-pegmatite complexes are identified and evaluated within Ingulets megablock of the Shield and Shpola-Tashlyk ore district.

Spodumene-containing pegmatites, lithium-bearing granites, and greisens of Zheltorechenskoie and Komendantovskoie areas are associated to poorly studied ore occurrences of Kryvyi Rih-Kremenchug zone. Lithium-caesium mineralization prevails in vein pegmatites of both areas. Lithium content in pegmatite of Zheltorechenskii area is 0,3-1,0%.

Komendantovskoie area is characterized by extensive greisenisation of vein aplite-pegmatoid granites which cut amphibolites and

biotite gneisses. Spodumene prevails here; it is in association with holmquistit and tantalum-columbite with increased contents: (Ta - 39,8%, Nb - 43,7%) and columbite (Ta - 11,3%, Nb - 66,1%). Maximum lithium content in spodumene-albite pegmatites is up to 0,9% [1].

Hydrothermally changed granites of Perzhanskoie rare-earth ore field as well as greisens of its adjacent Verbinnskoie bismuth-molybdenum deposit are considered to be prospective. In terms of Perzhanskoie aegirine and riebeckite granites, lithium is concentrated in high ferriferous fluorine mica in the form of isomorphic impurities reaching up to 1500 g/t of Li_2O .

In the context of Verbinskoie deposit, lithium is concentrated in zinnwaldite (Li_2O content is 1,98-2.04%) of ore-bearing greisens with accompanying molybdenum being up to 0,74%.

In terms of exogeneous processes, basic lithium mass is concentrated within the sedimentary thicknesses of Neocryptozoic (Vendian) of Podolskian Transdnestr and Donbass Carbon. As for Transdnestr, increased lithium content (up to 0,16%) is determined within thin-layered fine-grained feldspar-quartz sandstones. It has no commercial value.

In Donbass, lithium mineralization (Li_2O content within the range of 2-3%) is widespread within hydrothermal veins and terrigenous flushoid deposits of chlorite-sercite-hydromicaceous shales. Accompanying lithium is associated with chlorite-donbassit and cookeit of Yesaulovskoie gold-silver-polymetallic deposit. It is characterized by medium Li_2O content - 0,37% [1].

Lithium-containing granite-pegmatites. Two basic subtypes of lithium-bearing granite pegmatites are singled out within the Ukrainian Shield – spodumene and rare-earth. Spodumene one is more prospective; it is represented by numerous high angle veins with the thickness from 0.5 to 25 m located in parallel both to regional fault zones up to 20 km and downwards to 35 km. Spodumene content within the veins is up to 25%; impurities of Ta_2O_5 (0.005-0.01%), BeO (0,04-0,07%), and SnO_2 (0,03-0,08%) are also recorded [1].

Enclosing rocks are represented by para- and orthoamphibolites, gabbroic anorthosite, and biotite gneisses. It is noted that there is a poor zonality of pegmatite veins. As a rule, changes in the dimen-

sions of microcline from the edge to the center are accompanied by the increase in crystal sizes. Contact with amphibolites demonstrates tourmalinization and biotitization with the formation of holmquistit containing up to 8% of Cs_2O . Geochemical areolas of lithium and caesium, being prospecting indicators, are observed around spodumene pegmatites in the enclosing rocks.

Another type of lithium pegmatites (complex rare-earth one) forms flat or thick steep-dipping chimney or boss bodies with clear zonal structure of microcline-spodumene-albite or microcline-petalite-albite composition with high content of Ta, Be, and Cs. Ore mineralization in them is nonuniform; most often it is in the form of "pockets" or bunches. Central parts of pegmatite bodies demonstrate gigantic (up to 15 m long) crystals of spodumene. In terms of flat, subhorizontal pegmatite veins, their upper part is rich in tantalum while lower one is rich in lithium.

Polokhovskoie deposit is located within the eastern part of Shpola-Tashlyk rare-metal district, within southern-western margins of Korsun-Novomyrgorodskii pluton of anorthosites and rapakivi granites. The deposit mineralization has no outcrop being overlapped by Mesozoic-Cainozoic terrigenous sediments occurring on the weathering crust of Precambrian complexes. Total thickness of the rocks overlapping the deposit is 60-100 m. Lithium-containing substituted pegmatites [1, 5] in the form of steep-dipping bodies of lenticular shape occur in metamorphic rocks being complexly injected with granitoids and dislocated. The latter are represented by cordierite-biotite, garnet-cordierite-biotite, garnet- and diopside-biotite plagiogneisses. Aplite-pegmatoid and two-feldspar different-grained biotite granites belong to Kirovograd complex. According to [1, 5], three steep-dipping ore bodies occurring subconcordantly to gneisses banding and linearity of granitoid injections have been studied within the deposit. Length of the largest body is 550 m in terms of average thickness of 60 m and maximum thickness of 130 m. The body is unraveled from the surface down to 500 m of its dip. Second ore body is of 13-75 m in thickness; it is studied along its strike of 350 m and down to 400 m. Third body does not have such considerable dimensions; that is a blind ore body. Ore specialization of the deposit is lithium one. Associated minerals are as follows: rubidium, tantalum, niobium, beryllium, and stannum. Average Li_2O content in the

ore bodies is: the first - 1,25%, the second - 1,21%, and the third - 1,04%. The deposit contains only one mineral and technological ore type – dense fine-grained quartz-feldspar-petalite rock. Weathering crust has demonstrated no commercial concentrations of lithium minerals. Table 3 represents characteristics of chemical and mineral composition of dense petalite ore.

Table 3 - Chemical and mineral compositions (%) of fine-grained petalite ore of the first ore body of Polokhovskoie deposit (according to [1])

Components, minerals	Raw ore	Rich ore	Components, minerals	Raw ore	Rich ore
SiO ₂	74,10	73,60	Nb ₂ O ₃	0,002	0,002
Al ₂ O ₃	16,54	16,50	Ta ₂ O ₅	0,002	0,002
Fe ₂ O ₃	0,47	0,31	SnO ₂	0,011	0,011
CaO	0,59	0,59	BeO	0,034	0,031
MgO	0,07	0,07	Petalite	27,6	36,2
MnO	0,06	0,02	Albite	28,0	26,3
K ₂ O	2,26	2,06	K-spar	20,9	19,1
Na ₂ O	3,30	3,10	Quartz	21,7	15,8
Li ₂ O	1,30	1,80	Spodumene	< 0,5	1,5
Rb ₂ O	0,04	0,04	Triphylite	0,5	0,5
Cs ₂ O	<0,003	<0,003	Apatite	0,5	0,4
P ₂ O ₅	0,48	0,42	Garnet	0,6	-
all the rest of it	0,54	0,62	Chrysoberyl	0,1	0,1
Including CO ₂	0,11	0,15	Sillimanite (fibrolite)	0,1	0,1
Σ	99,75	99,13			

Lithium ore is light-grey, almost white, fine-grained rock of massive or not clearly maculose structure (sometimes maculose-band structure) consisting mostly of interconnected and interblending quartz-microcline-albite-petalite and quartz-microcline-albite structural-mineral complexes being characteristic metasomatic formations of metamorphosed original pegmatites.

The ore consists practically of four minerals: petalite (27,6-36,2%), albite (26,3-28,0%), pertite K-spar (19.1-20.9%), and quartz (15,8-21,7%). The constituents show total of 97-98%.

Petalite is the main lithium carrier; it covers 91-95% of total Li_2O amount in the ore.

Rubidium is totally connected (93,3-96,9%) with *K*-spar. Other accompanying components (Be,Ta,Mb,Sn) are sometimes completely concentrated within their proper mineral-carriers: chrysoberyl, tantalum-niobates, cassiterite, and stannum; Be is partially associated to cordierite, and Sn is partially associated to nigrite.

Stankovatskoie ore field, located 40 km to the south-west from Polokhovskoie deposit, is represented by two series of bodies of substituted lithium pegmatites; it is considered as two deposits: Nadiia and Stankovatskoie.

The ore field has two submeridional strikes with westwards steep-dipping ore bodies with the thickness from several meters to 30 m.

Together they form an ore zone with the depth of 130-150 m opened with boreholes down to 500 m from the daylight surface. Contrary to Polokhovskoie deposit, ore pegmatites occur only within amphibolites not going beyond their boundaries into the thickness of enclosing gneisses. The latter being high-aluminous in their mineral composition do not differ from gneisses of Polokhovskoie deposit [1, 5].

Stankovatskoie and nadiia deposits are represented by sequences (up to 8-12) of contiguous steep-dipping bodies of lithium pegmatites; their real thickness is within the range being from 20 cm up to 25-30 m.

The thickest bodies are associated to core shares of pegmatite formations. Thickness of production zone of Stankovatskoie deposit is 140-150 m. Li_2O content is from 0,345 up to 2,23% reaching the average amount of 1,25% throughout the deposit; accompanying components are rubidium, tantalum, niobium, beryllium, and stannum. Northern flank of the deposit is characterized by separate pegmatite bodies containing the increased amount of Ta_2O_3 (up to 0,01-0,02%) in terms of low Li_2O content.

Thickness of production zone of Nadiia deposit is up to 130-140 m. Li_2O content varies from 0,25 to 1,26%, on average – 1,06%; accompanying components are rubidium, tantalum, niobium, beryllium, and stannum (Table 4).

Table 4 - Some chemical characteristics of lithium ores of Stankovatskoie ore field (according to B.N. Ivanov and S.V.Nechaiev [1])

Deposit	Mineral type of ore	Content, %						
		Li ₂ O	Rb ₂ O	Cs ₂ O	Ta	Nb	Be	Sn
Nadiia	Petalite	1,48	0,08	0,0019	-	-	0,005	0,004
	Spodumene fine-grained	1,20	0,11	0,006		-	0,005	0,005
Stankovatskoie	Petalite	1,49	0,11	0,0046	0,004	0,008	0,036	0,005
	Spodumene fine-grained	0,99	0,08	0,006	0,005	0,007	0,037	0,004
	Spodumene	1,07	0,09	0,001	0,004	0,008	0,036	0,004

Pryazovia group of lithium ore deposits is located within the meridian rare-metal zone within the western share of Pryazovia block of the Ukrainian Shield striking from the Dnieper-Donets basin in the north up to the Azov Sea in the south. The group includes Shevchenkovoie deposit (northern flank of the zone) and Krutaia Balka deposit (its southern flank). According to geological, mineralogical, and geochemical characteristics, lithium ore deposit of Shpola-Tashlyk district are similar to the ones of Western-Pryasovia. The considered deposits differ in more typical pegmatite appearance.

Shevchenkovoie pegmatite field strikes in submeridional direction along the whole length (15 km) of the similarly-named graben-monocline up to 2.5 km [1]. The structure is limited from the east and west by Shevchenkovskii and Voskresenskii faults respectively; in the central and southern part, it borders the granites of Voskresenskii intrusive contacting actively the rocks of Osipenkovskii suite. There are no visible discontinuous faults within the zone of contact with granites that indicates their later formation. Southern structure closure is represented by synclinal fold opened up to the north. It is the closure share of synclinal fold to which rare-earth pegmatites of Shevchenkovoie deposit and Voskresenskoie ore occurrence are associated.

Rocks of Sorokinskaia suite making up the structure are represented mostly by various crystalline schists and gneisses, sometimes with interlayers of skarnified calciphyres and ferruginous quartzites.

Widespread occurrence of limestone (diopside, vesuvianite, and pyroxene-vesuvianite-garnet) skarns with tungsten mineralization (scheelite, molybdoscheelite up to 8.4% of MoO_3) is the specific feature of Shevchenkovoie pegmatite field. Thickness of separate skarnification areas reaches up to 15-60 m; thickness of skarn bodies are up to 8 – 15 m [1, 6].

Shevchenkovoie deposit is characterized by the stated temporal conditions and reserves according to C_1 and C_2 categories; the deposit belongs to the category of medium-size ones.

Pegmatites of the deposit are associated with the crystalline complex of Precambrian base plate; they are overlapped by loose formations of platform Cainozoic cover being up to 100 m thick.

Two varieties of lithium ores are defined within the deposit: spodumene and petalite-spodumene ones combined into common spodumene technological ore type. Spodumene in the ore is mostly large-sized (2-40 cm); it has characteristic pseudographic quartz interpositions and belongs to iron-bearing petrotypes (Li_2O is up to 7.4%). being common for spodumene pegmatites.

Following mineral types and subtypes of pegmatites are singled out [1, 6-8]:

- microcline with subtypes - ore-free and berylliferous;
- oligoclase-microcline;
- microcline-albite with subtypes - without lithium-bearing minerals and with them;
- albite-spodumene petalin-bearing. Genetic series of pegmatites include the ores from microcline to albite-spodumene ones.

Krutaia balka deposit is located within the western part of Sorokinskoie pegmatite field between the discontinuous faults of northern-western and southern-eastern strike along which there are overlapping displacements and plunges of pegmatite bodies from the north-west to the south-east. Pegmatites form mostly flat-lying sheet-like and mushroom-shaped bodies with the thickness from several decimeters up to 70 m and with the strike up to several hundred meters. Vertically, down to 240 m, they form a sequence of bodies with clear zonality from micaceous-ceramic (ore-free) to microcline-

albite, quartz-albite, albite, and albite-microcline-spodumene (ore) ones within the upper part of the veins. Micaceous lining of 30 cm thick along the pegmatite-ultrabasite contact as well as shales containing holmquistit and being rich in rare alkaline minerals are characteristic for that area [1, 8, 9].

Content of Ta_2O_5 and Nb_2O_5 respectively in pegmatites is as follows (%): albite - 0,001-0,012 and 0,004-0.014; microcline-albite - 0.0002-0.057 and 0.002; albite-microcline-spodumene - 0,012-0,014 and 0,007. Content (%): Li_2O – up to 6,55; Rb_2O - up to 0,395; and Cs_2O_3 - up to 0,129. Cs_2O content in glimmerites is up to 0,83%.

Rare-earth metals are localized in micaceous and amphibolite shales as well as in metaultrabasites. Lower levels of the deposit contain mostly microcline narrow veins while upper levels are characterized by large-sized quartz-albite and quartz-albite-spodumene veins [1, 6, 8, 9]

Results of analysis. Nowadays, lithium is processed by hydrometallurgical techniques due to its low content in minerals, especially in concentrates. Hydrometallurgical processing has two basic technological stages:

1. Decomposition of raw material – as a result, lithium is transformed into water-soluble or volatile compound;
2. Lithium concentration by chemical methods and separation of the accompanying impurities.

That is the material grinding in laboratory vertical vibrating mill designed in the NMU [11]. The experiments were carried out both in continuous and periodic modes; thus, milling chambers of various designs were used. In terms of continuous mode, the material is applied from a feeding bin into a milling chamber, passes distance L , m, through it and goes into the receiving bin. Value L , m is determined by the height of a milling chamber and number of the performed material passings. In terms of periodic mode, weighted portion of the material is supplied into the chamber, the chamber is closed leak-tightly, and the material is ground within the preset time. In this context, mass of the material portion being ground is measured.

In terms of periodic mode, the material to be grind is sent into chamber preliminarily. Chamber is closed leak-tightly to exclude any contamination from the environment. When electric motor is started,

milling chamber performed rectilinear oscillations within a vertical plane with the preset amplitude and frequency. When upper and lower dead points are being passed, grinding bodies interact with each other as well as with the bottom and cover of a milling chamber.

Hydrometallurgical processing of ores and concentrates is based upon the selective dissolution of minerals in water solutions of chemical agents to extract the required component from the solution.

Complex use of activation process (low-grade or refractory ores of nonferrous, rare, and precious as well as complex polymetallic ores) and hydrometallurgical method will make it possible to solve the problem of rational feedstock utilization; moreover, they may be prospective while developing the techniques of selective separation of various metals from iron ore waste.

General technological scheme is as follows:

1. Mechanochemical ore activation for complete or partial release of mineral grains.

2. Mechanochemical ore or concentrate activation to prepare for selective metal separation by means of decomposition of chemical compounds of the extracted components and their transformation into dissolvable form.

3. Leaching of the solutions or transformation of the components being extracted into the solution, separation and purification of the solution to eliminate suspended particles.

4. Dealing with the solution containing maximum amount of the required metal for its further processing.

It is rather hard technological operation to separate the mixtures of the compounds of copper, silver, gold, and platinum as well as rare-earth elements while ore processing since their physical and chemical properties are very much alike. In this context, extraction method by means of various chemical agents, in particular, phenolic ones is considered to be rather prospective.

Extraction method by various chemical reagents, in particular, by phenols is a quite perspective method (Arnold, Crouse & Brown 1965) [12]. But use of flotation reagents containing donor atoms N, O, S are quite effective reagents-collectors during clayish ores flotation (Khayduk 1961) [13]. The mechanism of such flotation includes

stages of coordination compounds formation due to reagents electrons transfer onto vacant orbitals of electrons.

It is known (Khayduk 1961 & Moscovits 1979) [14] that some inorganic salts of metals and also some minerals can form so-called inorganic polymers or polymer aggregates-clusters. For example, CuCl_2 forms foliated lattices consisting of the chains of halogens atoms serving as the bridges and copper atoms (II):

Interaction of dichloride copper with organosilicic methylides of pyridinium and their hydroxides at various conditions is described in the work (Svetkin, Kolesnik & Myagchenko 1984) [15].

Vibroimpact activation or fine ore grinding is a quite significant factor of the process although the concentration in size-sorted ore does not change depending on particles size [16].

However, after the process of vibroimpact load, the extraction of needed metals, particularly copper and silver, increases from 18% with average size being 27.3 micrometers to 93% with average particle size being 9.6 micrometers.

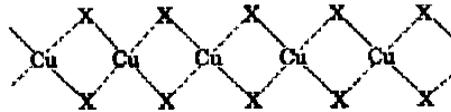


Fig.1. Foliated compounds of Cu

This is connected with the fact that during fine grinding of the minerals the ore activation occurs which leads to alteration of the parameters in crystal lattice. In connection with that, molecules of reacting matters can diffuse inside and on the crystal surface. This process is carried out when all the atoms of the crystal take part in the process.

The results of the potentiometric researches conducted by us i.e. change of the potential of azodien salt solutions titration and compound calculation based on Silen method using Bodlender equation, and also stability based on Leden method, show that adducts of variable compound form in the solution.

In connection with that the complex compounds effect of the azodien with minerals including metals of the I-IV groups (the representative elements or also called main group elements) on the matrix

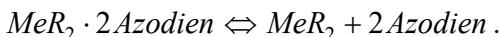
consisting of polyelectrolytes (PE) that allowed to suppose the formation of clusters with polymers.

In this case, the cluster “body” is defined by the following ratio: 1 mole of a complex compound to 80-200 elementary links of PE.

Thus, the following idea is forming: one molecule of a complex compound can favor chemical conversion along an extensive area of the polymer chain if not following any stoichiometric ratio but defining the aggregatization degree, i.e. vibroimpact activation.

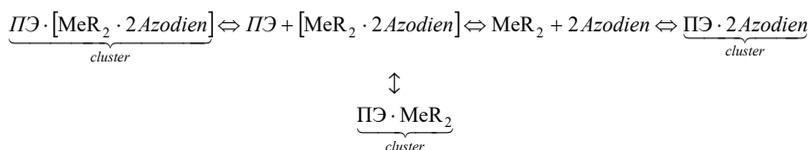
Natural analogues of such model are the metal enzymes containing 4, 12 and more atoms of metal in a molecule that creates so-called “coordinating cell” - limited area within which the reactions either do not evolve or limited by it without having exit to the system medium.

Aggregation formation is thermodynamically limited; it means that under the influence of temperature and other external factors, the complex is in the balance



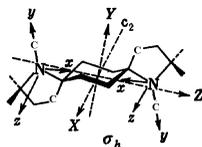
Kinetically, two free moles of azodien enter into interaction with sensitized areas of the polymer chain forming cluster embracing four carbon atoms.

General picture of the cluster “body can be expressed by the following balance”



Content and constants of the forming adducts stability depend on the initial components concentration that differs them from polyatomic complexes and testifies about cluster nature of the flotation mechanism. When introducing azodien’s molecules, aggregatization degree of the system, due to binding of the complexes $(MeX_2)_n$ (where $X=Cl^-, NO_3^-, O^{2-}$ so on) into clusters of $Azodien \cdot (MeX_2)_n$, increases that causes change of physicochemical properties of the solution (electro conductivity, viscosity).

Profitable geometry of this cluster (chair type) consisting of 12 atoms gives it energy stability



Process of the clusters formation was considered as a private case of the polymer-analogue transformation – reaction of inorganic salt reaction $(MeX_2)_n$ along energy profitable centers formed during activation from one side and by double diene links from the other side.

The interaction product is the new metal-silicon-organic (MS) cluster. There are significant differences in the formation process polyassociations copper and silver: silver is less inclined to this process. If under conditions of an experiment we succeed in receiving clusters for copper with $n=850$ then this value is smaller for silver and is equal to $n=650$. This process depends on pH solution.

Thus, clustering of the surface will provide reaction, i.e. the higher reaction rate, the more intensive the MS cluster forms. This defines the possibility of new compounds formation connected with structure change. The possibilities of surface reaction restructuring become richer with complication of a solid body compound.

Going from the structure to clusters properties, it is necessary to emphasize, first of all, that they depend on the number of particles in the cluster.

