SUSTAINABLE DEVELOPMENT OF RESOURCE-SAVING TECHNOLOGIES IN MINERAL MINING AND PROCESSING

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The multi-authored monograph considers the issues of working out and implementing technological designs of efficient complex extraction of raw materials, developing mineral mining and processing.

The book is intended for a broad mining audience of scholars, practitioners, postgraduates and students.

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PREFACE

We are glad to present the multi-authored monograph "Sustainable development of resource-saving technologies in mineral mining and processing".

Introduction of resource-saving technologies is one of the essential problems facing the mining and processing industry and scholars engaged in solving them.

The authors use a set of research methods including analysis of the theory and practice of deposit mining, analysis of indices of mining enterprises operation and mineral resource mining, statistic analysis, economic assessment of mining parameters and technologies, technical and economic computation to choose appropriate economic and technological solutions, designing new mining methods, pilot testing and implementation of recommendations.

Some articles of the monograph reflect urgent problems of the modern mining industry: strategies of georesource mining including that of technogenic raw materials, integrated development of mineral deposits, improvement of current and creation of new resource-saving environmentally-friendly geotechnologies and technical means of mineral mining, processing and concentration, optimization of technological scheme parameters of mining enterprises and natural resource management, intensification of ore pretreatment.

The multi-authored monograph is intended for a broad audience of specialists engaged in solving problems of the mining and processing industry.

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POSSIBLE USE OF URANIUM ORES BUCKET HOISTING IN "GLAVNYI" SHAFT OF NOVOKONSTANTINOVSKAYA UNDERGROUND MINE AT SE "VOSTGOK"

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Aim. The aim of the paper is to determine a possible level of air pollution with dust in "Glavnyi" shaft of Novokonstantinovskaya underground mine of the State Enterprise "VostGOK"

Methods. The dust pollution level is determined through the laboratory physical modeling of the process.

Findings. The size analysis of the rock to be hoisted by buckets in Glavnyi shaft has been performed and the process of dust formation has been modeled on the laboratory bench. It has been determined that the dust level is significantly impacted by moisture of rocks, additional binding of ore fines in the upper layer by surface-active materials and the fines distribution in the bucket resulted from the loading method. Loading the bucket by a vibrating feeder requires just natural moisture of rocks to provide the below-norm level of dust pollution whereas application of belt or plate feeders require additional treatment of the surface of the rock in the bucket with surface-active materials (bischofite-water solution) to achieve the permissible dust pollution rate (0.3-0.4 mg/m^3, which is 0.5-0.67 of the current norms).

Scientific novelty. It is proved that the integrated dust index is in polynomial-logarithmic dependency on rock mass moisture and, if ore moisture is 4%, decreases the dust pollution level to 0.4-0.45 mg/m^3 which is 0.67-0.75 of the current norm.

Practical relevance. The obtained results confirm possible use of a bucket in *Glavnyi* shaft to hoist uranium ores onto the daylight surface at Novokonstantinovskaya underground mine without exceeding the dust pollution norms if the sug-

gested recommendations are observed. As a result, production of the strategic raw material will grow considerably.

Keywords: *bucket hoisting, dust pollution, dust suppression measures*

Introduction. Novokonstantinovskaya underground mine is part of the SE "VostGOK" and ranks first in Europe in terms of uranium ore reserves. Uranium has been mined by three shafts (*Glavnyi*, R*azvedyvatelno-Ekspluatatsionnyi #6* (RE-6) and *Ventilatsionnyi*-1 (V-1) since 2011 at the depth of 180 to 300 m. With the designed output of the startup complex of Novokonstantinovskaya underground mine of 250 thousand t and the total designed capacity of 1500 thousand t, the current outputs of uranium ore are limited by hoisting capacity of the shafts RE-6 and V-1 and make about 330 thousand t a year.

To increase output of uranium ores at this mine, use of the shaft *Glavnyi* for bucket hoisting of the mined ore onto the daylight surface is now under consideration.

However, the shaft is simultaneously used as a ventilating one and this causes a problem of dust pollution. The current safety rules [1] allow for permissible concentration of dust not exceeding 30% of the maximum allowable concentration (MAC). With the current MAC of 2 mg/m^3 (for uranium ores with 10 to 70% of free silica), the dust pollution norm is 0.6 mg/m^3. Possible excessive dust pollution will violate the safety rules and become a potential source of corresponding occupational diseases.

In case of exceeding the allowable level, additional watering of the rock surface [2,3] or treating it with surface-active materials (SAMs) can suppress the dust. Due to SAMs' ability to increase dust wettability and prolong this effect, they are widely used at many mining enterprises of Ukraine. Also, practically tested high efficiency of some chloride-water solutions (e.g. particularly bischofite [4,5] which is a diluted electrolytic solution) provides high capillary autoadhesion of dust, i.e. binding (adhesion) of dust particles and their adhesion with larger particles/ones. Maximum efficiency of fines binding can be reached by the density of such solution which should be not less than 1170 kg/m^3 and its specific consumption should make 0.5-1.0 liter per 1 m^2 of the treated surface [5]. This results in considerable dust pollution level decrease due to counter air flows not blowing fine particles off the loaded bucket surface.

The investigations fulfilled the following tasks:

- determination of the particle size distribution in the rock mass to be hoisted in order to determine the size distribution of fines;

- study of the dust formation process at bucket hoisting on the laboratory bench and determination of the impact of ore fines distribution in the bucket and ore moisture on dust formation;

- in the case of exceeding of possible level of dust-ladenness of air to work out measures for her decline and coersion to the operating norms.

- development of measures for reaching the current dust pollution norms in case they are exceeded.

Methods. To study the process and determine the possible dust pollution level the laboratory physical modeling of the process was conducted on the laboratory bench in the wind tunnel AT-2K-250/500 with the open flow and the closed test section, an aspirator with a drive and hoses for air and its filtration.

Physical modeling of the dust formation process was performed on the laboratory bench consisting of the wind tunnel AT-2K-250/500 with the open flow and the closed test section, an aspirator with a drive and hoses for air and its filtration.

Results and discussions. Modeling the dust formation process requires information on the number of fine fractions in the rock mass which are intended for the process. For this purpose, the particle size distribution of the rock mass sample of about 70 kg was determined. The sample with size-sorted fractions is given in Fig. 1.

Fig. 1. The rock mass sample with size-sorted fractions

When sizing, separate lumps were measured and weighed; parameters of fine fractions (-15÷+0 mm) were determined by sieve analysis (apertures of 15, 10, 7, 5, 3, 2 and 1 mm) and weighing. The results of the size analysis of the sample investigated are given in Table 1.

Table 1

The results of the granulometric analysis of the sample investigated

Fraction sizes, mm	Fraction weight, g	Fractions in the sample, %
-200÷+100	47050	67.64
-100÷+50	19554	28.13
-50÷+5	1880	2.70
-15÷+0. incl.:	1063	1.53
-15÷+10	813	1.170
-10÷+7	84	0.121
-7÷+5	67	0.096
-5÷+3	31	0.045
-3÷+2	29	0.042
-2÷+1	18	0.026
-1÷+0	21	0.030
Total:	**69512**	**100.00**

As is seen, -1÷+0 mm fraction makes just 0.03 %. The БПСМ-4 bucket may contain about 7-7.5 t of rock mass with 2-2.3 kg of -1 + 0 mm fraction which is a potential source of dust formation while the bucket is moving along the shaft. But random character of size distribution in general and in the bucket in particular implies that the actual weight of this fraction in a bucket may make from 1-1.5 kg to 3.5-4 kg.

Distribution of ore fines in the bucket impacts the dust pollution level significantly and depends on the loading method. The impact of the loading method on the ore fines concentration was also investigated as dust-like and fine particles are only blown off the upper layer of the loaded rock mass. The rock mass loaded by a belt or a plate feeder is distributed more evenly due to its size composition and considering its natural fluctuations near the mean value.

A vibrating feeder causes segregation of the material on its surface according to its size: fine particles move to the lower layer, larger fractions that do not participate in dust formation are gathered in the upper layer. This size distribution is observed in the upper layer of the rock mass in the bucket as well and causes 3-4-fold decrease of the number of ore fines. Considering this fact, separate investigations into distribution of the material according to its size and with smaller concentration of ore fines in the upper layer caused by application of a vibrating feeder were conducted.

As mentioned above, the dust formation process was modeled in the wind tunnel AT-2K-250/500 with the open flow and the closed test section and an aspirator with a drive and hoses for air and its filtration. The laboratory bench and the aspirator for polluted air bleeding from the wind tunnel are given in Fig. 2 and 3.

Fig. 2. The wind tunnel AT-2K-250/500 with the open flow and the closed test section

Fig. 3. The aspirator

The air flow rate in the test section was established by a diffuser of a required diameter. The fan activated by an electric motor sucked down air through a nozzle with a straightening grille to the test section. In the section the bucket model was placed with a pipe for air sampling. The hoses delivered the air to the aspirator. Samples of the air from the test section went through a previously weighed filter in the sampler. After each sampling the filter was changed. Before and after the experiments the filters were weighed on the electronic scales ВЛР-200 with weighing accuracy of 0.05 mg.

As during physical modeling of the process observance of similarity criteria (particularly geometrical sizes of rock mass particles, the air flow rate and the kinematic coefficient of viscosity of the medium) is of considerable importance, the modeling scale change causes a problem of agreement of the above factors for the result of the modeling to correspond to the data in real conditions. The diameter of the wind tunnel cannot be changed but the air flow rate can be regulated. The actual material (rock mass) of the size composition characteristic of the underground mine was put in the model bucket and the bucket was placed in the wind tunnel for a series of experiments. The air flow rate in the test section of the tunnel should correspond to the speed of blowing off ore fines from the surface of the bucket.

The obtained data on dust pollution of the air in the model should then be corrected considering the relation between the БПСМ-4 bucket surface and the bucket model areas (treating this regularity as linear) and the actual amount of the air moving along *Glavnyi* shaft and in the air tunnel per time unit during the experiment. Due to this correction the obtained data are close to those in real conditions and enable forecasting the possible dust pollution level which may occur at bucket hoisting in *Glavnyi* shaft.

According to the information provided by the engineers of the enterprise, the section area of the shaft *Glavnyi* is S_{shft}=44 m^2, the amount of the air delivered through this shaft into the underground mine is $Q_{air\ shft}$=160.4 m^3/s, the rate of hoisting rock mass by the БПСМ-4 bucket is to be V_{buc}=6 m/s. Thus, the rate of the air flow which is to blow ore fines off is equal to the resultant of two counter rates: the rate of the downcast air delivered through the shaft and that of the loaded bucket hoisting speed.

The rate of the air flow along *Glavnyi* shaft can be determined from the expression, m/s

$$V_{air\ shf} = Q_{air\ shft}/S_{shft} = 160.4/\ 44 \approx 37.$$

Thus, the resultant speed of interaction of the air flow with the surface of the rock mass loaded into the bucket makes, m/c

$$V_{air\ flow} = V_{air\ shft} + V_{buc} = 3.7 + 6 = 9.7.$$

The rate of the air flow in the wind tunnel close to the one stated (10 m/s) was obtained with the help of a diffuser of the required diameter (140 mm). The difference between the obtained rate and the required one makes only 3.1% which is quite permissible in our opinion and does not produce any considerable impact on the results of the process modeling.

A small plastic bucket (the upper diameter of 120 mm and height of 115 mm) used as a bucket model was filled with the crushed rock mass of the sizes corresponding to those of ore fines (i.e. -1+0 mm fraction) which are a potential source of dust formation. During the first set of experiments when modeling loading the bucket by a belt or plate feeder, the amount of the mentioned fine fraction in the upper layer corresponded to the even distribution of the fines (i.e. 0.03%). When modeling the bucket loading by a vibrating feeder and determining dust pollution of the air, the amount of fines was decreased to 0.01% which corresponded to the determined segregation of the material loaded by this method.

The total time of hoisting the bucket from the 330 m level to the daylight surface (Fig.1) at the speed of 6 m/s and considering unevenness of its movement (acceleration at the start and deceleration at the end of hoisting) makes about 1 minute. The modeled process of fine particles blowing off demonstrated that the maximum intensity of the process at the beginning decreases as the bucket moves towards the shaft mouth due to fine particles blowing off at the previous part of the shaft, i.e. blowing off depends on the time factor. Due to this, dust pollution changes, too. To track this process, the dust pollution level was measured 3 times every 20 seconds. When processing the data, the dust pollution level was determined at these intervals and on average for the whole period of hoisting.

The forecast data on dust pollution in real conditions were obtained considering the relation between the БПСМ-4 bucket surface area (2.0 m^2) and the model bucket area (0.01131 m^2), that made

2/0.01131≈177. With the test section diameter of the wind tunnel of 0.25 m and air rate in it of 10 m/s, the amount of air going through it makes 0.49 m^3/s. As mentioned above, through the shaft *Glavnyi* 160.4 m^3/s of air is delivered to ventilate mining operations in Novokonstantinovskaya underground mine. So, the amount of air in real conditions is 160.4/0.49 ≈ 327 times larger. Thus, dust pollution in real conditions will be 327/177≈1.85 times less than in the model.

Table 2 gives the results of laboratory investigations into dust pollution when bucket hoisting rock mass in *Glavnyi*. Column 4 presents dust pollution resulted from measurements in the model, column 6 presents results of the recalculated level considering adjusting the obtained data to real conditions, Column 7 presents relation of dust pollution to maximum allowed concentration of dust for these conditions which makes 0.6 mg/m^3.

Each of the 5 series consisted of 5 experiments of 3 samplings to determine the dust pollution level. The numbered filters were weighed before and after the experiments on the electronic scales ВЛР-200 with weighing accuracy of 0.05 mg (Fig. 4).

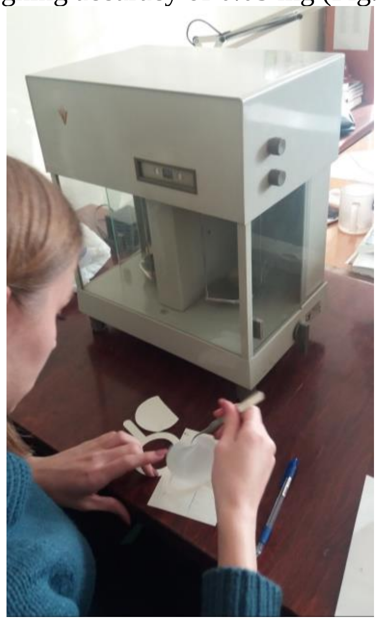

Fig. 4. Weighing the filter on the scales

The average data of each experiment are given in Table 2.

Table 2

Results of the laboratory investigations into dust pollution at bucket hoisting

Bucket loading means	Rock mass properties	Period of sampling and average per hoisting cycle	Dust pollution level, $mg/m^3 \cdot s$		Excess of permissible dust pollution, times, times
			modeled	calculated for real conditions	
Belt or plate feeder	Natural moisture	0-20 s	23	12.4	20.7
		21-40 s	9	4.9	8.1
		41-60 s	4	2.2	3.6
		0-60 s	12	6.5	10.8
	Watered bucket surface	0-20 s	0.8	0.44	0.73
		21-40 s	3.3	1.8	3.0
		41-60 s	6.7	3.6	6.0
		0-60 s	3.6	2.0	3.3
	Bischofite-treated surface	0-20 s	0	0	-
		21-40 s	0.85	0.46	0.77
		41-60 s	0.85	0.46	0.77
		0-60 s	0.57	0.31	0.52
Vibrating feeder	Natural moisture	0-20 s	6	3.2	5.4
		21-40 s	2.5	1.4	2.3
		41-60 s	1	0.54	0.9
		0-60 s	3.2	1.73	2.9
	Watered bucket surface	0-20 s	0	0	-
		21-40 s	0.5	0.27	0.45
		41-60 s	2	1.1	1.8
		0-60 s	0.8	0.44	0.73

The obtained results show that belt and plate feeders produce the average value of dust pollution at hoisting which is 11 times larger than its maximum allowable value. As it was assumed, during the first time period (0-20 s) the excess was maximal (20.7 times), gradually decreasing to 8.1 times during the second period (21-40 s) and was minimal at the end of hoisting (41-60 s) – 3.6 times. However, in any case, the observed considerable excess of pollution rates results in additional measures for decreasing it to the allowable level.

Watering the surface of the bucket loaded with rock mass decreases the average dust pollution by over 3 times (from 6.5 to 2 mg/m^3) but it still is 3.3 times larger than the maximum allowable concentration of dust. Dust pollution during separate time periods is completely different: minimum dust pollution which is even 1.36 times less than the allowable level occurs at the start of hoisting.

During the second time period, dust pollution is 3 times larger than its maximum allowable value, at the end of hoisting it is 6 times larger. These results can be explained by the fact that at the start of hoisting capillary forces of adhesion of the watered ore mass are sufficient for binding dust-like particles, but in the course of time high rates of the counter air flow result in the increased surface "drying". So, even watering of the surface of the ore mass loaded into the bucket does not ensure observance of the dust pollution norms.

Table 2

Results of the laboratory investigations into dust pollution at bucket hoisting

Bucket loading means	Rock mass properties	Period of sampling and average per hoisting cycle	Dust pollution level, mg/m^3·s		Excess of permissible dust pollution, times, times
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	Bischofite-treated surface	0-20 s	0	0	-
		21-40 s	0.85	0.46	0.77
		41-60 s	0.85	0.46	0.77
		0-60 s	0.57	0.31	0.52

Continuation of table. 2

Vibrating feeder	Natural moisture	0-20 s	6	3.2	5.4
		21-40 s	2.5	1.4	2.3
		41-60 s	1	0.54	0.9
		0-60 s	3.2	1.73	2.9
	Watered bucket surface	0-20 s	0	0	-
		21-40 s	0.5	0.27	0.45
		41-60 s	2	1.1	1.8
		0-60 s	0.8	0.44	0.73

That is why at the next stage of modeling the rock mass surface was treated with the bischofite-water solution according to [5]: the solution density is about 1.2 g/cm^3, its specific consumption is about 0.7-0.8 kg per 1 m^2 of the treated area. As the treated surface keeps moisture for a longer period, the adhesion between fine particles and with larger ones increases considerably and results in sharp decrease of dust pollution: no pollution at the beginning, steadily low pollution (0.75-0.8 of the maximum allowable dust concentration) during the second and the third periods. The whole hoisting cycle is characterized by the dust pollution level which is 2 times lower that allowable values.

A vibrating feeder applied to loading the bucket and low natural moisture of rock mass make dust pollution 3.5…4 times lower than use of belt or plate feeders. However, the average dust pollution value at bucket hoisting is still almost 3 times greater than its maximum allowable figures.

Watered surface of the rock mass loaded into the bucket decreases dust pollution considerably: there is practically no pollution at the start of hoisting, its growth is seen up to 0.4-0.5 and 1.5-2 respectively of the maximum allowable values during the second and the third periods. During the whole hoisting cycle the average dust pollution is 1.3-1.4 times lower as compared with its maximum allowable values, i.e. it satisfies the current safety regulations [1].

Conclusions. The conducted investigations into the dust formation process confirm the possibility of use of bucket hoisting of uranium ores on the daylight surface in *Glavnyi* shaft at Novokonstantinovskaya underground mine of the SE “VostGOK”. To ensure observance of the current dust pollution norms for the downcast air, the design of the underground loading facilities should provide for a vibrating feeder to load the bucket.

In this case, thorough watering of the surface of the rock mass loaded into the bucket or even its high natural moisture (not less than 4%) provides observance of current dust pollution norms (the pollution level is 0.7-0.75 of maximum allowable values for such conditions). However, it should be noted that increase of mining depth and, consequently, the height of the mined rock mass hoisting onto the daylight surface will result in the increased hoisting time. High natural moisture of ore or additional watering of its surface will not be able to provide sufficient decrease of the dust pollution level.

To observe dust pollution norms, use of a belt or a plate feeder requires treatment of the surface of the rock mass loaded into the bucket with SAMs (e.g. bischofite-water solutions).

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References

1. Pravyla bezpeky pid chas rozrobky rodovyshch eudnykh ta nerudnykh korysnykh kopalyn pidzemnym sposobom [Safety rules for mining ore and non-metallic minerals by underground methods]. (2017). Kharkiv: “Fort” [in Ukrainian].

2. **Tkachuk K.N., Hurin A.O., Beresnevych P.V.** et al. (1998). Okhorona pratsi [Labour Protection]. Kyiv: “Vyshcha shkola” [in Ukrainian].

3. **Hurin A.O., Beresnevych P.V., Nemchenko A.A., Oshmianskyi I.B., Beresnevych , P.V.** (2007). Kryvyi Rih [in Ukrainian].

4. **Nesterenko O.V.** (2001). Smachivayemost pyli vodnymi rastvorami na osnove nekotorykh khloridov [Wetting Dust with Chloride-Water Solutions]. Razrabotka rudnykh mestorozhdeniy – Ore Deposit Mining, 77 (pp. 140-142). Krivoi Rog: KTU [in Russian].

5. **Nesterenko O.V. (**2008). Pidvyshchennia efektyvnosti znepyliuvannia avtomobilnykh dorih u karierakh [Increasing Efficiency of Dust Control on Open Pit Roads] extended abstract of Cand. Sci. (Eng.) Dissertation: 05.26.04 / Kryvyi Rih Technical University. Kryvyi Rih [in Ukrainian].

TECHNOLOGICAL FEATURES OF PROCESSING OF MAN-MADE WASTE OF PHOSPHOGYPSUM

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Summary

This scientific work contains materials of research on solving the problem of rational nature management in relation to the use of man-made waste of phosphogypsum and reducing the negative impact on the environment. The complex processing of phosphogypsum with the associated extraction of rare earth metals is offered. The basic information about rare earth metals and their applications is presented. The feasibility study is presented, which is aimed at obtaining a basic scheme of the shop for the production of phosphogypsum radiation-protective bricks. Bricks made from raw materials after extraction of rare earth metals. The paper describes the necessary equipment and basic technical parameters for ensuring the technological process.

Introduction

The problem of environmental management and waste reduction in production of mineral fertilizers and their utilization is very serious now. These wastes have pernicious effects on human health, the environment, surface and ground water. The use and recycling of this production waste is an actual scientific and applied problem, the solution of which will greatly increase the ecological safety of the country, reduce the impact of wind erosion, and will have a significant economic effect. To solve this problem, connected with the accumulation and utilization of waste, it is necessary to conduct research works aimed at assessing the state of the industry and its development prospects, as well as develop a set of appropriate measures.

The purpose of the study is to investigate the physical and mechanical properties of phosphogypsum dumps and to substantiate the technology of integrated recycling of mining waste (for example, the dumps of the phosphogypsum of PJSC «Rivneazot») with the extraction of rare earth metals. As a result of research, the following tasks will be solved: 1. Assessment of the current state, justification of the necessity and ways of solving the scientific and technical problem of complex processing of phosphogypsum; 2. Research of world tendencies of use of rare earth metals; 3. Develop principles of processing phosphogypsum extraction of rare earth metals and the associated processing of building products for commercial premises.