It seems to be obvious that the properties change with the size should be the most abrupt for small clusters where an addition of one particle means big relative increase of the group. Unlike copper dichloride, nitric acid silver in the solutions is less prone to formation of polyassociation.

Not possessing high generalization degree they form less spacious clusters with organic agents, interaction process carries step-type character and is realized through the row of structures, the properties of which are being recorded by the potential-metric curves.

Experimental data presents the law of the potential and electro-resistance change of the system depending on the amount of injected silver salt. The area (A) characterizes process of a various compound MS cluster formation that is followed by an abrupt increase of the potential, and the binding of ions into associates leads to the medium electrical resistance increase. Zone (B) responds to creation of the

complex with compound of 2:1 (Me/salt) with constant stability 1,19. Further increase of the pyridine's salt concentration leads to its destruction (area C) and reconstruction into more stable complex of the 1:1 compound with $K_{est}=2,39$ (area D). Differences in potential-metric measures allow to selectively extract ions of silver and copper, and also to control formation of iron oxide.

Fig. 2 represents relation of the MS cluster depending on the concentration ratio of CuCl_2 and organic agent.

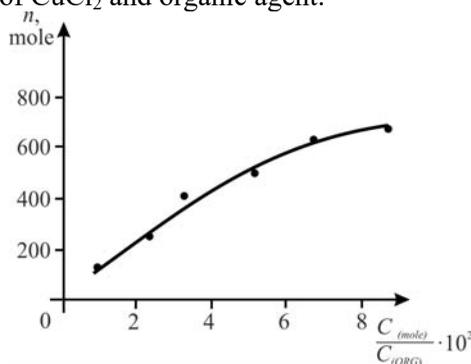


Fig. 2. Dependence of MS cluster composition on concentration of organic extractant at concentration of CuCl_2 equal to $10^{-4} M$

Composition of MS clusters is limited not by stoichiometric ratio but by the associates composition of inorganic salts. Introduction of a low-molecular electrolyte, for example, KNO_3 dislocates direction of interaction practically towards the stable complex formation with 1:1 composition that is connected with the increase of solution ion force.

Azodien having low concentration and possessing the bifunctionality is capable of binding the salts associates $(\text{CuCl}_2)_n$ forming extensive clusters. In water-organic and water media, due to hydrolysis, the associates of inorganic salts are not big, and this is indicated by moderate value of the complex composition index (Fig. 3).

Concentration decrease of a pyridine's compound solution favors formation of MS clusters with high content of copper-chloride links. In area of ylides concentrations equal to $10^{-7} \div 10^{-6} M$ with concentration of CuCl_2 equal to $10^{-2} M$, the condition when introduction of a donor does not cause destruction of clusters $(\text{CuCl}_2)_n$, and that is confirmed by the line 1 (Fig. 4) exit on the plateau. Under such condi-

tions it is possible to receive MS clusters with maximal content of metal.

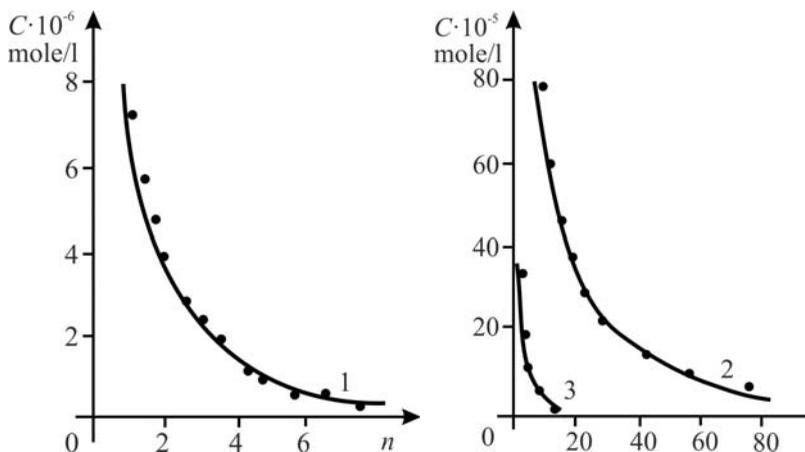


Fig. 3. Dependence of the cluster composition (ratio of a metal to a molecule of Azodien $(\text{MeX}_2)_n$ for Cu)- n - from concentration: 1 – in organic medium; 2 – in water; 3 – in 0.5 N KNO_3

Thus, received polymer clusters containing ions of metals were washed twice with 0.5 N KNO_3 . Distribution coefficient varied from 4 to 26 at extraction stages and had value of ~ 3 at the stage of washing. Extracted ions can be individually sorted out by washing at controlled pH level; each of the elements turns out to be well cleared from other ions.

Since the structure of the polymers is not stoichiometric then it leads to their “long-range action” and energy reasonability. Depending on molecular mass of the complex compound and its amount in matrix, the content of, for example, pyrazole ranges from 1 mole per 160 to 1 mole per 800 elementary links. If to take into account that the matrix contains $1,5 \times 10^{-4}$ mole / mole of carbonyl groups, $2,5 \times 10^{-4}$ mole / mole of double connections at the ends of a micro-molecule and 8 – 14 ramifications per 1000 links then it becomes obvious that the boundaries surrounding the “body” of the cluster are extremely fuzzy, and its structure, it seems, is layered, substantiated by the shell (cover) structure (matrix).

Another side of this question is that the cluster of a $(\text{Me}_e\text{R}_2)_{\text{act}} \cdot 2\text{Pyr}$ compound can overlap the ways of diene groups formation due to

chelation by the above shown scheme without preliminary break of coordination connection.

In this case, activated ore forms the “first layer” of a shell or zone of “short-action” at the expense of active centers formation in a shape of radicals during grinding into different mills and this zone prevents oxidation processes and reactions of elimination by the radical mechanism.

Conclusions

1. Experimental data make it possible to propose innovative complex approach to the mineral preparation which means mechanochemical ore activation and further selective floatation or extraction (by means of polyelectrolytes) of precious and rare-earth metals.

2. It is required to activate ore by shock-vibrating technique before its preparation as it helps improve both concentrates quality and the process of useful components extraction.

3. Thus, indirectly, it can be proved that during vibro-load the radicals are formed. Based on the experimental data analysis, the following results can be presented: properties of complex compounds, rates of metals extraction, formation of polyolefinic sequences and study of IR-spectr. Based on these data the cluster mechanism of flotation process is brought forward that allows to conduct the process both by a radical and ion-molecular methods.

4. In terms of shock-vibrating mineral processing, on the one hand, we observe formation of “stable chemisorbtion” of the products being ground that is connected with the changes in ionization yield process; on the other hand, changes in lattice parameters make it possible to judge on certain deviations of surface properties of natural materials comparing to pure chemical compounds.

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THE RESEARCH OF THE ENVIRONMENTAL SITUATION AROUND THE MINING COMPLEXES FOR THE PRODUCTION OF GRAVEL

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Abstract

The above monograph analyzes the ecological status of the territories near the mining complexes of Ukraine. An estimation of influence of blasting works on the state of atmospheric air is carried out.

Considering the methods of working out existing enterprises, namely - carrying out subversive works with the use of Granemite explosive, an analysis of the influence of poisonous gases and rock dust on the state of the environment and public health: an assessment of the risk to the health of the population at the current level of pollution of atmospheric air with oxide carbon can not be considered as quite acceptable and therefore needs to be taken to eliminate or reduce the risk, that is, to reduce emissions of this pollutant. The dependence of the change of radiation background on the height of the yield of a career is established.

Dependence of indicators is confirmed by one-factor dispersion analysis.

It has been found that the gamma background of the spent mining space increases with a deepening of the career.

This increase is due to shielding the radiation field with the sides and slopes of the quarry and the higher content of stable radioactive minerals in the deep granite horizons. The non-carcinogenic risk assessment for public health has shown that it is unacceptable. In addition, for the given conditions, this object can cause about 12 additional cases of cancer a year.

Introduction. The current level of nature management affects the state of ecological safety and is a source of a threat to the health of the population and the ecosystem in general. The mining industry of Ukraine, with an increase in the growth rate, greatly expands the territory of man-made influence: the areas where overlapping work is being carried out, minerals are developed, changes in not only the soil cover, but also the atmosphere, which subsequently determines the nature of their industrial and demographic development. Therefore, the question arises of the study and valuation of the zone of influence of underground development, subject to violation, destruction, complication; definition of measures to prevent the threat of population morbidity caused by the intensive exploitation of natural ecosystems. The theme of this work is the study of the environmental situation around the mining complexes for the production of crushed stone.

The purpose of the study is to assess the health risks of the population from atmospheric air pollution, soil and changes in the radiation background near the mining complexes.

The urgency of scientific decisions is to use component analysis of the state of the environment through the prism of the methods of mathematical modeling of its various components.

The research task is to study the atmospheric air and radiation background of the working space.

1 Estimation of the influence of poisonous gases and rock dust created as a result of mass explosions on the state of the environment of adjacent territories

The main sources of poison gas emissions during open development are blasting of explosives (EX). In most cases, when carrying out subversive works (SW) in quarries, exceeded the limits of maximum permissible concentrations (MPC) of poisonous gases, mainly carbon monoxide.

There are careers in which subversive work is carried out with the help of dangerous EX, such as Grammonit 79/21, Ammonite No. 6ZHV, Grammonite 50/50, Granulotol, Anemix 70, and others. However, more or less harmful gases are formed during the blasting of all industrial EX, including emulsion. Their number depends on

the chemical composition of EX, their detonation capacity and other factors that determine the completeness of chemical reactions[1].

The above substances are obsolete and their use is not appropriate from an environmental point of view because most of them contain TNTs. Modern and environmentally safe EX, which has become widespread in Ukraine, is Granemite [2]. Component composition of Granemite is shown in table. 1

Table 1 - Component composition and characteristics of Granemite

Name of characteristic	Value
Appearance	Plastic substance from light yellow to dark brown with the inclusion of granules of white or light yellow color
The bulk of the components, %	
nitrate ammonia	25-35
diesel fuel	0-1,65
Emulsion of the mark of the mark AH-Y	70±5
GHD (over 100%)	0,5-2,0
<i>Estimated</i>	
Heat of explosion, MJ/kg (kcal/kg)	
Specific volume of gaseous explosion products, l/kg	3,35 (800)
Oxygen balance,%	930
The cable equivalent of the heat of the explosion	- 0,6
Energy concentration at a density of 1.3 g/cm ³ , MJ/dm (kcal/dm ³)	0,8 4,36 (1040)
Volume of poisonous gases emitted during the explosion (in terms of carbon monoxide), l/kg	35-40
<i>Experimental</i>	
Water resistance: mass of ammonia and sodium selitrat, which turned into solution from the surface area of contact of explosive substance with water, kg/m ² , not more than for 24 hours	0,01
Density of charging Granemite, g/cm ³	1,15-1,35
Detonation rate in a steel tube 57 × 3 GOST 8732 at a density of 1.15-1.25 g/cm ³ and initiating a charge from an intermediate detonator weighing not less than 100 g, m/s	4400-4600
Critical diameter of detonation in a polyethylene shell, mm	60
Sensitivity to impact according to GOST 4545: lower limit, mm frequency of explosions,%	More than 500 4
Friction sensitivity on K-44-3 device: lower limit, MPa (kgf/cm ²)	900 (9000)

According to the methodology for calculation of harmful emissions for a complex of open mining equipment (based on specific indicators) [3], the mass of the emission of harmful gases was calculated in case of blasting of 50 wells with a diameter of 160 mm and a length of 16 m. The length of the slip according to [4] is 3 m. Therefore, the mass of Granemite, taking into account its density, according to table. 1 is 17,634·24 kg.

The mass of harmful gases emitted into the atmosphere and are components of dust and gas flue gas (DGC) were calculated by the formula (1)

$$m_{g1} = q_{sp}KA \cdot 10^{-6}, \quad (1)$$

where K is the conversion factor depending on the type of gas being determined (for CO: K=1,25 g/l, for NO_x: K=1,4 g/l); q_{sp}- specific content of harmful gases in DGC in the explosion of 1 kg EX, l/kg;

A is the number of EXs that will be blown up, kg.

Taking into account the fact that under the influence of the destruction of Grammonite I-30, in accordance with [5], l/kg: NO₂ - 0,21; CO - 27; CO₂ - 78; N₂ - 215, then the mass emissions of harmful normalized gases, in particular CO and NO₂, will be respectively

$$m_{(CO)1} = 27 \cdot 1,25 \cdot 17634,24 \cdot 10^{-6} = 0,6t;$$

$$m_{(NO_2)1} = 0,21 \cdot 1,4 \cdot 17634,24 \cdot 10^{-6} = 0,005t.$$

When carrying out mass explosions once a month, the mass of CO per year will be 7.2 tons, and NO₂ - 0.06 tons.

In addition to the gases that immediately form the DGC, there are harmful gases remaining in the bulk of the bombs that have been blown up and gradually released into the atmosphere [3]

$$m_{g2} = C_{mm} \cdot Q_{mm} \cdot 10^{-9}, \quad (2)$$

where m_{g2} - the mass of gas remaining in the mountain mass, t; C_{mm} - concentration of harmful gas in the blown mountain mass, mg/m³

$$C_{mm} = q_{mm} \frac{KA}{Q_{mm}} \frac{10^3}{(K_r - 1)}; \quad (3)$$

where Q_{mm} - volume of blown mountain mass, m^3 ; q_{mm} - specific content of harmful gas in the reflected mountain mass (depending on the strength of the breed and the composition of EX), l/kg ; K_r - coefficient of roughness of the mountain mass.

Assuming $K_r=1,6$, the volume of undrained mountain mass is $12,000 m^3$ ($15 \cdot 50 \cdot 16$), q_{mm} for CO is equal to 1,4, and for NO_2 - 0.4, we obtain

$$m_{(CO)2} = 0,051t; \quad m_{(NO_2)2} = 0,016t.$$

Calculation of the mass of dust emitted from the DGC beyond the boundaries of the quarry [6]

$$m_c^{mb} = K q_{sp}^c A(1 - \eta), \quad (4)$$

where K - dimensionless coefficient taking into account the gravitational settling of solid particles (taken as 0,16); q_{sp}^c - allocation of dust in the explosion of 1 t EX, t/ton (tabular data); η - the effectiveness of dust suppression means, the unit share (no dust suppression, = 0).

To determine the values of q_{sp}^c , preliminary calculation of the specific consumption of EX per $1 m^3$ of rock mass

$$\Delta = 1000(A/V_{mm}), \quad (5)$$

where V_{mm} - volume of blown mountain mass, m^3 .

To calculate the mass of dust, the amount of EX (A) is substituted in tons.

The result is a mass of dust equal to 0,5 t.

The most complete dispersion of harmful gases from the explosion of EX at the test site for open charges is determined by the formula [7]

$$C = \frac{Q}{(4\pi kt)^{3/2}} e^{-\frac{(x-Wt)^2}{4kt}}, \quad (6)$$

where C - concentration of harmful gas, mg/m^3 ; W - average speed of air flow, m/s ; k - coefficient of turbulent diffusion, m^2/s ($k=,95 m^2/s$); Q - intensity of instant release of harmful substance, mg ; t

- time after the explosion, s; x - distance from the center of the explosion, m.

The instantaneous emission of a hazardous substance Q is calculated by the formula

$$Q = mV(M/V_m) \cdot 1000, \quad (7)$$

where m - mass of EX, undrawn, kg; V - volume of harmful gas produced as a result of submergence 1 kg EX, l/kg; M - molar mass of harmful gas, g/mol; V_m - molar volume of gases under normal conditions (22,413), l/mol.

Table 2 shows the results of calculating the concentration of CO and NO₂ at the distances of the location of settlements from the site of the explosion, and the graph of scattering of gases is presented in Fig. 1. Industrial studies have shown that through 55-65 with DGC begins to lose its clear contours and in a few minutes the speed of development becomes minimal and equal to the wind speed near the surface of the career [8], the same process of explosion lasts less than 1 s [9]. Taking into account this, the emission intensity was taken taking into account the time of formation of the DGC and its beginning at the wind speed ($W=2$ m/s).

Table 2 - Value of concentrations of pollutants after the explosion of Granemite at different distances (500 s after the explosion)

Distance m	Concentration of CO, mg/m ³	Concentration NO ₂ , mg/m ³	Dust concentration, mg/m ³
800	0,018	0,00015	0,015
900	0,84	0,007	0,7
1000	3	0,025	2,5
1100	0,84	0,007	0,7
1200	0,018	0,00015	0,015

In order to determine the degree of hazard of atmospheric air pollution, the obtained values of concentrations of carbon monoxide and nitrogen dioxide are compared with the corresponding MPCs established by the normative documents of Ukraine [10]. According to the current sanitary norms, the concentration of carbon monoxide should be: daily average permissible concentration in the atmospheric air of settlements - 3 mg/m³; maximum permissible concentration in the atmospheric air of settlements - 5

mg/m³. For NO₂ - daily average permissible concentration in the atmospheric air of settlements - 0,04 mg/m³; maximum permissible concentration in the atmospheric air of settlements - 0,2 mg/m³.

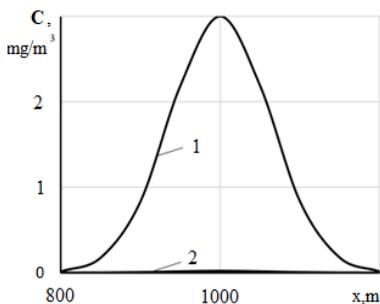


Figure 1 - Dependence of concentrations of CO (1) and NO₂(2) from the distance to the epicenter of the explosion

As can be seen from Fig. 1 at a wind speed of 2 m/s, the harmful effect of CO extends beyond the sanitary protection zone (SPZ) and reaches the MPC by calculation only at a distance of 1 km. Excess MACs increases the risk of the morbidity of miners and residents living near the quarry. The concentration of NO₂ at the same distance is 0.025 mg/m³, which satisfies the norms.

Carbon oxide binds to hemoglobin 200-300 times faster than oxygen, so even a small amount of this gas in the atmosphere is enough to cause severe poisoning. Its concentration in the air, which exceeds 0.1%, leads to death within 1 hour of stay in a poisonous atmosphere [11]. Often accompanied by dizziness, headache; noise in the ears, rapid heartbeat, flickering in front of the eyes, reddening of the face, general weakness, nausea, or even loss of consciousness.

Taking into account the possible health effects, it is expedient to calculate the risk to the health of the population from atmospheric air pollution with carbon monoxide. The risk assessment was conducted on the basis of a methodology for assessing the risk to the health of the population from atmospheric air pollution [12]

$$HQ = C_i / C_{MACi} , \quad (8)$$

where C_i - average concentration of i-th pollutant, mg/m^3 ; C_{MACi} - MAC of the i-th pollutant, mg/m^3 .

The risk to the resident population, for example, in the village. Granite (800 m from the Pinyazevitsky Granite deposit), at a concentration of carbon monoxide, $3 \text{ mg}/\text{m}^3$, will be equal to

$$HQ = (3/3) = 1$$

The criteria for characterizing the hazard ratio are given in Table. 3 [12].

Table 3 - Classification of non-carcinogenic risk levels for public health

Risk Characteristics	Risk factor, HQ
The risk of harmful effects is regarded as disparagingly small	<1
The limit value, which does not require urgent measures, can not, however, be regarded as sufficiently acceptable	1
The likelihood of the development of harmful effects increases proportionally to the increase HQ	>1

The assessment of the health risks of the population at the current level of atmospheric air pollution with carbon monoxide showed that it can not be considered sufficiently acceptable and therefore requires measures to eliminate or reduce the risk, that is, to reduce emissions of this pollutant. With an increase in the number of EX such a risk will pass into the group of unacceptable.

2. Dynamics of change of radiation-hygienic background in granite career

Since a large territory of Ukraine is located on the Ukrainian crystalline shield, the building stone stocks in our country are quite large, and the volume of production of crushed stone and construction products from decorative stone grows with each passing year [13]. All crystalline rocks contain natural radionuclides such as radium-226, thorium-232, potassium-40, uranium-238 and uranium-234, so national radiation safety standards set strict control over the use of natural stone products. At the same time, all the career in the

construction industry is characterized by an increased radiation background, and the territory of radiation contamination increases due to the expansion of quarries, dumps and scattering of raw materials [14].

One of the important problems in the production of buto-gravel raw materials is that man-made formations in mining enterprises often serve as sources of pollution of toxic substances, in particular, radionuclides adjacent to the enterprise's territories. In connection with the heterogeneity of the structure of non-metallic raw materials and the distribution of mineral impurities in it, gypsum from it is obtained and architectural and construction products can become a source of human radiation at the expense of long-lived natural radionuclides and products of their decay contained in rocks and minerals [15-17]. Study of the patterns of formation on the granite quarries of the radiation-hygienic background serves as the main prerequisite for the development of effective measures to reduce the radiation burden on the environment in local cells of enterprises of the construction industry.

Problems of the study of radioactive contamination of the environment as a result of the work of the granite industrial quarry devoted to many works of domestic and foreign scientists [18-20].

For the analysis of the radiation background, the values of the gamma background on the five ledges of the granite quarry of the Malinsky stone crushing plant are taken. In tabl. 4 shows the mean values of the gamma background for each ledge.

Table 4 - Average values of the gamma background at the ledges of the granite quarry of the Malinsky stone crushing plant

Altitude, <i>x m</i>	58	72	99	124	143
Gamma background, <i>microR/year</i>	19,98	18,17	17,03	16,49	9,9

The study of the effect of granite quarrying heights on its radiation background was carried out using the one-factor dispersion analysis method [21-24]. The calculated variance caused by the variation of values in the middle of the options is 0.57, the variance expressing variations of mean in variants relative to the general

average is 307,24. The empirical value of Fisher's criterion $F_{\text{em}}-539,02$.

$$F_{\text{emp}} = \frac{S_f}{S_{\text{fin}}} = \frac{307,24}{0,57} = 539,02, \quad (9)$$

where S_f - factor variance expressing variations of mean in variants relative to the general average; S_{fin} - the final variance caused by the variation of values in the middle of the options.

When checking the hypothesis about the equality of dispersions, the critical value F_{cr} for a certain level of significance and the corresponding numbers of degrees of freedom (2,45) is less than calculated from the data of the research (539,02), therefore it is assumed that the experimental data contradict the hypothesis of equality of dispersions. Since the null hypothesis was discarded, the dependence of the indicators of the γ -career background on the yield of the ledge is confirmed.

For the estimation of the tightness of the connection between the altitudes and the magnitude of the gamma background, the correlation coefficient of Pearson

$$r_{xy} = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2 \sum (y-\bar{y})^2}}, \quad (10)$$

where \bar{x} - average value x ; \bar{y} - average value y .

In tabl. 5 shows the necessary intermediate data and their amounts to calculate the correlation coefficient.

Pearson correlation coefficient

$$r_{xy} = \frac{-484,8}{70,504 \cdot 7,925} = -0,868.$$

Since the absolute value of the calculated correlation coefficient is greater than the critical value with a probability of error $p=0,05$, taken from the table data ($0,868 > 0,81$), the zero hypothesis of the absence of a correlation dependence between the samples is rejected and an alternative hypothesis of statistical significance is adopted at 5% Levels (probability of error 0,05) difference of the coefficient of correlation from zero, and the presence of the connection between the samples.

The value of the correlation coefficient, which is close to 1, indicates a fairly close connection between the height of the yield of the career and the indicator of the γ -background.

Table 5 - Interim calculations to determine the correlation coefficient

x	y	$x - \bar{x}$	$y - \bar{y}$	$(x - \bar{x})(y - \bar{y})$	$(x - \bar{x})^2$	$(y - \bar{y})^2$
58	19,98	-41,2	3,2	-131,84	1697,44	10,24
72	18,17	-27,2	2,2	-59,84	739,84	4,84
99	17,03	-0,2	1,2	-0,24	0,04	1,44
124	16,49	24,8	0,2	4,96	615,04	0,04
143	9,9	43,8	-6,8	-297,84	1918,44	46,24
Σ -	-	-	-	-484,8	4970,8	62,8

According to the calculation results, the linear dependence of the gamma-background value on the height of the yield of a career with regression coefficients $a=-0,096209$; $b=25,8579$.

The linear equation has the form $y=25,8579-0,096209x$ or $\gamma_f=25,8579-0,096209h$.

Graphically, the equation is depicted in Fig.2. When reducing the height of the yield of the career (increasing depth) gamma background increases [25].

For a more accurate determination of the dependence of the radiation background on a granite quarry, interpolation was performed using the Lagrange polynomial. Polynesian Lagrange 4th degree

$$L(x)=19,98l_0+18,17l_1+17,03l_2+16,49l_3+9,9l_4,$$

l_0, l_1, l_2, l_3, l_4 - basic functions.

$$L(x)=-9,8271 \cdot 10^{-7} \cdot x^4+3,2073 \cdot 10^{-4} \cdot x^3-$$

$$-0,0365 \cdot x^2+1,6321 \cdot x-3,2149.$$

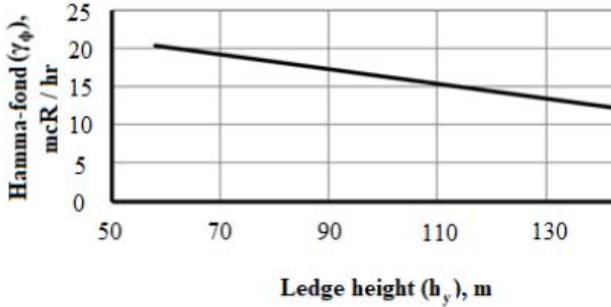


Figure 2 - the linear dependence of the gamma background γ_f on the height of the openings of the quarry h_y

Graph of the dependence of the height of the yield curve on the gamma background for the 4-rd Lagrange polynomial is shown in Fig. 3.

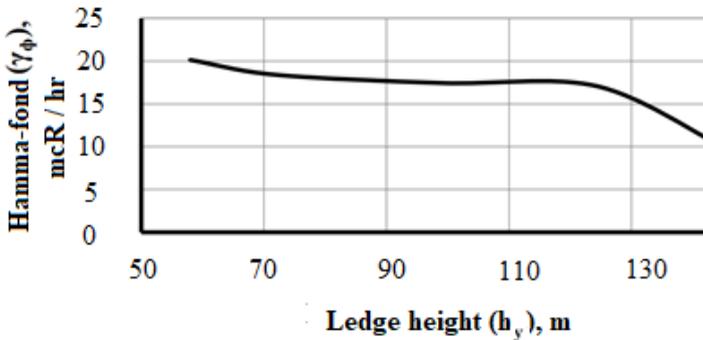


Figure 3 - The dependence of the gamma background value on the height of the career yield for the 4th degree Lagrange polynomial

It is determined that the gamma background gradually decreases as the height of the mark increases (decreasing the depth of the quarry) from 60 to 120 m.

After the altitude of 120 m, the radiation background of the career is more sharply reduced (approximately 1,5 times) [25].

3 Assessment of atmospheric air in the areas of dumps of quarries

One of the decisive sources of dust formation in the open field development is the debris from the surfaces of the dumps of the quarry. In order to assess the impact of dust in full, it is necessary not only to know its concentration in the air and emissions, but also to predict its dissipation, taking into account meteorological conditions (temperature, velocity and direction of wind movement, humidity, etc.). Such a forecast allows us to obtain a map of the concentration of dust from which it is possible to draw conclusions about levels of pollution of territories by dust, compliance with established norms for dust both within and outside the SPZ [26].

The estimation of scattering of dust at dual formation was carried out on the Gauss model and the method of VNIIBPG (A. Loboda, V. Tyshchuk) [27-28]. Typical granite quarry in Zhytomyr region was used for calculation [29]. From the results of calculations it can be concluded that using the method based on the Gaussian model, the determination of dust concentration is more accurate than the Loboda-Tyshchuk method. This is due to the fact that the first method involves more meteorological conditions. However, at distant distances, the results are close [30]. It should be noted that the concentration of dust exceeds the average daily MPC and comes standard only at a distance of 1 km, which is 2 times the size of the SPZ [10, 31].

to eliminate or reduce the risk, that is, reducing emissions of In addition to predicting the scattering of dust when cutting dust, the criterion for assessing the impact on the environment can be the radius of the pollination zone. The paper [32] establishes the dependence of the radius of the pollination zone on the mass of dust that is blown away from the dump of a career using a cubic spline. This dependence will allow to choose methods and means of decontamination based on specific climatic conditions and sizes of dumps.

The peculiarity of dust action on the human body has a fibrogenic and carcinogenic effect. Excess MACs increases the risk of the morbidity of miners and residents living near a career with bronchial asthma, chronic bronchitis, pneumoconiosis, and in particular silico-

sis. The risk of non-carcinogenic effects for people living in urban areas. Granite, at a dust concentration of $0,4 \text{ mg/m}^3$, will be equal to 1,4 [12]. The assessment of the non-carcinogenic risk to the health of the population at the current level of air pollution with dust showed that it is unacceptable and therefore requires urgent implementation of measures this pollutant.

Quantitative assessment of the carcinogenic risk of the health of the population caused by the pollutant was carried out according to the method of A. Shvyriaev. and V.Menshikova [30].

The number of toxic effects of toxicants on the population is determined by the expression

$$q_e = \sum_{i=1}^n \sum_{j=1}^k [P_e(D)]_{ij} \cdot N_{ij}, \quad (13)$$

where N_{ij} - the number of people exposed to toxicants, people; k - number of toxicants, pcs; n - number of dose levels of each toxicant, pc; $[P_e(D)]_{ij}$ - the risk of a dose that is determined by the following formula

$$[P_e(D)]_{ij} = (F_r D)_{ij} = (F_r c v t)_{ij}, \quad (14)$$

where F_r - risk factor of toxicant, mg^{-1} ; D - dose of a toxicant, mg ; c - concentration of toxicant, mg/m^3 ; v - its daily intake in the body, m^3/day ; t - time of toxicant, years.

The symbol "e" indicates that it is an additional (excess) case of the disease caused by the considered toxicant [33].

A quantitative estimate of the population risk of cancers per year was carried out for residents of urban areas. Granite (in the number of 1508 people [34]), located at a distance of 0,8 km from the dump of a career. The concentration of dust is $0,14 \text{ mg/m}^3$, the risk factor is $1,4 \cdot 10^{-4}$ according to the "Multipurpose Data Presentation System Version 2.0" program. If we assume that the average volume of inhaled breath is 7,5 liters/min [33], then the volume of polluted air passing through the lungs of every person daily will be $10,8 \text{ m}^3/\text{day}$.

The calculation of formulas (8) and (13) showed that the risk is unacceptable, $q_e=12.31$, that is, for the given conditions, this object can cause about 12 cases of cancer of the year.

Conclusions. 1. Was conducted the estimation of the impact of blasting on the state of atmospheric air. It was established the

concentration of CO is observed outside the sanitary protection zone and reaches the maximum permissible by calculation results only at a distance of 1 km for the wind's speed of 2 m/s. The concentration of NO₂ is 0.025 mg/m³ for the same distance and it satisfies the norms. The assessment of the health risks of the population at the current level of atmospheric air pollution with carbon monoxide showed that it can not be considered sufficiently acceptable (the Risk factor is equal 1) and therefore requires measures to eliminate or reduce the risk, that is, to reduce emissions of this pollutant.

2. The dependence of radiation background on the height of the career yield.

The dependence of the indices was confirmed by a one-factor's dispersion analysis according to the value of Fisher-Snedecor's criterion ($F_{emp}=539,02 > F_{cr}=2,45$). The density of the connection is determined by the coefficient of correlation of the Pierson. The value of the correlation's coefficient is 0.868, it is close to 1, which indicates as the rather close relationship between the parameters under consideration. The dependence is established by the method of the least squares and by the means of the Lagrange's polynomial.

3. The change of the gamma background with the depth of the career along the local planes of the distribution of the career is described by the linear dependence. The gamma-background of the spent quarry space increases with a deepening of the career. It is increase that due by shieldings of the radiation field with the sides and slopes of the quarry and the higher concentration of stable radioactive minerals in the deep granite horizons.

4. The dispersion of dust from a dump of a quarry is investigated. It is shown that the dust concentration exceeds is the maximum permissible outside the sanitary protection zone. The risk to the resident population, for example, in the village (near the Pinyazevitsky deposit of granite in the Zhytomyr region) is calculated. The assessment of a non-carcinogenic risk to public health has shown that it is unacceptable. In addition, for the given conditions, this object can cause about 12 additional cases of cancer year.

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INTERACTION OF SEISMIC–EXPLOSIVE WAVES WITH UNDERGROUND AND SURFACE STRUCTURES

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Abstract

Numerical simulation of interaction of wave processes in the system "soil massif – underground pipeline" in explosion of charge on the surface of ground is carried out. Construction is considered in framework of nonlinear theory of shells of Tymoshenko type. Soil is modeled by a solid porous multicomponent visco-plastic medium. Patterns of changes in stress-strain state of system depending on depth of pipeline laying and its diameter are established.

Based on the used mathematical model and algorithm the program for the PC, which allows conducting the calculation of seismic stability of protected object for the specific conditions of the explosion with the possibility of rapid adjustment of blasting parameters was developed.

It is established that with a decrease diameter of pipeline the stress increases, and pipe undergoes plastic deformation and loses its efficiency. With an increase in depth of pipeline location, there is a decrease in stress: thus area of elastic deformations of a pipe with diameter of 1,5 m begins with a depth of 6 m, and for diameter of 0,4 m – from a depth of 7 m.

Introduction

Because of increase of quantity of mining operations and the approaching of quarry fields to objects protected in practice, the question of seismic safety of these objects is acutely raised. This situation confronts scientists with two priority tasks at the same time: ensuring high quality crushing of rock mass and seismic safety of structures during blasting operations. Existing methods for assessing the seismic safety of blasting operations have several disadvantages. Experimental techniques are costly and effective only for specific conditions. The most commonly used calculation methods are based on the perfection of the formula of academician M.A. Sadovsky with different coefficients or connection them with the passport physical and mechanical constants of soils. Increasing the reliability of calculation methods can be ensured by maximum consideration the properties of the soil mass and the conditions for its destruction by explosion, which is impossible without a detailed study of the mechanism of dynamic deformation, as well as means of information support for explosive operations.

Although the selection of the parameters of explosive operations determines both the useful effect of the explosion on rock crushing and the seismic effect of the explosion, so far this issue is not sufficiently investigated in the related setting. Therefore, the study of the parameters of seismic explosive waves (SEW), which affect the seismic stability of surface constructions during explosions of cylindrical charges, taking into account the conditions of explosion operations and the amplitude-time and physical and mechanical properties of soils and objects using computer technologies, is the actual scientific practical task.

Aim of the study is to determine the impact of seismic-explosive waves on underground and surface constructions.

Mathematical formulation of problem. Two problems are considered: 1) the effect of the explosive action of a surface charge on an underground pipeline; it was assumed during the simulation that an explosive charge explodes on the surface of the soil, while an explosive wave spreads into the soil massif with the pipeline, located inside; 2) the interaction of a seismic explosive wave with a ground base and a building.

Simulation of seismic explosion waves with underground pipe in-

teraction. When modeling it is assumed that charge of explosives detonates on surface of soil. At the same time, an explosive wave propagates into soil massif with pipeline, located inside.

In the cylindrical coordinate system r, z equations of motion of soil within framework of mechanics of continuous medium have the form

$$\frac{\partial \sigma_{rr}}{\partial z} + \frac{\partial \tau_{rz}}{\partial r} + \frac{\tau_{rz}}{r} = \rho \frac{du}{dt}, \quad (1)$$

$$\frac{\partial \tau_{rz}}{\partial z} + \frac{\partial \sigma_{zz}}{\partial r} + \frac{\sigma_{zz} - \sigma_{\theta\theta}}{r} = \rho \frac{dw}{dt}, \quad (2)$$

$$\frac{1}{V} \frac{dV}{dt} = \frac{\partial u}{\partial z} + \frac{\partial w}{\partial r} + \frac{w}{r}, \quad V = \frac{\rho_0}{\rho}, \quad (3)$$

$$u = \frac{dz}{dt}, \quad w = \frac{dr}{dt}, \quad (4)$$

$$\sigma_{zz} = S_{zz} - P, \quad \sigma_{rr} = S_{rr} - P, \quad \sigma_{\theta\theta} = S_{\theta\theta} - P, \quad (5)$$

$$P = \frac{1}{3}(\sigma_{rr} + \sigma_{\theta\theta} + \sigma_{zz}), \quad (6)$$

where $\sigma_{rr}, \sigma_{\theta\theta}, \sigma_{zz}, S_{rr}, S_{\theta\theta}, S_{zz}$ – components of tensor and deviator of stress tensors; τ_{rz} – tangential stress, ρ_0, ρ – initial and current density of medium, t – time.

The soil is modeled by a solid porous multicomponent viscoplastic medium with a constant viscosity coefficient [7], and its equation of dynamic volume compression and discharge has the following form

$$\dot{\varepsilon} = \varphi(P, \varepsilon) \dot{P} - \frac{\alpha_1 \lambda(P, \varepsilon)}{\eta} \psi(P, \varepsilon). \quad (7)$$

Functions included in equation (7), for loading and unloading S_i

are different and are determined according to [7].

The condition of soil plasticity is the modified condition of Mises–Botkin [8].

The theory of shells of the Tymoshenko type and physical relations of differential plasticity theory with linear kinematic hardening are used to describe dynamic behavior of the pipeline [9, 10]. Equations of fluctuations for a cylindrical shell have the form

$$\begin{aligned} \frac{\partial T_{11}}{\partial x} &= \rho h \frac{\partial^2 u_1}{\partial t^2}, \\ \frac{\partial \bar{T}_{13}}{\partial x} - \frac{T_{22}}{R} + P_3(x, t) &= \rho h \frac{\partial^2 u_3}{\partial t^2}, \\ \frac{\partial M_{11}}{\partial x} - T_{13} + P_3(x, t) &= \rho \frac{h^3}{12} \frac{\partial^2 \phi_1}{\partial t^2}; \end{aligned} \quad (8)$$

Expressions for the values of forces-moments are the following:

$$\begin{aligned} T_{11} &= B_{11}(\varepsilon_{11} + \nu_{21}\varepsilon_{22}), \\ T_{22} &= B_{22}(\varepsilon_{22} + \nu_{12}\varepsilon_{11}), \\ T_{13} &= B_{13}\varepsilon_{13}, \quad M_{11} = D_{11}\kappa_{11}; \end{aligned} \quad (9)$$

Where

$$\begin{aligned} \varepsilon_{11} &= \frac{\partial u_1}{\partial x} + \frac{1}{2}[\theta_1]^2, \quad \varepsilon_{22} = \frac{u_3}{R}, \quad \varepsilon_{13} = \phi_1 + \theta_1, \\ \theta_1 &= \frac{\partial u_3}{\partial x}, \quad \kappa_{11} = \frac{\partial \phi_1}{\partial x}; \end{aligned} \quad (10)$$

$$\begin{aligned} B_{11} &= \frac{E_1 h}{1 - \nu_{12}\nu_{21}}, \quad B_{22} = \frac{E_2 h}{1 - \nu_{12}\nu_{21}}, \\ B_{13} &= G_{13}h, \quad D_{11} = \frac{E_1 h^3}{12(1 - \nu_{12}\nu_{21})} \end{aligned} \quad (11)$$

In formulas (8)–(11) the following designations are taken: ρ, h, R – density of material, thickness and radius of pipe; u_1, u_3, ϕ_1

– components of generalized vector of displacements;
 $T_{11}, T_{13}, T_{22}, M_{11}$ – components of tensors of forces and moments;
 P_3 – pressure; $\varepsilon_{11}, \varepsilon_{22}, \varepsilon_{33}$ – components of deformation tensor;
 $E_1, E_2, \nu_{12}, \nu_{21}, G_{13}$ – elastic constants of pipeline material.

In the case of plastic deformations, relationships between corresponding deformations and stresses are written in the form of incremental theory of plasticity with the Mises condition.

Equations (1)-(11) are supplemented by the corresponding initial and limit conditions.

With the help of the finite elements method, modeling of soil medium, in which an underground gas pipeline is located, is carried out. For numerical simulation a calculating grid of 9635 elements is constructed.

It is assumed that the pipeline, which is located in clay soil at a depth of 2,0-6,0 m, is made of steel with the following physical and mechanical characteristics: yield limit $G=240 \text{ N/m}^2$, Poisson coefficient $\nu=0,3$, elasticity modulus $E=240 \text{ N/m}^2$, density= 7855 kg/m^3 .

The explosion of charge of 10 kilograms of trotyl on a soil surface is considered. It corresponds to the minimum power of loaded charge, a bomb or a small rocket. Dependence of stress on time on the surface of the soil massif is shown in Fig. 1.

Isobars of average hydrostatic pressure (in GPa) in plane rOz at different moments of time $t=1,0 \text{ s}$ are presented in Fig. 2.

It's shown in the figure, that field of isobars is a difficult depiction due to interaction of waves with different limits and angular points, and also between themselves. At considered moment of time, the greatest load is achieved in gas cavity and in soil near it.

The stress wave, spreading in soil, reaches pipeline and causes deformation in these mediums (Fig. 3).

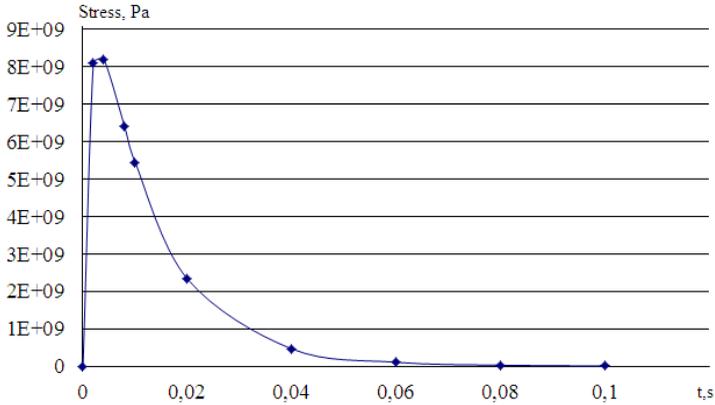


Fig. 1. Dependence of stress on time on the surface of the soil massif

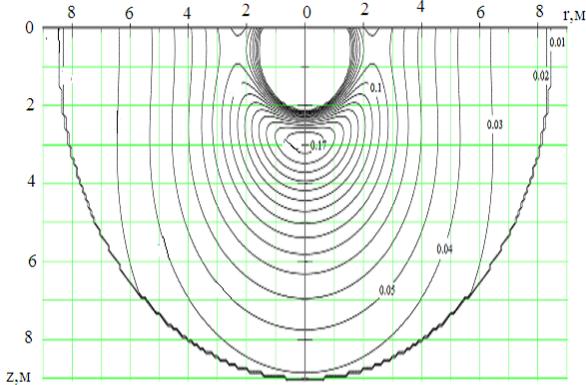


Fig. 2. Isobars of average hydrostatic pressure (in GPa) in plane rOz at different moments of time $t=1,0$ s

Distribution of stresses in a steel pipe of 1.5 m in diameter at a laying depth of 5 m is shown in the Fig. 4.