In the final result of the implementation will be created rational, for specific conditions, economic, technogenic and environmental methods of integrated processing of phosphogypsum for the manufacture of building materials for commercial premises with the associated mining of precious rare earth metals. Expected results should establish the basic physical and mechanical properties of man-made phosphogypsum deposits and promote the development of technologies for the integrated processing of man-made phosphogypsum wastes. This will allow optimizing the technological process, reducing the negative impact on the environment, and rationalizing the use of nature.

1. The state of research and development topics

The imperfection of mining technology and the work of chemical industry enterprises lead to the formation of man-made deposits [1-5]. Modern developments in processing and utilization of phosphogypsum dedicated work of many researchers and scientists in Ukraine and abroad, including A.F. Bulat, V.A. Ivanov [2], I.A. Trunova [2] R.V. Zhomyruk [2,4,6-10], C.R. Canovas [11]. As the analysis of scientific literature has shown, world tendencies testify to the necessity of development and substantiation of complex technologies of digging dumps with phosphogypsum. So, according to studies by L.L. Tovazhnyanskyi, P.A. Kapustenko [2], A. Jarosiński, Manis Kumar Jha [12], V.S. Moshynskiy [13-16], Z.R. Malanchuk [17-21], V.P. Nadutiy [22, 23], Ye.Z. Malanchuk [24-31], promising and economically profitable direction of integrated processing of phosphogypsum is the extraction of rare earth metals through the development of reserves of man-made deposits, the constant growth of demand and cost of rare earth metals.

According to research A.G. Olginskiy and E.V. Kraynyuk [2] Manis Kumar Jha [12], M.A. Lychova [2] In phosphogypsum in large quantities there are heavy metals such as cadmium, chromium, cobalt, mercury, copper, lead, nickel, zinc and strontium, as well as valuable rare earth metals.

The greatest threat to the quality of groundwater is those organic compounds that are relatively soluble, do not evaporate and do not decompose chemically or biologically. In water, organic matter under the action of bacteria eliminate. Their disintegration leads to a decrease in the concentration of dissolved oxygen in the water, and thereby puts on environmental risk balance reservoir [4]. A special threat to the inhabitants of the city of Rivne and the surrounding villages, as well as the Goryn river basin, is represented by dumps of phosphogypsum located on the territory of PJSC «Rivneazot», west of the distance of 20 km from the city of Rivne [2, 4].

As for the specific recommendations for the rationalization of the integrated processing of phosphogypsum with the possibility of extraction of rare earths, there is practically no such development to date.

Phosphate raw material for the production of mineral fertilizers in Ukraine was apatite concentrate is supplied from Khibiny deposits. Apatite $Ca_5(PO_4)F$ is not soluble in water and is not absorbed by plants. To obtain mineral fertilizers, it should be converted into a soluble form, and for this apatite must be treated with sulfuric acid. As a result, soluble phosphates are formed, and calcium and fluorine are released into the waste. Solid reaction products, which mainly consist of gypsum ($CaSO_4 \cdot 2H_2O$), called phosphogypsum. For the production of 1 t phosphate acid, depending on the type of raw material spend from 4.3 to 5.8 tons of phosphogypsum.

In terms of dry matter of phosphogypsum contains 94% $CaSO_4$, 1,8% unresolved apatite, phosphoric 1,8%, 0,22% hydrofluoric acid silicon insoluble, residue 1,92 to 1% iron oxide and aluminum. Humidity of freshly prepared phosphogypsum is 42%, of which 17-19% of water included in the crystal lattice of gypsum and 22-24% - free. The chemical composition of phosphogypsum [5] is presented in Table 1.

Table 1

The chemical composition of phosphogypsum

Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	Na_2O	P_2O_5	F
Content %	1.5	0.4	0.59	31.8	45.3	0.4	0.6	0.31

The presence of phosphoric and silicon fluoride acids causes acidic reaction of pore moisture. The chemical composition of pore water (Table 2) is characterized by the following data (laboratory Rozdil deposit «Sirka»):

Table 2

The chemical composition of pore water Rozdil deposit «Sirka»

Components	SO_4^{2-}	Cl^-	$K^+ + Na^+$	H_2SiF_6	P_2O_5	The dry residue	pH
Content mg/dm^3	4200	265	1269	4800	17040	13700	2,4

Rozdil dump phosphogypsum has an area of 14,2 hectares with a dam height of 3m. About 4 million m^3 of phosphogypsum has been accumulated. Water, which is washed out from phosphogypsum by atmospheric precipitation, was neutralized by liming. After the cessation of production in the central recess career accumulated about 0,5 million m^3 of acidic water (Figure 1).

Fig. 1. Career to dump phosphogypsum in New Rozdil

Since the 1970s intensive searches for phosphogypsum utilization were carried out in three directions:

production of building materials and products;

application as mineral fertilizers;

improvement of storage methods.

Gypsum binders are divided into kilns and autoclave. Kilns are obtained by heating at atmospheric pressure up to 110...170°C, while crystallization water is evaporated. Autoclave is made by heating up to 120...150°C under pressure of 130...140kPa.

The barrier for the production of building materials from phosphogypsum is the presence of acids that corrode equipment, as well as volatile fluorine, which, when burned out, is released in the air. The Institute for Environmental Problems (UkrNIIEP, Kharkiv) developed a scheme for conditioning phosphogypsum by processing its limestone milk containing CaO 100 g/l. Several schemes of production of wall panels, dry building mixtures, gypsum binders are offered.

In Voskresensk Chemical Company project institute «Hiprohim» was built factory for production of phosphogypsum gypsum products. There were recycled 360 thousand tons of phosphogypsum, but the production turned out to be unprofitable.

The employees of the Institute of Building Materials and Products (Kyiv) investigated the old deposits of phosphogypsum in Rivne and found that the upper layers at depths up to 10 m are already deoxidized as a result of natural processes and are conditioned for non-laundered construction products.

In 2002, the scientists of the GIRHIMPROM Institute developed a comprehensive project to restore the landscape in the area of activity of the Rozdil deposit «Sirka», which included measures for the waterproofing of the phosphogypsum dumps by the impermeable clay and the neutralization of acidic waters. However, the project was not implemented due to lack of financing. So far, the acid is washed out of the dump, resulting in the formation of a lake of acidic waters (pH 4...5) in the central quarry.

Phosphogypsum is not sufficiently studied for the presence of rare metals in it, which are part of apatite ore. Maybe in the future technology of its utilization will be mastered as phosphogypsum should be stored for the future.

Overview of mining waste (on the example of dumps of phosphogypsum of PJSC «Rivneazot»)

In the development of mineral deposits, their mining and processing are usually generated waste that pollute the environment, including soil and groundwater. At present, the total volume of solid waste accumulated in Ukraine is 25...28 billion tons. They are located in dumps, the total area of which is about 180 thousand hectares and annually increases by 3...6 thousand hectares. In the first place, this applies to the mining and metallurgical complex, since the generation of waste in this sector is 90% of the total volume of all industrial waste produced in Ukraine.

According to the materials of the Rivne exploration expedition in Rivne region, there are almost 1,200 stationary sources of potential pollution of soils and groundwater. In particular, a considerable danger to the health of the population of the Rivne region is the dumps of the phosphogypsum of PJSC «Rivneazot».

The production of phosphate fertilizers and phosphoric acid occurs on the basis of mineral raw materials, namely phosphorites and apatite ore, imported to Ukraine from abroad (Kola Peninsula). After the production of this type of fertilizer, a significant amount of phosphogypsum waste is produced, which requires the removal of agricultural land for their storage. Thus, as a result of long-term storage of phosphogypsum, man-made phosphogypsum deposits were formed that were not further used and processed due to heterogeneous chemical and structural composition [7].

A feature of the Rivne region is the placement on its territory of the «chemical giant» for the production of mineral fertilizers PJSC «Rivneazot».

Phosphogypsum is a multi-trash waste, which for many years is stored in the dump and in connection with its large amount of impurities is not used massively. Among these impurities are also available rare earths, the removal of which is usually not happening.

When phosphogypsum storage in dumps that are usually found in open plots phosphogypsum pollutes the land, and the remnants of acids and contaminants under the action of rain fall in the groundwater.

The use of phosphogypsum makes it possible to obtain products that meet all existing requirements, as well as to solve an environmental problem by utilizing large-tonnage waste from the production of mineral fertilizers - phosphogypsum with minimal fuel and electric energy consumption.

Research conducted at the National University of Water and Environmental Engineering (Ukraine, Rivne.) to implement the principles of integrated waste processing of mining production with the extraction of rare earth metals. Standard and sufficiently tested experimental test methods were used. The methods of mathematical modeling based on the planning of the experiment, which allow obtaining the necessary regressive dependencies, are essential in the work. On the basis of the experimental-statistical mathematical models, the influence of the main factors determining the properties of the phosphogypsum and its composition, their interaction, the optimal parameters of the parameters are determined, the main algorithms for the complex waste processing are developed [32-34].

Since there are significant deposits of phosphogypsum in Ukraine that contain the required fraction of rare earth metals (REM), the extraction of which can be economically advantageous by using the correct method of extracting REM.

The use and processing of waste product data is an actual scientific and applied problem.

In Ukraine compared to others (Japan, USA, Germany, etc.), digester phosphogypsum is practically not processed, because more well-known processes are costly, energy intensive and multi-stage. As a result, the processing of dusted phosphogypsum in Ukraine does not exceed 2-10% of the amount that is accumulated annually. As a result, the number of dumps and their area is constantly increasing.

In the Rivne region, dumps of phosphogypsum are located near the enterprise of PJSC «Rivneazot», which is engaged in the production of mineral fertilizers. According to the materials of the Rivne exploration expedition in the Rivne region, it has been established that the phosphogypsum dumps of PJSC «Rivneazot» are located in the Rivne region at a distance of 1,5 km northeast of the village of Metkiv and at a distance of 1 km east of the village of

Rubche. As regards the terrain south and west of the object, there is a decrease in the territory towards the Goryn river, which flows at a distance of 1,6 km to the south and 1,1 km to the west of the phosphogypsum storehouse. These dumps cover an area of more than 58 hectares, and their total amount is 15,2 million tons (Fig. 2).

Fig. 2. Waste mining (PJSC «Rivneazot»)

At the moment it is possible to consider several variants of disposal of dumps of phosphogypsum, as well as avoidance of their formation in the future. So in this paper we consider the method of utilizing phosphogypsum already from the formed dump, as well as inclusion in the technological scheme of production of mineral fertilizers, a device that would enable to process the sludge of phosphogypsum immediately into finished products.

2. The level of environmental safety within the storage of mining waste of phosphogypsum

Significant contribution to the increase of the ecological index is made by nitrite nitrogen, which is for PJSC «Rivneazot» specific indicators of the station of denitrification.

The data of the observation of the State Department of Environmental Safety in the Rivne region on the analysis of water samples in the Gorin River in the spaces near the dumps of phosphogypsum indicate that the content of phosphorus in the formation, which is 0,8 km higher of Rubche is an average of 5.5 times smaller than in a site that is 0,8 km below Rubche. Samples of drainage waters from the territory of gypsum phosphate dumps are selected in the dumps and after indicating that the phosphorus content is increased 10 times. Analyzing samples of soil, selected from phosphogypsum dumps, it can be argued that there is a tendency for accumulation of mobile phosphorus in the soil.

The materials of the State Environmental Safety Department in the Rivne region indicate the urgent need to address this problem and the inadmissibility of contamination of the waters of the Goryn river and groundwater, as well as the negative impact of the phosphogypsum dumps on the environment.

For the sampling of the soil, the experimental plot was divided into five sections, which were designed at the lowest points of the terrain. The first three are west facing from the storage to the side of Rubche length 1km; fourth to the south of the object of 1.5 km in length; fifth to the east of the object towards the forest, length 0,9 km. Total number of wells 22 pcs.

Wells for sampling were drilled by hand drill, 50 mm in diameter to a depth of 6 m. Soil samples were taken every meter, starting from the surface with a threefold repetition of each sample. The distances between the wells in the first three spaces respectively 50, 250, 300, 400m. Along all three spaces there is a decrease in the territory towards the Goryn river. The distances between the wells in the fourth section, respectively, 50, 250, 300, 400, 500 m.

As a result of chemical analysis, the content of trace elements in the prototype samples was determined on the territory of the experimental site of water and soil samples The content of fluorine *F*, mobile sulfur *S*, zinc, iron, cobalt, nickel, lead, manganese, copper and chromium in soil samples in mg/kg has been established. The graphic dependences of the content of trace elements in the soil on the length of the structure for each depth of the sample were constructed (Figures 3-5).

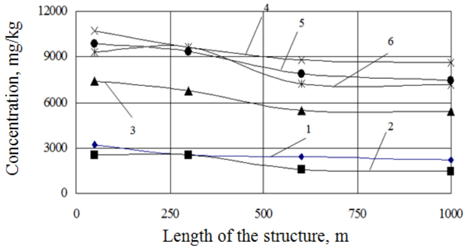


Fig. 3. Dependence of the iron content on the length of the structure: *1* - *h*=1m; *2* - *h*=2m; *3* - *h*=3m; *4* - *h*=4m; *5* - *h*=5m; *6* - *h*=6m

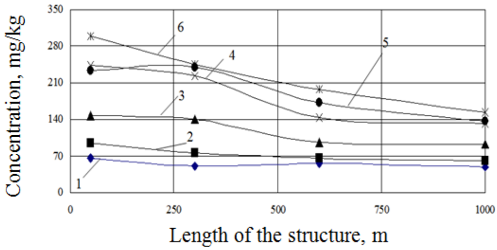
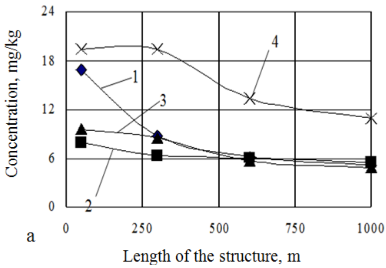


Fig. 4. Dependence of the content and manganese on the length of the structure: *1* - *h*=1 m; *2* - *h*=2m; *3* - *h*=3m; *4* - *h*=4m; *5* - *h*=5m; *6* - *h*=6m



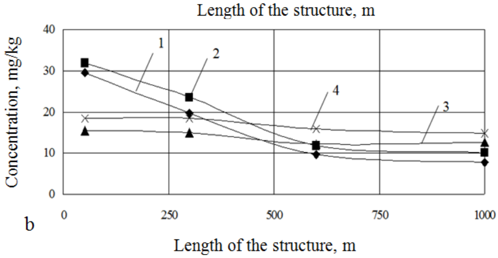


Fig. 5. Dependence of the content of micronuclei on the length of the cavity at a depth of 3 m (*a*) and 6 m (*b*) from the soil surface, mg/kg: *1* - fluorine; *2* - sulfur is mobile; *3* - zinc; *4* - nickel

By comparing the data obtained experimentally, and data from the State Department of Ecology and Natural Resources in the Rivne region, it was found that the content of lead, zinc, copper, cadmium, nickel, cobalt, nitrites, manganese, phosphorus exceeds the maximum permissible standards. So in samples taken at a distance of 500m to the west in 2000, the content of mobile phosphorus in the soil was 332 mg/kg., And in 2016 - 670 mg/kg. One can conclude that there is a need to reconstruct the system of protection of soils and groundwater from contamination by harmful substances in the territory of dumps of phosphogypsum near the production site of PJSC «Rivneazot», or introduction of new more effective methods that will ensure high-quality interception of pollutants at the outlet of the facility and prevent the occurrence environmentally unfavorable state of the environment.

3. Technology for the extraction of rare earth metals from phosphogypsum

Modern work on the processing and utilization of phosphogypsum is devoted to the work of many scholars of Ukraine and abroad, in particular A.F. Bulat, K.S. Holov [2,33,34], Z.R. Malanchuk [34-36], C.R. Canovas [11].

According to studies of apatite ore originating from the Kola Peninsula, there is a significant amount of man-made minerals, namely rare earth metals (REM). Their content in phosphogypsum is: Yttrium - 100 mg/kg; Yetterium - 10 mg/kg; Lanthanum - 500 mg/kg [2,6,7].

Stage of obtaining rare earth metals:

the disclosure of minerals with acid or chlorination and the production of semi-products (salts or oxides) enriched with REM;

separation of REM from the accompanying metals;

rough separation of REM compounds into fractions enriched with metal, but containing less compounds of other metals;

fine processing of fractions for obtaining rather clean solutions of compounds of separate components and extraction of these compounds of one or another metal in its pure form;

restore connections to the metal.

Rare earth metals are used in various industries. Below are examples.

In metallurgy, REM (scandium, yttrium, hafnium, cerium) are often used in aluminum lighthouses. REM additives sharply increase the quality of metallurgical products, and improve mechanical properties and corrosion resistance. Alloys with REM are used in the military-industrial complex, in particular, aircraft building and space technology.

Lanthanum, cerium, neodymium and praseodymium are part of a high-tech glass of special purpose, for example, passing infrared and absorbing ultraviolet rays. REM connections are used to create laser and other optically active elements in optoelectronics. Dysprosium is necessary to create a hybrid automobile engines.

Alloys of neodymium and samarium-cobalt are used for the manufacture of permanent magnets, which are the main element in instrument making. Samarium and neodymium are the basis of powerful permanent magnets for mobile phones, computer hard drives, monitors.

In ceramics, REM (oxides of ytterbium and yttrium) are needed to stabilize the properties of refractories.

Another modern direction of use of phosphogypsum is the creation of X-ray protective structures from composite X-ray protective materials with high X-ray protective properties [2]. The parameters of the X-ray protective structure, as well as the effectiveness of its application in protection against X-ray and gamma-radiation, are substantiated. It was found that the greatest excess of the level of personnel protection against X-rays by constructions from composite materials based on phosphogypsum over the level of protection regulated by Bouguer's law is achieved at the concentration of rare earth metals in the composition material in the range of 28-33% of its mass. It has also been proved that the effectiveness of personnel protection when using constructions made of composite material based on phosphogypsum depends both on the concentration of rare earth metals in the matrix and on the density of the material, which improves the efficiency of personnel protection in 1,4-1,5 times in comparison with constructs that contain lead. [2]

On the basis of the review of technical decisions aimed at the extraction of rare earth metals from technogenic deposits of phosphogypsum, we distinguish the following.

Method for processing phosphogypsum and device for its implementation. Patent № 200901637, published 28.02.2011. Authors: Kovderko V.A.;Malyavko L.P. (By); Fomchenkov G.P. (Ru).

The main technical result is achieved by the fact that in the method of phosphogypsum processing by hydrogen-gravitational separation monomineral commodity gypsum and a concentrate of rare earth elements are obtained. To implement it does not require non-standard expensive equipment, special technologies, pre-preparation of material with significant energy costs. It can easily be included in the existing technological scheme for the production of phosphate fertilizers, making it non-waste.

The claimed technical result is achieved by the fact that the phosphogypsum processing unit includes a capacity for collecting a heavy fraction, a feeder of the feed material, a capacity for water-gravity separation, in which, unlike the prototype, the role of the mixer is performed by a tangentially-integrated gidromontore with a slotted nozzle. A water-gravity separation vessel is made with a nozzle for the discharge of a light fraction into a sedimentation tank, which is connected in series by means of a pipeline with acid reflux containers.

In fig. 6. shows a schematic diagram of the device for utilizing phosphogypsum in the proposed method.

Water-gravitational separation of dusted phosphogypsum is carried out in a container (1), which consists of two parts: the upper cylindrical and the lower conical.

The material that is washed comes into it, for example, on the belt conveyor (2). The mixing of the bulk mass to the formation of the gypsum suspension is carried out by a tangentially built-in hydromonitor (3), located, for example, 10…20cm above the conical part of the container. The nozzle of the hydro-monitors is offered slit, sector-type, with a cutting angle, for example, 45°. The water jet of such a configuration will provide the most effective cyclic rotation of the material that enters the entire water column, including the lower conical portion of the container. Its volume is calculated on the basis of the daily productivity of the plant with an average yield of heavy fraction of 5%.

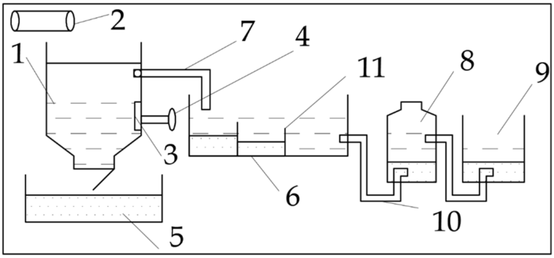


Fig. 6. Principal scheme of the device for utilization of phosphogypsum

The hydromonitor is powered by a centrifugal pump (4). Thus, due to the fact that the density of the gypsum component of the boiler is less than the density of the minerals forming the concentrate of rare earth elements, a heavy fraction (a concentrate of rare earth elements), which is periodically discharged into a container (5), is accumulated in the conical part of the container (1). Before this operation, the pump is stopped and the liquid over the precipitate is poured into the settling tank (6) through an outlet (7), equipped, for example, with a shut-off device. Due to the small size of the gypsum crystals, the light fraction forms a suspension which is constantly discharged into a multisection tank (6), where almost monomineral plaster accumulates by settling. In (1) also the washing of the whole mass of phosphogypsum from technological acids (sulfuric, phosphoric, fluorocarbon) and other water-soluble impurities is also carried out.

From (6), water enters into (8), where it, passing through the reagent, is liberated by a known method from hydrofluoric acid as a result of the formation of gaseous SiF_4. In (9), water, passing through the reagent, is separated by a known method from sulfuric and phosphoric acids to the formation of simple superphosphate.

This material (superphosphate) without redistribution can be used as fertilizer. The purified water can be used for the next cycle. Capacities and pipes (10) should be protected from the action of acids.

For control of the amount of heavy fraction in the conical part of the container (1) it can be fitted, for example, a safety glass, which provides a review of adjacent parts of the capacity of the conical and cylindrical.

As the main element of the device (installation) - capacitance (1) - you can use half of the rail oil tank, coated inside with acid-proof material. As tanks you can use reinforced concrete trays, which are used for laying pipes of larger diameters. Everything else can be made even in small repair shops.

An example of the method.

The hydraulic system, which includes the working capacity (1), with the pipe (7) tank (6), containers for the neutralization of acids (8,9) and pipelines (10), is filled with technical water. A bulking agent is loaded into the container (8), for example, sand for the removal of hydrofluoric acid, and in the settling tank (9) a sulfur and phosphoric acid neutralizing reagent, for example, limestone. Include the pump and after boosting the water in (1) feed the boiling mass. After filling the conical part of the container (1) with a heavy fraction, stop the pump, drain the gypsum suspension from (1) through the nozzle (10), remove the heavy fraction in (5). Then the operations are repeated.

This method will enable not only to modify the dump phosphogypsum but also to create a non-waste production of mineral fertilizers with the removal of phosphogypsum from rare earth elements, gypsum and other substances in the process of production.

4. Technology of complex processing of phosphogypsum

The technology of complex processing of phosphogypsum includes the manufacture of building materials (slabs, blocks) for non-residential premises and the associated extraction of rare earth metals.

According to the data of Ukrainian scientists, it is not possible to obtain high-quality products of the 100 mark by the method of β-polygurat casting, then at the stage of formation it is envisaged to carry out semi-hard pressing on the knee-lever press. With this method of formation it is easy to switch to the production of other types of products, for example, gypsum tile, architectural products, etc.

The production of β-half hydrate is carried out by heat treatment in a gas stream at an initial temperature of 300°C and a final 100°C. At the same time it is possible to dehydrate small (up to 0.1mm) grains of gypsum of a second due to intensive mass and heat exchange with the environment.

Phosphogypsum is developed by an excavator on the tailing dump. If it is possible to resolve positively the issue with the city administration and PJSC «Rivneazot» about the placement of production in the immediate vicinity of the quarry, it is expedient to provide transportation by conveyor transport, the cost of which will not exceed 30% of the cost of traditional transport by road. At the same time, the efficiency of exploitation of excavating machinery will increase. In the development of phosphogypsum in this case, periodic action excavators may be replaced by cheaper multi-axle loaders of elevator type.

In this feasibility study, we will rely on a more unfavorable case that results in the use of motor vehicles. The phosphogypsum extracted from the deposit is loaded into a receiving hopper with a volume of 20m^3 with a belt feeder with a width of 1000mm. Dosing of the flow of raw materials is carried out by the method of the embossing. The basic scheme of the shop for the production of phosphogypsum radiation-protective bricks is presented in Fig. 7.

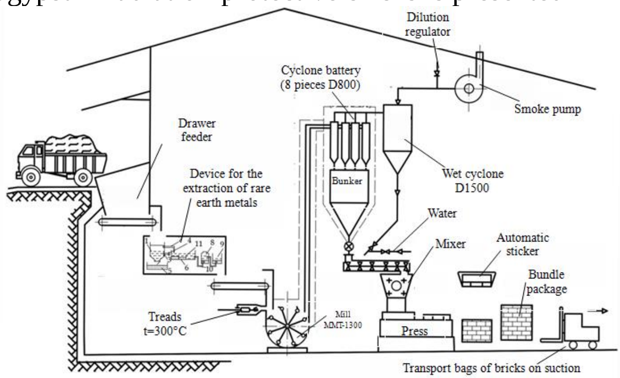


Fig. 7. Scheme of complex processing of dumps of phosphogypsum with the accompanying extraction of rare earth elements

Crushing and partial dehydration are carried out in a MMT-1300 mine mill with a productivity of 16-20t/h with a rotor diameter of 1300 mm and a power of 150 kW with a rotational speed of 960rpm. Since the source material in the form of phosphogypsum has good crushing it is assumed that the resistance would be about two months.

It should be emphasized that all machines, apparatuses and technological pipelines operate in an aggressive environment, so they must be made of acid-resistant steels.

Purification of air flow at the first stage is carried out in a battery with 8 cyclones in diameter of 800 mm, and then in a wet hydrocyclone with a diameter of 1500 mm. This purification allows you to allocate 99,8% of the particles, which can be considered satisfactory. The smoke exhaust fan must have the following characteristics: performance - 40 thousand m^3/h, vacuum - 450 Pa. The mill is supplied by combustion products of combustion of fuel (gas) with a temperature of 800°C under vacuum of 300-320 Pa.

After a series of cyclones, the phosphogypsum continues to be dehydrated in a bunker of 30 m^3 where its temperature drops to 100°C and below, and the sludge of the wet cyclone is collected in its lower part, from which it is transported by gravity. From the hopper, the gypsum is fed into the blade feeder into a blade single-acting mixer with a capacity of 16-20 t/h, where partially sealed with wet sludge and technical water to a moisture content of 20-22% with a theoretical moisture content of 18,6%. Pressing of products is carried out by the knee-lever press with the productivity of 5-7 thousand pieces of conditional brick per hour, which corresponds to the productivity of the mill. Pressure of pressing up to 200 kg/sm^2. Ready-made products are packed on pallets by an automaton-inlayer and transported by a forklift truck to the warehouse of finished products, which solidify for 2 hours to the transport strength of 30 kg/cm^2. The loading of the motor transport of finished goods is carried out by an onloader with a carrying capacity of 1t. The possibility of using mobile power loaders with cable power is foreseen.

All technological equipment works under vacuum, therefore there is no dust formation

To clean the outflow of air from the acid pairs, it is necessary to install a rectification column or scrubber after the smoke exhaust fan, in which harmful vapors will be absorbed into the water. It is supposed to separate about 1% of acids by weight from the weight of phosphogypsum with a content of 1,5%.

Power supply is supposed to be made from existing power lines of a chemical plant without the construction of a substation. The length of the cable line is up to 300m. Water supply is also organized from existing networks. The need for technical water up to 15% by weight of phosphogypsum or 15000 m^3 per year. In the day will be consumed technical water 58,4 m^3.

The amount of drinking water is calculated as 0,5 m^3 per worker. When calculating the number of employees 28 people need 14m^3 per day. Hot water comes from existing plant networks. Heat supply is performed from existing networks in the form of a pair. It is possible to provide heat supply to workplaces and electric heaters. In this case, the power of electric heaters will not exceed 30kW.

The profitability of production is 5,7 times higher than standard profitability. The profit from sales of products will be 1383000 UAH per year.

Conclusions

The result of long-term storage of waste from the production of mineral fertilizers at PJSC «Rivneazot» is the formation of man-made phosphogypsum deposits, which amount to 15,2 million tons, and require a steady increase in the allocation of storage areas.

Toxic waste is stored in dumps, which leads to pollution of soils, surface and groundwater, negatively affects the health of the population.

The main factor causing soil contamination in the territory of dumps of phosphogypsum is the filtration of contaminated water. This indicates contamination of soils, which in 5 ... 10 times higher below the level of occurrence of groundwater. And over time, this value grows.

So the phosphorus content in the soil at a distance of 200m from the dumps during the control period increased by 2 times, lead by 1,15, chromium by 1,35.

Based on the contemporary trends in the use and processing of man-made phosphogypsum deposits, it has been found that rational extraction of rare earth metals (yttrium, lanthanum, cerium, plutonium, thorium), as well as manufacturing of building materials for non-residential premises. In this work an overview of technologies for the complex processing of man-made phosphogypsum deposits with the production of phosphogypsum radiation-protective bricks with the associated extraction of rare earth metals has been carried out.

References

1. **Malanchuk Z., Korniienko V., Malanchuk Ye., Soroka V., Vasylchuk O.** (2018). Modeling the formation of high metal concentration zones in man-made deposits . DOI: 10.15407/mining12.02.076.

2. **Malanchuk Z., Vasylchuk O., Oksenyuk R.** (2016). Current trends and processing application fields technogenic phosphogypsum. Rivne: Bulletin NUWWE. Collection of scientific papers «Technical sciences». Volume № 2 (72). PP. 225-231.

3. **Malanchuk Z., Korniienko V., Vasylchuk O. Zaiets V.** (2018). Problems processing and extraction of rare earth metals from technogenic deposits of phosphogypsum [E-Reader Version]. Retrieved from http: // seanewdim.com/uploads/3/4/5/1/34511564/httpsdoi.org10.31174send-nt2018-179vi21-14.pdf.

4. **Malanchuk,Ye., Volk, P., Vasylchuk, O. Zaiets V., Semeniuk** (2018). Evaluation of environmental safety in the storage of phosphogypsum wastes. Kryvyi Rih: Mining Bulletin. Volume № 103. PP. 110-115.

5. **Gaydin A., Rudko G., Chikova** I. (2017). Mining-chemical potential of Ukraine. Kyiv-Chernivtsi: Bukrek.

6. **Vasylchuk** O. (2016). Rational directions for processing technological development phosphogypsum. International Scientific and Technical Internet Conference «Innovative Development of the Mining Industry», State University «Kriviy Rih National University». P. 205.

7. **Malanchuk Z., Vasylchuk O., Zhomyruk R.,** (2017). Assessment of the content of elements in the storage zone of the technogenic deposit of phosphogypsum. II International Scientific and Technical Internet Conference «Innovative Development of the Mining Industry», State University «Kriviy Rih National University». P. 235.

8. **Stashuk V., Malanchuk Z., Rokochinsky A., ZhomyurukR. (**2014). For the benefit of pollution of landscapes by household and industrial wastes on the basis of the use of natural sorbents. Monograph. Kherson: Grin D.S.

9. **Zhomyruk R.** (2012). Investigation of the process of contamination of soils and groundwater by mining waste. Collection of scientific works «Geotechnical mechanics» . Dnipropetrovsk: IGTM NAS of Ukraine. Vol. 95. PP.133-140.

10. **Malanchuk Z., Korniienko V., MalanchukYe., Zhomyuruk R.** and otherю (2018). Minerals of the Rivne region. In the book «Reclamation and equipment of the Ukrainian Polissya». Collective monograph. Kherson: OLDI-PLUS. Volume 2. Chapter 57. PP. 600-617.

11. **Canovas C**. (2018). Exploration of fertilizer industry wastes as potential source of critical raw materials. DOI: 1016/j.jclepro.2016.12.083.

12. **Manis Kumar Jha**. (2016). Review on hydrometallurgical recovery of rare earth metals hydrometallurgy. DOI: 10.1016/j.hydromet.2016.01.035.

13. **Chui Y., Moshynskyi V., Martyniuk P., Stepanchenko O.** (2018). On conjugation conditions in the filtration problems upon existence of semipermeable inclusions. DOI: 10.17654/HM015030609.

14. **Moshynskyi V., Fylypchuk V., Ivanchuk N., Martyniuk P.** (2018). Computer modeling of water cleaning in wetland taking into account of suffosion ang colmatation. DOI: 10.15587/1729-4061.2018,123455.

15. **Moshynsky V., Riabova O.** (2013). Approaches to Aquatic Ecosystems Organic Energy Assessment and Modelling. Retrieved from http:// link.springer.com/chapter/10.1007/978-94-007-6152-0_12

16. **Malanchuk, Z., Moshynskyi, V., Malanchuk, Ye., Korniienko, V.** (2018). Physico-Mechanical and Chemical Characteristics of Amber. DOI: 10.4028/www.scientific.net/SSP.277.

17. **Lozynskyi V., Saik P., Petlovanyi M., Malanchuk Z., Malanchuk Y.** (2018). Substantiation into mass and heat balance for underground coal gasification in faulting zones. DOI: 10.29227/IM-2018-02-36.

18. **Malanchuk Y., Moshynskyi V., Korniienko V., Malanchuk Z.** (2018). Modeling the process of hydromechanical amber extraction. DOI: 10.1051/e3sconf/20186000005.

19. **Dychkovskyi., Lozynskyi V., Saik P., Petlovanyi M., Malanchuk,Ye., Malanchuk Z.** (2018). Modeling the process of hydromechanical amber extraction. DOI: 10.1016/j.acme.2018.01.012.

20. **Khomenko O., Sudakov A., Malanchuk Z., Malanchuk Ye.** (2017). Principles of rock pressure energy usage during underground mining of deposits. Retrieved from http:// ir.nmu.org.ua/bitstream/handle/123456789/150685/02_2017_ Khomenko.pdf?sequence=1&isAllowed=y.

21. **Malanchuk Z., Malanchuk Ye., Korniyenko V., Ignatyuk I.** (2017). Examining features of the process of heavy metals distribution in technogenic placers at hydraulic mining. Retrieved from http://nbuv.gov.ua/UJRN/Vejpte_2017_1(10)__7.

22. **Naduty V., Malanchuk Z., Malanchuk E., Korniyenko V.** (2015). Modeling of vibro screening at fine classification of metallic basalt. DOI: 10.1201/b19901-77.

23. **Naduty V., Malanchuk Z., Malanchuk E., Korniienko V.** (2016). Research results proving the dependence of the copper concentrate amount recovered from basalt raw material on the electric separator field intensity. DOI: 10.15587/1729-4061.2016.79524.

24. **Malanchuk Z., Korniienko V., Malanchuk E., Khrystiuk A.** (2016). Results of experimental studies of amber extraction by hydromechanical method in Ukraine. DOI: 10.15587/1729-4061.2016.72404.

25**. Saik P., Dychkovskyi R., Lozynskyi V., Malanchuk Z., Malanchuk, Ye.** (2015). Revisiting the underground gasification of coal reserves from contiguous seams. Retrieved from http:// /www.researchgate.net/publication/313608133 _Revisiting_the_underground_gasification_of_coal_reserves_from_contiguous_sea ms.

26. **Malanchuk Z., Korniienk, V., Malanchuk Y.** (2017). Mathematical modeling of hydraulic mining from placer deposits of minerals. mining of mineral deposits. DOI: 10.15407/mining11.01.093.

27. **Malanchuk Z., Malanchuk Y., Khrystiuk A.** (2016). Results of experimental studies of amber extraction by hydromechanical method in Ukraine. DOI: 10.15407/mining10.02.013.

28. **Malanchuk Y., Malanchuk Z., Korniienko V., Gromachenko,** S. (2016). The results of magnetic separation use in ore processing of metalliferous raw basalt of volyn region. DOI: 10.15407/mining10.03.077.

29. **Malanchuk Ye., Korniienko V., Moshynskyi V., Soroka V., Khrystyuk, A, Malanchuk, Z.** (2019). Regularities of hydromechanical amber extraction from sandy deposits. DOI: 10.33271/mining13.01.049.

30**. Malanchuk E., Malanchuk Z., Korniyenko V.** (2018). Modern geotechnical methods of management of the process of amber extraction . Sofia: Monograph:»Innovative development of resource-saving technologies of mining of minerals» «St. Ivan Rilsky «Mining and Mining University of Geology. P. 80-103.

31. **Korniyenko V., Malanchuk E., Soroka V., Khrystyuk, A.** (2018). Analysis of the existent technologies of amber mining. Resources and resource-saving technologies in mineral mining and processing. Multi-authored monograph. – Petroșani, Romania: UNIVERSITAS Publishing. PP. 209-232.

32. **Malanchuk Z., Kozyar V., Polischuk A.** (2016). Mechanics of rocks. Laboratory Workshop. Textbook. Retrieved from http://ep3.nuwm.edu.ua/6133/.

33. **Malanchuk Z., Malanchuk E., Korniyenko V.** (2017). Special mining technology. Retrieved from http://ep3.nuwm.edu.ua/6659/.

34. **Malanchuk Z., Korniyenko V., Soroka, V., Vasylchuk, O.** (2018). Transportation systems of mining enterprises . Rivne: NUWWE. P. 190.

35. **Malanchuk Z., Zaiets V., Vasylchuk O., Novak, A**. (2018). Current status and problems of new technologies for coal mining in the western region Ukraine. Resources and resource-saving technologies in mineral mining and processing. Multi-authored monograph. – Petroșani, Romania: UNIVERSITAS Publishing. PP. 54-77.

36. **Malanchuk E. Malanchuk Z,. Korniyenko V.** (2018). Efficiency of using magnetic separation for the processing of metal-containing basalt raw materials. Topical issues of resource-saving technologies in mineral mining and processing. Multi-authored monograph. – Petroșani, Romania: UNIVERSITAS Publishing. PP. 65-89.

DEGASSING COAL SEAMS AS METHANE SAFETY METHOD

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Purpose. Reducing the flow of gas into the mine workings, preventing its sudden emission.

Methodology. Methods for degassing objects (worked out spaces or seams), the intensity of rock pressure on the seams (with pressure release or without pressure release) and their state (natural, after torpedoing, breaking and using other ways to increase the intensity of degassing).

Result. As a result of using two main trends:

- reducing methane emissions by ventilation due to optimization of its application parameters and rational use of degassing;
- increasing the volume of utilized methane recovered by means of degassing and early degassing preparation of specially processed seams.

Within the period of the Coal Department of ArcelorMittal Temirtau JSC work from 2007 to 2010 certain results were achieved:

- methane emission into the atmosphere over five years was reduced by 54.9 million m3;
- the amount of harmful emissions into the atmosphere of coal combustion products reducing due to replacing it with methane in the amount of about 5.92 thousand tons;

- a multi-year work plan was made up and implemented to determine the parameters of early degassing preparation with the aim of organizing large-scale methane production in all the mines in the Shakhtinsk region.

Scientific novelty. Utilization of coal mine methane will reduce the cost of coal mining in the mines, depending on their specific conditions, by 3-4 %. In addition, it will have a positive effect on other indicators of the economic activity of coal-mining enterprises. Firstly, the amount of profit per unit of production will increase, as the difference between the existing price and the cost of coal production increases, or the losses will decrease, and, secondly, the consumption of primary fuel (coal) for domestic needs will decrease, resulting in coal commodity resources and the cost of their implementation, respectively.

Practical significance. The results obtained are the basis for the development of a feasibility study on utilization of coal mine methane, which will make it possible to involve large resources of a new energy carrier in the region fuel and energy balance and to improve the environmental situation by reducing methane emissions into the atmosphere.

Introduction. The problem of ensuring the methane safety of mining continues to be a priority. According to experts, in accidents involving explosions and sudden methane outbursts, about 100,000 miners died in the past century.

Methane safety of mining seams with loads on the long-wall face of more than 4-5 thousand tons per day is provided by the complex degassing of the mining unit with then efficiency of 75-85 %.

The level of methane extraction by degassing on average in the Karaganda basin is 7.1 m^3 per ton of coal mined, and in breakage faces with effective complex degassing it reaches 20 m^3/t or 75 % of the total gas emission.

Ensuring methane safety requires a significant amount of energy. In particular, the energy consumption for mining tons of coal is up to 140 MJ, and of them up to 65 % is the energy consumption for ventilation and degassing. However, recoverable gas is a valuable energy carrier. With its energy processing, the efficiency of electricity can be 0.20-0.35. Taking into account the useful energy value of one cubic meter of methane in 10 MJ, it can be seen that at the level of degassing with the energy gas processing over 15 m^3 per ton of coal mined, this process can be turned into commercially efficient, environmentally friendly and integrated development of coal-gas formations.

At present the main amount of methane extracted in the development of coal seams in the CIS countries is emitted into the atmosphere. In the Karaganda coal basin coal bed methane in amounts of up to 25 million m^3 per year is utilized by burning in boiler houses, which makes up to 20 % of gas extracted by degassing. The economic efficiency of such processing is achieved only by replacing coal with gas and does not exceed 19.4 c.u. per 1000 m^3 of methane, which does not cover the cost of its extraction that makes 37.7 c.u. on the average for the basin.

Coal mine gas is a significant but practically undeveloped resource with major reserves located in about a dozen countries. China, Russia, Poland and the United States of America are the largest "polluters" of the atmosphere, jointly responsible for three quarters of the total world emissions of mine gas. According to forecasts, the amount of emitting mine gas in the world will increase by 2 % by 2020, mainly due to the growth of coal mining in China.

When mining for coal extraction from gas-bearing seams in the world practice and in the Republic of Kazakhstan, coal-mining enterprises are experiencing man-made disasters associated with methane emission leading to dire consequences.

Only in recent years in the mines of Karaganda methane explosions have taken 138 lives, this indicates that the existing methods of degassing do not allow reducing gas emission to safe limits. Therefore, the work aimed at preventing such tragic consequences is of the paramount state importance.

It should be noted that for the first time in the world, experimental and pilot works for early degassing by vertical wells drilled from the surface was successfully carried out in the Karaganda basin and formed the basis of commercial gas production at the fields of the leading coal-mining countries.

This technology will not allow only localizing the danger, but also using methane as an energy and chemical raw material, therefore gas-bearing coal deposits can be considered as gas-coal.

The estimated reserves of methane in Kazakhstan are more than 8 trillion m^3, the main part of which is concentrated in the Karaganda and Ekibastuz coal basins. The introduction of the early methane extraction technology makes it possible to extract 3–4 billion m^3 of methane per year and meet all the gas needs of Central Kazakhstan and Astana within over 50 years. It can become the basis for the development of a new fuel and energy industry.

1 Methods of degassing coal deposits

At the beginning of developing the works for degassing, G.D. Lidin constructed a classification of methods according to the signs characterizing the degassing facilities (wells or special workings), the state of the working seam (natural, in undermining or overmining) and reference to mining operations.

O.I. Chernov [1] proposed to divide the methods according to the objects of degassing (worked out spaces or seams), the intensity of rock pressure on the seams (with pressure release or without pressure release) and their state (natural, after torpedoing, breaking and using other ways to increase intensive degassing). The classifications of G.D. Lidin and O.I. Chernov do not take into account the duration of degassing, which is very important for degassing works, the choice of facilities, methods of degassing and its final results.

According to the duration and nature of reference to mining operations, it is logical to distinguish 5 types of degassing:

- early, that starts in the absence of mining operations;
- preliminary that if carried out from the workings of the current level for the areas to be developed;
- advanced that is carried out from the existing workings for areas ahead of the mining front;
- joint, in the process of mining;
- subsequent, that is carried out behind the front of mining.

The object of degassing [2] can be developed (working) and undeveloped (non-working) seams, enclosing rocks and coal-bearing strata.

In all cases of forced gas extraction (degassing), around one or another engineering structure (well, working, etc.) a depression funnel is formed that covers the entire adjacent formation. When separating by objects, only those degassing areas that are located near the working part of the engineering facility or structure should be taken into account.

Engineering facilities (structures), depending on the type of degassing and the object, may be different:

- wells drilled from the earth surface (vertical, directional) or from underground workings (of various directions);
- mine workings (special or subsequently used for mining);
- rooms stored in the developed space; pipes, perforated ducts left in the developed space.

A degassed object, depending on the methods of action on it, can have various states:

- natural (no impact);
- with increased permeability due to hydraulic seam fracturing, pneumatic seam fracturing (implosion, torpedoing), undermining, overmining, hydraulic erosion;
- with increased gas recovery (by displacing free gas, replacing gas in the sorption volume, heating, etc.).

Of the variety of possible methods, early degassing is distinguished by the following advantages:

- autonomy (it does not depend on the general technology of mining operations);
- extraction of useful raw materials (gas);
- the possibility of concentrating technical facilities and developing operations on the earth surface, over the entire area of the deposit;
- the possibility of a multi-stage impact on the coal-bearing strata, limiting or completely eliminating a lot of dangerous phenomena.

In the future, with sufficient knowledge of the degassing properties of the coal-bearing strata, the regularities of degassing and accumulating experience, it is advisable to form a special service for gas removal preparation of fields and the use of methane.

2 Criteria of the need to use mine degassing

Methane emission into the mine workings during the underground mining of coal seams is one of the main natural factors that hinders the effective use of the new mining technology and significantly worsens the state of safety. The experience of developing methane-bearing coal seams at great depths shows [3] that, without the use of degassing, the rate of driving workings and loading the breakage faces are so small that this does not provide an economically profitable use of modern high-performance equipment, in connection with which there is a need to artificially reduce the amount of methane emission in the mines, degassing methane sources [4].

For predicting methane emissions in the mine workings of projected and reconstructed mines there are needed the following initial materials:

- hypsometric plans of coal seams with values of natural gas content of coal or isogase deposited on them, as well as structural columns of seams and results of technical analysis of coal seams (density, volatile matter, natural ash and moisture content of coal);
- rock sections on exploration wells, indicating the distances along the normal between the seams and inter-seams of coal and coal shale and their thicknesses;
- the data of the sequence of mining formations in the suite, the development system and the order of mining formations, the speed of advancement of the breakage and development faces, the method of coal mining in breakage and development faces, the loss of coal in the formation thickness, the number of seams in the thick formations and procedure of their mining, the extracted thickness of each seam, the distance and time of the breakage faces advancing of the first layer relative to the breakage faces of the second and subsequent layers, the duration of the surface outcrop of non-removable strata in the breakage area, roof control methods, methods of driving development workings (by single or double faces), the size of sections of development workings, the width of the pillars between the double development workings and the intended methods of degassing.