It is seen from the figure that the maximum stress in the pipeline is reached at 360 MPa, which is significantly greater than the steel yield limit (240 MPa), especially in frontal surface of pipe, therefore pipeline loses its bearing capacity and is destroyed.

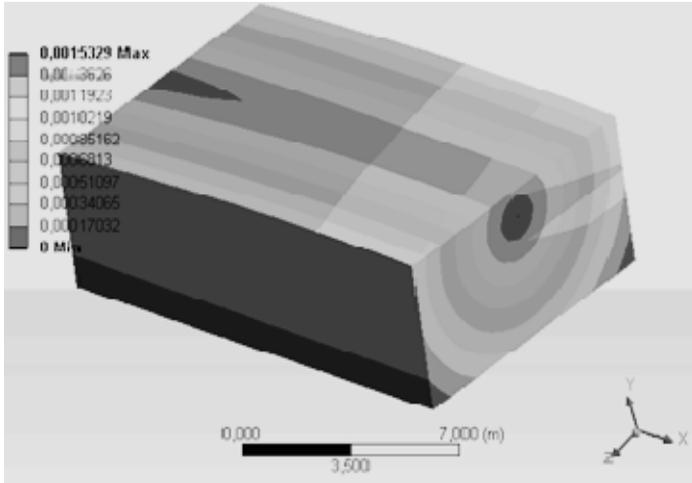


Fig. 3. Distribution of volumetric deformations in soil and pipelines

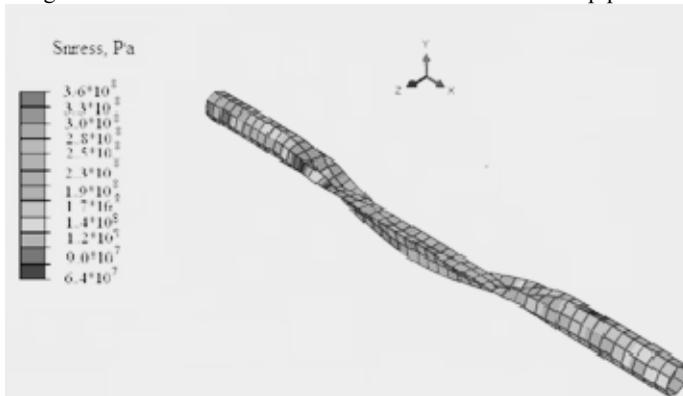


Fig. 4. Distribution of stresses in the steel pipe of 1.5 m in diameter at a laying depth of 5 m

Dependence of stress on pipeline from depth of its laying at different diameters of pipeline: 1 – $D=0,4$ m, 2 – $D=1,5$ m is shown in Fig.5. It is established that with decreasing of diameter, the stress increases, and the pipe undergoes plastic deformation and loses its ability to work.

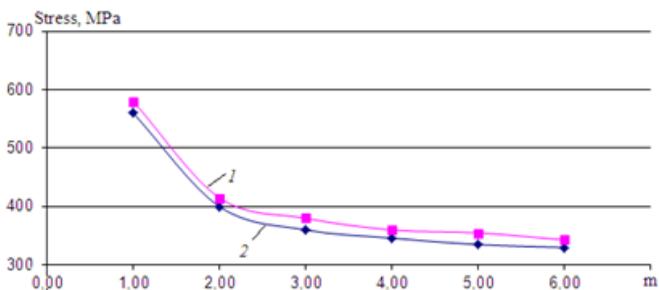


Fig.5. Dependence of stress on pipeline from depth of its laying at different diameters of pipeline: 1 – D=0,4 m, 2 – D=1,5 m

With increasing depth of pipeline arrangement, there is stresses decrease, but area of elastic deformations for a pipe with a diameter of 1,5 m starts at a depth of 6 m, and with diameter of 0,4 m – from a depth of 7 m.

Dependences of polynomial stresses on depth of laying of pipeline, which allow carrying out predictive calculations of durability of pipe under different dynamic loads, are obtained

– for a pipe with a diameter of 1.5 m:

$$\sigma = -5,92y^3 + 78,04y^2 - 337,76y + 882,00, Pa; R^2 = 0,991,$$

– for a pipe with a diameter of 0,4 m:

$$\sigma = 1,94y^4 - 33,47y^3 + 211,66y^2 - 591,51y + 990,83, Pa; R^2 = 0,9981$$

Dynamic interaction of seismic waves with a soil foundation and a multistory building. Currently, the problem of seismic safety exploitation of buildings located near the explosive works is acute in the territory of Ukraine, as the negative dynamic effect, which arises when the seismic load effects on the building of different purposes, is not studied enough. Explosive works are the main methods of destruction of solid mediums at explosion in mining of mineral resources, mining operations and construction. They are accompanied with the emergence of seismic waves, which create a danger to natu-

ral and engineering objects. Therefore, there is a need for a detailed assessment of the energy of the explosion, the intensity of the spread of seismic explosive waves, the strong properties of the material of the structures for their proper design and use.

A large number of works in the area of decision of problems of the dynamics and seismic resistance of the construction are devoted to the impact of seismic waves on buildings as a result of earthquakes [11-14]. However, it should be noted that the number of studies of the impact of seismic waves on natural and engineering objects is much less, although the intensity of their influence is much stronger [15].

Therefore, at present, research on the peculiarities of the spread of seismic waves in soils and the dynamics of their possible influence on natural and engineering objects is especially actual.

The interaction of a seismic explosive wave with a soil base and a building is considered [16]. Construction and soil are studied in the framework of continuous medium mechanics. The motion of the building and the soil is described by the laws of conservation of mass, impulse and internal energy, which in general form have the form [17]

$$\frac{d\rho}{dt} + \rho \left(\frac{\partial v_i}{\partial x_i} + \frac{\partial v_i}{\partial y_i} + \frac{\partial v_i}{\partial z_i} \right) = 0, \quad (12)$$

$$\rho \frac{dv_i}{dt} = F_i + \left(\frac{\partial \sigma_{ij}}{\partial x_i} + \frac{\partial \sigma_{ij}}{\partial y_i} + \frac{\partial \sigma_{ij}}{\partial z_i} \right), \quad (13)$$

$$\rho \frac{dE}{dt} = \sigma_{ij} \dot{\varepsilon}_{ij} - \left(\frac{\partial q_i}{\partial x_i} + \frac{\partial q_i}{\partial y_i} + \frac{\partial q_i}{\partial z_i} \right), \quad (14)$$

$$\frac{du_i}{dt} = v_i, \quad (15)$$

$$\dot{\varepsilon}_{ij} = \frac{1}{2} \left(\left(\frac{\partial v_j}{\partial x_i} + \frac{\partial v_j}{\partial y_i} + \frac{\partial v_j}{\partial z_i} \right) + \left(\frac{\partial v_i}{\partial x_j} + \frac{\partial v_i}{\partial y_j} + \frac{\partial v_i}{\partial z_j} \right) \right), \quad (16)$$

$$\dot{\varepsilon}_{ij} = \frac{1}{2} \left(\left(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_j}{\partial y_i} + \frac{\partial u_j}{\partial z_i} \right) + \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_i}{\partial y_j} + \frac{\partial u_i}{\partial z_j} \right) + \left(\frac{\partial u_k}{\partial x_i} + \frac{\partial u_k}{\partial y_i} + \frac{\partial u_k}{\partial z_i} \right) \left(\frac{\partial u_k}{\partial x_j} + \frac{\partial u_k}{\partial y_j} + \frac{\partial u_k}{\partial z_j} \right) \right), \quad (17)$$

$$\sigma_{ij} = \sigma_{ij}(\varepsilon_{ij}, \dot{\varepsilon}_{ij}, T), \quad (18)$$

where $(i=1,2,3)$; $(j=1,2,3)$; t - time; v_{ij} - speed components; u_{ij} - displacement components; $\dot{\varepsilon}_{ij}$ - components of the strain rate tensor; ε_{ij} – components of the deformation tensor; σ_{ij} – components of the voltage tensor; T - absolute temperature; E - mechanical energy.

Soil is modeled by a multicomponent visco-plastic medium with variable viscosity coefficient (7).

Initial conditions are the next: for soil $v_{ij} = 0$, $u_{ij} = 0$, $\rho = \rho_0$, $\sigma_{ij} = 0$; where ρ_0 – is the density of the soil; ρ_σ – is the density of the material of the building.

As a boundary condition, hydrostatic pressure is set at a distance of 210 m from the source of the explosion.

To solve the problem, a finite element method with a calculation grid of 1458 elements is used.

The 9- and 5- floor brick and panel houses, which are located on a soil basis, with a thickness of 20 m layer, are considered. Geometrical parameters of the building are characteristic for most settlements of Ukraine and correspond to the State building codes [179]. The main parameters of buildings are shown in Table 1. Calculations are made for the face and frontal direction of the fall of the seismic explosive wave on the construction. It is assumed that the hydrostatic pressure at the seismic load is 10^5 Pa, 10^6 Pa, 10^7 Pa.

Table 1

The main parameters of buildings

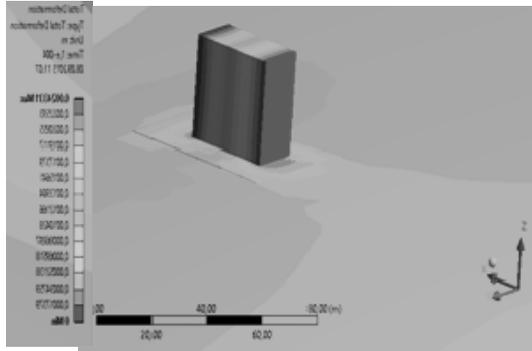
Material/Number of floors	Concrete	Brick	Concrete	Brick
	9	9	5	5
Length, m	32,85	32,85	67,33	67,33
Width, m	16,85	16,85	12,50	12,50
Height, m	31,00	31,00	16,00	16,00
Volume, m ³	17159,19	17159,19	13466	13466
Weight, kg	39,46·10 ⁶	33,46·10 ⁶	30,97·10 ⁶	26,25·10 ⁶
Density, kg/m ³	2300	1950	2300	1950
Modulus of elasticity, Pa	3,0·10 ⁹	2,32·10 ¹⁰	3,0·10 ⁹	2,32·10 ¹⁰
Poisson's coefficient	0,25	0,18	0,25	0,18

Physical and mechanical properties of the soil basis are as follows: for loam – $\rho_0=1760 \text{ kg/m}^3$, $E=1,9 \cdot 10^6 \text{ Pa}$, $\nu=0,2$, $n =34,3-37,0\%$, $w=12,5-16,1\%$, $\alpha_1=0,648$, $\alpha_2=0,247$, $\alpha_3=0,105$, $E_D=21,7-24,2 \text{ Pa}$, $\sigma_0=2,2-5,6 \text{ Pa}$, $C=0,54 \text{ Pa}$, $\varphi=31^\circ$, $E_I=800 \text{ Pa}$, $E_S=500 \text{ Pa}$, $E_p=1000 \text{ Pa}$; for clay – $\rho_0=2600 \text{ kg/m}^3$, $E=2,0 \cdot 10^6 \text{ Pa}$, $\nu=0,37$, $\alpha_1 = 0,093$, $\alpha_2 = 0,353$, $\alpha_3 = 0,554$, $\rho_0 c_s^2 = 12,9 \cdot 10^5$, $\eta_D = 229 \text{ Pa} \cdot \text{s}$, $\rho_0 c_D^2 = 39,5 \cdot 10^6$, $k = -26,6 \cdot 10^5 \text{ Pa}$; $\gamma_s = 0,5$.

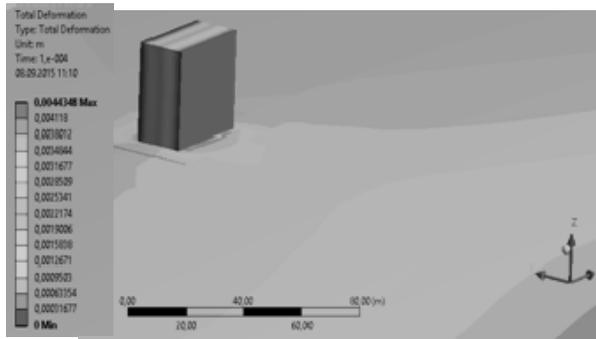
As a result of calculations parameters of the stress-strain state of soil foundation and structures are obtained. In Fig. 6. the general deformation of a 9-floor panel building with a applied load of 10^5 Pa at different directions of the fall of a seismic explosive wave is presented. The figure shows that the total deformation is more in the frontal direction of the wave fall at 2.01 mm (1.82 times) compared with the face direction. This is explained by the fact that in the frontal direction the interaction area is more than in 1.92 times compared to the face one, thereby the corresponding force applied to the building increases.

Similar results are obtained for the load $P=10^6 \text{ Pa}$ and $P=10^7 \text{ Pa}$: the deformation is increased on $2,0 \text{ mm}$ (in 1,6 times) and $2,03 \text{ mm}$ (in 1,6 times), respectively at the frontal direction of the fall of the wave compared with face.

It is established, if the 9-floor building consists of a brick, then at load $P=10^5 \text{ Pa}$ with the frontal direction of the fall of the wave deformation is more on $1,44 \text{ mm}$ (in 1,36 times) than at the face.



a



b

Fig. 6. Maximum total deformation of a 9-floor panel building with an applied load of 10^5 Pa: *a* - the face direction of fall of the wave; *b* - the frontal direction of fall of the wave

When considering the general deformation of nine floor panel and brick buildings with a load of $P=10^5$ Pa, it is found that the deformation of the brick building is more than 1,6 mm (in 1,65 times) in the frontal direction and more on 1,02 mm (in 1,23 times) at the face direction.

Next, similar calculations are made for the maximum total deformation of 5-floor panel and brick buildings. It is established that the maximum total deformation of a panel building with a load $P=10^5$ Pa is more on 4,77 mm (in 5,1 times) at the frontal direction of the wave fall than at an face direction. Similar results are obtained for load

$P=10^6$ Pa and $P=10^7$ Pa: deformation is more in the frontal direction on 4,97 mm (in 5,5 times) and 5,76 mm (in 4,5 times), respectively, compared with the face.

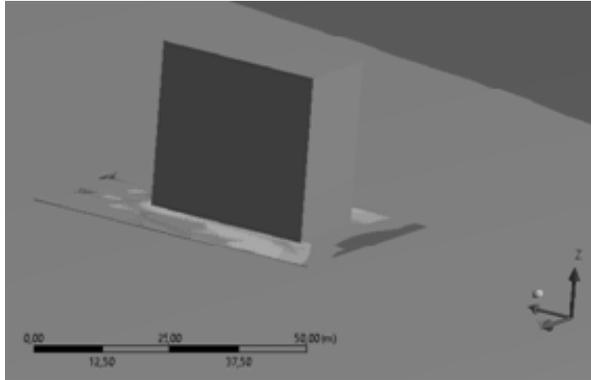
As a result of the calculations, it is found that when a 5-floor building, constructed from brick, is exposed to a seismic load 10^5 Pa with a frontal direction of the fall of the wave the deformation is increased on 6,3 mm (in 3,0 times) compared with the face direction of fall. Similar results are obtained at load $P=10^6$ Pa and $P=10^7$ Pa: deformation is increased on 6,43 mm (in 2,62 times) and 6.8 mm (in 1,99 times) compared with the face direction.

When calculating the deformed state of buildings on a clay soil basis, it is established that under the same seismic load, much smaller general deformations are achieved at any direction of the fall of the wave. For example, in Fig. 7 the maximum total deformation of a 9-floor panel building at $P=10^5$ Pa is shown. From the figure it can be seen that at the frontal direction the deformation is more on 0,56 mm (in 1,51 times) than at the face.

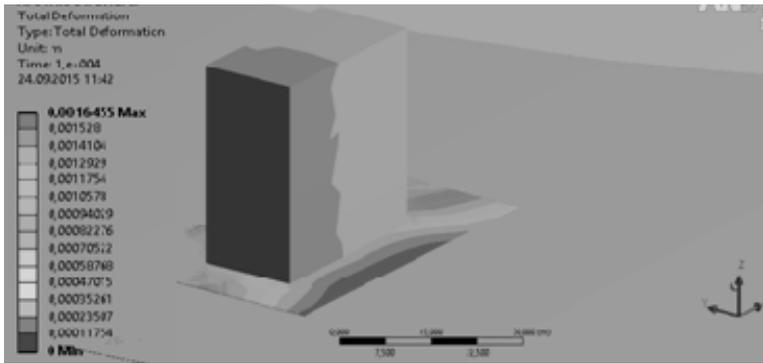
Similar results are obtained for the load $P=10^6$ Pa and $P=10^7$ Pa: the total deformation increases with a frontal fall direction on 2,46 mm (in 2,84 times) and 2,9 (in 2,14 times) respectively, compared with face direction.

It is also realized the numerical simulation of the interaction of seismic waves with layered granular bases and multistory buildings. The deformation of the layered soil foundation and nine-floor brick and panel buildings located on this basis are researched. The main parameters of the building are typical for most constructions of settlements of Ukraine and correspond to the State building codes, and are shown in the Table 2. Calculations are made for the face and frontal directions of the fall of the seismic wave on the building. It is considered that the hydrostatic pressure at the seismic explosive load is equal to 10^6 Pa and 10^7 Pa.

The physical and mechanical properties of the soil foundation are as follows: for the sand - $\rho_0=1500$ kg/m³, $E=5,0 \cdot 10^5$ Pa, $\nu=0,3$; $n=34,3-37,0\%$, $w=12,5-16,1\%$, $\alpha_1=0,648$, $\alpha_2=0,247$, $\alpha_3=0,105$, $E_D=21,7-242$ Pa, $\sigma_0=2,2-5,6$ Pa, $C=0,54$ Pa, $\varphi=31^\circ$, $E_1=800$ Pa, $E_2=500$ Pa, $E_p=1000$ Pa; for loam are shown earlier.



a



b

Fig. 7. Maximum total deformation of a 9-floor panel building with an applied load 10^5 Pa: *a* - the face direction of the fall of the wave; *b* - the frontal direction of the fall of the wave

As a result of the numerical simulation, parameters of the deformed state of soil bases and buildings are obtained. In Fig. 8 the distribution of the total deformation of the soil base and the nine-floor panel building at the face direction of the fall of the wave with $P=10^7$ Pa, depending on the soil texture and its physical and mechanical properties is shown.

Table 2

Basic building parameters		
Material	Concrete	Brick
Number of floors	9	9
Length, <i>m</i>	32,85	32,85
Width, <i>m</i>	16,85	16,85
Height, <i>m</i>	31,00	31,00
Volume, <i>m</i> ³	17159,19	17159,19
Weight, <i>kg</i>	39,46·10 ⁶	33,46·10 ⁶
Density, <i>kg/m</i> ³	2300	1950
Modulus of elasticity, <i>Pa</i>	3,0·10 ⁹	2,32·10 ¹⁰
Poisson's coefficient	0,25	0,18

Analyzing the results of the calculations of the distribution of the total deformation of the nine-floor panel building, one can come to the conclusion that the smallest deformation of 4,4 mm is achieved when it is located on a soil base, in which the upper, more powerful layer is represented by less dense soil (loam 15 m, variant *a*), where the underlying surface is more dense soil with greater acoustic rigidity (clay 5 m). The greatest value of the deformation of the building is 5,5 mm, in the case when the top layer is presented with less dense soil (sand 15 m, variant *b*), and the substrate is more dense soil (clay 5 m). In this case, the minimum value of the deformation of the soil base is 2,8 mm, and the maximum - 3,84 mm, respectively. This is due to the fact that less dense, porous soils are damping media in which the energy of waves is attenuated.

Also, the general deformation of the layered soil base and nine-floor panel and brick buildings with $P=10^6$ Pa are calculated, the obtained data are given in Table 3. From the analysis of the Table 3 we can conclude that in all cases, in any direction of the fall of the seismic waves and for any buildings, their deformation is much greater if the upper layer of the ground substrate is represented by sand, and the lower dense – by clay comparing with cases when the upper layer is represented by denser soils (loam, clay). This is explained by the fact that the sand is more porous, less dense than clay and loam so it is much deformed and this, in turn, causes more deformation in a building based on this soil base.