The technical feasibility of using degassing depends, on the one hand, on geological conditions and technological parameters of the mining industry, and on the other hand, on the parameters of degassing methods. The issues of expediency of using degassing are multifaceted and affect both technical and economic aspects [3 (60)]. Since degassing is only one of the ways to combat methane emission, in general case, there is first established the feasibility of implementing measures to artificially reduce methane emission, and then the feasibility of a particular method of carrying out degassing in particular.

The main condition for the need to implement measures to regulate methane emission is the excess of the air amount required for dilution of emitted into the breakage face methane over the capacity of the development workings and the bottomhole space of the breakage faces. Reducing the risk of methane accumulation in the mine workings is achieved by:

- using a rational scheme of ventilation of the excavation unit, in which methane emission from the worked-out space into the bottom face of the long-wall face decreases, and accumulation of methane is prevented by air cooling;
- improving the efficiency of degassing coal seams and the open space of the existing excavation unit or waste floors;
- reducing the performance of the excavation machine versus the technically feasible by reducing the ratio of machine time or productivity of the excavation machine.

Another condition for the need to reduce methane emissions is increasing the amount of air required to dilute the emitting methane when driving a development working, over the maximum possible amount of air that can be supplied to the development working. In the development working there are three main possibilities for adjusting the required and supplied quantities of air: using a more efficient booster fan; reducing in comparison with the normative speed of driving a working; using an efficient degassing method.

Methane emission control can be performed at a given set of uncontrollable natural parameters by changing the controlled technological (regulatory and technological) parameters of stoping and preparatory operations so as to obtain an extremum. So, the task is reduced to the comparison of costs and effects resulting from the implementation of a particular method of controlling methane emission (or their combination), at this the methods of degassing are also being considered.

Decreasing the excavation machine productivity is usually a forced temporary measure that is to be taken if all the ventilation and degassing possibilities are exhausted. To reject the use of degassing from the economic point of view, there must be at least one of the following conditions:

- if degassing does not provide significant increasing the load on the breakage face;

- due to low technological efficiency;

- when the load on the face is not limited by the condition of ventilation;

- if changing the ventilation parameters or parameters of other technological processes makes it possible to achieve no lower effect with lower costs.

The studies and the practice data [3] indicate that the consequences of degassing appear in almost all major technological links and can have a significant positive impact on the technology and the economy of faces, units and mines in general. In general, there are two groups of sources of the effect obtained during the degassing of coal mines.

Direct effect:

- ensuring security conditions;

- increasing the load on the breakage face according to the "methane" factor as a result of decreasing methane emission into the working space of the face and, as a result, decreasing the cost and increasing the productivity of labor in the face;

- increasing speed, decreasing cost and labor input of driving development workings;

- obtaining captured methane, suitable for use in industrial and domestic purposes.

Indirect effect:

- improving ventilation conditions that provide the possibility of reducing the workings cross-sections (or the possibility not to increase cross-sections on deeper levels) and the associated costs for airing and supporting the workings and for ventilation;

- the possibility of increasing the level of concentration of mining, improving the length of the network of mine workings and, as a consequence, reducing the cost of underground transport, driving workings, their support and ventilation;

- the possibility of increasing the load on the mine, implementation of which provides for obtaining additional products and reducing unit costs for all the main technological processes (objects) in the mine as a whole.

These types of effect in some parts can be alternative and appear differently depending under specific mining and geological conditions in which degassing is planned. Their presence or absence determines the number of degrees of freedom of selecting (or changing) the decisions related to the equipment, technology and organization of coal production.

Identifying and studying technical and economic consequences of degassing requires consideration of the schematic structure of the whole “mine” system, which is understood as a set of elements involved in the implementation of the system function, as well as their many links, manifested in the form of technical and economic consequences of the fight against methane emission.

Sequential analytical division of this system into parts and consideration of the processes and objects of mining production makes it possible to single out a complex direct or indirect interaction of degassing with other elements of the system and their interdependence. Implementation of degassing measures that are closely related to ventilation, affects not only the underground technological processes but also, through the volume of production in the mine, the technological complex of the surface. In carrying out these activities, the unconditional requirement is to effectively balance the elements of the system in order to achieve the best total effect.

The state of the system (in which measures for degassing and improveming ventilation must be implemented) can be determined by combining three uncontrollable variables:

- the nature of the object of degassing: an existing unit of the mine, a new unit (level) of the existing mine, a new projected mine;
- the state of the degassing object: the capacity of the mine is limited by the carrying capacity of technological units or by other factors and cannot be increased; increasing the capacity of the mine as a result of implementing measures for degassing (ventilation) is possible;
- condition of ventilation: ventilation possibilities are exhausted; the load on the breakage face can be increased by improving the unit ventilation.

From the analysis of the "mine" system it follows:

- under the conditions of maximum restrictions on the existing unit (mining-preparatory work has been carried out or their parameters are predetermined), its degassing while maintaining the total number of faces working in the mine and maintaining the capacity of the mine can be ensured only by reducing the unit costs in the lon-wall face of the degassed unit. In some cases there can be small changes in the cost of underground transportation and ventilation;

- in the newly prepared unit of the existing mine or a new mine with a stable number of faces and the load on the mine, in addition to reducing unit costs in the lon-wall face, the effect can be cause by increasing the speed of driving workings due to improved conditions;

- under the conditions of the working degassed face, when compulsory compensatory reduction of the loads on the faces that work simultaneously with the degassed ones is not required, but it is possible to reduce the total number of faces and increase the concentration of work with a constant load. Alongside with decreasing the unit costs in long-wall faces, the costs of mining, underground transport, ventilation are reduced;

- degassing of the existing unit accompanied by a corresponding increase in the capacity of the mine while maintaining the topology of the network of workings, the number of operating (together with the degassed) faces and loads on them, leads to economic consequences. They can be manifested in the degassed face (reducing the unit costs), as well as in the all-mine transport, lifting, ventilation, surface complex (due to the conditionally fixed part of the costs);

- degassing the newly prepared unit provides the possibility of reducing the cost of driving workings in the seam being degassed;

- in the most favorable conditions for the existing unit, when the reserves obtained through its degassing can be fully used to increase the capacity and changing the concentration of mining operations. The sources of obtaining the effect can be costs both in the degassed face and beyond it, in the common-level links (supporting the network of workings, transport, lifting, surface complex, etc.);

- for the new unit of the existing mine, which has power reserves, as well as for the new mine, the use of degassing provides the possibility of obtaining an effect within the unit (increasing the load on the face in connection with reducing the air supplied through it) and the mine as a whole by increasing the concentration of mining operations and increasing the load on the mine.

The presented systematics makes it possible to determine the nomenclature of the processes (objects) and costs that should be taken into account in a comprehensive assessment of the economic efficiency of degassing. Technological efficiency of degassing is characterized by decreasing gas emission, the indicators of which are the coefficients of the degassing efficiency of a separate source of gas emission, separate production or their combination (a working area, wing, mine).

The efficiency of degassing a separate source is relative decreasing gas emission from the degassed source equal to the ratio of the amount of reducing gas emission from it to the amount of gas that would be emitted into the mine workings from the specified source in the absence of gas extraction. The efficiency ratio of the degassing of a separate working (a working area, wing, mine) is relative decreasing the gas-abundance of the working due to the use of degassing.

Mining-and-geological and organizational measures to improve the efficiency of degassing are carried out in three main trajectories:

- increasing the drilling density, i.e. reducing the distance between wells;
- establishing the optimal time for degassing;
- reducing the gap in time between the end of drilling a well and connecting it to the degassing system.

Reducing the distance between the degassing wells in relation to the optimal radius of degassing determined by gas dynamics, leads to increasing the cost of degassing works. The duration of degassing is usually determined by the mining conditions in accordance with the plan of preparing and mining coal. Reducing the gap in time between the end of drilling and connecting the well to the gas pipeline increases the efficiency of degassing by 10–12 %.

When designing a preliminary coal seam degassing at the working area (field), the degassing parameters taken are the degassing duration period, the preliminary degassing coefficient and the initial well productivity, and the derived parameters are the well spacing, the well length and number of wells in the degassed field. The duration of the degassing period (the period of active well service) is determined by the mining conditions in accordance with the calendar schedule for preparing and mining of coal reserves. The coefficient of preliminary degassing is taken depending on the size of the coal mining and the gas balance structure of the unit, the vacuum depth, the gas permeability of the seam and the initial intensity of gas recovery in the well.

The efficiency of pre-degassing of coal seams depends on the environmental factors (gas content, gas permeability, humidity and thickness of the coal seam) and organizational-and-technological factors (the development system used and the procedure for mining the mine field, the duration of drilling the network of wells, the connection of drilled wells to the gas pipeline, the value vacuum).

Methane production of the underground degassing system operating within the mine field (unit) and uniting several working areas is established taking into account the calendar plan for input of degassing methods (schemes) in separate working areas by summing the methane flow rates of individual degassing methods (schemes) for the period of their joint functioning. If the mine is supposed to use degassing methods that function independently of the underground degassing system, for example, degassing methods using hydraulic seam fracturing, vertical wells (VW) drilled from the surface, or degassed out of the newly developed spaces, then the amount of methane captured by such degassing methods are accounted for separately. If degassing methods used in a mine (a group of mines) are linked by a single system of methane accumulation, methane production is established taking into account the calendar plan for entering degassing methods by summing up their flow rates. At this, it is necessary to take into account the flow rate of capturing methane dependence on the time factor.

The total volumes of methane extracted by means of degassing within the analyzed period are determined by integrating the dependencies of methane production by separate degassing methods (schemes). In some cases, when the effect of the time factor is not established, the amount of methane extracted by means of degassing is calculated from the average flow rates of methane captured within the period of operation of the degassing method (scheme).

Integrated calculations to determine the volume of methane extraction by means of degassing can be performed as follows.

According to the current regulatory document [4] taking into account the accepted methods of degassing at the mine being designed or reconstructed, the coefficient of each gas emission source degassing efficiency is established. For the existing mine, the actually achieved values of the degassing efficiency coefficient are used as the main initial value.

Knowing the efficiency of degassing and the estimated volume of methane emissions in the mine workings there is determined the volume of methane extraction from each source.

The total volume of methane extraction from the mine workings by means of degassing is found by summing the gas flow rates from each degassing source (taking into account the time factor).

When using degassing, the balance of methane in a coal mine consists of:

- methane emitting in the mine and carried with the ventilating air to the surface;
- methane absorbed by the degassing system and brought to the surface through pipelines in isolation from the mine workings;
- methane brought from the mine to the surface alongside with coal and emittinged on the surface without affecting the methane abundance of the mine;
- methane that remains in the depths, in the pillars of coal, in the non-extractable coal seams and in the enclosing rocks.

Volumes of methane emitting into the mine atmosphere and carried by ventilating air to the surface, as well as methane captured, depend primarily on the natural methane content of coal (rock). When designing for mines under construction, they can be taken from the data of geological prospecting organizations, and for deepened levels of the existing mines according to gas dynamics and methane-bearing prediction [5,6]. The values of the residual methane content of coal $x_{oг}$ and methane remaining in the depths are determined depending on the degree of metamorphism of coal (rocks).

3 Analyzing the degassing methods used and their efficiency

Essentially, the mines of the Coal Department of ArcelorMittal Temirtau are moving to a more advanced mine-long wall face technological process in terms of concentration and intensification of mining, when the mine can provide the required production from one long-wall face.

Providing this task is possible only on the basis of effective degassing of coal seams and working areas being prepared for development at the level of 75–90 %.

From the middle of the XX century safe mining operations on high-gas and outburst-dangerous seams of the Karaganda coal basin required the development of methods and facilities for degassing. Historically, the degassing of reservoirs being prepared for development and being developed was an engineering measure aimed at ensuring the miners' work safety and increasing the efficiency of mining production. The development of methods and facilities for degassing were dealing with in the works by A.A. Skochinsky, V.V. Khodot, G.D. Lidin, S.A. Khristianovich, A.E. Petrosyan, N.V. Nozhkin and others

Depending on the source of gas emission and the object of degassing, the following main methods can be distinguished:

- early degassing through the wells from the surface by hydraulic seam fracturing;
- preliminary degassing of the seam under development (reservoir degassing);
- degassing contiguous (adjacent) coal seams and satellites;
- degassing the worked-out area of the existing breakage faces;
- degassing when driving development workings (barrier degassing).

When carrying out mining operations on thick seams, methane production from uncapable coal packs left in the developed space, from contiguous seams and enclosing rocks that fall into the zone of deformation and destruction of the massif when the dome collapses, plays a major role in the gas balance of the breakage face. To reduce the amount of this methane emission in the Karaganda coal basin, the degassing of the worked-out area of the operating breakage faces is widely used.

Degassing the worked-out area of the existing breakage faces can also be performed in the following ways:

- using perforated pipes introduced into the worked-out space of the long-wall face before the roof collapses or into a special lintel erected in the ventilation drift;
- using gas drainage wells drilled from ventilation drifts to the area of domes resulting from the collapse of the roof;

- using wells drilled from special chambers in the rocks of the seam parallel to the bedding towards the movement of the long-wall face [7].

Studying the changes of the efficiency of degassing with depth show that with increasing the gas content of the coal seam, the amount of recoverable gas increases to the depth of 400-500 m. Then decreasing the permeability of the seams leads to decreasing the methane production from wells.

In the conditions of high-performance long-wall faces with a high speed of faces moving, the possibility of using conventional pre-degassing schemes is significantly reduced due to decreasing the interval between completing preparation of the excavation column and starting the stoping operations. This shortens the period of active operation of the degassing wells. According to the MakNII, preliminary degassing cannot provide the needed reduction of gas emission at the speed of advancing the breakage face 1.5 to 1.8 times higher than the existing ones.

The efficiency of pre-degassing is determined by the gas permeability of coal seams, the network of wells and the duration of their operation. The amount of methane recovered when using this method with the depth of the seam increases steadily; this is not due to the expansion of its field of application but due to increasing the density of drilling wells and increasing the degassing period.

Considering the need to utilize recoverable methane-air mixtures, the degassing methods that provide high degassing efficiency when extracting gas with the standard methane concentration are of particular interest. At present regulatory documents allow using methane-air mixtures with the gas concentration exceeding 25 %.

4 Working experience of degassing in the Karaganda basin

In the Karaganda coal basin there has been accumulated the unique experience of concentration of degassing works in the specialized department “Spetsshakhtomontazhdegazatsiya” (DSSMD) that was organized in 1970. The department drills underground degassing and technical wells for various purposes in the coal mines of the CD “ArcelorMittal Temirtau” JSC, manufactures and mounts underground and surface gas pipelines, carries out chemical strengthening of coal and rock in mine workings to prevent underground endogenous fires, performs vacuum gas surveys of mine degassing systems and monitoring their operation. The control functions include designing and maintaining coal-methane heating plants. The DSSMD includes a sanitary-preventive laboratory that controls emissions of harmful substances at the enterprises of the Coal Department and the sanitary condition of the staff workplaces. In addition, the department produces hydraulic coal seams fracturing from the surface in order to extract methane from coal prior to mining. The department cooperation with the leading scientific organizations is very wide.

The company is equipped with the necessary equipment and technology for carrying out the work, there is a mechanical workshop for its repairing, manufacturing spare parts and a number of special products. From the day of its organization and up to present, the department had to carry out and to substantiate scientifically and practically the parameters of specialized works that contribute to the forming safe working conditions for miners:

- performing the degassing works;
- early degassing preparation of coal seams;
- utilization of coal mine methane
- controlling the comfort of workplaces, determining their dustiness, gas pollution, noise, vibration, illumination, harmful emissions of combustion products into the atmosphere and the quality of mine water discharged;
- controlling ventilation, degassing, outburst danger of coal seams;
- preventing and extinguishing underground fires.

Alongside with these works, the activities of the department has covered: the extinguishing and developing of mine rock waste heaps with the subsequent recultivation of the surface; controlling and optimizing the parameters of the main mine ventilation; chemical strengthening of the coal massif and construction of hardening concrete strips at the interfaces of the stoping and development workings.

Organizing the department that specialized in integrated safety issues had a positive effect on the work of the mines of the Karaganda coal basin.

Thanks to technically competent engineering policy, the department specialists have introduced complex degassing of coal seams and working areas being prepared for development into the practice of mines, taking into account peculiarities of mining individual mine seams which efficiency reaches 60–80 %.

5 Prospective trends of mine degassing development

The development of methods and facilities for capturing methane led to the fact that the cost of coal mined in mines with degassing decreased both as a result of reducing the ventilation costs and increasing the productivity of degassed breakage faces, and due to the mine income. Further development of methods of mining coal bed methane, suitable for use in the national economy, should take place in two main trajectories:

- improvement of existing and development of new ways of coal mine degassing, significantly reducing the amount of methane in mine workings and thus ensuring the work safety in methane-abundant mines, and simultaneous increasing the productivity of mining machines and mechanisms by the gas emission factor;
- development of highly efficient methods for degassing coal seams not related to mining operations: degassing coal seams using directional vertical-inclined wells drilled from the surface using artificial methods of increasing the natural gas permeability of coal seams (hydraulic fracturing, special processing methods) [3,5,8,9], and without using these methods.

Producing the gas suitable for utilization when developing the first trajectory is a subordinate (indirect) effect of degassing, the main purpose of which is to ensure the work safety by the methane emission factor. Therefore, this trajectory should also allow using such methods, schemes and degassing options, in which the methane content in the gas being captured can be significantly lower that the the permissible lower limit for the possibility of using the gas (below 25 %).

The use of these methods, schemes and options is especially important in complex degassing the units with exceptionally high methane abundance (30-50 m^3/min). First of all, various methods of suction of methane-air mixtures from the worked-out area of the existing units are referred to the specified degassing methods, when methane is supplied to the unit from reservoirs located in the immediate vicinity of the seam under development and associated with mine working by operation cracks.

Mixing the gas captured from the worked-out space with the gas during preliminary degassing, etc. can raise the methane content in the gas to 30 % or more, but in such conditions it is almost impossible to obtain a gas suitable for utilization in internal combustion engines, as raw materials for the chemical industry, etc. [3, 5]. Therefore, gas captured in mines in this way is primarily suitable for utilization as a fuel for mine boiler-houses, replacing coal or natural gas.

This type of utilization should not be disregarded, since in the areas of high concentration of coal industry enterprises utilization of a by-produced fuel can be of great importance.

The second trajectory of methane-bearing coal deposits degassing methods development is, first of all, a very promising method of producing methane (gas with a high stable methane content) for a wide range of utilization methods in the national economy:

- as a motor fuel in internal combustion engines and gas turbines;
- as a raw material of the chemical industry for producing industrial carbon soot, producing plastics, methanol;
- as a replacement of natural gas primarily in the mining towns and local thermal power plants.

At the same time, the use of the methods discussed above without mine degassing contributes to the reduction of the natural methane content in coal and ultimately also contributes to increasing the work safety in gas mines for the future.

Vertically directed wells can be used to produce gas containing 75-97 % methane under the following conditions:

- for degassing coal seams without pressure release, without using and using special methods of increasing gas permeability of the seams;
- for degassing coal-bearing strata being mined in conjunction with performing the underground works.

The experience of seams degassing by wells from the surface shows [5, 7, 15] that with the well depth of 600-900 m, the gas to be absorbed contains at least 70 % methane (when choosing the optimal degassing parameters, the methane content is 95-97 %), and the wells flowrate depending on the volumes of coal to be degassed and the natural methane content of coal is within the range of 1,000 to 16,000 m^3/day of methane.

In the coming years, the amount of methane captured by this method can amount to 96-135 billion m^3/ year [3,11].

The trends of improving the method of degassing coal-bearing strata produced by directional vertical-inclined (horizontal) wells are as follows.

For the purpose of early preparation of the gas-bearing strata containing a suite or suites of slightly inclined distant seams.

The development of a suite of methane-bearing coal seams begins with an underlying seam of the suite with preliminary drilling from the surface the directional vertical-inclined degassing wells (VIDW) that cross the overlying layers in the area of their future undermining. In some cases, with relatively weak lateral rocks, the VIDW should be drilled with intersection of the seam under development ahead of its breakage face.

he drainage of the degassing well with pipes is made for the entire length, except for the lower ones, 25-35 m that are lined with perforated pipes or (with strong rocks) are not lined.

Vertically inclined directional wells are drilled to the seams under development (rock layers) and further from one well bore along the underworked massif (coal seams or inter-seam rocks) there are drilled the inclined-horizontal part of two to four degassing wells, thereby increasing the contact area of gas-producing seams within the level [12].

Conclusions

Utilization of coal mine methane will reduce the cost of coal mining in the mines, depending on the specific conditions, by 3-4 %.

Coal mine gas is a significant but practically undeveloped resource with major reserves located in about a dozen countries.

China, Russia, Poland and the United States of America are the largest "polluters" of the atmosphere, jointly responsible for three quarters of the total world emissions of mine gas.

According to forecasts, the amount of emitted mine gas in the world will increase by 2 % by 2020, mainly due to the growth of coal mining in China.

When mining for the production of coal from gas-bearing strata in the world practice and in the Republic of Kazakhstan, coal-mining enterprises are experiencing man-made disasters associated with methane emission leading to dire consequences.

The duration of degassing is usually determined by the mining conditions in accordance with the plan for coal preparing and mining. Reducing the gap in time between completing the drilling and connecting the well to the gas pipeline increases the efficiency of degassing by 10-12 %.

The total volume of methane recovery from the mine workings by means of degassing is found by summing the gas flow rates from each degassed source (taking into account the time factor).

The volumes of methane emitting into the mine atmosphere and carried by ventilating air to the surface, as well as methane captured, primarily depend on the natural methane content of coal (rock).

The capture of mine gas in order to reduce methane emissions in the mine workings is carried out, as a rule, in the most high-abundant mines, where the removal of methane using only ventilation is difficult.

Studying the changes in the efficiency of degassing with depth shows that with increasing the gas content of the coal seam, the amount of recoverable gas increases to the depth of 400-500 m.

Then decreasing the permeability of the seams leads to decreasing the methane production from wells.

The methods of degassing the developed space are widely used. The proportion of methane emission from it reaches 80 %.

Reducing the gas content of the working areas in the mine is performed both by means of ventilation, and using complex degassing methods that include the gas recovery from the seam unde development and from the worked-out space.

The use of methods without mine degassing reduces the natural content of methane in coal and ultimately also contributes to the improvement of the gas mine safety in the future.

Vertically directed wells can be used for producing gas containing 75-97 % of methane.

List of literature used

1. **Baimukhametov** S.K. et al. The results of industrial tests of a new method of preparing a particularly hazardous thick formation d6 in the mines of the Karaganda basin. Mining information and analytical newsletter. 2005.

2. Karaganda coal basin: Reference book / **Drizhd N.A., Baimukhametov S.K.**, Tobler V.A. et al. – M.: Nedra, 1990.

3.**Karagodin L.N., Voloshin H.E., Osipov S.N.** et al. Opening outburst-dangerous formations. - M.: Nedra, 1968. – 91p.

4. Gas abundance of coal mines of the USSR: Effective methods of artificial degassing of coal seams at great depths // **R.A. Galazov, A.T. Ayruni, I.V. Sergeyev** et al. - M.: Nauka, 1968. - 91 p.

5. **Golitsyn, M.V., Prokofyev, L.M., Kolesnik, V.Ya., Tyurenkova, G.I.** Combustible shale resources, their extraction and use / / 27th Intern. geol. congr. “Energy Resources of the World”: Reports. - M.: Nauka, 1984. V.2. P. 21-39.

6. **Dmitriyev A.M., Kulikova N.N., Bodnya G.V.** Problems of gas content of coal deposits. - M.: Nedra, 1982. - 263 p.

7. Ermekov M.A. Studying reservoir pressure of methane in the Karaganda basin. - M.: **CNIEIUgol, 1968. No. 7. P. 26-30.**

8. **Mudron** M. Degazace па dolech Ostravsko-Karvinskeho reviru // Uhli. 1980. No. 7. P. 5-8.

9.**Treskov A.** Heizt und Treibt von Unten // Energie. 1986. N8. P. 13-16.

10. Web-ресурс: Mining Encyclopedia, (http://www.mining-enc.ru).

11. Mining problems. - M.: Nedra, 1974. - 288 p.

12. Evaluation of methane safety methods in the mines of the Karaganda basin: Monograph / **N.A. Drizhd, D.R. Akhmatnurov, A.M. Zakharov et** al. - Karaganda: KSTU, 2016. - 224 p.

ANALYSIS OF THE POSSIBILITY OF USING STONE POST-MINING WASTE WITH UNKNOWN PROPERTIES TO MAKE A MULTI-LEVEL EMBANKMENT AND LAND RECLAMATION

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Abstract: Mining of useful minerals, both in underground and open pit mining, causes side-effects, including post mining waste and change of relief of the mining areas. Therefore, it is beneficial to use post mining waste to the reclamation of post-mining areas. It happens that the contractor is not informed thoroughly enough on properties of the waste material. Often, laboratory tests can not be carried out. The chapter presents set of actions needed for determining the strength properties of the waste stone and the stability forecast of the multi-level embankment undertaken for storing waste in land reclamation.
Keywords: environmental protection, land reclamation, post-mining waste, waste storage, multi-level embankment, slope stability, numerical modelling, cohesion, internal friction angle.

1. Introduction

The chapter thoroughly explains the problem of post-mining reclamation in the open pit mining area and it is also the problem presented during the conference "International scientific and technical internet conference".

Because of the issues complexity resulting from incomplete information on strength properties of the stone waste and the necessity of designing a multi-level embankment as an element of already existing natural attractions the problem is a subject of analysis. The "Limes" open pit mine is located administratively in the western part of the Lesser Poland Voivodeship.

According to the physico-geographical Kondracki's zonation, it is located in the eastern part of the mesoregion of the Jaworznica mound, and it is a part of the Silesian Upland macroregion plus the western part of the Tenczyński Ridge in the Cracow-Czestochowa Upland mesoregion.

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1.1. Climatic conditions

The climate characteristics are typical as for the Silesian Upland sub-region. It is moderately warm and humid with specific influence of processes occurring in urban-industrial areas. The sum and average of yearly rainfall and air temperature classify it as humid climate with a clear predominance of precipitation over evaporation. The average yearly amount of atmospheric precipitation varies from 770 to 811 mm.

1.2. Land morphology

The open pit mine area is morphologically divorced. It is formed of hills with heights of 360 to 400m AMSL with steep slopes separated by ravines with streams. In the area of the "Limes" mine, the land morphology is changed by mining activity. Mine excavations subsided the natural terrain elevations to +295m AMSL. The past mining waste formed around the dumps changed almost completely the natural terrain relief. In the lime-landfill site there are lime-sand waste with different grain size distribution and a volume of approx. 2 million m^3. The wastes are used for filling and land reclamation. The mine waste dump covers an area of over 4 ha and has a height of 40÷60m.

2. The characteristic of the exploitation of limestone, dolomite and marl deposits undertaken to date

The first notes on the open pit mine of limestone, dolomite and marl in the outcrop of Triassic limestone in the area of the Limes open pit mine dates back to the 19th century. After the Second World War, the open pit mine was expanded. In the years 1947-1949, the first lime burning kiln was built. In the years 1956-59 the production capacity of lime was increased by launching an additional two kilns. Also, limestone for the food and chemical industry, building and road aggregate, sorbents for flue gas desulphurisation installations, bituminous dust and calcium-magnesium fertilizers were started.

In 2013, the sale of material from mine waste dumps, mining of limestone was started. At present the open pit mine produces dolomite and limestone as a stone mix, crushed stone, key aggregates, broken stone and unsorted stone, as well as limestone dust and calcium-magnesium fertilizers.

The exploitation of the limestone deposit was carried out in the heading No. 1 located in the northern part of the mining area. For now, the exploitation has been completed. At present, the exploitation of the limestone, dolomite and marl deposits is conducted in the heading № 2 at three levels: +322, +314 and +305. In the northern part of the open pit mine, the exploitation reached level III, i.e. +305±3m AMSL. There is also a sump. At present, the exploitation is carried along the east face of the open pit mine in the southern direction to the excavation boundary. The exploitation is carried out simultaneously on the levels +322 and +305.

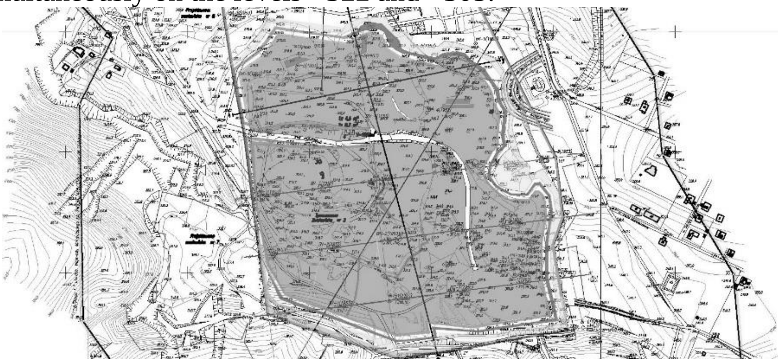

Fig. 2.1. The final stage of exploitation in the northern part of open pit mine

The planned exploitation in the heading No. 2 is a continuation of the excavation previously carried out along the eastern boundary of the excavation. Subsequently, the direction of exploitation would change to the west and would be conducted along the southern border of the mining area. Afterwards the exploitation fronts would be carried out to the northern direction until the excavation limit is reached. The planned exploitation would be implemented on three levels, i.e. +322, +314 and +305m AMSL (Fig. 2.1). No operation is planned for the IV level +297m AMSL.

3. Characteristics of the land reclamation area

Initially, the deposit of limestone, dolomite and marl has been exploited in the open pit heading No. 1 in the northern part of mining area (Fig. 3.1). The open pit exploitation in this area has been completed, and now the silted water is being dropped into the old excavation. There are 8 million tonnes of mining waste on the dump, of which around 6.5 million tonnes are stone aggregates with granulation up to 60 mm.

At present, any mining activity is carried out in the heading № 2 located in the southern part of mining area (Fig. 3.2). The exploitation is carried out on three mining levels: I - +322 m AMSL, II - +314 m AMSL and III - +305 m AMSL. Level IV - +297 m AMSL is classified as recoverable reserve.

Fig. 3.1. Heading №. 1

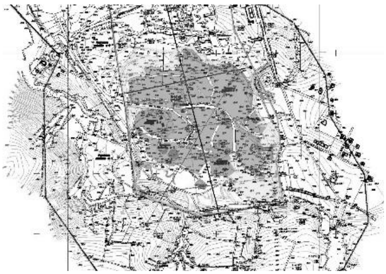

Fig. 3.2. Present stage of mining works in heading No. 2. Level I - yellow, level II - red, level III - green

The excavation is available from the west side and there is also laid a transport route enabling access to all working levels.

On the northern side of the transport route there is a sump of 1080 m^3. Presently, the water level is at 304 m AMSL. Water supply inflows into the sump by infiltration through the slopes of the upper levels.

The main sump water supply comes from atmospheric precipitation (Fig. 3.3).

While the deposit exploitation was carried out, the overburden and deeper parts of the low-quality stone material stored at the working levels directly (Fig. 3.4).

Fig. 3.3. Open pit sump

Fig. 3.4. A dumping ground at the eastern part of the open pit

At present, the exploitation is carried out along the western part of the open pit area (Fig. 3.5), from the surface, i.e. from the ordinate approx. 350m AMSL, to the lowest level that is at the depth of 305±3 m AMSL. The exploitation results in steep slopes with height of up to 50m (Fig. 3.6).

Fig. 3.5. View from the top of the eastern slope to the open pit excavation

Fig. 3.6. Forested slopes from the east side of the open pit excavation

3.1. Geological structure

The open pit mine area lies in the Upper Silesia Hole, in the Carpathian Piedmont part. The structural formation present in there comes from Upper Palaeozoic (Carboniferous, Perm), Mesozoic (Triassic, Jurassic) and Cainozoic.

3.2. Hydrogeological conditions and hydrography

There is a link between the underground waters of the mine area, Triassic sediments and Carboniferous formation. According to the

Hydrogeological Map of Poland, the main usable groundwater level of the open pit region subjected to analysis is a part of the Upper Silesia Region and the Chrzanowski Subregion. Considering the water quality and capacity, the water reservoir includes to the Main Underground Water Reservoirs. The second groundwater level of the open pit region is the C/2 Tychy - Siersza water reservoir with a Carboniferous formations.

The mine area is located in the Chechło river basin, which is a left-bank tributary of the Vistula river (IInd Vistula river basin). Closest to the open pit mine is located the Stara Woda stream. Springs of the stream are located at an altitude of about 320m AMSL at the top of left slope of the valley. Output of the spring is about 1.5÷2.0l/s. At spot of the spring output a water reservoir was built and its natural form was transformed. The open pit mining activity results in progressively infiltration of the stream into the ground and flowing as an intermittent stream.

4. Planned reclamation and a method of developing the post-mining area

The decision of the District Office has determined for the post-mining area forest branch of land reclamation with deciduous trees. A partial macro-levelling of headings No. 1 and 2 has been planned as dumping of the open pit mine waste located in the northern part of the open pit mine. The waste material from the dump should be used in the land reclamation process, even though the amount of the stone material is insufficient. Thus a post-mining material delivered from the outside underground mines and transported partially should be used for macro-levelling.

In accordance with the guidelines of the National Fund for Environmental Protection and Water Management the land reclamation processes, including macro-levelling, is required. Methods and conditions of reclamation, including macro-levelling with using waste, depend on many factors. The waste regarded as a substitute of primary material should meet certain technical requirements, i.e. it may not violate the environmental quality standards nor contain any contaminants.

Due to sanitary requirements and hydrogeological conditions, PKW crushed mining waste stone with the technical approval of IB-

DiM №. AT/2010-03-2576 will be used for macro-levelling. Crushed stone holds the Hygienic Certificate HK/B/0558/01/2010 issued on May 13, 2010 by the National Institute of Public Health - National Institute of Hygiene in Warsaw.

Waste stone PKW gets a positive technical opinion of using it for any technical land reclamation. It can be a substitute of primary soil or rock material, replacing native material.

It can be used for macro-levelling and levelling areas, while maintaining the remaining conditions of the land reclamation process.

5. Analysis of embankment stability for consecutive land reclamation stages

The basic task to define the stability of the embankments and slopes is to determine the presumable slip surfaces and the balance of forces sliding and supporting the embankment.

There are many analytical methods for determining the stability of embankments and slopes.

The progress of computer techniques makes use of computer programs for calculations. For determination of the embankment stability, the RocScience's Slope computer program was used. The numerical calculations were based on the simplified analytical methods of Janbu and Bishop.

The stone waste was described by the Coulomb-Mohr failure criterion. The assumptions taken should allow to solve the problem of embankment stability at the engineering level.

Due to the lack of data on strength and deformation properties of the stone waste material intended for the embankment construction, back analyses were carried out to determine cohesion *c* and the angle of internal friction .

After determining these constants, two variants calculations were made:

- from +305 to +360 without backfilling up to +321;
- from +321 to +345, with filled levels + 305- +321.

The calculation results for individual stages are presented on the stress maps.

6. Determination of geotechnical parameters of mining waste intended for macro-levelling

6.1. Results selection of researches on the properties of mine stone material to date

The coarse-grained structure of the material *f*>30 mm means that determining the value of internal friction angle and cohesion *c* causes many problems and requires the use of large-scale specialized laboratory test machines.

Table 6.1

Type of material	Material specification	Cohesion *c* kPa	Angle of internal friction □ °	Authors
Post coal waste	Gravel fraction (40÷2mm) 66%	16.0÷30.1	32.5÷32.8	(Baran et al., 2009)
Stony post-mining materials	Depth 0÷2m Depth 2÷16m	1,8 26.8÷47.6	36.4-45.0	(Sternik, 2011)
Post-mining materials	Dry Water saturated	40 12	17	(Charanpret, 2009)
Post-mining dump materials	Waste with (only) 5% dust and clay content	23	39	(Zapał, 2007)

Many researchers assume that for coarse-grained soils, gravitational forces due to the size of the "grains" of the material are much greater than the cohesion forces and should take for these materials *c* equal to 0. However, in fact the results of laboratory tests (e.g. Baran, Zawisza and Szymacha, 2009) show that for coal stone waste the value of cohesion *c* is different (greater) than 0. It should be emphasized that in general there are significant differences in the values of *c* i □ determined with various test methods by different authors (Tab. 6.1).

Based on the literature research, it was assumed that the value of *c* is different/greater than 0. Documented results were only subjected.

7. Back analysis of the embankment stability

To perform a back analysis was the next stage of the research. The results of the field inspection of local mine waste dump in Czerwionka-Leszczyny were taken into account and applied. The object was chosen because of the knowledge and experience in setting its stability and parameters of its embankment.

Stated that the natural angle of repose for the post-mining stone of the embankment in Czerwionka-Leszczyny ranges from about 50° to 60°. Even though it is generally assumed that the angle of natural repose of non-cohesive materials is an average of 33° and approximately is equal to the angle of internal friction □ of the material in a very loose state of consolidation. If, therefore, the angle of natural repose of the stability embankment in Czerwionka-Leszczyny ranges from about 50° to 60°, then it is possible to estimate the value of cohesion *c* of waste material by back analysis.

Cohesion *c* calculations for over 64 embankment numerical models were carried out (Fig. 7.1) assuming:

- natural repose angle $\square_{rz}$ equal to 60, 50 and 45°,
- 16÷18kN/m^3 weight by volume.

The detailed results of the simulations are presented on the Figs 7.2-7.6.

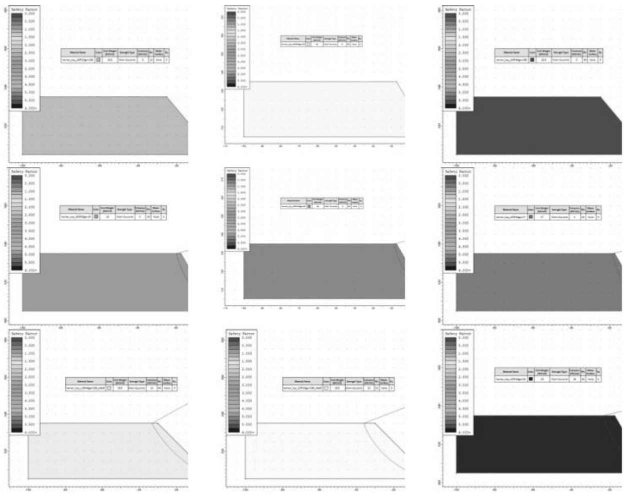

Fig. 7.1. Selected models from over 64 numerical back analysis simulations of the embankments to determine cohesion *c*

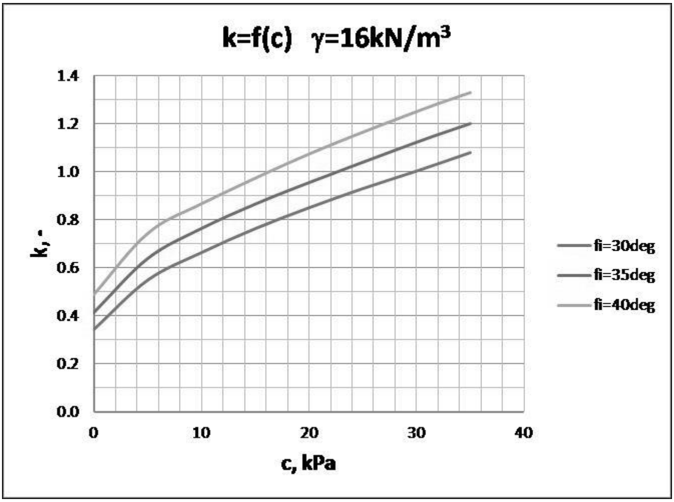

Fig. 7.2. Cohesion *c* for different values of the angle of internal friction □ (fi) and for the angle of the natural repose □*rz* (fi_rz) equal to 60°; *k*(*F*) - safety factor, □ (gamma) - volumetric weight

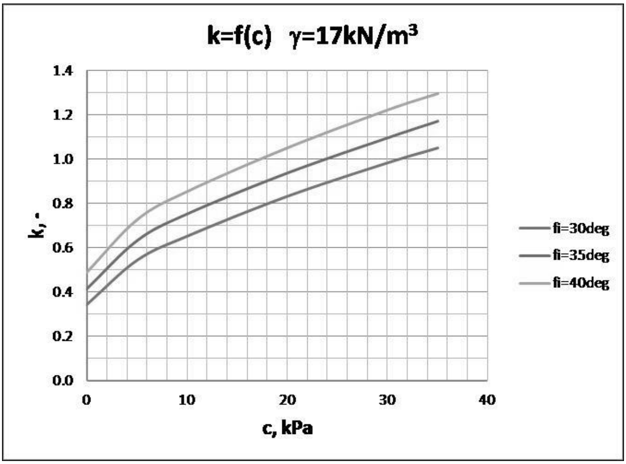

Fig. 7.3. Cohesion *c* for different values of the angle of internal friction □ (fi) and for the angle of the natural repose □*rz* (fi_rz) equal to 60°; *k*(*F*) - safety factor, □ (gamma) - volumetric weight

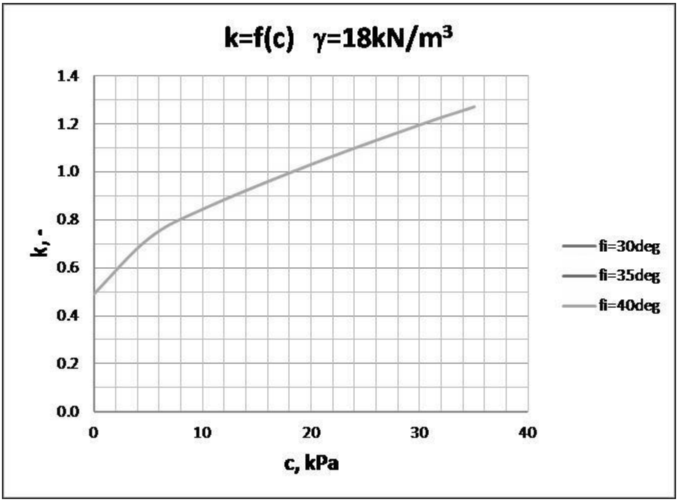

Fig. 7.4. Cohesion *c* for different values of the angle of internal friction □ (fi) and for the angle of natural repose □*rz* (fi_rz) equal to 60°; *k*(F) - safety factor, □ (gamma) - volumetric weight

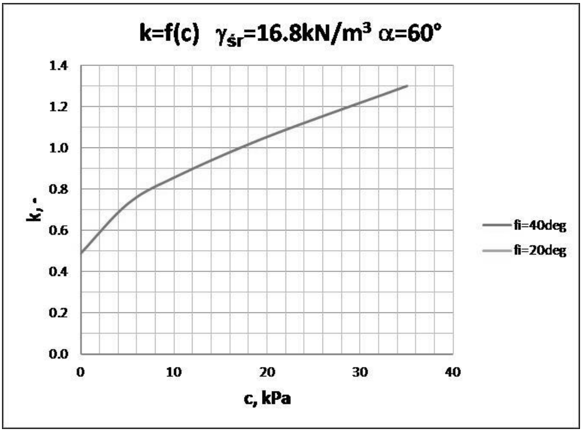

Fig. 7.5. Cohesion *c* for the angle of internal friction □ (fi) equal to 40° and for the angle of the natural repose □*rz* (fi_rz) equal to 60°; *k*(*F*) - safety factor, □ (gamma) - volumetric weight

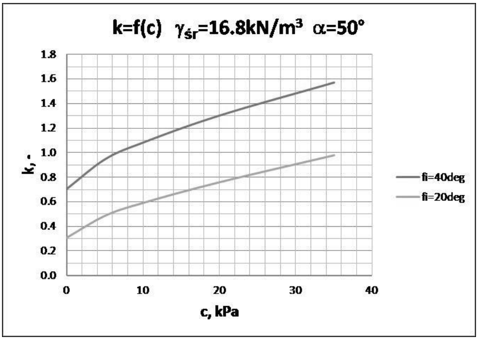

Fig. 7.6. Cohesion *c* for the angle of internal friction (fi) equal to 40° and 20° and for the angle of natural repose $\square_{rz}$ (fi_rz) equal to 50°; *k*(*F*) - safety factor, (gamma) - volumetric weight

The analysis made resulted in limitation to taking into account only the calculations that follows criteria listed below (Fig. 7.7, Tab. 7.1):

- rejected angles of natural repose of 60°÷50° despite of the knowledge based on the field inspection of the local Czerwionka-Leszczyna embankment. The values of cohesion *c* were too high in relation to the cited test results of different authors;

- tested values assumed for cohesion *c* for the angle of natural repose $\square_{rz}$ equal to 45° with the assumed volume weight ;

- assumed cohesion values *c* of the lower ranges given in tab. 7.1, i.e. cohesion *c* of 10 to 20 kPa.

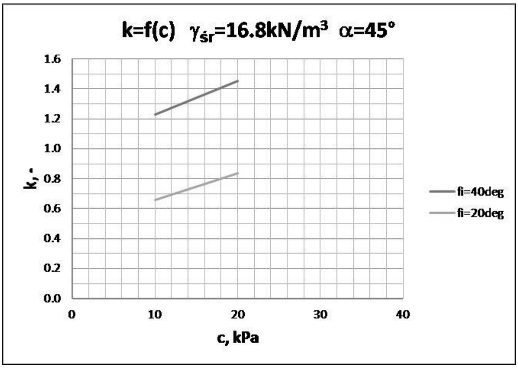

Fig. 7.7. Cohesion c for the angle of internal friction (*fi*) equal to 40° and 20° and for the angle of natural repose $\square_{rz}$ (fi_rz) equal to 45°; *k*(*F*) - safety factor, (gamma) - volumetric weight

In conclusion, based on:

- literature studies,
- a field inspection of the Czerwionka-Leszczyny embankment,
- own experience,
- and back analysis results,

assumed for the post-mine stone to be reliable if accept the following parameters:

cohesion *c* equal to 10 kPa,

internal friction angle □ equal to 40°,

volumetric weight □ equal to 18kN/m^3.