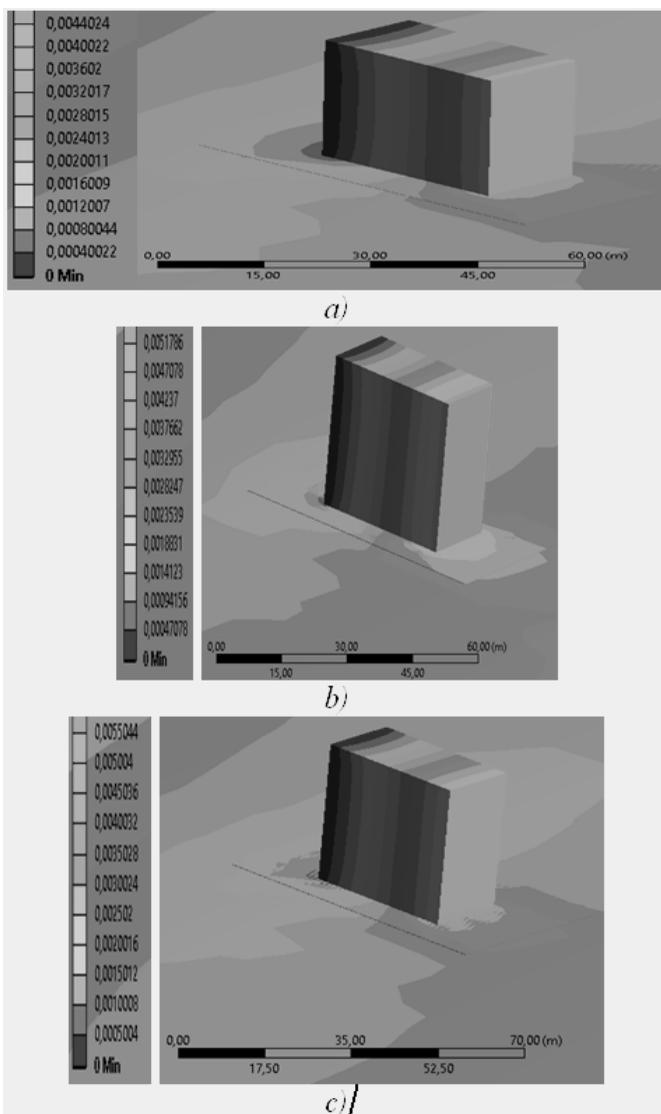


Fig. 8. Distribution of general deformation of soil foundation and nine-floor panel building at the face direction of the wave with $P=10^7$ Pa, depending on the soil layering: *a* - loam 15 m - clay 5 m; *b* - clay 15 m - loam 5 m; *c* - sand 15 m - clay 5 m

With same parameters (intensity of seismic load, wave fall direction, physical and mechanical properties of the foundation and the building), brick buildings deform more than panels. For example, the deformation of a nine-floor brick building at face direction with $P=10^6$ Pa is more than 0,8 mm (in 1,22 times) than the panel.

Table 3

General deformation of the nine-floor building (*B*) and soil base (*O*)

Deformation of building and base – loam 15 m – clay 5 m, mm								
Material of building								Value of seismic load, Pa
Concrete				Brick				
Direction of wave fall								
Face		Frontal		Face		Frontal		
B.	O.	B.	O.	B.	O.	B.	O.	
2,48	1,8	3,62	2,77	2,98	2,15	4,01	3,07	10^6
Deformation of building and base – clay 15 m – loam 5 m, mm								
Material of building								Value of seismic load, Pa
Concrete				Brick				
Direction of wave fall								
Face		Frontal		Face		Frontal		
B.	O.	B.	O.	B.	O.	B.	O.	
3,58	2,57	4,64	3,46	4,38	3,11	6,04	4,47	10^6
Deformation of building and base – sand 15 m – clay 5 m, mm								
Material of building								Value of seismic load, Pa
Concrete				Brick				
Direction of wave fall								
Face		Frontal		Face		Frontal		
B.	O.	B.	O.	B.	O.	B.	O.	
5,11	3,58	6,09	4,42	6,24	4,75	6,14	4,43	10^6

It is established that at the frontal direction of the fall of the wave there are more deformations than at the face, which is explained by an increase in the area of interaction of the wave with the building in 1.94 times.

As a result of the study, the following results are obtained.

The deformed state of soil bases and buildings during the action of seismic explosive load is researched. It is established that the most seismically safe is the location of the soil layers, when the upper, less dense layer has more thickness, and the underlying surface is more dense with greater acoustic rigidity.

In layered soils, lower rates of particles displacement are

achieved, and for the three-layered massive they are minimal (in comparison with clayey soil on 17-19%). This is due to the fact that in denser soils, the rate of spread of waves is greater than in the porous soils. In addition, in the transition of a wave from a more dense soil in less dense soil, there is a decrease in its parameters, including the rate of displacement of soil particles. It insures seismic stability, provided that the top layer of the soil is porous, and the underlying surface is denser.

It is established that the five floor buildings are more seismically stable than nine floors, that is, the smaller the interaction surface of the seismic explosive wave and the structure, the lower the stresses arise on the basis of the building.

It is revealed that the seismic hazardous is the face direction of the fall of the waves in the building. At the frontal direction of the wave fall, depending on the level of load, the amplitude of the "soil base-building" system increases substantially and resonant phenomena can be observed.

It is established that buildings constructed of concrete panels are more seismically stable, as practically all the walls of the building are bearing and the ceilings are tightly connected with each other, in comparison with brick buildings.

The study found that when the building is constructed on clay base, the deformation is reduced on 1.35 mm (55.5%) in the panel building and on 1.61 mm (39.9%) in the brick building.

Consequently, we can conclude that low-rise panel buildings, which are located on a dense clay soil base, with face side to the direction of the spread of the seismic explosive wave, are seismically resistant. This corresponds to the established norms, indicates the effectiveness of the method used and allows it to be recommended for use in the design of buildings near explosive operations.

Conclusions

Based on the research and the analysis of obtained results, the following conclusions can be formulated.

Methodics of numerical solution of problem of explosion of a charge of a trotyl on surface of a soil massif with a pipeline placed inside is developed. It makes it possible to investigate regularities of variation of wave processes in heterogeneous "soil-pipeline" system.

Mathematical model, algorithm and program for numerical solution of problem of dynamic change of stress-strain state by "soil massive-underground pipeline" system in explosion, of physical-mechanical characteristics of soil and pipeline material, as well as geometric dimensions of the last one (pipe diameter and thickness), are developed.

It is established that with a decrease diameter of pipeline the stress increases, and pipe undergoes plastic deformation and loses its efficiency. With an increase in depth of pipeline location, there is a decrease in stress: thus area of elastic deformations of a pipe with diameter of 1,5 m begins with a depth of 6 m, and for diameter of 0,4 m - from a depth of 7 m.

Polynomial dependences of stresses on depth of laying of pipeline, which allow carrying out predictive calculations of durability of pipe under different dynamic loading, are obtained.

The method of study of the deformed state of soil bases and buildings during the action of explosive load is developed.

It is revealed that earthquake-resistant low-rise panel buildings, which are located on a dense clay soil basis, with a face side to the direction of spread of the seismic explosive wave. This corresponds to the established norms, indicates the effectiveness of the method used and allows it to be recommended for use in the design of buildings near the explosive operations.

Results of the research can be used for determining the safe depth of laying of pipelines of various purposes when they are subjected to dynamic shock loads, and the methodology for calculating seismic resistance of buildings can be recommended for use in the design of construction works near the explosive operations.

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OCCUPATIONAL SAFETY AND HEALTH IN THE COAL INDUSTRY

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Abstract

In the year 2012, there were seven million people working in the mining industry, but in the 2015, due to employment situation, their number declined, especially in China. The world's largest coal producer starts exploiting its reserves more effectively, even though still needs a larger number of employees, unlike the USA, where 90 thousand people extract 0,9 billion tons of coal in underground mines with the help of modern equipment and optimized processes. Still, lives and health of the mine workers are in a greater danger. Mining accidents cause many casualties and attract public attention.

The results of the analysis showed that order to take appropriate measures to reduce industrial accidents and occupational diseases, at the state level, it is necessary to identify the differences between law and reality and predict their improvements, starting with the mining and coal sector concerning high-risk production, assess the implementation of legal acts of occupational safety and health.

Introduction

We got the Earth loaned from our children. We have to leave the world for our descendants in a better condition, than we inherited. Today, this principle encourages us to do everything that is possible

in order to stop the climate change and its destructive consequences. This means, that by the end of the century our economy and our society need to be decarbonized. And the key milestone on this journey is to avoid the use of coal, which is a challenge: it has been and still remains the fuel of industrialization and global economic growth. To shift towards renewable sources of energy and more efficient economy none the less than a worldwide energy revolution is required.

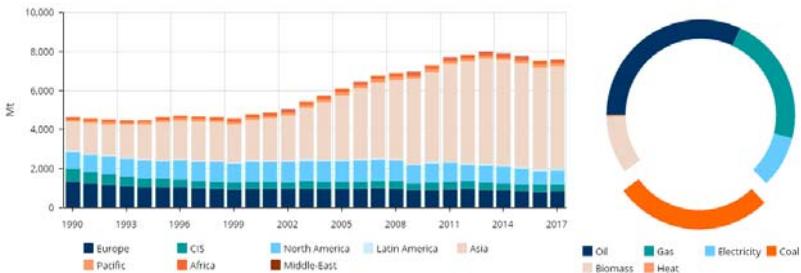


Fig. 1. Consumption of coal and lignite. Trend over 1990-2017

The statistics show (fig. 1) that coal demand around the world keeps on growing: The annual growth by the 2019 is roughly 2,1 per cent. Slightly more than a half of world coal usage accounts for China, which is the largest coal user and importer. International Energy Agency (IEA) projects reduction of coal usage for energy production in medium term. There are signs that even China has reached the peak of coal consumption [1].

Negative impacts from mass coal usage for people and environment outweigh its economic benefits. Coal does not just damage the climate. Working conditions in coal mines are horrible, accidents are common. From the ecological and health-care point of view, use of coal for electricity generation is extremely expensive.

Ecology in mining and minerals processing industries.

The main stocks of economically viable hard coal are located in Asia, Australia, North America and Eastern Europe (Fig.2).

The largest hard coal and anthracite deposit (223 gigatons) is located in the US. China is on the second place (121 gigatons), followed by India (82 gigatons). In 2013 China extracted 3,7 gigatons of hard coal, which is more than a half of world's generation, the

USA – 12 per cent, India – 8 per cent. Around 20 per cent of world hard coal is produced for export. Brown coal, on the other hand, is difficult to transport and contains more energy, therefore is used as fuel in the immediate area of its open casts.

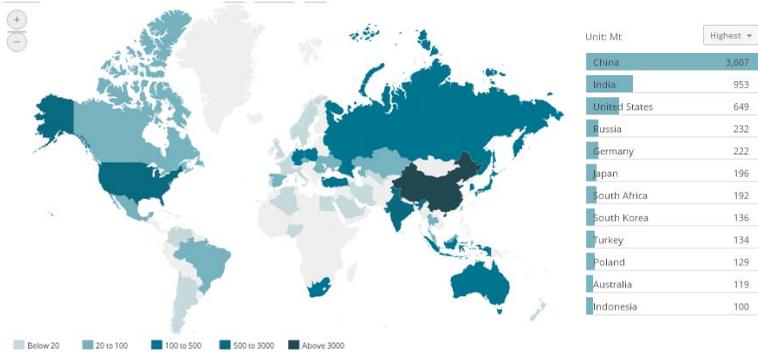


Fig. 2. Coal and lignite domestic consumption

Lignite is used in 37 countries, only 11 of which produce 82 per cent of world brown coal generation. In 2013, world’s largest producer was Germany (183 million tons), followed by China and Russia. Lignite production in Germany increased dramatically after country’s refusal from nuclear power. According to official data, we’re safe from the lack of coal. In the long term the output will decrease, since the atmosphere will be incapable to take that much CO₂. However, the international panel of experts of the Energy Watch Group insists that the official coal deposits are highly over-valued. The calculations were repeatedly revised downwards - twice between the years 1980 and 2005. The experts believe that world coal output will reach its peak in 2020 [1, 2].

Coal is mainly used for heat and power (fig. 3), with huge amounts of carbon dioxide (CO₂), slightly smaller amounts of methane (CH₄) and nitrous oxide (N₂O) released. Various greenhouse gases effect climate in different ways, therefore it is easier to convert them into CO₂ equivalent for calculations. The amounts of CO₂ and other greenhouse gases introduced into the atmosphere as a result of every kilowatt-hour energy production depend on the carbon content in the coal and energy generation productivity. Only about a third of

the produced heat transforms into electricity, after water boils to steam and spins the turbine.



Fig. 3. A coal fired power plant in China

Generally, coal electricity production damages the climate the most: gas stations produce half the CO_2 produced by modern coal stations. Due to carbon footprint of the coal industry the accumulation of mine gas, which appeared with the formation of coal and consists mainly of methane.

In 2010, mine gas emission was as high as 500 million tons of CO_2 equivalent. Besides that, hard coal is often transported on long distances, which requires energy consumption and contributes to climate change. Soot particles, which are formed during coal combustion at power plants or fireboxes, contribute to the greenhouse effect. The process of production and transportation of brown coal has lower emissions, however using it for energy production damages the climate more than using hard coal. This is due to brown coal's lower heat values – it requires more of it than hard coal to produce the same amount of energy. Coal is used not only on power plants. It is also used in ferrous metallurgy and steel industry, where it is transformed into coke and used as fuel, as well as for excluding oxygen from iron ore. This process is also accompanied by CO_2 emission. Using a lot of energy, it is possible to turn coal into liquid or gas and use it in chemical industry or as a replacement for fuel oil. These actions are economically justifiable only if oil prices are sky-high and coal prices are very low. Nowadays, this climate-destroying technology is used on an industrial scale in China, India and South

Africa. The levels of greenhouse gases in the atmosphere are high enough to increase the average surface temperature by 1,5 °C. Scientists, social organizations and the most endangered to the climate change consequences countries are calling for harmonious existence, otherwise many people all over the globe will be deprived of their livelihood. If the temperature will continue to rise beyond this limit, climate change may cross its critical point. The permafrost at high latitudes might melt, which can lead to methane release. The West Antarctic Ice may melt too. After crossing such turning-points, there will be no way of turning our climate back to its present state or predict its further changes.

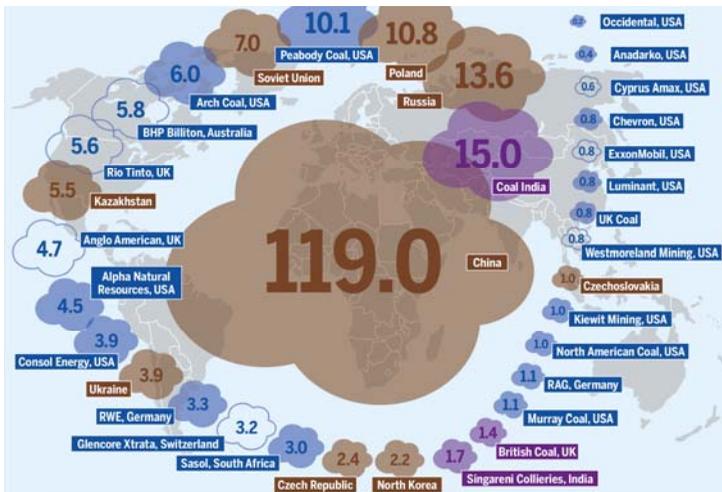


Fig. 3. The world's 35 largest private or state-owned coal producers by carbon dioxide and methane emissions, cumulative 1988-2013, in billion tonnes of CO₂-equivalent

In 2010, at the Climate Change Conference in Cancun the international community has come to an agreement to stay below the two-degree limit. If the CO₂ level in the atmosphere remains below 450ppm, the chances of staying under the limit are 50 per cent. This means that by the year 2050 emission levels should stay below 1000 GT CO₂. But this can be possible only if 88 per cent of explored reserves of coal remain underground, as well as one third of world's oil and half world's natural gas. Coal consumption shall decline dramatically: from 1,7 tons per person today to 80 kg by the 2050.

Coal mining and combustion cause harm to human health both directly and indirectly. European Pollutant Release and Transfer Register includes 53 pollutants, which are released into air, water and earth due to coal plants work (fig 3). Combustion of one kilogram of hard coal releases more pollutants, than brown coal. But, again, producing the same amount of energy requires three times the amount of brown coal than hard coal. Therefore, lignite is considered a dirtier fuel.

According to World Health Organization (WHO), air pollution is of the biggest threats for human health. WHO estimates that in 2012 around 3,7 million premature deaths due to conditions associated with air pollution took place [7]. Smog in Asian cities is a result of vehicle emission and coal combustion. Calculations of coal industry casualties vary. The Chicago Public Health schools' study showed that coal combustion in China is the cause of 250 thousand deaths per year. According to this study, there are 77 deaths per every terawatt-hour of electricity, produced at coal-fired plants. According to Health and Environment Alliance which includes 65 European social organizations, products of coal processing cause 18200 deaths and 8500 cases of chronic bronchitis in Europe annually. Taking into account coal-fired plants in Croatia, Serbia and Turkey, the number of deaths rises up to 23 thousand per year. HEAL says that medications cost around 43 billion each year. These costs should be considered while analyzing various types of energy production. The amount of emissions depends on the power plant's filtering system. Even though these systems have been advanced significantly over the last few decades, coal-fired plants still produce 70 per cent of world's Sulphur dioxide emissions and half the industrial mercury emissions in the EU. When breathed into the lungs or absorbed into the bloodstream, particles of these elements are dangerous for the organism. They cause chronic pneumonia and weaken the lungs which can lead to such diseases as asthma, chronic bronchitis and, in long-term perspective, lung cancer. Because of the chemicals blood coagulates faster and carries less oxygen, blood stops flowing to the brain, which leads to high blood pressure, arrhythmia and heart attacks. Officially established safety level of small particles does not exist. Children are especially susceptible to lead, mercury, cadmium and arsenic exposure.

Table 1 - Heavy metals and their potential effects on human health

Element	Potential health effects from exposure
Antimony	Increase in blood cholesterol; decrease of glucose levels
Arsenic	Skin damage or problems with circulatory systems, and may increase risk of cancer development
Barium	Increases blood pressure levels
Beryllium	Intestinal lesions
Cadmium	Kidney damage
Chromium (total)	Allergic dermatitis
Copper	Short term exposure: Gastrointestinal distress. Long term exposure: Liver or kidney damage. People with Wilson's Disease should consult their personal physician if the amount of copper in their water supplier exceeds the permitted action level
Lead	Children: Delays in physical or mental development; children could show slight deficits in attention span and learning abilities; Adults: Kidney problems; high blood pressure levels
Mercury, inorganic	Kidney damage
Selenium	Hair or fingernail loss; numbness in fingers or toes; blood circulatory problems
Thallium	Hair loss; pathology in blood; kidney, intestine, or liver problems
Uranium	Increased risk of cancer, kidney toxicity

If the lungs are damaged in a young age they might remain weakened for the rest of the life. Children, who were lead-contaminated in the womb, are at high risk of cognitive disorders and lower mental maturity, as well as irreversible organ damage. Power plant with higher levels of carbon dioxide emissions emit other various toxic pollutants. If CO₂ emission decreases, so do Sulphur dioxide and nitrogen emissions. This is exactly why The American Lung Association supports Obama's climate plan, targeted towards reducing coal-fired station's emissions by 30 per cent. But coal combustion is only one of the health threats, the other one is mining. People who live nearby opencast mines are strongly effected by coal dust, which leads to respiratory diseases and allergies. Mining tailings contain heavy metals and other toxic substances, which might enter groundwater and air. Another problem is radioactivity. Brown coal contains uranium, thorium and potassium-40. In Rhineland, the largest opencast coal mining region in Germany, there are 100 million tons of brown coal and 460 tons of overburden rocks, which contain 388

tons of uranium, extracted annually [3]. These radioactive materials are also contained in dust and can cause unpredictable health problems, if inhaled. Such problems are particularly acute in South-African coal mining region Mpumalanga, where 12 of the world's biggest coal-fired power stations are located.

Toxic elements and waste waters pollute limited local freshwater resources. Half the deaths from respiratory and cardiovascular causes in the region are coal-related [4, 6].

Respiratory diseases, such as asthma and bad cough, are very common among the local population. Children and the elderly are in particular risk.

Most of the power plants do not follow the national air purity standards for financial reasons. Acceptable levels of pollutants differ from country to country.

In the USA acceptable Sulphur dioxide and mercury concentrations are significantly higher than in the European Union, so many coal-fired plants had to be closed and upgraded.

Climate changes caused by coal use poses an indirect threat for human health

Labor safety and protection of workers at the coal industry

In the year 2012, there were seven million people working in the mining industry, but in the 2015, due to employment situation, their number declined, especially in China.

The world's largest coal producer starts exploiting its reserves more effectively, even though still needs a larger number of employees, unlike the USA, where 90 thousand people extract 0,9 billion tons of coal in underground mines with the help of modern equipment and optimized processes.

In China it requires 5,7 million people to extract 3,7 million tons of coal. Only in 2013 there were 10 thousand jobs cut in the USA, which was partially connected to the shale gas boom that made coal production less profitable.

Countries with fast-growing productivity require fewer workers. For example, the Government of China closed thousands small coalmines. India requires fewer people to extract the same amount of coal. The staff of a state company CoalIndia went from 500 thousand people in 2005 down to 350 thousand in 2014. The output, in the

same time, rose by one third. Besides that, India and China invest in Australia's coal mining in order to meet their own coal needs.