Table 7.1

Cohesion *c* for the angle of internal friction □ (fi) equal to 40° and 20° and for the angle of natural repose $□_{rz}$ (fi_rz) equal to 45°; *k*(*F*) - safety factor, □ (gamma) - volumetric weight

gamma_śr=16,8kN/m^3			fi_rz=45deg		
fi			*c*		
deg			kPa		
	0	5	10	20	35
			k		
40	-	-	1.227	1.452	-
20	-	-	0.657	0.835	-

The analysis covered the consolidation influence to which the post-mine stone should be subjected. The analysis results stand that with the increase of the density (and the volume weight □□□ there is:

- only a small, approximately 0.1÷0.2% decrease of the safety coefficient *k*(*F*) (assuming a constant value of consistency *c*, *c*=const.);
- a relatively large increase of cohesion *c* by around 5 kPa.

The consolidation of the post-mining stone layers of the embankment should increase the cohesion value *c* and, as a result, the safety factor *k*(*F*) by about 0.3.

8. Stability simulation for the 1st variant embankment with filling to level +321 and shelves up to +345m

For the 1st variant, calculations were made with the following assumptions:

- up to the height of the first two shelves (1st and 2nd), i.e. +305÷+313 and +313÷+321 the void-space was limestone rubble filled (+305÷+306), and next followed by a post-mine stone (+306 ÷ +321);

- from the level +321÷+345 would be build 3 shelves with a width of 6m each:

a - shelf 3. +321÷+329,

b - shelf 4. +329÷+337,

c - shelf 5. +337÷+345,

- after finishing the building of the embankment, the slopes would be covered with approximately 0.3m grassland soil layer and the shelves and the top surface of the embankment - 0.8 m grassland soil layer,

- tracks riding on shelves would generate vertical forces of 2×150 kN/m; the collapsing wheels of the loaded tracks in the shelves' surfaces was not calculated (Fig. 8.1-8.3).

The values of the adopted material constants are presented in Tab. 8.1.

Table 8.1

Material type	Volume weight, kN/m^3	Cohesion *c*, kPa	Internal friction angle □, °	Comment
Dolomite	20	2000	26	The values taken were based on the lower range for dolomite (incl. Hoek, 2014)
Nonweathered post-mining stone	18	10	40	The values taken were based on the results of back analysis, local investigation, previous results of post-mining waste tests (a.o. Baran et al., 2009; Charanpret, 2009; Koda and Przysiadka, 2007; Sternik, 2011; Zapał, 2007).
Weathered post-mining stone	18,5	12	36	
Limestone rubble	17	8	36	as above
Grassland soil	16	15	22	as above, a.o. (Śnieg i in., 2007)

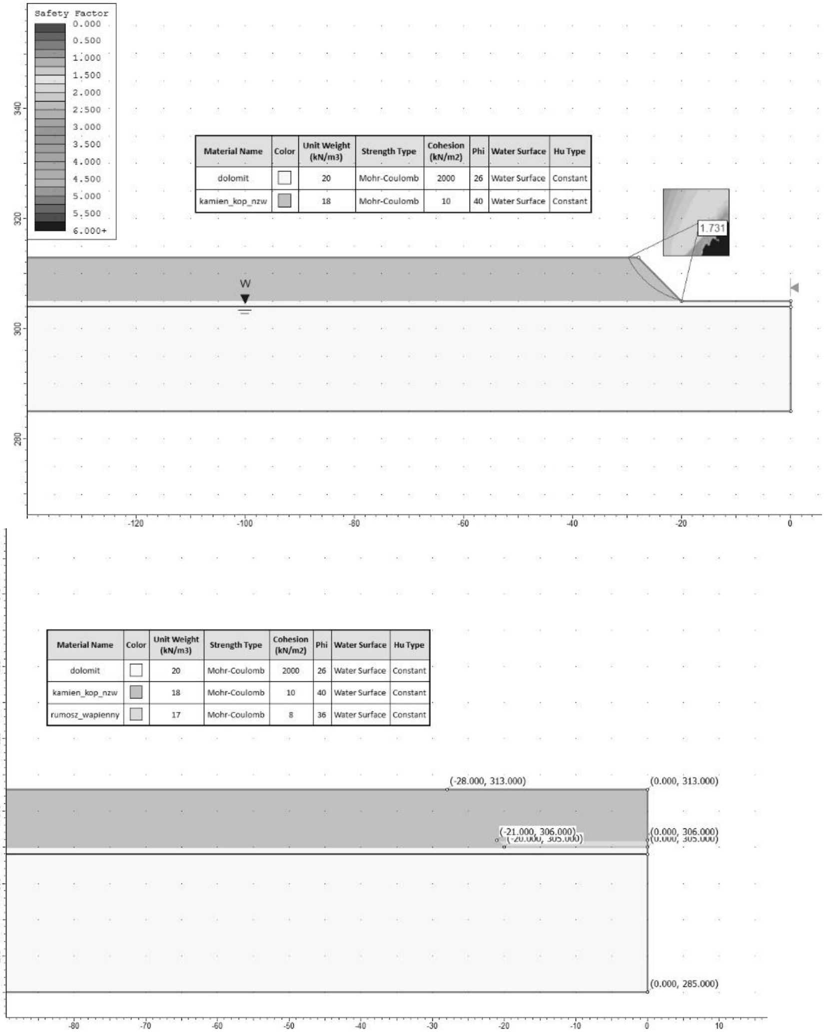

Fig. 8.1. A view of the model after building 1st shelve (+305÷+313), filling the excavation by a 1m height lime rubble and levelling up to the level of +313 by post-mine stone

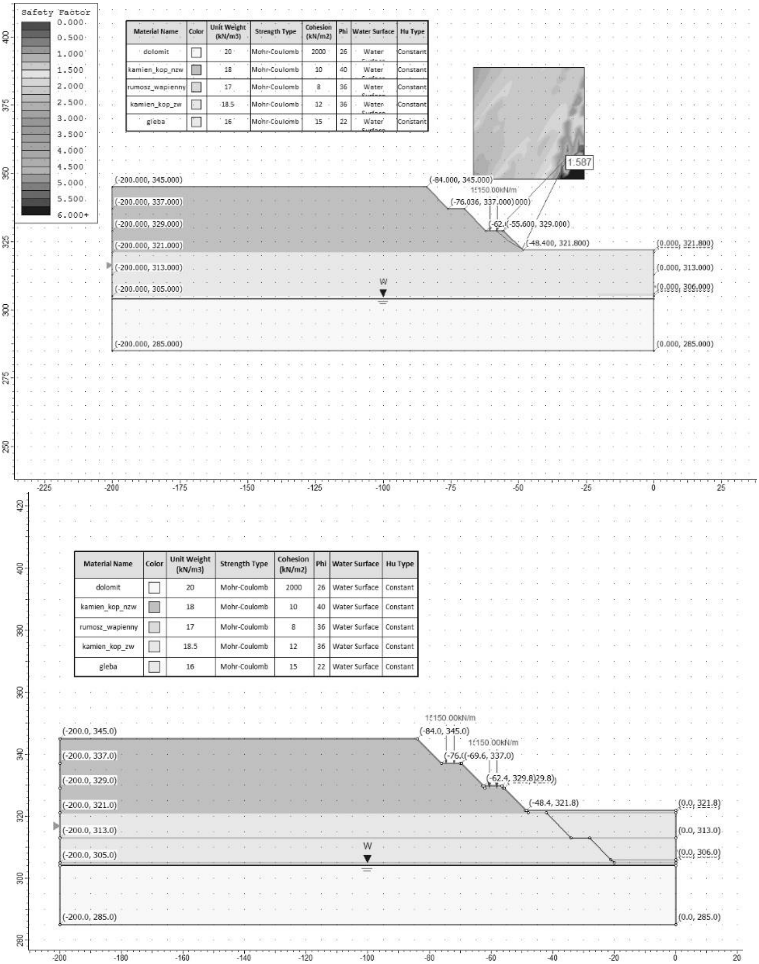

Fig. 8.2. A view of the model after building 5th shelve (+337÷+345) and grassland soil layers on level +321÷+337. The angle of slope is equal to 45°, the value of the stability factor *k*(*F*) - 1.59 (above). A view of the model with the force vectors (2×150 kN/m) applied as a result of loaded trucks on the 3rd and 4th shelves (at bottom)

The analyses carried out indicate that the value of the safety/stability coefficient *k*(*F*) of the presented variant is always greater than 1.5 (Fig. 8.3).

Considering the value of cohesion *c* of post-mine stone, it may be predicted that the stability of the embankment with the proposed geometry would be obtained.

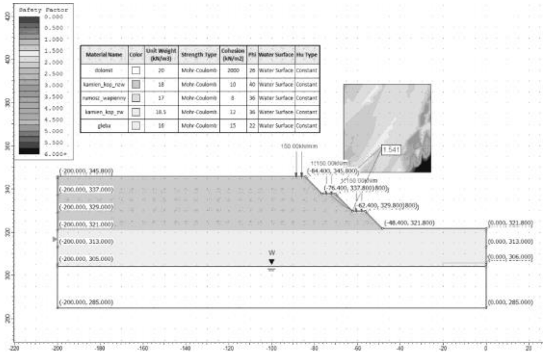

Fig. 8.3. A view of the model after building 5th shelve (+337÷+345) and grassland soil layers on level +321÷+337. The angle of slope is equal to 45°, the value of the stability factor *k*(*F*) - 1.59 (above). A view of the model with the force vectors (2×150 kN/m) applied as a result of loaded trucks on the 3rd and 4th shelves (at bottom)

9. Stability simulation for the 2nd variant embankment with shelves up to +360 m

Simulations of the embankment behaviour and its stability were also carried out for the case as:

- shelves were built from +305 m,
- the height of shelves No. 1,2,3,4,5 and 6 was equal to 8m, and shelves № 7, from level +353÷+360 - 7 m,
- the angle of the slope was 45°,
- the width of the shelves was equal to 7 m,
- after completion of the embankment building, the slopes would be covered with about 0.3m grassland soil layer, and the shelves plus the upper surface of the crown - 0.8 grassland soil layer,
- tracks riding on shelves would generate vertical forces of 2×150 kN/m; the possibility of collapsing wheels if the loaded trucks would be in the shelves' substrates were not calculated.

The values of waste material constants were the same as for the 1st variant (Tab. 8.1). Calculation results for selected stages of the simulation are shown on Figures 9.1-9.2.

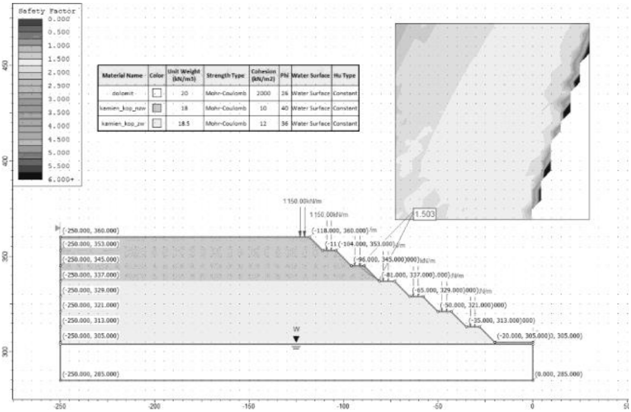

Fig. 9.1. A view of the model after building 6. shelve (+305÷+360) and with the force vectors (2×150 kN/m) applied as a result of loaded trucks on the shelves. The angle of slope is equal to 45°; the value of the safety/stability factor *k* (*F*) is 1.50

Also if the embankment building ranging from +305 to +345, the value of the safety/stability coefficient *k*(*F*) of the presented variant was always greater than 1.5. Therefore, it may be predicted that the stability of the proposed geometry embankment would be obtained.

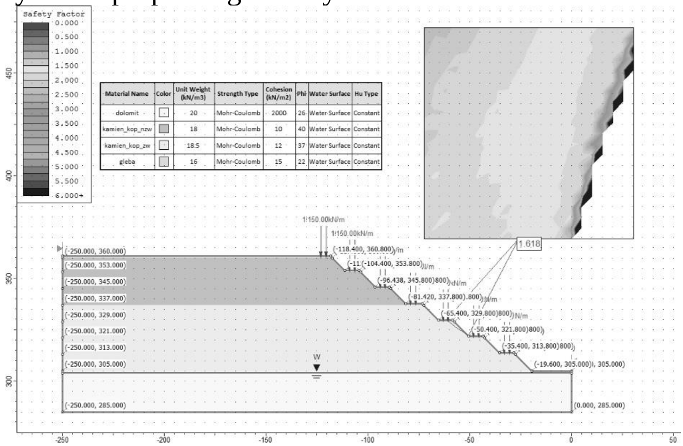

Fig. 9.2. A view of the model after building 6. shelve (+305÷+360), with the force vectors (2×150 kN/m) applied as a result of loaded trucks on the shelves and grassland soil layers on slopes - 0.8m and top of the embankment. The angle of slope is equal to 45°; the value of the safety/stability factor *k* (*F*) is 1.62

10. Summary and final conclusions

The aim of the analyses was to assess the stability of the post-mine waste embankment built of stone grains with diameters larger than 35mm. According to the assumptions, the embankment would be built from +305 m to +345 m (or +360 m). The width of the shelves *s* was equal to 6 m (or 7 m) and their height *h* - 8 m. The surfaces of the shelves, the lower and upper level of embankments were covered with a 0.8m thick layer of grassland soil and the surface of the slopes with a layer of 0.3m. For full use of the working space, the slope angle should be as large as possible. Laboratory tests of cohesion *c* values and internal friction angle □ of coarse-grained materials because of nature of such tests have been rarely evaluated so far.

Because of no cohesion value c for mine stone was known, the value determination was based on:

- literature researches; the authors presented c equal to 12,0-47,6kPa and the angle of internal friction □ from 17° to 45°;

- back analyses for behaviour of Czerwionki-Leszczyny embankment made of similar material. After over 64 analyses of numerical models with slope angles equal to 60°, 50° and 45°, volumetric weights from 16 to 18 kN/m^3 and (known) angle of internal friction □ equal to 40°, the cohesion *c* equal to 10kPa was reliable. The values of constants of dolomite, grassed soil and lime rubble were used according to selected results from literature research and own experience.

So-called embankment models were built on the base of material constants. Its stability was determined on the values of the safety factor/slope stability *k*(*F*). The methods of Bishop and Janbu (and in some cases Fellenius) were used.

The calculations were carried out for the assumed slope angle □ equal to 45°.

The calculations were divided into stages. The following stages of the calculations were:

- building each successive shelf with a height *h* of 8m and a width *s* of 6 or 7 m;

- covering the surfaces with grassland soil layers with simultaneous adding vertical force on the shelves, with a value of 2×150 kN/m simulating a loaded trucks. The possibility of collapsing wheels if the loaded trucks would be in the shelves was not calculated.

Calculations were carried out for two variants:

a - to the height of the first two shelves (1st and 2nd), i.e. item +305÷+313÷+313÷+321 the void-space was filled with limestone rubble (+305÷+306), followed by a post-mine stone (+306÷+321). From the level +321÷+345 would be made 3. shelve with a width of 6m each: shelf 3. +321÷+329, shelf 4. +329÷+337 and shelf 5. +337÷+345;

b - shelves were built from +305 m. The heights of shelves *h* No. 1,2,3-5 and 6 were equal to 8m, and shelve №. 7, from level +353÷+360 - 7 m. The width of the shelves *s* was equal to 7 m.

For both variants, the values of the safety/stability coefficient *k*(*F*) were always greater than 1.5. In general, for the assumed values of constants *c* and □, the embankment stability would be predicted for: the slope angle □ equal to 45°, shelves with height *h* equal to 8m and width 6÷7m for the height of the embankment from level +305 ÷ +360 m.

In order to improve mechanical properties of the material, to reduce fraying, rutting, water absorbability and capillary action, as well as to increase wheel load capacity, at any stage of the embankment building density compaction should be carried out and use of kneading machines, e.g. road rollers, ought to be applied.

Bibliography (selected)

1. Baran P., Zawisza E. i Szymacha A.: Próba weryfikacji parametrów wytrzymałościowych odpadów powęglowych metodą granicznego stanu naprężenia. An attempt to verify the strength parameters of mining waste by the limit stress state method. Górnictwo i Geoinżynieria, Rok 33, Zeszyt 1, 47-55, Gliwice 2009

2. Baffinland Iron Mines Corporation: Mary River Railway Slope Stability Analysis for the Waste Rock Dump. February 2012

3. Cała M.: Mechanika Gruntów. Soil Mechanics. Cykl wykładów, AGH, (home.agh.edu.pl/cala/prezentacje/ , available 12.06.2018r.), Kraków 2016

4. Charanpreet S. F.: Evaluation of slope stability for waste rock dumps in a mine. A thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Technology in Mining Engineering. Department of Mining Engineering National Institute of Technology, No. 769008, Rourkela 2009

5**. Domagała L. i Różański Z**.: Bezpieczna technologia eksploatacji zwałowiska odpadów powęglowych. The safe technology of exploitation of the coal wastes dump. Górnictwo i Geologia, Tom 8, Zeszyt 2, 5-20, Gliwice 2013

6. **Drenda J., Domagała L., Różański Z., Poloczek M. i Bujok A.:** Eksploatacja i możliwości zagospodarowania centralnego zwałowiska odpadów powęglowych Przezchlebie w gminie Zbrosławice. The exploitation and management possibilities of the Przezchlebie central coal waste dump in Zbroslawice district. Górnictwo i Geologia, Tom 6, Zeszyt 2, 25-37, Gliwice 2011

7. **Hoek E.:** Fundamentals of slope design. Keynote address at slope stability 2009. 9-11 November, (https://www.rocscience.com/, available 9.11.2018), Chile, Santiago 2009

8. **Качурин Н.М., Хмелевский М.В. и Волоков Д.А.:** Оценка физико-механических свойств материалов из отходов производства для укрепления пород в отвалах известняковых карьеров. Журнал, Известия Тульского Государственного Университета “Науки о земле”, 13-22, 2015

9. **Kleta H.:** Zagrożenia geotechniczne w obrębie składowisk odpadów pogórniczych. Geotechnical hazards at landfills and mining wastes. Górnictwo i Geologia, Tom 6, Zeszyt 1, 85-93, Gliwice 2011

10. **Ломтадзе В.Д.:** Физико-механические свойства горных пород. Методы лабораторных исследований. Л.: Недра, 1990

11. **Mikoś T. i Stewarski E**.: Górnicza eksploatacja hałd odpadów pohutniczych. Mining exploitations of the steelwork waste tips. Warsztaty z cyklu „Zagrożenia naturalne w górnictwie” 2003. Mat. symp., 435-451, 2003

12. **Riley S.J. and East T.J**.: Investigation of the erosional stability of waste rock dumps under simulated rainfall. A proposal, Technical Memorandum 31, Australian Government Publishing Service, Canberra 1990

13. Rocscience Inc.: Slide. 2D limit equilibrium slope stability for soil and rock slopes. Slope Stability Verification Manual. Part I. 2010

14. **Sternik K.:** Wpływ degradacji parametrów mechanicznych odpadów kopalnianych na stateczność skarpy głębokiego wykopu. Influence of degradation of mechanical parameters of mining waste on slope stability of deep excavation. Czasopismo Techniczne: Środowisko, Wydawnictwo Politechniki Krakowskiej, Zeszyt 3-Ś/2011, 165-179, Kraków 2011

15. **Tomiczek K.** Badania wytrzymałości skał na ścinanie. Shear strength tests of rocks. Wydawnictwo Górnicze, Kwartalnik Budownictwo Górnicze i Tunelowe, nr 3, 11-20, Katowice 2008

16. **Tomiczek K**. - co-editor I-IXth and author of the Xth chapter of the project, head of the project and photos author (phs: 3.1, 3.3, 3.4, 3.5 and 3.6): J. Konior, (unpublished): Opracowanie projektu rekultywacji i zagospodarowania terenu zakładu górniczego wraz z operatami wodno-prawnymi. A project for land reclamation and development of the pit mine with water and legal operators. NB-114/RG-4/2014, Politechnika Śląska, Wydział Górnictwa i Geologii, KGBPiZOP, Gliwice 2014

17. **Tsytovich N.:** Soil Mechanics. Mir Publishers, Moscow 1981

18. Verruijt A. and van Baars S.: Soil Mechanics. Published by VSSD, Netherlands 2017

19. **Wiłun Z**.: Zarys Geotechniki. An Outline of Geotechnics. WKŁ, Warszawa 1987

20. **Zapał A. i Ratomski J.**: Geotechniczna ocena przydatności odpadów kopalnianych w hydrotechnicznym budownictwie ziemnym. Geotechnical assessment of suitability of mine waste in hydrotechnical earth structures. Czasopismo Techniczne: Środowisko, Wydawnictwo Politechniki Krakowskiej, Zeszyt 2-Ś/2007, 227-237, Kraków 2007

METHODS OF INCREASING EFFECTIVE USE OF CYCLIC AND CONTINUOUS TECHNOLOGY COMPLEXES ON ORE OPEN PIT MINES

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Abstract. *Subject of the research is* analysis and search for solutions of increasing high-productive use of cyclic and continuous technology (CCT) complexes on deep ore open pit mines.

Objective of the the research is sustaining high productive use of unloading equipment from dump trucks to conveyor and from a conveyor to in-pit railway transport, also construction of steeply inclined hoists for transportation of large scale rock mass.

Tasks of the research are aanalysis of problems of implementing cyclic and continuous technology complexes on deep ore open pit mines and recent foreign achievements in field of designing of lift-transport equipment; development of through point of dump trucks unloading to conveyor; improvement of bunker-storage point of unloading dump trucks; creation of steeply inclined tubular conveyors for transportation of large scale rock mass.

Methods of the research are: systematic analysis of designing and implementation of CCT complexes; patent search and development of new designs of CCT complexes elements.

Improving the efficiency of the application of the CCT will be ensured by the inventions developed at the level of: through unloading of dump trucks, eliminating their maneuvering and ensuring the maximum uniform loading of the conveyor hoist on a permanent basis; a device for reloading from a conveyor to dump carts with a reduction in the width of transport and loading platforms by 1.3-1.5 times; steeply inclined belt-trailer conveyor of tubular type for transportation of large scale rock mass with minimization of the volume of primary crushing.

Introduction. The main reasons for the conservative attitude of some subsoil users to CCT are related to the long payback periods of its complexes due to incomplete use of the design capacity of the conveyors and the high cost of mobile crushing and reloading complexes, as well as the lack of conveyor steeply inclined lifting of hard abrasive rocks. The constrained conditions of deep open pit mines limit the maneuverability of loaded dump trucks at transfer points to conveyor lifts. This is one of the reasons for the incomplete use of their design capacity. The need for crushing, in addition to ore in an open pit mine, overburden rock to a particle size of 300-400 mm also limits the use of CCT in deep and ultra-deep open pit mines (with a depth of more than 600 m).

Nevertheless, the transportation problem of deep open pit mines can be solved mainly only during the transition to the CCT. The operating experience of the CCT systems shows that most of them have not reached their design capacity, in fact it has been mastered only by 50-60%, the equipment utilization rate is low in time. However, in connection with the deepening of open pit mines and lowering of mining operations, the value of the CCT increases more and more.

The steeply inclined conveyor SIC-270 implemented on Muruntau open pit mine with the clamping belt produced by NKMZ and ordered by the Mikhailovsky MEP and more powerful SIC-315 are reassuring.

The problem of transportation of large-scale rock mass has not been solved; this is especially related to overburden, which is mainly stored as solid waste without further processing.

In the cramped conditions of deep open pit mines, problems of placing devices for crushing rocks, especially modular surface execution, and maneuvering of loaded dump trucks at transfer points occur. A significant drawback of unloading points being operated from the conveyor to the railway transport is the significant width of the loading and transport platforms, which increases the separation of the pit walls. Expanding boundaries of the effective application of the CCT is a strategically important area of development in solving the transport problem on deep and ultra-deep open pit mines.

1. Analysis of CCT implementation on deep open pit mines

Many scientific works have been devoted to solving the problems of the effective application of the CCT on deep ore open pit mines. This underlines the strategic direction of the CCT in the development of geotechnology and geotechnics. Recent worth mentioning works on CCT are studies of the Mining Institute of NITU “MISiS” together with the Technical University of the Freiberg Mining Academy [1-3], IPKON RAS [4], the Mining Institute of the Kola Scientific Center [5], UroRAN [6 9], Ukrainian [10-12] and foreign countries [13-17] scientists. Results of research are presented in these works and the experience of work of mining enterprises, in which CCT is applied using truck-conveyor transport, is evaluated. The main conclusion is the feasibility of its use in existing and implementation in new mining enterprises. Currently, a number of large mining enterprises are carrying out pre-project studies for the introduction of CCT and implement new solutions to improve the efficiency of this technology, and in general, open pit mining.

Since the beginning of the 70s of the last century, the formation of transport systems has started to go in a way of using the combined truck-conveyor transport. CCT is used on iron ore open pit mines: Butler, Delaware, Hill Annex, National Steel, Plummer, Republik (USA), Keland, Nock Lake (Canada), as well as copper ore open pit mines: Twini Bjuts, Sierrita (USA), Exotica, Chukikamata (Chile), Cananea (Mexico). The experience of industrial development of the combined truck-conveyor transport showed its efficiency in comparison with independent truck transport, despite an increase in initial capital investment by an average of 11%. This can be explained by two main reasons. First, the replacement of dump trucks with conveyors on lifting rocks from the open pit mine is the most difficult part of their operation, where engine wear and fuel consumption are maximum, can significantly reduce operating costs [18]. Secondly, the increase in initial capital investment may be limited by the open arrangement of conveyors and crushers on an open pit mine.

A new stage in the development of transport systems is associated with the beginning of the 80s. It is characterized by the manufacture and industrial development of equipment complexes adapted to the dynamics of mining operations. The initiator of this was the enterprise Weatherchute (FRG).

The first qualitative leap is associated with the use of a combined truck-railway transport with in-pit rock transfer. The system of combined truck-railway (TCR) transport exceeds the system of independent truck and independent railway transport by its indicators. Therefore, it was widely introduced on deep iron ore open pit mines, where all the necessary conditions were available for its effective use. They differed by various indicators of the dynamics of technological processes.

As international experience has shown, the problem of increasing costs could be solved by replacing dump trucks with conveyors while lifting rocks [19]. A qualitative leap in the development of transport systems in open pit mines occurs when the motor transport is replaced by an automobile-conveyor transport. A feature of the formation of transport systems on the iron ore open pit mines of Ukraine and Russia was the use, along with the truck-conveyor, of truck-conveyor-railway transport.

Uro RAS proposed a design that includes elements of bunker and excavator loading of dump carts in the schemes of TCR transport. Institute of Yuzhgiproruda carried out “Design studies of loading complexes of dump carts directly from conveyor belts” based on this [20].

The effectiveness of the combined bunker-excavator loading dump cart method is confirmed by the experience of its industrial use. It is used in almost all TCR transport systems introduced after 1980. The bunker overburden reloading complex built earlier at the Annovo open pit mine was reconstructed and became a bunker-excavator complex.

According to a number of researchers, the most promising, in the mining industry, are steeply inclined conveyors with clamping tape of the “snake sandwich” type; they have found use in US coal mines [21].

According to the Navoi Mining and Metallurgical Enterprise for 2012, the economic effect obtained from the introduction of the SIC-270 technological transport chain (productivity - 3500 t/h, tilt angle - 37°, lifting height - 270 m, belt speed - 3.15 m/s, the drive power on the cargo belt - 3780 kW, on the presser - 1260 kW) was about 1.5

million US dollars, the distance of transportation by trucks was reduced by 40%, and the mileage by 3.6 km [22].

Also, the steeply inclined conveyor with the pressure belt NAS-1 is installed at the copper mine Maydanpek (Serbia), with a capacity of 4000 t/h, with a tilt angle of 35.5°, a lifting height of 93.5 m, a stave length of 192 m, with belt movement speed - 2.67 m/s, conveyor belt width - 2000 mm, drive power on the cargo belt - 2×430 kW, on the pressure belt - 430 kW [23].

The steeply inclined double-belt conveyor produced by the company “Paakkola Conveyors Oy” transports the crushed ore with a size of 0-80 mm from the open pit mine level of -64.00 m to the level of +60.00 m [24]. Vertical lift height is 124 m.

A steeply inclined conveyor belt FLEXOCON (FLEXOKON) produced by “KMZKO” was developed in the Russian Federation [25]. It is used to transport bulk materials with a bulk weight of up to 3.5 t/m^3 with a rise to a height of only up to 40 m. The belt is equipped with corrugated boards. Pocket-type belts tapes are used on conveyors with shaped sides and corrugated boards made by CONTINENTAL, GUMMILABOR, which allows increasing the volume of load 2 times and transport it at an angle of up to 90°.

It was found that timely transfer to the CCT under conditions of their constantly increasing depth reduces the cost of transporting rock mass from large depths by 15-20%, reducing the cost of mining by 10-15%, increase labor productivity in the main technological processes by 1.2-1.5 times, as a result of the analysis of 15 crushing and conveyor complexes operating at the iron ore open pit mines in Ukraine and Russia.

Analysis of the development and testing of new material handling equipment on deep open pit mines made it possible to single out the truck-conveyor system manufactured in recent years by the company Thyssenkrupp Fördertechnik [26], the tubular conveyor of the company Beumergrop [13] and the steeply-inclined conveyor with clamping tape PJSC "Novokramatorsk Machine-Building Plant" (Ukraine) [22] and Paakkola Conveyors Oy "(Finland) [24].

The basis of the Thyssenkrupp Fördertechnik system is a cable conveyor system that transports material in trolleys (loaded as a dump truck) at an angle of 75 degrees along the shortest route to the grinding plant located on the surface of the open pit mine [26]. It should be noted that this system was used as early as the 80s of the last century at the Sibay career (Bashkortostan). Installation was called skip hoist. True, it was applied to a depth of about 250 m, after which it was dismantled.

Tubular conveyors of the Beumergrop company are produced for transportation of pre-crushed ore at an incline angle of 15 and 30°, their productivity reaches 10,000 tons / hour [13].

Foreign analogues of steeply inclined conveyors without intermediate crushing on running supports with partitions on a belt and the tubular conveyor of the "Fleksovol" (USA) corporation provide transportation of rock mass with a maximum piece size of up to 400 mm [14].

A steeply inclined double-belt conveyor manufactured by Paakkola Conveyors Oy [24] transports crushed ore between two belts: the lower belt is load carrying, the upper belt presses the transported material to the lower belt. The bottom belt forms a gutter with three-roller supports with an incline angle of side rollers of 30°. The top belt presses the ore to the load-carrying belt using a special swing spring clamping mechanism (a system of pressure rollers).

The presence of a pit side put in the design position is necessary for the arrangement of the stationary reloading point (SRP) with the installation of a steeply inclined conveyor. SRP can be equipped with crushing and screening equipment and storage bunker. A storage of rock mass should be placed with its overload by an excavator or a wheel loader in the absence of a storage bunker near the SRP.

According to S.P. Reshetnyak [27] the most promising for rocky overburden of medium firmness are screw-toothed crushers with which the SIC-270 is equipped at the Muruntau open pit mine. They are compact and have a relatively small mass. However, the main reason for the downtime of the SIC-270 is related to failures in the operation of this crusher.

2. Reloading equipment from trucks to conveyor

Unloading of dump trucks into the bunker can be carried out both with a dead-end turn, and through. Reloading can be provided both on the lower horizon of the conveyor installation and on several concentration horizons. The crusher, the screen and the storage bunker can be located in the body of a pit bank. Otherwise, it is necessary to provide a plate feeder for transferring rock mass to the crusher and racks for unloading dump trucks [10].

A device for unloading dump trucks into a bunker is known, which contains a swivel bridge connected to the bunker hinge, a rigidly mounted counterweight on the swivel bridge, supports, pedals for interacting with the wheels of the car, levers driving the swivel bridge, guides for the dump truck wheels and the conveyor [Pavlov , A.Yu., Rogach, M.S., Klubnichkin, E K., Ivanova, E.E., & Propletin, A.P. (1993) Device for unloading dump trucks into a bunker. Patent number 880931, USSR].

The disadvantage of this device is a limited number of dump trucks, which can be simultaneously discharged into a storage bunker, which reduces the performance of the conveyor. In addition, there is a significant chance that the dump truck will leave the lever after pressing it and closing the bunker lid. Repeated arrival of the dump truck in reverse for unloading is not possible due to the presence of a lever. Thus, it is necessary to provide sufficiently wide platforms for the possibility of reversing the dump trucks while using this device.

A number of designs of reloading points with drive beams are known [Menshikov, B.A., & Sisin, A.G. (1978). Bridge for dumping dump trucks. Patent number 606796, USSR.]. Their operation is as follows: the loaded dump truck passes over the bunker along the turning beams, unloads on them, after which the beams rotate, thanks to which the rock mass from the surface of the beams falls into the bunker.

However, the drive of beams requires additional energy consumption for their rotation. Also, the beams on which the dump truck is moving must be of such a design as to withstand the weight of the vehicle, the impacts of the rock mass, correctly rotate and return to its original position. In addition, there is a risk of failure of the stoppers, which may lead to the slide of a dump truck from a track.

According to the proposed device, the exclusion of maneuvering of dump trucks and the loss of time for this is achieved by ensuring the through passage and unloading of dump trucks in a given mode of continuous technological transportation line, especially rocks on deep horizons of existing open pit mines.

The task is solved by the fact that in a known device for unloading rock mass from dump trucks to a conveyor there is a bridge with a bearing element on the rotary supports and differs in that after passing of a dump truck, the rock is unloaded onto the rotary bridges that are connected to the beams by hinges (basic bearings) located perpendicular to the beams on which motor vehicles are moving and ensure their opening due to the weight of the rock mass. In this case, counterweights serve as a barrier fence, are located on both sides of the beams on the outer side of the passage, and ensure the straight-line movement of dump trucks of the corresponding carrying capacity.

Figure 1 shows a device for unloading dump trucks onto a steeply inclined conveyor on one side of a bunker.

a *b*

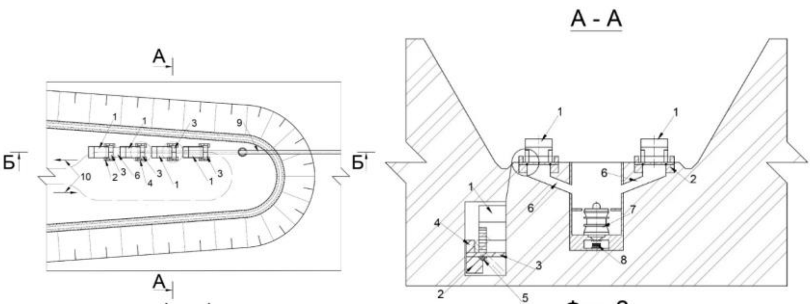

Figure 1 - Through point of unloading of dump trucks in design a and section *b*: *1* - dump truck; *2* - enforced concrete support beams; *3* - unloading bridges; *4* - counterweight fences; *6* - ore pass; *7* - cone crusher CKC-1500/180; *8* - plate feeder; *9* - steeply inclined conveyor; *10* - direction of dump trucks movement

A pick-up truck loaded with rock dump truck 1 on reinforced concrete beams 2 arrives at a reception point with an accumulation bunker to unload between the barrier fences-counterweights 4 onto the swivel bridge 3 and stops with the possibility of unloading onto the nearest swivel bridge 3, which is located behind the dump truck 1. After unloading, the rock under the action of its weight draws the rotary bridges in a horizontal plane around the hinges of rotation 5 (plain bearings) with their resolution in the open position, and rocks get into the ore pass 6. Next, barrier fences-counterweights 4, under the action of their weight, return to their original position and close the pivot bridges 3, after which the cycle of unloading dump trucks 1 is repeated.

After passing the rock through the discharge bridges 3, it passes for crushing through the ore discharge 6 to the cone crusher CKC-1500/180 7, after which it is reloaded through plate feeder 8 to the steeply inclined conveyor 9, which is transported to the surface for further processing.

The main advantage of simultaneous unloading up to 4-5 or more dump trucks is the constant full loading of the conveyor belt, which, in contrast to the existing unloading points with a dead end reversal of dump trucks and the simultaneous unloading of no more than two, guarantees the development of the design performance of the CCT complex in practice. Maneuvering loaded dump trucks at the transfer point constantly loosens the ground of the site base and increases the additional costs of its planning and compaction by rolling, which also increases the forced downtime of the operated conveyor lifts.

The use of a device for unloading rocks into a bunker with a through passage of dump trucks reduces the duration of the voyage of a dump truck by reducing the time of the unloading cycle, and also provides simultaneous unloading of several dump trucks, which will increase their productivity. In addition, reducing the parameters of the reloading point decreases the amount of mining and capital operations during its construction on the deep horizons of the open pit mine.

The introduction of a device for unloading rocks into a storage bunker with through-passage of trucks in the conditions of iron ore open pit mines in Kazakhstan will provide a total economic effect of 30-100 million USD while using dump trucks with a carrying capacity of 130-136 tons.

3. Reloading from a conveyor to in-pit railway transport

Deep iron ore mines of Kazakhstan are characterized by an ever-increasing depth of mining, the advancement of the front of mining on overburden and minerals. This in turn leads to the separation of the operating pit side, which directly affects the increase in the overburden volume.

The question remains of the application of a CCT with a combined truck-conveyor-railway type of transport for them. The combination of this type of transport requires the development of fundamentally new technical solutions for handling equipment to ensure the increase in ore productivity while reducing excavation of overburden.

Thus, the specialists of the Novokramatorsk Machine Building Plant (NMBP) proposed a set of equipment for the central processing room consisting of a crushing and reloading point, an inclined part of a steeply inclined conveyor (SIC), a horizontal part of the SIC and a loader stacking machine rocky LSMR-350, a warehouse conveyor WC-3500 (nkmz.com) . The principle of operation of the transfer device is as follows: after the rock mass is lifted to the surface by a steeply inclined conveyor, reloading to the warehouse is conducted with transfer to the stacker loader followed by loading onto the railway transport or stack.

The load-carrying belt of the warehouse conveyor lifts the load to the place of reloading to the conveyor of the loader arm of the loader-stacker. The belt is returned to the rollers of the warehouse conveyor through the deflecting drums after unloading. The main disadvantage of using this device on the deep horizons of the open pit mine is the significant width of the reloading site due to the location of the two-lane transport line along the loader-stacker, as well as the placement of the stack on the same platform.

A device that provides stacking load in piles and railway cars is known, containing a self-propelled trolley, lifting telescopically sliding rack, a lever mechanism, a conveyor consisting of six sections hinged between each other, each of which has an individual drive, including an electric motor. [A. USSR № 141811, IPC B65G 57/00, B66F 9/06, B65G 17/26. Stacker. / T.A. Skoda; declare 08/19/1960, publ. 01/01/1961, Byul. №. 19. - 3 p.].

A disadvantage of this device is that it is intended only for fixed stacking in rows of loads, for example, bags in railway cars, while it has a significant length of the dump part of the conveyor, which contributes to an increase in the width of the loading and storage area.

The closest to the technical solution is a loading and storage complex (LSC), which consists of a dump-loading machine (DLM), which moves along the railway line, a dump conveyor with an auto steel and a reversible conveyor of the DLM. At the same time, the DLM is designed for a 2-load of railway transport by dump carts without pulling them and dumping the rock mass into the stack of the ore stockpile. The design of the loading device does not contain any closures or slide gates in the areas of flow, and the sliding surface is protected by self-lining in the form of rock pockets [http://loginov.com.ua/stacionarnij-konvejer11.html].

The disadvantages of this device are sufficient complexity of the device and double-track loading of railway cars, which contributes to an increase in the length of the transport dumpsite and, accordingly, the volume of excavation of overburden.

Also close to the technological solution is a complex of cyclic-flow technology equipment consisting of a crushing and reloading station, an inclined part of a steeply inclined conveyor (SIC), a horizontal part of the SIC and a loader-stacker of rocky LSMR-3500, located on the railway track. At the same time, the load-carrying belt of the warehouse conveyor with the help of the autostella lifts the load to the point of reloading onto the conveyor belt of the loader arm of the loader-stacker. After unloading the belt through the deflecting drums returns to the rollers of the warehouse conveyor [http://nkmz.com/fileadmin/data/prospekts/NKMZ-KNK-web.pdf].

The disadvantage of the developed device is the significant width of the dump site due to the location of the two-lane transport line along the loader-stacker, as well as the placement of the stack on the same platform.

A fundamentally new technological scheme of rock overload with the stack location on the upper ledge was proposed considering the above-mentioned drawbacks, (Fig. 2). It is possible to provide reloading work in cramped conditions in a given mode of a continuous technological transportation line by introducing new elements and placing the ore stack on the upper scarp site, especially rock from existing iron ore open pit mines up to 600 - 800 meter depth.

The task is solved by the fact that in the known device for loading rocks into railway cars, including a self-propelled carriage, a conveyor of six sections, differs in that the design of the reloading device includes an inclined part of the reverse loader conveyor, an interstitial conveyor loader, as well as a stack dump, due to the interaction of the component parts of the reloading loader, the train is loaded, and up to 30% of crushed rock enters the upper scarp site and, it is stored in a pile and shipped by an EKG transfer excavator.

A device for reloading rocks from the conveyor 4 into dump carts 8, which are located on the railway track with the possibility of further transportation to the stack 11 using the inclined part of the conveyor 9 of the reversing loader 6, the inter-access conveyor loader 3 and the stack dump 10, while the steeply inclined conveyor 1 is arranged with racks with movable rollers 14 in the area of the drive station 13 and the inter-access conveyor material handler 3, which makes it possible to place steeply inclined conveyor as the mining front moves at an angle to the slope edge of the pit side, and the continuity of the process overload crushed rock is provided by interaction of the components of the device.

a *b*

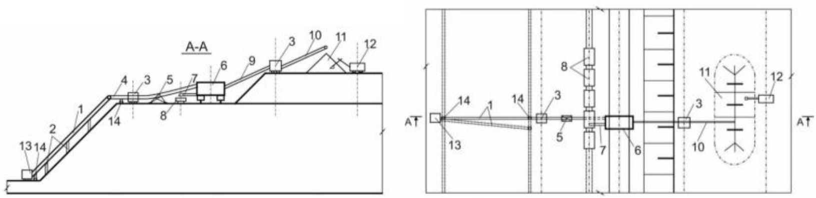

Figure 2. Equipment for non-stop unloading of rock mass from a conveyor and stacks to railway transport in a section *a* and design *b*: *1* - conveyor hoist; *2* - bearings; *3* - conveyor loader between pit banks (PBCL); *4* - horizontal part of conveyor hoist; *5* - autostella of height compensation; *6* - reverse loader; *7* - unloading console of reverse loader; *8* - dump cart; *9* - inclined part of a conveyor of reverse loader; *10* - unloading console of PBCL; *11* - stack; *12* - excavator; *13* - drive station; *14* - stands with movable rollers

The operation of the device is as follows:

The crushed rock enters the steeply inclined conveyor 1, which is driven by the drive station 13 and mounted on supports 2 and racks with movable rollers 14. The movable rollers 14 are placed on a rail track to provide a change in the angle of rotation of the steeply inclined conveyor. After climbing to the horizontal part of the steeply inclined conveyor 4, the rock is conveyed through the conveyor loader 3 and the height compensation autosteel 5 is fed to the reloader 6, mounted on a rail turn. Under the action of the blade of the reversing loader 7, the dump carts 8 are loaded.

Rock mass is further reloaded into the railway or into another type of transport, by which the rock is delivered to the surface after entering the pile 11.

The economic effect from the use of the device for handling rock from the conveyor to the railway transport is calculated by the formula

$$E=(Q_з-Q_д)\cdot(C/Q_д)=(25,81-23)\cdot(73/23)=8,9 \text{ million USD/year}$$

where $Q_з$ - the annual capacity of the steeply inclined conveyor using the proposed device for unloading rocks, tons/year; C - the total cost of operating a steeply inclined conveyor, million USD/year; $Q_д$ - the annual capacity of the steeply inclined conveyor with the unloading of rocks using an operating device, tons / year.

The use of a device for reloading rocks into railway transport allows reducing the transport and loading platform by 25-30 m, thereby reducing the amount of excavation of overburden rocks to 250-280 thousand m^3, rational use of excavation and transport equipment in the same line with decrease of loading time of dump carts and the formation of the stack.

4. Perspecive conveyor hoist

Professor A.Y. Dryzhenko and design engineer A.K. Dudcheko developed a special steeply inclined conveyor without rollers - a steeply inclined belt-carriage conveyor (SIBCC) for transporting rock mass with a piece size of up to 700 mm was first developed (A.S. USSR. 1803355, 1993. - published in bulletin number 11). However, it had low reliability. Computer simulation has shown that the side tapes at the time of pressing receive significant lateral deformation, which leads to its rapid wear. This design of SIBCC has been improved [28].

It is possible to hold the large-scale rock mass on the traction belt under the force of its weight while driving and thereby significantly increase the reliability of the transport process with the new design scheme of SIBCC.

The problem is solved by the fact that in a known design of a steeply inclined belt-carriage conveyor, which includes a housing, a load carrying belt, a leading and tension drums, arcuate traverse on the running supports, interconnected by chains, according to the invention, the mechanism for holding the bulk cargo on the belt is sectional, each section is made with the presence of two pairs of clamping levers on the corresponding cross bar and two side belt segments that are rigidly fixed to the inner surface of the joint levers closest to the traverse and made in the form of rotating elements, which are located symmetrically along the axis of the carrier tape with the possibility of closing in a circle above it.

In this case, the working branch of the open carrier belt with the load moves on traverses (running supports) in the middle of the closed chain contour, and the idle branch of the open carrier belt moves on the stationary lower roller support of each frame.