Fig. 4. Brown coal mining Garzweiler in North Rhine Westphalia, Germany

Thus, Australia remains one of a few countries where employment rate in the coal sector has risen. In the European Union thousands of jobs in coal industry vanish annually. In 2008 there were 342 thousand mineworkers working underground and on the surface, but in the year 2013 their number was 326 thousand. In heavily dependent on coal Czech Republic the number of mineworkers decreased dramatically. Structural changes begin in Poland, where coal is the main source of energy. The United Kingdom had almost completed the transition: in 2016 there will be only two open-cast coal mines, an old one and a new one, both owned by the working groups. In 1950 almost 540 thousand people worked in Germany's hard coal mines, 360 thousand on the surface. Today there's only 12 thousand left and by the year 2018 there will be no workers left underground. When it comes to brown coal, the number of workers on power plants has decreased from 130 thousand in 1990 to 21 thousand today. While coal is using its ground as an employment source, the importance of renewable sources of energy is growing. According to International Renewable Energy Agency (IRENA), there were 6,5 million people employed in the RES sector in 2013 - 800 thousand people more, then the last year. Now, employment rates in RES and

coal sectors are about the same. In Germany and other European countries, the RES employment rate is higher. In developing countries, however, employment statistics ignore such areas like infrastructure and operation of power stations. Nevertheless, the certain tendencies still can be discerned. China is the leader in the RES employment district – 2,6 million people in 2013, with the majority in manufacturing and installing power-generating units. Then there is Brazil (900 thousand employees), the USA (600 thousand) and India (400 thousand). Germany is in the fifth place with 370 thousand employees by the 2013. In comparison, in Germany in the brown coal district there are 70 thousand people involved [4-8]. Even though RES district has its risks (chemical production), its working conditions are generally better than is the coal district. Still, lives and health of the mine workers are in a greater danger. Mining accidents cause many casualties and attract public attention.

After 150 years of working in the coal industry, detailed instructions for industrial disasters prevention have been developed. If any happen, they're caused by reckless endangerments due to negligence.

Accidents and occupational illnesses in Ukraine

Comparative analysis of accidents and occupational illnesses in Ukraine by the first half of 2018 and 2017 does not include the accidents and occupational illnesses that happened in facilities located on uncontrolled territories, pursuant to the Orders of the Council of Ministers from 07.11.2014 №1085-r (changed).

During the first half of 2018, the working bodies of the executive directorate registered 2 385 (with 173 fatalities) acts of industrial accidents, reported following the H-1 format. Including 1 928 (with fatalities) acts in the H-1 format for the cases that happened during the reporting period, and 457 (with 85 fatalities) acts for the accidents over the years [11].

Comparing to the first half of 2017, the number of accidents decreased by 4,2% (from 2 489 to 2 385) in the first half of 2018, while the number of fatalities rose by 4,2% (from 166 to 173).

The number of accidents has risen in: Vinnitsa region – by 35 cases or by 46,2%, Nikolaev region - by 30 cases or 1,9 times, Ivano-Frankivsk region - by 15 cases or by 38,5%, Luhansk region - by 14 cases or by 26,9%, Volyn region - 13 cases or 15,9%, Zhitomir region - by 10 cases or 14,9%, Kherson region - by 22,9%, Cherkasy

region - by 15,1%, Rivne region - by 5 cases or 10,4%, Chernivtsi region - by 4 cases or 25,0%, Odessa region - by 3 cases or 3,9%, Kharkiv region - by 2 cases or 2,0%, Transcarpathia and Kyiv regions - by 1 case or 3,8% and 1,0% respectively [12].

The number of fatal insured industrial accidents has rose in: Ivano-Frankivsk region – by 6 cases or 2,5 times (from 4 to 10), Poltava region - by 4 cases or 1,6 times (from 7 to 10) and Cherkasy region - by 4 cases or 2 times (from 4 to 8).

Significant decrease of the number of insured accidents is noted in: Poltava region - by 24,7% (from 93 to 70), Khmelnytsk region - by 24,6% (from 61 to 46), Kyiv - by 22,5% (from 275 to 213) and Donetsk region - by 17,5% (from 361 to 298).

The highest number of insurance accidents is registered in Dnipropetrovsk region (14,0%), Donetsk region (12,5%), and Kyiv (8,9). The number of traumatized in these regions is 35,4% out of the total number in Ukraine.

On Ukrainian enterprises were traumatized 70,7% (1 687) of men and 29,3% of women out from the total number of injured in Ukraine.

56 people were injured at the enterprise under the influence of alcohol (2,3% from the total number of injured in Ukraine), which is 5 people more, compared to the first half of 2017. Thus, 21 were injured lethally.

The jobs with the highest injury rates are: motor vehicle drivers (129), miners (65), guides (58).

The highest work injury level can be seen among workers of 50-59 year of age (640 people, which is 26,8% of the total number of injured in Ukraine in the first half of 2018) [13].

Among all the accident causes, organization related ones dominate – 64,8% (1 546) cases. Psycho-physiological causes resulted 22,7% (540) of accidents, technical causes – 12,5% (299) of accidents.

The most common organization cases are:

- non-compliance with the occupational safety requirements - 34,5% (824 traumatized people) of the total number of injured in Ukraine;

- non-fulfillment of duty – 8,3% (199 people);

- violation of movement security (flights) - 8,3% (197 people);

- violation of the technological processes - 2,7% (64 people);
- violations of equipment maintenance safety measures –1,7% (41 people);
- violations of vehicle exploitation safety measures - 1,7% (41 people)
- non-use of personal protection supplies - 1,2% (29 people).

The most common psycho-physiological causes are:

- injury (death) as a result of other people’s illegal actions - 4,7% (112 people);
- other causes – 3,6% (86 people).

The most common technological causes are:

- poor equipment, buildings, territory - 4,7% of the total number of injured in the country (111 people);
- unsatisfactory conditions of facilities - 1,7% (41 people);
- design weaknesses and imperfections, unreliability of machines – 1,5% (35 people);
- other technical causes - 1,5% (35 people);
- technical process deficiencies - 1,0% (24 people).

The main accident causes are:

- victim’s fall at the time of movement - 26,0% (621 people);
- moving and rotary parts– 12,1% (289 people);
- road accidents - 9,9% (236 people);
- falls from heights - 7,5% (179 people);
- avalanches - 4,8% (114 people);
- murder or willful trauma - 4,4% (105 people);
- falls - 4,1% (97 people).

In the first half of 2018, the number of accidents caused by maintenance of equipment, machines and mechanisms was 735 cases (89 fatal), which is 30,8% of the total number of injured in Ukraine [14].

The types of equipment that usually leads to accidents are:

- vehicles - 7,3% of the total number of injured in Ukraine (175 people);
- specialized vehicles, road trains, box bodies, trailers, trolley-buses, motorcycles and bicycles - 3,9% (92 people);
- mining equipment (Fig.5) - 3,1% (75 people).



Fig. 4. Mining equipment

The main traumatic branches of economy and types of work are:

- mining factories and quarrying - 18,0% of the total number of injured in Ukraine (430 people, 18 - fatal);
- transport, warehousing, postal and courier activity - 9,3% (222 people, 28 - fatal);
- health care – 7,8 % (186 people, 4 -fatal).

The number of injured in these fields is 35,1% of the total number of injured in Ukraine.

In the first half of 2018, compared to 2017, the number of professional diseases decreased by 15,5%, or 159 diseases (from 1 029 to 870). The number of professional diseases increased in Luhansk region – by 23 cases (from 8 to 31), in Kharkiv region - by 7 cases (from 25 to 35),in Zhitomir region - by 7 cases (from 6 to 13),in Dnepropetrovsk region - by 6 cases (from 357 to 363),in Volynsk region - by 4 cases (from 24 to 28), in Kirovograd region - by 3 cases (from 38 to 41), in Sumy region and Kyiv - by 2 cases (from 22 to 24, from 3 to 5 respectively), in Vinnitsa, Ivano-Frankivsk, Rivne, Kherson and Cherkasy regions - by 1 case (from 2 to 3, from 0 to 1, from 0 to 1, from 0 to 1 and from 1 to 2 respectively) [15].

The largest decline of professional diseases number was in: Lviv region – by 58,3% (from 331 to 138) and Donetsk region - by 10,3% (from 165 to 148).

The largest number of professional diseases was registered in Dnepropetrovsk region (41,7%), Donetsk region (17,0%) and Lviv region (15,9%). The number of injured, who got professional diseases in these regions is 74,6 % of the total number of injured in Ukraine, who suffer from professional diseases [16].

The main circumstances that initiated professional diseases in the first half of are: frameworks and working tools inadequacy - 25,6%,

technical process inadequacy - 17,4% personal protective equipment inefficiency - 14,4 % of the total amount [17].

The total number of established diagnoses in the first half of 2018 in Ukraine is 1 469 cases.

Among all the professional diseases the first place is taken by respiratory diseases – 38,9% of the total number of cases in Ukraine (571 cases). Disease of the locomotor system take the second place (radiculopathy, osteochondrosis, arthritis) - 28,7% (421 cases). The third place is taken by auditory - 12,5% (184 cases), the fourth is taken by the vibration disease - 7,4% (108 cases).

The greatest number of occupational diseases occurred in the extractive industry and the development of quarries - 80,8 % of the total number in Ukraine (703 people), which is 18,7 % (162 people) less, than in the relevant period last year [18].

Thus, in order to take appropriate measures to reduce industrial accidents and occupational diseases, at the state level, it is necessary to identify the differences between law and reality and predict their improvements, starting with the mining and coal sector concerning high-risk production, assess the implementation of legal acts of occupational safety and health.

Consideration of production in the analyzed industry sector produced the following results [19-23]:

1. Execution and processing of internal safety and health documents

32% - are determined by the approval of the policy;

16% - use the directory;

58% - developed their own rules.

2. Organization of occupational safety and health at work: 47% - specialists in safety and labor protection; 41% - members of the informal council; 37% - specified the established units and defined the functions performed.

3. Risk management: 37% of enterprises apply measures aimed at observing safety at workplaces in terms of working conditions.

4. Occupational safety and health training in mines: 16% of specialists studied relevant documents; 37% are familiar with the plans and programs; 74% conducted training for workers in this area over the past 12 months.

Studies have shown that training should be focused on areas such as employer training, professional training in safety and labor protection, training workers in working with toxic chemicals, pressure vessels, pipelines. At the same time, 50% of the respondents reported that, in accordance with their functions, the provisions of the Laws of Ukraine "On labour protection" [24, 25], "On Fire Safety" [26], "On Ensuring the Sanitary and Epidemiological Welfare of the Population" [27], and 18% of respondents rated their knowledge as "bad", "not very good".

5. Exploitation, technical diagnostics, basic processes when using the equipment in mining enterprises: 68% have general safety requirements for production equipment; 84% have developed operating instructions and entered the data sheets. However, only 21% have permission to exploit the equipment.

6. Methods of control of the toxic and hazardous chemicals: 57% of companies use hazardous chemical elements in their activities, inform workers about the substances used, and also provide first aid training to victims.

7. Fire safety: 68% regularly check fire extinguishing equipment. There are teams of professional firefighters working at state and largest private companies; there is a specialized transport: fire trucks, emergency rescue equipment, and an automatic fire alarm system.

8. Overalls and protective equipment: 74% of enterprises regulated in accordance with the rules of the rules for the issuance of clothing, protective equipment, work wear.

9. Internal supervision of labor protection at the workplace: 37% - employees of internal control; 42% - comply with the rules of internal control in accordance with the production features of the organization; 37% - do not comply with the approved regulation of internal control.

10. Mining technologies - 63% of coal companies acquire equipment and necessary components according to the mining passport. State-owned and largest private mines use modern technology, while local and artisanal mines are in a more difficult position.

11. The electrical safety of a coal mine - 42% of companies provided a system of organizational measures and technical means that prevent harmful and dangerous effects on workers from electricity. These activities are carried out in a timely manner at state and largest

private mines, and electrical safety is not always ensured at local and artisanal mines.

12. Conveyor transport of coal mines - only 4 of the total number of companies use conveyor transport, have full access to emergency stop facilities during the required unloading position at any point along the conveyor, technician constantly monitor the normal operation of the equipment.

13. The working conditions of the employees - the assessment of the factor (47% of organizations) showed a violation of the norms in the following positions: above the average level of the amount of mine dust in large areas of a coal mine; high vibration associated with transportation and used technologies; insufficient lighting in quarries and premises with conveyor transport. The impact of these factors causes occupational diseases of workers.

14. The problems of coal industry workers are: working in hazardous conditions; exposure to hazardous production factors; occupational disease risk; deterioration of relations in marriage due to a forced long stay away from the family; psychological crisis due to early retirement.

The findings of the study indicate:

1. Despite legal framework, there are common weaknesses within the national system, which negatively affect occupational safety and health in the coal.

3. Due to coal price changes on the world market, coal mining companies encountered financial difficulties, which can rarely compete with public and large private mines.

4. It is necessary to develop new conceptual approaches to the prevention of occupational diseases of employees of coal enterprises, allowing to increase the effectiveness of preventive measures.

Therefore, it is safe to say that in Ukraine there is a legal environment for occupational safety and health. The government only needs to revise the existing regulations to officially approve the list of measures aimed at preventing the harmful and dangerous effects of the factors of the working environment and the labor process on workers in the mining industry.

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DEVELOPMENT OF METHODS FOR OPTIMIZING GEODESIC MONITORING BASED ON ZONING

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Abstract

In scientific work, a method of optimizing geodetic monitoring based on zone zoning of the earth's surface according to the degree of weakness has been developed. For this purpose, the zoning method by energy parameters was chosen, based on the difference in geoenergy between the initial and current states of the element of the rock mass. The geoenergy potential is chosen as the zoning criterion. The technique allows to increase the effectiveness of geodesic monitoring due to the problem-oriented choice of building an additional profile line, coupled with the direction of the navigator. Such a line, in combination with the division of the earth's surface by equipotential lines into areas of the same problematic nature, replaces the entire series of profile lines that penetrate the zone. At the same time, monitoring costs are reduced by several times.

The aim of the work is to develop a method and methodology for the zoning of the earth's surface according to the degree of weakness based on energy parameters.

Introduction

The intensity, depth and scale of mining, as well as the duration of the development of the field lead to an increase in the magnitude of the displacement of rocks. At the same time, large volumes of the massif are shifted, the geometry of the voids in the massif changes due to the growth of the volume of the destroyed rocks (pillars, roof, overlying stratum, and sometimes the ground surface).

This imposes special requirements for the organization of geomonitoring. Before the start of mining operations, the working benchmarks are laid along the main profile lines located along the strike and across the ore deposit. As a rule, along the strike - one profile line, across the strike - two.



Fig. 1 - The layout of the observation stations of the main profile lines on the example of the Orlovsk deposit

With such a construction, a significant part of the earth's surface is out of monitoring, carried out through observation stations of the main profile lines. At the same time, as the field is developed, the surface area extends into the zone of influence of geomechanical

processes initiated by mining. The situation is aggravated by a large loss on the profile lines of working benchmarks.

In this regard, it is necessary to build additional profile lines to maintain the effectiveness of monitoring.

The construction of additional profile lines with the laying of new observation stations, the organization and conduct of high-precision leveling at them, increases the cost of monitoring several times. The rational concept of the proposed methodology for optimizing geodesic monitoring lies in the targeted selection of an additional profile line focused on problem areas of the surface identified by zoning.

In addition to solving its main task of forecasting geomechanical processes, zoning methods allow to increase the efficiency of geodesic observations as a result of targeted allocation of problem areas on the earth's surface. At the same time, the lack of a unified methodology for organizing monitoring under the conditions of zoning conducted makes planning difficult and reduces the possibility of monitoring due to the influence of subjective factors when choosing local sites and the frequency of the observation cycle.

At the stage of processing ore deposits, the depletion of ore reserves and the steady downward trend in the content of the useful component in raw ore require, in this connection, increased extraction of mineral raw materials and necessitate the involvement of ore reserves in the undermined rock mass, including supporting thickness of pillars.

However, geotechnical processes complicate mining, posing a threat to safe mining operations, leading to loss of ore, causing destruction of structural elements of mine workings and damage to objects on the surface. At the same time, major geodynamic events (collapses and man-made earthquakes) can be causes of death and huge material costs.

Different geological conditions for the occurrence of mineral deposits, a variety of physical processes occurring in an array of rocks, various types of applied loads to the rock massif, numerous geometric forms of mine workings, varying physical, mechanical and strength properties of rocks create specific conditions for stress-strain state analysis (SSA) mining range [1]. The importance of such an analysis is dictated by the problems associated with the manifestation of rock pressure, which can be realized in the form of physical proc-

esses of loss of stability of workings, significant deformation of rocks and can lead to destruction of inter-chamber pillars and formation of dips on the earth's surface. In this regard, the development of methods for zonal zoning of the surface of a field according to the degree of weakness, as part of the SSA analysis of the mining massif, is of considerable interest.

Development of the method of zonal zoning of the earth's surface of the deposit according to the degree of weakness based on the energy parameters

To study the pre-crisis anomalies of the development of geomechanical processes preceding geodynamic phenomena, in recent years much attention has been paid to energy parameters characterizing the state of the rock mass as an open, dissipative, non-linear, natural-technical system [1, 2].

In the course of its change, this system in some parts of rock massifs due to internal and external energy sources, provided that the rate of energy accumulation exceeds its dissipation, reaches a certain critical state in which it becomes unstable.

Considering the rock mass into which the development of any purpose is being introduced, as a single system with a certain reserve of potential energy consisting of the gravitational component and the energy of elastic deformation changing under the influence of mining, it is possible to significantly simplify the study of the development of various geomechanical processes. The basis of various energy schemes, forecasts is the dependence of the potential energy on the depth of the element of the mining massif and its redistribution during the development of mining operations and the influence of various geomechanical processes.

In the methods of zone zoning of the deposit surface by the degree of weakness [3, 4], the difference in the potential energy of a stable and unstable equilibrium is taken as a criterion for zoning and the potential energy of elastic deformation of the massif is not taken into account. Taking this energy into account when calculating the energy criterion makes it possible to expand its capabilities.

To calculate the zoning energy criterion, an element of the mining massif is considered in the form of a column extending from the base to the surface of the field (Fig. 1)

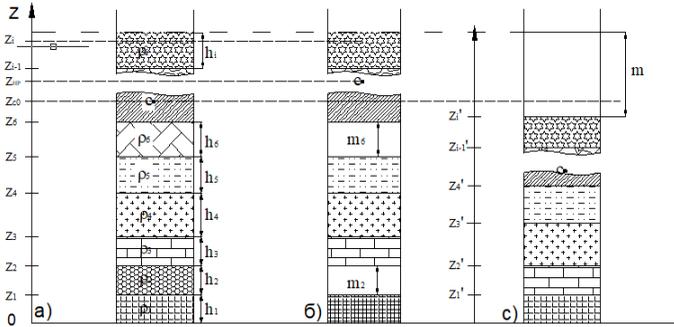


Fig. 2 - The element of the mining range

a - in the initial state. *c* is the center of mass, z_i is the coordinate of the upper boundary of the *i*-th layer, ρ_i is the density in the interval h_i of the column.

b - in a state of unstable equilibrium. m_2, m_6 - power workings.

c - state of stable equilibrium $m = \sum m_i$ - total capacity of workings

$$\begin{aligned} z_2 - z'_2 = z_3 - z'_3 = z_4 - z'_4 = m_2, z_7 - z'_4 = z_8 - z'_8 = \\ = \dots z_i - z'_i = m_2 + m_6. \end{aligned}$$

The main part of the geoenergy of the mining column of the W column is made up of the potential energy of elastic deformation W_d and the potential energy of W_p

$$W = W_d + W_p \quad (1)$$

It follows from the property of energy additivity

$$W = \sum W_{ci} = \sum W_{di} + \sum W_{pi}, \quad (2)$$

where W_{ci} - is the total energy; W_{di} - potential energy of elastic deformation; W - the potential energy of the *i*-th layer of the column.

The potential energy of the pillar in the field of the Earth is determined by the expression

$$W_p = p z_c \quad (3)$$

where p is the weight, z_c is the vertical coordinate of the center of gravity of the column. Accordingly, the potential energy of the i -th layer

$$W_{pi} = \gamma_i v_i z_{ci} \quad (4)$$

where γ_i is the specific weight of the rock mass; v_i -volume, z_{ci} is the vertical coordinate of the i -th layer. Zero level of potential energy is chosen plane $z=0$.

When finding the total energy of the column in the initial (Fig.1a) and current states (Fig. 1b), an option is considered in which, within the accuracy of the solution of the problem, the difference in the physicomechanical properties of the layers can be considered insignificant, which makes it possible to use the average specific weight γ in calculations and coefficient of elasticity E

$$\gamma = \sum \gamma_i h_i / \sum h_i ; \quad (5)$$

$$E = \sum E_i h_i / \sum h_i , \quad (6)$$

where E_i is the coefficient of elasticity of the rock mass, h_i is the thickness of the i -th layer. The vertical coordinates of the center of gravity of the column and its i -th layer are equal to

$$z_c = \left(\int_0^H z \gamma S dz / \int_0^H \gamma S dz \right) = \frac{1}{2} H ; \quad (7)$$

$$z_{ci} = \left(\int_{i-1}^i z \gamma S dz / \int_{i-1}^i \gamma S dz \right) = \frac{1}{2} (z_i + z_{i-1}), \quad (8)$$

where S - is the cross-sectional area of the column (taken $S=1$).

The elastic energy of the mass of the column W_d and the i -th layer W_{di} , respectively, is equal to

$$W_d + \int \omega dv . \quad (9)$$

Accordingly, the energy of the i -th layer is equal to

$$W_{di} = \int_{v_i} \omega dv , \quad (10)$$

where ω - the volume density of the energy of the elastic deformation of the array;

v - pillar volume;

v_i - layer volume.

For an isotropic array, you can accept

$$\sigma_x = \sigma_y = \sigma_z = \sigma = \gamma z, \quad (11)$$

where $\sigma_x, \sigma_y, \sigma_z$, - mechanical stress components σ at depth z . The bulk density ω of the deformation of the array is

$$\omega = \left(\sigma^2 / 2E \right), \quad (12)$$

The elastic energy of the column array in the initial state W_{do} is from (9) with (11) and (12) taken into account

$$W_{do} = \frac{\gamma^2}{2E} \int_0^H z^2 dz = \frac{\gamma^2 H^3}{6E}. \quad (13)$$

The geoenergy of the column massif in the initial state W_0 from (1) with (3), (7), (13) equal to

$$W_o = \gamma \frac{H^2}{2} + \frac{\gamma^2 H^3}{6E}, \quad (14)$$

where $\gamma(H^2/2) = W_{po}$ - the potential energy of the pillar in the initial state.

In the process of mining the massif, the mass of the column and its energy decreases in proportion to the volume of the goaf and the position of the center of gravity. At the same time, the massif of the column as a system passes from the initial (initial) state of stable equilibrium with energy to the state of unstable equilibrium at the current time with energy W_{us} . A certain part of the energy released

$$\Delta W = W_0 - W_{up} \quad (15)$$

as a result of the physicommechanical processes accompanying such a transition, it is redistributed in the volume of the mining range of the surrounding mine workings, causing the activation of existing ones and initiating the manifestation of new geomechanical processes, which can provoke crisis situations. The likelihood of such a situation increases with growth. Thus, the energy difference between the initial and current states of the mining massif can be used as an energy criterion for zone zoning. The energy difference is determined by the loss of energy by the column mass in the initial state as a result of its discontinuity and is equal to the sum of the potential gravitational energy W_{pv} and the elastic deformation of the

mining massif of W_{dv} layers that filled the mine before the start of mining. Power W_{pv} is equal to

$$W_{TB} = \gamma \sum_j m_j z_{cj}, \quad (16)$$

where m_j - power of the j -th generation, z_{cj} - is the vertical coordinate of the center of gravity of the j -th layer of the mining massif, which was within the boundaries of the considered generation.

With the inequality of the power output of the height of the layer ($m_j \neq h_j$), the number of layers or parts of one layer equal in height of the power output is determined. The energy W_{dv} of the layers that filled the workings before their formation from (10), taking into account (11) and (12), is equal to

$$W_{\delta\delta} = \frac{\gamma^2}{2E} \sum_j \int_{z_{j-1}}^{z_j} z^2 dz = \frac{\gamma^2}{6E} \sum_j (z_j^3 - z_{j-1}^3). \quad (17)$$

Using the decomposition of the difference of cubes, given that $z_j - z_{j-1} = m_j$, counting $z_{j-1}^2 \approx z_j^2$, $z_{j-1} z_j \approx z_j^2$ and leaving the values of one degree of smallness, we obtain

$$W_{\delta\delta} = \frac{\gamma^2}{2E} \sum_j m_j z_j^2. \quad (18)$$

Thus, the difference in the geoenergy of the rock mass of the column between the initial and current states, chosen as the energy zoning criterion with regard to (15), (16), (18), is equal to

$$\Delta W = W_{m\delta} + W_{\delta\delta} = \gamma \sum_j m_j z_{cj} + \frac{\gamma^2}{2E} \sum_j m_j z_j^2. \quad (19)$$

In accordance with this criterion, zonal zoning of the surface of a mineral deposit is carried out as follows. Using geological and mining-technical data for the entire area of the field or its individual sections, the geoenergy of a rock mass element in the form of a column in the initial and current states is found at every point on the surface.

Calculate the difference of geoenergy and the results put on the plan. On the plan, using the extrapolation method, connecting the points with the same value, construct isolines that divide the surface of the field into certain zones. The degree of weakening of the zone

increases with growth. For the classification of zones according to the degree of weakness, an important place belongs to the motivated choice of the numerical value of the criterion. Theoretical calculations can only give an approximate result due to the lack of a reliable method, since many factors need to be taken into account in combination with difficulties in assessing the degree of their influence on various geomechanical processes. As practice shows, the required reliability and reliability of the results of calculations of the numerical value of the zoning criterion are achieved using methods combining theoretical and experimental approaches, based on the analysis, results of geodetic surface monitoring and cause-and-effect investigation of the crisis events that occurred. The established numerical values of the criterion make it possible to objectively distribute zones into groups of a certain degree of weakness (danger to collapse). The number of such groups (levels) in each specific case follows from the goal and conditions of the stated zoning task.

To select the division of zones into two danger levels, one numerical value of the criterion is necessary. In this case, when zoning, it is convenient to determine the value of the difference in geo-energy of the two states by taking the value of the criterion as the beginning of the energy report. In this case, zones with > 0 will belong to the dangerous group, and with < 0 , they will be safe. If necessary, a more complete classification of the surface of the group is divided into subgroups with a given interval and its own criterion value. The practical feasibility in the implementation of zoning showed the advantage of using in the calculations of the criterion of relative values. In our model, the relative value ε is chosen as the criterion

$$\varepsilon = \frac{\Delta W}{W_0} = \frac{6E \sum m_j z_{cj} + 3\gamma \sum m_j z_j^2}{H^2(\gamma H + 3E)} \quad (20)$$

It is of interest to evaluate in the relationship between the potential energies of elastic deformation and the massif of a mining massif with depth. For the element of the rock mass in the form of a column in the initial state, these relations from (13,14) have the form

$$\frac{W_{\partial o}}{W_{TO}} = \frac{\gamma H}{3E}, \quad (21)$$

Accordingly, their share of total energy:

$$\frac{W_{\partial o}}{W_0} = \frac{\gamma H}{\gamma H + 3E}, \quad (22)$$

$$\frac{W_{TO}}{W_0} = \frac{3E}{\gamma H + 3E}. \quad (23)$$

For the rock mass of the i -th layer, the same relations from (16), using (18) and (19) are equal

$$\frac{W_{\partial i}}{W_{Ti}} = \frac{\gamma z_j}{2E}, \quad (24)$$

$$\frac{W_{\partial i}}{W_{0i}} = \frac{\gamma z_j}{\gamma z_j + 2E}, \quad (25)$$

$$\frac{W_{Ti}}{W_{0i}} = \frac{2E}{2E + \gamma z_j}, \quad (26)$$

It follows from the above relations that as the height of the column or the depth of the layer increases, the fraction of the potential energy of the elastic deformation of the rock mass increases.

Underground mining of a mineral deposit is accompanied by progressive disturbances in the continuity of the rock mass, as a result of which certain areas of it turn into a state of unstable equilibrium. Being in this state, the system is motivated to move to a state of stable equilibrium, corresponding to the minimum energy. Such a transition is initiated by geomechanical processes occurring in the massif and is accompanied by the redistribution of the rock mass in order to fill the developed space. The energy released at the same time goes on activating the existing and forming new geomechanical processes covering the entire rock mass. With an increase in energy emission, enhanced by the resonant effects of superposition of various geomechanical processes, an avalanche-like development of the transition is possible, which can lead to crisis situations. The probability of

such a development is proportional to the difference in the geoenergy of the rock mass between the states of stable and unstable equilibrium. The interrelation between the magnitude of the excess of the geoenergy of these states and the transition probability underlies the zone zoning method according to the energy criterion. In this method, when calculating the zoning criterion, the potential energy of elastic deformation is not taken into account, which, together with the potential energy, is the basis of the geoenergy of the rock mass, which largely affects the accuracy and reliability of the forecast. In this regard, in order to increase the zoning efficiency when calculating the energy criterion, which is based on the difference in the geoenergy of the rock mass between unstable and stable equilibrium states along with the potential energy, the potential elastic energy is taken into account. To find the difference, it is necessary to find the geoenergy value of the rock mass of the column at the current time (unstable equilibrium state) W_{ss} and the subsequent virtual transition to a stable equilibrium state with energy W_{us} . Substituting from (19) into (15) we get

$$W_{np} = \gamma \frac{H^2}{2} + \gamma^2 \frac{H^3}{6E} - \gamma \sum_j m_j z_{cj} - \frac{\gamma^2}{2E} \sum_j m_j z_j^2, \quad (27)$$

To find the geoenergy of the column in the state of virtual stable equilibrium W_{ss} (Fig. 1c), we use the algorithm for finding the energy of the rock mass of the column in the initial state W_0 (3), (7), (13), (14). According to this algorithm

$$W_{yp} = \gamma \frac{(H-m)^2}{2} + \gamma^2 \frac{(H-m)^3}{6E}. \quad (28)$$

The sought geoenergy difference selected as an energy criterion

$$\Delta W = W_{np} - W_{yp}. \quad (29)$$

Substituting into (29) the expressions (23) and (24)

$$\Delta W = \gamma \frac{H^2}{2} - \gamma \frac{(H-m)^2}{2} + \gamma^2 \frac{H^3}{6E} - \gamma^2 \frac{(H-m)^3}{6E}. \quad (30)$$

After converting the difference of squares and cubes

$$\Delta W = \gamma(mH - \sum_j m_j z_{cj}) + \frac{\gamma^2}{2E} (mH^2 - \sum_j m_j z_j^2). \quad (31)$$

Despite the difference in the initial positions and approaches to the development of zoning methods, with the aim of unifying the implementation of zoning technology and the possibility of direct comparison of the results obtained, the relative value is used as a criterion:

$$\beta = \frac{\Delta W}{W_0} = \frac{2E(mH - \sum_j m_j z_{cj})\gamma \left(mH^2 - \sum_j m_j z_j^2 \right)}{EH^2}. \quad (32)$$

Practical testing of the developed zoning methods was carried out at the Annensk deposit. The results of zone zoning, carried out on the basis of theoretical calculations by various methods, were compared with data obtained by ground-based geodetic measurements and space-based radar interferometry. Verification of the results showed an increase in the accuracy of zoning by the energy criterion by 15–20% relative to traditional methods, which are based on geometric criteria determined by the ratio of the depth of generation to its thickness. A comparative analysis of the results of regionalization of the two proposed methods according to the energy criterion showed good convergence of the results of zoning for $m < 0.05H$. For higher total output, the zoning method according to the energy criterion based on the difference in geoenergy between unstable and stable equilibrium states is more efficient.

Development of methods for optimizing geodetic observations of the earth surface of an ore deposit based on its zoning according to the degree of weakness

In underground mining of ore deposits, the stability of the host rocks is disturbed and a shift in the rock mass occurs in the area affected by mining. As the size of the developed space increases, the area of influence of the mine workings increases and the process of rock shifting reaches the earth's surface. Different points in the rock and on the earth's surface are not equally shifted, resulting in vertical

(slopes, curvature) and horizontal (tension, compression) deformation, as well as cracks, ledges, dips. To predict the possible development of critical situations, it is imperative to know the magnitudes of displacements and deformations of the earth's surface, for this it is necessary to carry out systematic monitoring in accordance with the requirements of the "Instruction on monitoring the displacement of rocks and the earth's surface during underground mining of ore deposits".

For the vertical column of the rock mass (Fig. 1), extending from the base to the earth's surface of the field, selected as a mass element in the calculation of the energy criterion [3, 4] W_0 , W_p and ΔW , respectively, are

$$W_0 = \gamma \frac{H^2}{2} + \gamma^2 \frac{H^3}{6E}, \quad (1)$$

$$W_T = \gamma \frac{H^2}{2} + \gamma \frac{H^2}{6E} - \gamma \sum m_j z_{cj} - \frac{\gamma^2}{2E} \sum m_j z_j^2 \quad (2)$$

$$\Delta W = W_0 - W_T,$$

$$\Delta W = W_0 - W_T = \gamma \sum m_j z_{cj} - \frac{\gamma^2}{2E} \sum m_j z_j^2, \quad (3)$$

where Z_{cj} , Z_j - vertical coordinates of the center of gravity and the upper boundary, m_j - power generation j -th layer; γ - specific gravity, E - coefficient of elasticity of the rock massif (an isotropic massif is considered), H - the height of the post.

Each element of the rock mass, being in a geoenergy field, has energy proportional to its mass M . Given that all components of geoenergy are potential, it is also potential and for its characteristics you can enter the value of φ - the potential of the geoenergy deposit

$$\varphi = W/M, \quad (4)$$

where W - potential energy that mass M has at a given point of the geoenergy field. M is the mass of the column

$$M = \frac{\gamma}{g} (H - m) S, \quad (5)$$

where g - acceleration of gravity; m - total capacity of workings; S - the area of the base of the column (taken $S=1$); γ is the average specific weight of the rock mass, H - is the height of the column.

Potential energy is a relative value determined to a constant. When choosing the geenergy value of the rock mass in the initial state for the zero level, its energy in the current state W_T in this frame of reference from (3) takes the form

$$W_T = -\Delta W. \quad (6)$$

Accordingly, the potential φ of this state from (3) with regard to, (5) and (6)

$$\varphi = -\frac{2Eg \sum m_j z_{cj} + \gamma g \sum m_j z_j^2}{2E(H - m)}. \quad (7)$$

For each point on the earth's surface, the potential value chosen as the energy criterion for zoning is put on the plan. On the plan, using the extrapolation method, connect points with the same potential value by isolines. Such lines are equipotential and are described by the equation $\varphi(x,y)=\text{const}$. An equipotential line can be drawn through any point on the surface of a field. Consequently, such lines can be built infinitely many. Therefore, they arrange to draw lines so that the potential difference for two adjacent lines would be the same. By thickening the isolines, one can judge the intensity of the expected development of the rock process. The direction of the greatest concentration of lines, by definition, indicates the potential gradient. The greater the gradient, the greater the density of the thickening. To rank the zones according to the degree of problematicity in accordance with the problem to be solved, the number of problematic levels N is determined on which it is necessary to divide the surface of the field, from which follows the number of boundary criteria $l (N=l+1)$.

The numerical value of the zoning criterion for each field is established on the basis of a retrospective, causal analysis of geodynamic events taking place, taking into account the structural features of the rock mass (geological structure, tectonic disturbance, fracturing, applied development systems), physical and mechanical properties and stress-strain state mining range. The criterion is accepted uniformly throughout the field.

As the practice of zoning shows, the best way to divide into three levels of problematic:

- 1 - G - non-hazardous (green);

- 2 - *O* - dangerous (orange);
- 3 - *R* - especially dangerous (red).

In this case, two numerical values of K_1 and K_2 are established. On the field plan, zones are divided into levels by equipotential lines $\varphi(x,y)=K_1$ and $\varphi(x,y)=K_2$. For detailing regionalization, levels are quantized to sublevels with the same potential difference $\Delta\varphi$ between themselves, determined by

$$\Delta\varphi = \frac{K_2 - K_1}{h} . \tag{8}$$

where h is the number of sublevels. Each sublevel of the zone is denoted by Latin letters: a (boundary) $b, c, d, f \dots$.

Zones of the same problem level are ranked as the potential of the boundary contour increases with the assignment of a sequence number. Observation points are indexed according to the following scheme: the letter indicates the hazard level of the zone, the next digit indicates the ordinal number of the zone, the Latin letter indicates the sublevel of the zone, the next digit indicates the ordinal number of the point on the sublevel (Example: O2d1).

All observation points that are on the same contour, under the conditions of zoning are identical with respect to the problematic nature of the studied surface area.

Moreover, parts of the earth's surface belonging to different zones, but lying on equipotential lines of the same magnitude, are also identical with respect to the problematic nature of their state. Therefore, geodetic observations of the movement of the earth's surface can be limited to monitoring the state of one randomly selected area, broadcasting the measurement results to the corresponding identical areas.

This allows you to significantly reduce the time of monitoring the entire surface and increase the frequency of measurements due to its localization and significantly reduce costs. The informativeness and objectivity of the monitoring result directly depends on the optimal choice of geodetic observation sites on the surface of the field.

In the proposed method, using the advantages of zoning according to the energy criterion, [3, 4], the choice of an additional profile line focused on problem areas of the surface identified by zoning is as follows. In each zone of the field put on the plan, along and across

the strike, so-called navigation lines of measurement (navigators) are carried out, the tangents to which at each point coincide with the direction grad φ .

The potential gradient by definition indicates the direction of the greatest change in geoenergy, which corresponds to the manifestations of the most rapid increase in the weakening of the earth's surface.

To optimize geodesic monitoring, a line is selected from the presumed parallel row of additional profile lines that is paired with the navigator according to the χ -square criterion and penetrates all the sublevels in the direction of increasing the state of surface problem-aticity.

In accordance with the principles laid down in the zonal zoning, such a line in its functionality replaces all profile lines passing through this zone without reducing the effectiveness of monitoring and at the same time significantly reducing costs. In this case, the greatest coverage of the problem areas by observation stations is provided.

The discrepancy between the chosen criterion level χ -square indicates a significant discrepancy in the directions of the navigator and the additional profile line (parallel to the main one), and therefore the impossibility of their conjugation. In this case, two options are considered: in the first version, the direction of the additional profile line is not associated with the navigator, but requires the condition of intersection of all sublevels of the zone.

In the second variant, the additional profile line is mated with the preferential direction of navigators of different zones, but is no longer parallel to the main profile lines. The presence of a stable system of profile lines on the surface of the field allows to increase their efficiency of use when selecting observation stations using a navigator.

In this case, observation points are working frames that are located within the zone and belong to the profile line crossing all the sublevels, or the maximum possible number of them. In the case of a reference between two sublevels of lines, it is considered to belong to the nearest one.

If necessary, the exact value of the potential at the location of the frame is determined by the ratio of the distances between the frame

and the sublevels. To index the observation point, the following notation is introduced (Example 8RLSh - 15 Z1d2).

The beginning indicates the profile line cipher (8JIII - the eighth line of the roadway), the next digits are the number of the reference frame on this line (15), the capital letter indicates the danger level of the zone (3 is the first green level), the next digit is the ordinal number of the zone of this level as increasing potential of the boundary isoline (1), then the sublevel index (d), the next figure indicates the ordinal number of the point of intersection of the profile line with the level (2).

The profile line and the navigator intersect the sublevels an even number of times. When indexing an observation point lying at the input of these lines, the zones are designated by even numbers, at the output - odd numbers (respectively, the observation points are considered even or odd). Deployed indexing is due to the need for continuous maintenance of observation points during the transition from the current to the zoning forecast.

As a result, it is possible to change the configuration and size of the zones, as a consequence of the displacement of the sublevels and the distance between them in conditions of constant positions of the benchmarks on the profile lines. When a reference frame falls between the sublevels during indexing, the observation point is assigned to the closest one.

Predicted zoning is necessary to take into account the expected changes in the state of the surface as a result of mining planned for a certain period. The use of forecast zoning is an important part of operational risk assessment and control is risk management, i.e. set of measures to prevent dangerous situations.

In this regard, the creation of a specialized geo-information system of geomechanical monitoring, based on the integrated application of modern surveying, topographic-geodetic and aerospace technologies.

For the effectiveness of geomonitoring analysis, a digital geo-information model of the field (DGMD) and a geo-information model of geomechanical risks (GMGR) have been created. According to the simulation results, continuous situational maps of geomechanical risks are constructed, reflecting the development of deformation processes in the mining massif.

To make forecasts, the parameters of various mining options are loaded into the management system in the database (DBMS) of the models, and predictive situational maps of each option are issued at the output.

Based on the analysis, an optimal plan for the development of mining operations is established.

In accordance with which, the forecast zoning of the surface of the field is carried out on the DGMD model according to the degree of weakness [5].

The technology of geodetic observations of the state of the earth's surface using the main profile lines traditionally has a number of advantages.

These include the initially deployed system of working benchmarks on each profile line and a large amount of accumulated and newly obtained monitoring results since the start of field operation.

At the same time, the approach to the construction of profile lines can be called a purely geometric (static), independent of the processes of change in the states of individual sections of the surface.

If it is necessary to monitor the surface areas located outside the zone of responsibility of observation stations, a significant number of lost working benchmarks and the impossibility of restoring them in the same place, as well as the need for more detailed monitoring, preferably a monitoring organization using the navigator.

This is achieved by the fundamental difference in the approach of building lines.

To build a navigation line, a problem-oriented approach is used, as a result of which the line is drawn on the plan of the earth's surface of the field in such a way that with respect to it at each point coincides with the gradient of geoenergy potential and therefore covers its most problematic areas.

In this regard, it is proposed to take advantage of profile lines and the capabilities of navigation measurement lines by combining them into a single system for the optimal choice of observation points.

The algorithm of such a system is as follows.

On the surface plan of the field with the core lines and observation stations located on it, the results of zoning are carried

out. Navigation lines are measured along the strike and across each zone.

The intersection point of the navigator is a reference point for establishing the nearest working reference point in the area of responsibility at which it fell.

The area of responsibility is determined by the area of the circle, the radius of which is equal to half the distance between adjacent working reference points.

Selected benchmarks form a surveillance system.

The implementation of the methodology for optimizing geodetic observations of the movement of the earth's surface based on zone zoning involves the following stages of work (Table 1).

Table 1 - The content of the stages of work on geodetic monitoring of the earth's surface of the deposit

№ stages	Stages of work	The main content of the work
1	Predicted zonal zoning of the earth's surface of the field according to the degree of weakness	Choice of prognostic zoning method; input to the database management system (DBMS) of a digital geo-information model of the field (DGMD) mining parameters based on the annual mine plan; analysis of the development processes of the earth's surface and determination of the numerical values of zoning criteria K_1 and K_2 ; building zones on the plan and ranking them by levels of weakness in accordance with established criteria; determination of the number of sublevels and the values of the intervals between them. construction of navigation lines; construction of an additional profile line connected with the navigator and installation of observation stations; linking observation points with working reference points and their identification.
2	Perform annual measurement cycle	analysis and selection of the optimal interferograms of the surface of the field, obtained by tandem pairs of spacecraft of various systems using the methods of space radar interferometry (SRI); decoding of interferograms (archival and current);

		<p>organization and conduct of geodetic surveying of an unmanned aerial vehicle (UAV) (zone 3 hazard level);</p> <p>processing the results of filming and building a digital elevation model;</p> <p>conducting high-precision leveling of surface areas along the main and additional profile lines;</p> <p>processing the results of geodetic measurements;</p> <p>verification of the results of high-precision leveling and SRI, their adjustment and assessment of accuracy;</p>
3	<p>Perform quarterly measurement cycle</p> <p>I quarter</p> <p>II quarter</p> <p>III quarter</p> <p>IV quarter (annual)</p>	<p>Conducting high-precision leveling of surface areas along an additional profile line at observational stations associated with:</p> <p>Even points of observation;</p> <p>All observation points;</p> <p>Odd observation points;</p> <p>Interpretation of newly obtained interferograms.</p> <p>Conducting high-precision leveling on all profile lines.</p> <p>Geodetic survey of UAVs (zones of the third danger level).</p> <p>Processing the results of geodetic measurements.</p> <p>verification of the results of high-precision leveling and SRI, their adjustment and assessment of accuracy;</p> <p>Comparative analysis with the results of previous measurements;</p> <p>Building a map of earth surface displacement⁴</p> <p>Building a current situational map.</p> <p>Comparative analysis of maps and forecast zonal zoning. Correction of zoning.</p>

Conclusion

A technique has been developed for optimizing geodesic monitoring based on improving the method of zonal zoning of the earth's surface according to the degree of weakness.

The effectiveness of monitoring is achieved by the problem-oriented choice of building an additional profile line, coupled with the direction of the navigator.

Such a line, in combination with the division of the earth's surface by equipotential lines into areas of the same problematic nature, replaces the entire series of profile lines that penetrate the zone.

At the same time, monitoring costs are reduced by several times.

The improved zonal zoning method showed an increase in accuracy of more than 10 percent compared to its counterpart.

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INNOVATIVE TECHNOLOGY OF PHOSPHORITES PROCESSING

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Abstract

A new innovative technology for the processing of phosphate mineral raw materials, based on the use of environmentally friendly leaching agents of microbial origin - organic acids (such as lactic, citric, oxalic and others) is described. The principal rejection of traditional strong mineral acids (sulfuric, phosphoric) can significantly reduce the environmental load by toxic agents and greatly expand the range of leachates. In addition, the use of crystalline (dehydrated) citric acid as a leaching factor of phosphates in the melt (426 K) allows the process to be carried out in a non-aqueous medium, which greatly reduces the consumption of fresh water for technological needs and reduces the amount of industrial waste requiring additional utilization. In addition to mineral fertilizers - calcium phosphate monosubstituted and phosphoric acid, which are traditional products of the phosphate fertilizer industry, new concomitant derivatives of lactate, citrate and other organic acids appear, which can be used as food additives, immunomodulating agents or new polyelement fertilizers. The economic expediency of the new technology using is considered on the example of processing of nodular quartz-glaucanite carbonate-fluorapatite (Zhvanivske deposit, Ukraine).

1. Introduction

The annual consumption of phosphate rock approached 150 million tons [1, 2], but the marketable phosphate is only usually 30% P_2O_5 . However, the average content of phosphorus in the ores of most deposits in Europe and Asia is much less than the generally accepted limit of economic feasibility. The latter is based on the traditional technology of processing of raw materials, which has rather significant deficiencies (on the impact on the environment) and requires significant additional investment for the recycling of waste products – phosphogypsum $CaSO_4 \cdot 2H_2O$.

However, in order to justify the expediency of developing deposits with low content of phosphates (with P_2O_5 content of 8 - 10%), we consider it appropriate to take into account the content of these deposits as well as other minerals whose elemental composition can compensate for the costs of processing of poor raw materials.

For example, the technical and economic calculations of the “Ukrphosphority” consortium for the development of the Zhvanivsky deposit (Khmelnitsky region, Ukraine) of the quartz-glaucanite carbonate-fluorapatite indicate that the total stock of the latter is about 27,5 Mt of ore and 0,55 Mt of ore per year's productivity (by traditional technology), the term of provision of reserves will be more than 50 years. In this case, the yield of phosphorous flour containing 8% P_2O_5 will be 0,4 Mt, and the selling price per 1 ton with a profitability of the company 30% will be 10 US dollars. Under these circumstances, the estimated self-sustainability of the company will be 4,5 years [3].

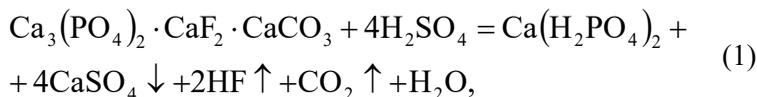
The purpose of the research is to develop a new innovative technology, based on a fundamentally new concept for the processing of phosphate raw materials. According to research carried out on the basis of the chemical and bacteriological laboratory of the department of technology of inorganic substances, water purification and general chemical technology of the chemical and technological faculty of the National Technical University “KPI im. Igor Sikorsky”, received convincing results, indicating the fundamental need for the integration of biotechnological (microbiological) techniques into the technology of industrial processing of mineral raw materials [4, 5]. One of the main arguments of the new concept was the microorgan-

isms that were found in samples of minerals from various deposits of Ukraine. Several types of microorganisms (endemic strains) - the genus *Clostridium sp.* have been identified (butyric acid fermentation agents), nocardioform *actinomycetes* (typical soil microorganisms) (Fig. 1), as well as a number of *bacteria* and *micrococci*s that require further identification. About the findings in phosphorites of microorganisms, only phosphatized, reported earlier Yu.N. Zanin and AG Zamiraylova (2011) [6].

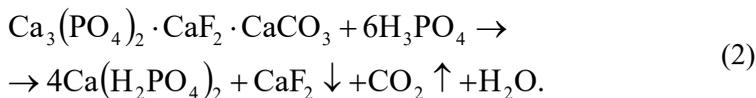
However, as it was determined in further studies, the main factor that determines the survival of microorganisms in ore bodies is precisely the organic acids that they produce in the aquatic environment and provide leaching (dissolution) of the minerals of nutrients (phosphorus, potassium, sodium, magnesium, manganese, ferrum, etc.) needed for their livelihoods. A number of microorganisms are known to be able to survive even in the most aggressive environments that synthesize organic acids as of the mineral solvents: citric (*Aspergillus niger*), butyric (*Clostridium spp.*), formic acid (*Oxalobacter formigenes*) [7] etc.

2. Research results

The use of organic acids purified from microorganisms has confirmed the feasibility of a new approach to leaching a number of industrially important minerals. For example, the use of lactic acid (synthesized by lactic acid bacteria *Lactobacillus bulgaricus* or *L. plantarum*) in the concentration of 0,5-1,0 M for the enrichment of carbonate fluorapatites, allows you to obtain 120% more useful mineral components (water soluble) than at use of sulfate (H₂SO₄) or phosphate (H₃PO₄) acid, traditional in the production of phosphate mineral fertilizers according to the classical scheme



or



Analyzing the products of reaction (1), attracts the attention of the ratio of the useful product - simple superphosphate $\text{Ca}(\text{H}_2\text{PO}_4)_2$, and the accompanying product- phosphogypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O} \downarrow$), which forms an insoluble precipitate in an aqueous solution. In this case, 1 mole of a useful product accounts for 4 mole of the harmful salt derivative of sulfate acid, which during the functioning of the domestic phosphate and fat industry accumulated in the tailings of about 2 billion tons [1].

With the use of phosphate acid H_3PO_4 as a leaching factor (reaction 2), the product of the reaction is also superphosphate $\text{Ca}(\text{H}_2\text{PO}_4)_2$, however, the cost of such fertilizer is quite controversial, since 6 mol of phosphate acid is required to processing of the 1 mol of carbonate-fluorapatite.

In addition, the phosphate feed contains calcium fluoride CaF_2 and silicium (IV) oxide SiO_2 , which, when using sulfate acid (reaction 1), react with the latter, forming a rather toxic gaseous compounds - fluoride hydrochloric acid (reaction 3), silicon tetrafluoride (reaction 4) and hexafluorosilicic acid (reaction 5)



The processing and neutralization of these compounds creates additional technological complications and causes the high cost of the target product (phosphate fertilizers).

In the processing of phosphate raw materials with organic acids, the basic requirements are the preliminary determination of the mineral composition and the assessment of carbonate content.

In the primary samples of phosphorites from the Zhvanovsky deposit, live nocardioform microorganisms (of the genus *Nocardia sp.*), which are a producer of organic acids, were found (Fig.1).

In the primary samples of phosphorites from the Zhvanovsky deposit, live nocardioform microorganisms (of the genus *Nocardia* sp.), which are a producer of organic acids, were found. Therefore, the specific microflora present on phosphorites may be a promising source for obtaining strains used in the biotechnological conversion of phosphorites.

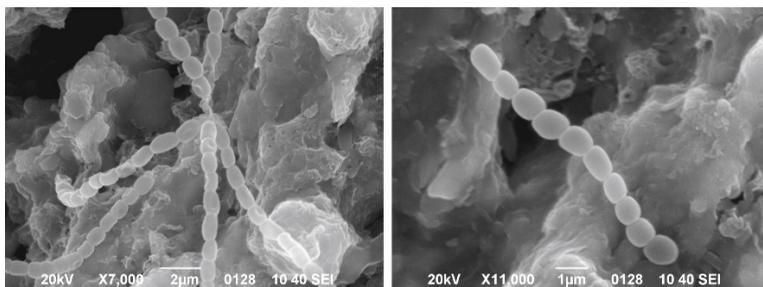
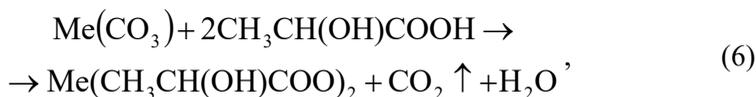


Fig. 1. Non-phosphatized nocardioform actinomycetes on the surface of fluorapatite (growth of "*de novo*"). Samples from the outcrop of Vendian Argilites, Anton Yar. Laboratory of Physical Methods of Research of IGS NAS of Ukraine: Electronic Scanning Microscopy, Secondary Electron Mode

The research findings from our laboratory indicate that all carbonate-containing phosphorous ores must necessarily be pre-treated with weak organic acids such as lactic, acetic, or butyric. The purpose of this treatment is removal from the ore of carbonates, which allows you to significantly enrich the phosphate content in the mineral raw materials, as well as obtain new useful commercially significant products. These products include, in the first place, calcium lactate (E327), calcium acetate (E263) and calcium butyricum (feed supplement "Buti PEARL" to stimulate the growth of intestinal villus and regenerate the mucous membrane in pigs and poultry). Calcium salts above the named organic acids are valuable nutrient media for the cultivation of probiotic cultures of microorganisms and for the organic synthesis of medicinal products.

By its nature, organic acids - typical protogenic solvents (proton donors) and in the reactions of decarbonization "provide" their own protons to form bicarbonate acid H_2CO_3 . The latter is an unstable compound and it is easily hydrolyzed in an aqueous solution to form

a water molecule H_2O and gaseous carbon (IV) oxide $CO_2 \uparrow$. In this case, there are active reactions between the carbonates and the corresponding acids to form essentially new products. As an example of the interaction of carbonates contained in phosphates, with lactic acid, we can give the processes of formation of water-soluble salts - lactate of the corresponding cations



where $Me - Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+}$ etc.

The resulting reaction products are non-toxic, safe for the environment and can be used as mineral fertilizers and nutrient media for growing, for example, cucumbers, tomatoes or green onions in hydroponic systems. In addition, lactates of calcium, magnesium, ferum and manganese can be used as feed additives for the production of feed for domestic and industrial use. A characteristic feature of the reactions of decarbonization that occurs with the participation of "weak" organic acids is the absolute selectivity of their interaction with carbonate-containing minerals such as calcite $CaCO_3$, magnesite $MgCO$, siderite $FeCO_3$, dolomite $CaCO_3, MgCO_3$, rhodochrosite $MnCO_3$, and others like that. With other minerals that are part of phosphorite ores - apatites, sulfides, aluminosilicates and oxides, "weak" organic acids do not interact.

The selectivity of the interaction between acids and minerals is due to the physical and chemical properties of both the minerals itself and organic acids. Since carbonates are the salts of the weakest inorganic acid-carbonate H_2CO_3 , there is a reaction of displacement of carbonate-ion CO_3^{2-} from the crystalline lattice of the mineral with anions of stronger acids (for example, acetate-ion CH_3COO^- , lactate-ion $(CH_3CH(OH)COO^-)$) or ions of any type of acids stronger than carbonate). At the same time there are reactions with the formation of water-soluble salts of the corresponding anions with reactive cations of carbonates: $Ca^{2+}, Mg^{2+}, Fe^{2+}, Fe^{3+}, Mn^{2+}$ and others. Along with the process of decarbonization, the enrichment of phosphorous raw materials takes place. In this case, the degree of enrich-

ment depends on the previous content of carbonates, since the latter are almost completely ($\approx 98\%$) dissolved, and the products in the form of aqueous solution are removed outside the reactor.

After decarbonization, the insoluble residues are subjected to treatment with stronger organic acids capable of dissolving the minerals of the apatite group - fluorapatite $\text{Ca}_{10}(\text{PO}_4)_6\text{F}_2$, hydroxyapatite $(\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2)$, chlorapatite $(\text{Ca}_{10}(\text{PO}_4)_6\text{Cl}_2)$, carbonate-fluorapatite (francolite- $\text{Ca}_{10}(\text{PO}_4, \text{CO}_3)_6\text{F}_2$), dalith $(\text{Ca}_{10}(\text{PO}_4, \text{CO}_3)_6(\text{OH})_2)$, and others [8]. Fluorapatite and vermiculite (Fig.2) are quite common in the deposits of Zhvanivske deposit [9].

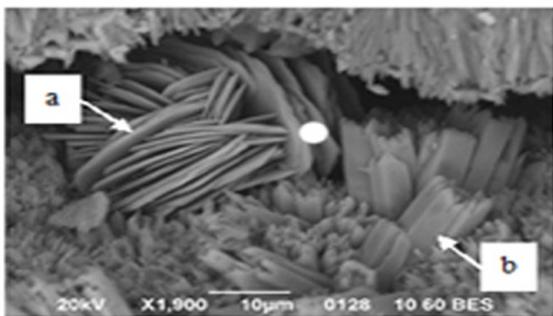
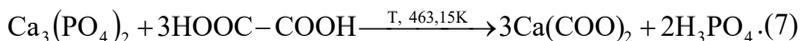
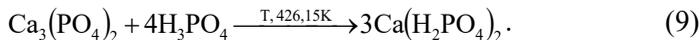
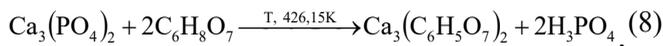


Fig. 2. The main minerals of phosphate from Zhvanivske ore deposit (Zhvanchik river, Khmelnytsky region, Ukraine); “a” - Vermiculite - aqueous magnesium, calcium and iron (III) aluminosilicate, has the structural formula: $(\text{Mg}, \text{Ca})_{0.7}(\text{Mg}, \text{Fe}^{3+}, \text{Al})_6(\text{Al}, \text{Si})_8\text{O}_{20} \cdot 8\text{H}_2\text{O}$; contains 9,13% P_2O_5 ; “b” - Fluorapatite $(\text{Ca}_3(\text{PO}_4)_2 \cdot \text{CaF}_2)$, contains 40,21% P_2O_5

One of the strongest organic acids is oxalic acid. Its ionization constant in aqueous solution (the index of the ionic strength of acid) $K_{i_{\text{C}_2\text{H}_2\text{O}_4}} = 5,6 \cdot 10^{-2}$ is 7 times higher than that of phosphatic acid $K_{i_{\text{H}_3\text{PO}_4}} = 8 \cdot 10^{-3}$ and indicates the ability of oxalic acid to leach phosphates in the form of phosphate acid from apatites

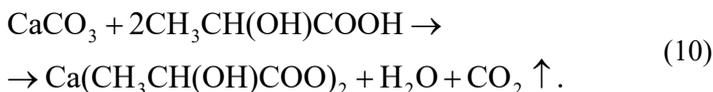


Similar reactions occur, also, when using citric acid as a leaching agent



Taking into account the chemical composition (shown in Table I) of Zhvanivsky phosphorites, a universal technological scheme of non-waste processing of raw materials was created, which ensures the economic expediency of large-scale processing of even poor phosphorus content of ore containing only 8-10% P_2O_5 .

The obtained results testify that domestic Zhvanovsky carbonate fluorapatite is a rather promising source for the production of phosphate fertilizers. Given the presence of about 10% of carbonates in it, the latter can be removed by simple decarbonization, for example, treatment with lactic acid



In this case, the leaching of the carbonate component occurs with its transformation into water-soluble salts, which are separated by a liquid phase by filtration from the insoluble residues of the enriched mineral - fluorapatite. In the process of bioconversion, 1 ton of phosphorite containing about 10% calcium carbonate, you can get about 250 kg of calcium lactate dihydrate (water soluble), which is a valuable commercial product - food additive E327.

If as a decarbonising factor acetic acid is taken, in this case it is possible to obtain 190 kg of calcium acetate (food preservative E263), which can then be converted to an organic solvent, dimethyl ketone (acetone), by thermal decomposition



Table I - The chemical composition of the phosphate ore of Zhvaniyske deposit [9]

Compound	Content, %
SiO ₂	3,13 – 9,82
TiO ₂	0,05
Al ₂ O ₃	1,38 – 2,7
Fe ₂ O ₃	0,17 – 1,22
FeO	1,81
MnO	0,09 – 0,50
MgO	0,08 – 0,25
CaO	47,32 – 52,50
Na ₂ O	0,16
V ₂ O ₅	0,005
P ₂ O ₅	30,48 – 39,58 (21,9*)
S	0,29
F	2,37 – 3,35
CO ₂	1,42 – 5,3

note: * - according to the authors of the article

After such a procedure, the content P₂O₅ will increase by 2,4%, that is, it will be 24,3%, which will allow the use of a mineral mixture for the production of phosphorous flour or feed phosphates. In addition, the latter can be used as a filler for the production of antibiotics of veterinary purpose "Biovit" (chlortetracycline).

After the preliminary decarbonization of Zhvanian phosphorite (enrichment stage), it is expedient to use crystalline citric acid for leaching phosphates. When fusion of 1 ton of enriched phosphorite with acid in the ratio of 1: 0,5, it is possible to obtain by reaction (8) 320 kg of calcium citrate (food additive E333) and 126 kg of phosphate acid.

3. Technological features of the production of phosphatic acid with the help of organic acids

The process of obtaining phosphate acid H₃PO₄ from phosphorite consists in the gradual removal from the ore initially of carbonates (lactic acid), then the enriched phosphorus is melting with citric acid at the melting point of the latter.

Three stages of phosphate acid production:

Stage 1: decarbonization (removal of CaCO_3 (reaction 6);

Stage 2: dephosphatization (leaching of calcium phosphate with dry citric acid in fusion) (reaction 8);

Stage 3: Extraction of phosphatic acid with diethyl ether and separation of phosphate acid from ether by distillation in a vacuum (ether is directed to recycling).

The first stage (decarbonisation) occurs at a temperature of 348,15 K–368,15 K (+75÷+95°C), which results in the formation of calcium lactate $\text{C}_6\text{H}_{10}\text{O}_6\text{Ca}$.

The second stage (dephosphatization) consists in removing from decarbonated phosphate of the phosphoric acid with the use of dry citric acid at a temperature of 426,15 K (+ 153 ° C), that is, in fusion. In this case, a chain of heterogeneous reactions occurs, among which the main reactions are (8) and (9). The products of these reactions are a ready-made fertilizer, which only needs to be presented in a commercial form: chop, granulate and pack.

The third stage - the separation of phosphatic acid (nutritional purpose) from insoluble precipitate (SiO_2 , aluminosilicates, etc.) occurs at room temperature.

The separation of orthophosphate acid from the ether, occurs at a temperature of about 283,15 K (10 °C).

The orthophosphoric acid derived from phosphorite is an oily liquid of green-brown color with a characteristic smell, which it gives impurities of organic compounds.

The molecular weight of acid 98,04, liquid orthophosphate acid has a density of 1,834 g/cm^3 a temperature of 25 °C, boiling at 486,15 K (213 °C) with the release of water vapor in the gas phase.

On the Fig 3 presents the principal technological scheme of integrated non-waste processing of mineral raw materials, including phosphates, with the highest possible commercialization of attractive products.

The economic expediency of processing even the poor on ore phosphates is ensured by the rational use of industrial waste from sugar production and the developed infrastructure of biotechnological productions (such as the production complex of the State Enterprise “Enzim”, Ladyzhin, Vinnitsa region, Ukraine).

phate acid (E338) and a number of nutritional supplements - calcium lactate (E327), calcium citrate (E333), lactate of iron (II) (E585) and lactate of magnesium (E329) etc.

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