Figures 3-5 show the design of a SIBCC in longitudinal and transverse sections and a design view. The steeply inclined belt-carriage conveyor consists of a carrier belt *1*, which bends around the drive *2* and tension *3* drums, shutters with guides *4*, on which arc-shaped traverse *5* is mounted, interconnected throughout the whole chain by chains *6* with driving gears *7*. Traverse *5* is able to move along the guides *4* on the rollers *8*. On each traverse *5* on both sides of the carrier belt *1*, which overlaps them, two unequal arms 9 are hingedly mounted. To the inner surface of adjacent unequal arms *9* near traverse 5 symmetrically to the longitudinal axis and the carrier belt on both sides rigidly fixed belt segments *10* which are shown as rotating elements on hinges *11* in a clamping of the carrier belt *1*.

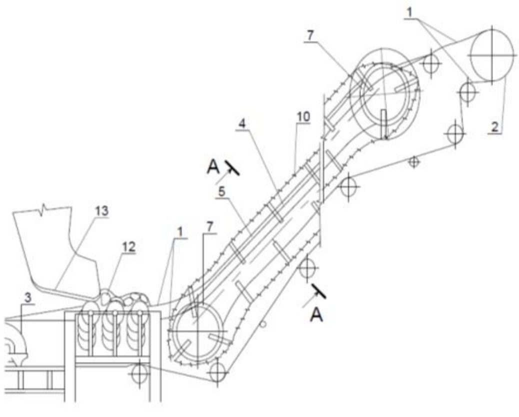

Figure. 3. Design of SIBBC in a longitudinal section

The operation of the nodes of the design of the steeply inclined conveyor is as follows: the movable carrier belt 1 passes through the tension drum 3 and lies on the crosshead *5*, which through the chain *6* captures the other crossheads. Bulk material *12* feeder *13* is loaded on the carrier belt 1, which moves with the necessary speed to ensure a given performance. The partitioned mechanism for holding bulk material *12* on carrier belt 1 operates in this way. Loaded tape 1 under the influence of gravity bends and presses on the smaller shoulders of the levers *9*.

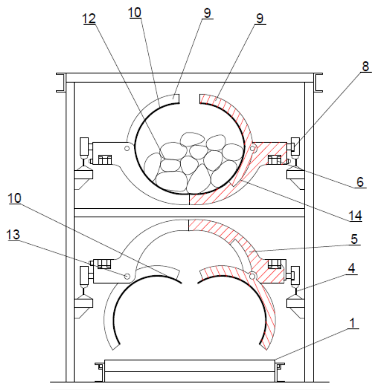

Figure 4. SIBBC design in a longitudinal section

Adjacent double-arm levers near crossheads *5* and rigidly connected with them belt segments *10* under the influence of the torque of rotational forces are transferred to the hinges *11* from idle position to the working state, when the smaller arms of the levers *9* are fixed to the supporting surface *14* of the traverse *5*. At the same time, the tape *1* with loose material *12* is lowered onto the cross arms *5*, and the holding mechanism section is closed above the belt *1*. Then the following sections are successively attached to the operation as the tape 1 moves with the bulk material *12*. Due to this, a pipe is formed from the carrier belt 1 and sections of the mechanism for holding the bulk material *12*, which in the closed space on the belt 1 moves along a steep incline and passes into a horizontal discharge position. Here, the side sections of the load holding mechanism are opened, the carrier belt *1* with loose material is released from them and is discharged into the receiving bunker.

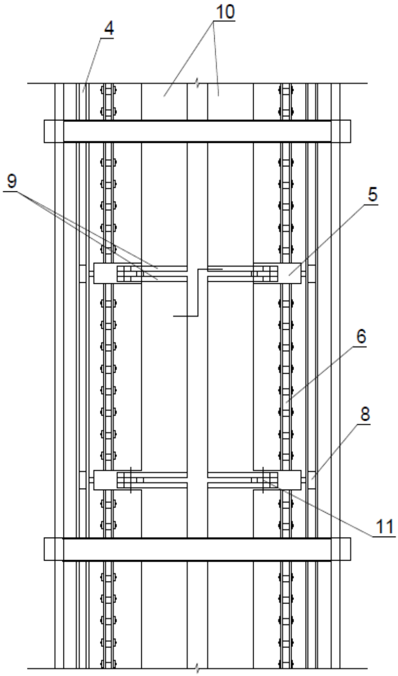

Figure 5. SIBBC design in a plan

At the same time, the technical result can also be obtained due to the full loading of the operating CCT complexes with crushers of large crushing without transferring them to the deep zone of the operating iron ore open pit mines, from working horizons of which the large-scale rock mass will be transported by steeply inclined belt and carriage conveyors, which ensure the shortest possible distance by car dump trucks and significant economic effect.

So, for the conditions of the Kacharsky open pit mine, the proposed design of steeply inclined conveyors will allow them to be loaded at intermediate horizons and build up individual rates in depth after 45-60 meters.

Foreign counterparts of steeply inclined conveyors without intermediate crushing on chassis supports with partitions on a belt and the tubular conveyor of the corporation "Fleksovol" (USA) provide transportation of rock mass with a maximum piece size of up to 400 mm. The proposed steeply inclined conveyor is designed for transportation of rock mass with a maximum piece size of up to 700 and 900 mm with a pit angle of 40 and 30 degrees, respectively.

Conclusions:

1. The construction of reloading points with a through passage over the bunker on the deep horizons of the open pit mine will reduce the volume of excavation of rocks, thereby reducing the cost of mining by 10-30 million USD. In addition, by reducing the cycle time of unloading dump trucks, diesel fuel consumption will be reduced by 100-200 thousand liters per year or more;
2. According to a number of researchers, the most promising are steeply inclined conveyors with clamping tape of the “snake sandwich” type, operated in the USA and at the copper mine Maydanpek (Serbia).

SIC-270 steeply inclined conveyor with clamping belt was put into operation in 2011 At the Muruntau open pit mine, manufactured at PJSC "NKMZ". It has no analogues in the world by the lifting height, performance, operating conditions. The initially declared annual design capacity of 16 million tons of ore was reduced to 13 million tons (reduced by 18.75%). Actual annual volumes for the first four years of operation did not exceed 10.7 million tons. The coefficient of development of the design capacity of the complex averaged 82%, actually 67%, which again confirms the need to increase dump trucks simultaneously loaded into the receiving bunker from 2 to 3-5 or more through the implementation of a through point of unloading.

A steeply inclined two-belt conveyor manufactured by the company Paakkola Conveyors Oy transports crushed ore with a grain size of 0-80 mm to a lifting height of 124 meters.

A steeply inclined belt conveyor FLEXOCON (FLEXOKON) manufactured by KMZKO was developed in the Russian Federation. The lifting height of the load is limited to 40 m. But in a number of projects for the technical re-equipment of open pit mines quarries, the lifting height of the ore using these conveyors is assumed to be 205 m.

The main difference of the proposed design of the steeply inclined belt-carriage conveyor is the possibility of a significant reduction and even exclusion of the primary in-pit crushing of rocky overburden. It was previously established that in this case, the high costs of its creation would be offset by lower costs for the preparation of overburden rocks for transportation by steeply inclined conveyors, a decrease in the volume of mining preparatory and mining capital works and their delivery dates.

References

1. **Drebenshtedt K., Ritter R., Suprun V.I., Agafonov Y.G.** (2015) World experience of implementing cyclic and continuous technology complexes with in-pit crushing: Mining journal. DOI: 10.17580/gzh.2015.11.17.

2. **Agafonov Y., Suprin V., Pastikhin D., & Radchenco R**. (2014) Problems and prospects of cyclic-and-continuous technology in development of large one and coalfields: Proceeding of the 12th International Symposium Continuous Surface Mining, Aachen: Springer, pp . 437-445.

3. **Galkin V. I., Sheshko,E. E.** (2014) Justification of effective use of special types of conveyors on open-pit mines: Mining information-analytical bulletin. Separate issue of I works of international symposium «Miners' week-2014», pp. 400-410.

4. **Trubetskoi K. N., Zharikov I. F., Shenderov A. I.** (2015) Improving design of open pit mine CCT complexes: Mining journal. DOI: 10.17580/gzh.2015.01.04.

5. Reshetnyak, S.P. (1998) Justification and development of cyclic and continuous technology schemes with in-pit mobile crushing-unloading complexes: Diss. Of doctor of technical sciences. Apatites, p. 423.

6. **Yakovlev V.L., Karmayev G.D., Bersenev V.A., Glebov A.V., Semenkin A.V., & Sumina I.G.** (2016) About efficient implementation of cyclic and continuous technology of mining on open pit mines: Physical and technical problems of mining. № 1., pp. 100-109.

7. **Karmayev G. D., Glebov A. V.** (2012) Selection of mining transport equipment of cyclic and continuous technology of open pit mines: Monograph. Yekaterinburg: IM UrO RAS, p. 296.

8. **Karmayev G.D., Bersenev V.A., Semenkin A.V., & Sumina I.G.** (2014) Technical and technologicalaspects of implementing steeply inclined conveyors on open pit mines: problems of subsoil use. № 4, pp. 154-163.

9. **Stoliarov V.F.** (2004) Poblems of cyclic and continuous technology of deep open pit mines: Monograph. Yeakaterinburg: IM UrO RAS, p. 232.

10. **Chetverik M.S., Peregudov V.V., Romanenko A.V**., et al. (2012) Cyclic and continuous technology on deep open pit mines. Development perspectives: Monograph. Kryvoy Rog: Dionis (FL-P Chernyavskyi D.A.), p. 356.

11. **Drizhenko A.Y., Kozenko G.V., Rykus A.A**. (2009) Open pit mining of iron ore of Ukraine: state and improvement ways: Monograph. Dnepropetrovsk: NMU, p. 452.

12. **Shapar A.G., Lashko V.T., Novozhilov S.M.,** et al. (2001) Unloading points during truck-conveyor transport on ore open pit mines: Monograph. Dnepropetrovsk: Plygraphist, p.139.

13. **Molnar V., Buchala V**. (2017) Desing of a feeding station in ecological transportation system of raw materials // Proceeding of International Multidisciplinary Scientific GeoConference SGEM 2017. V. 17, pp. 519-528.

14. CBC News. URL: http://www.cbc.ca/news/canada/sudbury/mining-labour-shortage-coming-in-next-10-years-1.1864383 (дата обращения: 12.10.2015). Mining labour shortage coming in next 10 year.

15. **Londono J. G., Knights P., Kizil M.** (2012) Review of in-pit crusher conveyor application: Austrailian Mining Technology Conference, pp. 63-82.

16. Duvall J. L., McCarthy R., Cooper A., Tutnbull D., & Morriss P. (2009) In-pit crushing and conveying – not a new idea, but a new reality: Phoenix. AZ U.S.A., pp. 21.

17. **Luchinger P., Maier U., Errath R.A.** (2006) Active front end technology in the application of a down hill conveyor // Cement Industry Technical Conference, pp. 20.

18. **Volotkovskyi V.S., Karmayev G.D., Drya M.I**. (1990) Selection of open pit mine conveyor transport equipment. M.: Nedra, p. 192.

19. **Russell A.** Carter Powerful Design Tools - and Common Sense - Can Control Conveyor Cost and Complexity Issues http://www.womp-int.com/story/2010vol05/story027.htm

20. **Bersenev V.A.** (1984) To a question of opening deep horizons of open pit mines during cyclic and continuous technology: Coll. Of sc. Works of IM MCM USSR. Sverdlovsk. №76, pp. 41-47.

21. **Kartavyi A.N.** (2009) Comparative assessment of steeply inclined of belt conveyors: Mining informational-analytical bulletin. № 12, pp. 98-113.

22. **Sanakulov К.S., Shemetov P.A.** (2011) Development of culic and continuous technology based on steeply inclined conveyors on deep mines: Mining journal. № 8, pp. 34-37.

23. **Grujic M., Stanisic Z.** (1995) Application of high angle conveyor at Maijdanpek open pit cooper mine: Mine planning and equipment selection. Rotterdam: A.A. Balkema Publishers, pp. 403-407.

24. Semenyuk A.A., Reshetnyak S.P., Baichurina N.I., & Sultanova N.R. (2015) Innovative technology of ore transport of Olenegorsk deposit using steeply inclined conveyor // Mining informational-analytical bulletin. Special issue № 56, pp. 413-420.

25. Steeply inclined belt conveyor FLEXOCON [Kindle Version]. Retrieved from https://www.youtube.com/watch?v=qAy7UHqASWI.

26. Wagon-conveyor system on ore mines: approach to optimization of costs and energy efficiency during mining of solid minerals (by materials of Thyssen Krupp) [Kindle Version]. http://e-mj.com/index.php/features/2834-cost-efficient-transport-for-open-pit-mines.

27. **Reshetnyak S.P.** (2015) Modern tendencies in designing cyclic and continuous technology on open pit mines: Mining informational-analytical bulletin. № 3, pp. 126-133.

28. Patent on invention RK № 32586 «Steeply inclined conveyor of tubular type for transportation of large scale rock mass» from 29.12.2017. by application № 2016/06.13.1 from 08.07.2016 / **Dudchenko A.K., Moldabayev S.К., Nikonenko V.P., Dryzhenko A.Y., Yussupov K.A.** Publ. in bul. № 26 (II).

POSSIBILITIES OF SUSTAINABLE MINING IN SERBIA MODERN WAY OF THINKING AND PLANNING

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Absract

The concept of sustainable means "meeting the needs of present generations without compromising the ability of future generations to meet their own needs." Sustainable development consists of three components: society, environment and economy. In order to achieve the objectives of sustainable development all three components must be fulfilled simultaneously. The sustainable technologies are part of the whole sustainable concept. The linear model of development seems not to be sustainable. The results are exhaustion of the natural resources and waste accumulation.

The Republic of Serbia has made National strategy for sustainable development defining sustainable development as target oriented, long-term, continuous, all including and synergetic process that has influence on all aspects of life and at all levels.

The world production of mineral raw materials has for some time been moving in the direction of mass production and large capacities in deposits that in most cases are very poor. Such orientation cannot completely eliminate a certain role and significance of small deposits. Exploitation of small deposits in the world is known as "small-scale mining" or "small volume mining" and it still exists due to several reasons. Essential reasons that favor keeping up of exploitation of small deposits are connected partly with the genesis of these deposits, and on the other hand with exceptionally favorable technical, organizational and financial possibilities in the course of their exploration. This in turn poses some new questions, sustainability of raw materials contained in small deposits.

Keywords: mining, sustainable development, legal regulations, small deposits

Introduction

The world of today has already been faced with a common responsibility and need to harmonize its development with the needs of people and nature as well as with the awareness that Earth has to be kept for the generation of today as well as for the future generations of humankind. This obligation that generation of today has, is to leave to its descendants at least as many chances for development as it had, and this results from the fundamental principle of moral justice, meaning that all human beings have equal rights to the most acceptable basic rights that on the other hand do not jeopardize the rights of the others. The generation of today has the right to have resources and healthy environment, but it must not jeopardize those same rights that belong also to the generations that will follow.

Sustainable development understands designing models that in a qualitative manner satisfy socio-economic needs and interests of citizens, and at the same time remove or considerably decrease influences which threaten or damage environment and natural resources. A long-term sustainable development concept understands continuous economic growth which besides economic efficacy, technological advance, more clean technologies, innovativeness of the society as a whole as well as responsible business dealings secures decrease of poverty, long-term better use of resources and advancing of health institutions as well as the quality of life and decrease of pollution to the level bearable for all who live in that environment, also preventing new pollutions and protecting bio diversities. One of the most important objectives of the sustainable development is making possible new working places and decreasing the rate of unemployment, as well as having influence on the decrease of gender and social uniqueness of marginalized groups, stimulating employment of young people and those with handicap, as well as other risk groups.

Sustainable development understands also harmonizing different developmental aspects and opposing motives contained in the programs of some sectors. In order to solve such conflicts political will and commitment are needed. Key assumptions necessary for the application of the sustainable development concept both of economy and society, as well as for its successful realization, are appropriate leadership, wide political, social and media support, as well as agreement of the society that it is indispensable to accept the concept. Also, strong political will, dedication from the Government and support from the public represent the most direct factors of success.

One of the characteristics of sustainable development is greater inclusion of the public in decision making to solve the problems of environment. It is not sufficient to have the political establishment declare its agreement, but public has to be stimulated, and above all it has to be informed and trained in time so that it could objectively have influence on the outcome of the problem solving that it is interested in.

The Republic of Serbia has made National strategy for sustainable development defining sustainable development as target oriented, long-term, continuous, all including and synergetic process that has influence on all aspects of life (economic, social, ecological and institutional) and at all levels.

The aim of the Strategy is to get into balance three key factors, i.e. three pillars of the sustainable development, and they are: sustainable development of economy, industry and technology, sustainable development of the society on the basis of social balance and protection of environment together with rational managing of natural resources. At the same time, the aim of the strategy is to connect all three pillars into a whole that will be supported by adequate institutions.

The strategy considerably contributes to harmonization of possible opposing objectives defined from different aspects of socio-economic development. It also helps to bridge the gap between policies of different sectors and to form the system of mutual advantages. This has been achieved as all key social groups took part in the making of the Strategy.

Mineral resources in the republic of Serbia

Republic of Serbia belongs to the group of counties with various, but not sufficiently rich mineral resources. As regards the diversity a significant place holds energy mineral raw materials, first of all coal, oil and gas. Then follow metallic raw materials such as copper, zinc, antimony, nickel and to that group belong also gold, silver, bismuth, cadmium, platinum, selenium, molybdenum, titanium, radium, palladium and other rare and precious metals. Also there should be mentioned nonmetallic mineral raw materials that have great application in industry and constructing, agriculture and for protection of environment (zeolite and others).

Metallic raw materials and industrial minerals

Most of the deposits of metallic raw materials are not very rich however they can contribute to the economic development of the Republic of Serbia. Copper is one of the economically most significant raw materials. Its deposits are concentrated mostly in the part of Carpatho-Balkanides, in eastern Serbia (metallogenic zone of Bor). Copper is being exploited in deposits with low metal content (0.3-0.4% copper): Majdanpek, Veliki Krivelj, Cerovo, etc.

Potential of metallogenic zone of Bor has been estimated on 8 Mt copper and 350 t gold in porphiric mineralization and 1.5 Mt copper and about 100 t gold in mineralization of sulphide massives. The most important area in the Republic of Serbia for the lead and zinc ore is metallogenic zone of Kopaonik.

Geologic reserves of lead and zinc ore have been estimated at 45 Mt ore with content of metal of about 6.3% or 140 Mt with content of 3.0-4.5% of lead and zinc. Antimony deposits are characteristic for Podrinje area, in western Serbia, the most important are: Zajaca, Rujevac and Stolice. A great concentration of nickel in deposits Rudjinci and Veluca, in the upper part of the river Morava the reserves being estimated at 17 Mt and content of nickel at 1.15% to 1.20%.

In the western part of the Republic of Serbia deposit called Mokra Gora has a great accumulation of ferronickel (milliards of tons with content of 26.5% iron and 0.7% nickel). Tin in the Republic of Serbia appears in the north-eastern part of the country, locations are Cigankulja and Iverak.

There is also gold in many deposits in Serbia It is separated as a by-product from the deposits in the zone of Timok where it represents additional value for the copper concentrate. In that zone are also epithermal vein deposits where can be found free gold in quartz or linked to pyrite (Lece).

Aluminum bauxite ore has limited reserves and it is connected to lime Dinaric terrains.

Deposits of industrial mineral in the Republic of Serbia are numerous and diverse. Undoubtedly, economically significant are raw materials that have been or are still exploited (barite, dolomite, kaoline, refractory clay, feldspath, white bauxite, zeolites, bentonite, ceramic and fireclay, construction and architectonic rock, natural mineral pigments, expanding clay, limestone, gypsum, diatomites, rocks for petrolurgy, magnesite, silicium raw materials - quartz send, quartzite, opalic silicium); raw materials whose reserves and quality have been defined, but have not been exploited unitl present time (fluorite and bor minerals); raw materials with conditionally-balanced reserves (phosphates, wollastonite, alunite, aluminum-silicates, vermiculite, granite, pyrophylite) and raw materials whose deposits may be expected to be in Republic Serbia (salt and mica).

Magnesite is referred to in connection with deposit Lisca in western Serbia, with horizontally elongated ore bodies of several hundred meters and depth that usually is over 100 m. Magnesite is linked with small quantities of dolomite, quartz and calcite. Near Bela stena, at the localities Piskanja and Pobrdjski potok recently have been found new extensions where borates are dominant (7 Mt with content of 35% to 39% borate). It is also worth mentioning a new project for exploitation of basalt at the Vrelo locality, near Kursumlija. Basalt fibres will replace asbestos which has known damaging effects. Planned annual production is 2.700 t of continual basalt fibres. In Republic Serbia there are three active cement factories - Beocin (1.2 Mt annually), Popovac (0.8 Mt annually), Kosjeric (0.5 Mt anually). Minera raw materials, marl and limestone are exploited near cement factories. Deposit Lipnica (gypsum) is also exploited for the needs of cement industry. Feldspath, mica and quartz are from deposit of pegmatite called Vidovacki krs near Prokuplje. Annual production is 50,000 t of feldspath concentrate, 36,000 t of quartz and 14,000 t of mica concentrate. Deposit of the quartz sand Rgotina is exploited as two open pit mines. Tuf and opal breccia in Katalenec are mostly use in the cement industry. Wollastronite deposit Jaram (or Duboka) is loctd on the eastern side of the Kopaonik granodiorite massive. The ore contains 60-70% wollastonite, 2-16% carbonate and 4-12% quartz. Although commercial prduction has not been strated, the tests show that wollastonite content is of adequate quality.

The problems are due to resources that are not used according to a plan and are unsustainable. There is no analysis of the state and degree of exploration of natural resources according to species up to the present date. There is no space layout, diversity, volume and quality and there are no balance categories. Sector objectives include:

harmonization of regulations dealing with resource management with EU legislature;

making and applying strategic documents for use of sustainable resources and goods;

finding new deposits and rational use of the existing natural resources by applying clean technologies, integrated preventing and controlling pollution;

examining the validity of remaining mineral raw materials in waste banks and waste dumps of active and closed up mines in view of economic aspects and aspect of environment protection.

Fossil fuels

Lignite makes almost 90% of the energy resources of the country, while oil and gas make the remaining less than 10%. Republic of Serbia does not have sufficient reserves of coal, and those that it has is mostly lignite of poor quality. Lack of resource may be significantly limiting factor for energy development when relying on domestic resources as due to the fact that economic reserves of lignite in Kolubara mines are 2.2 Gt and in Kostolac 700 Mt, and annual exploitation of lignite is 37 Mt. if it is at the present annual level. Reserves in the Kolubara and Kostolac basin guarantee some 55 years of exploitation at the present level of operation. Significant data is that only one of Kolubara open pit mines participates with 32% of mined coal in the production of electric energy in Republic Serbia. Republic Serbia does not have at its disposal any significant reserves of oil and gas. Existing deposits are in the Pannonian basin

Annual production is about 0.7 Mt raw oil which is 17% of what Republic of Serbia needs, since annual consumption is about 4.13 Mt Further directions in the sector of oil and gas depend on the results of geologic explorations that are done in order to find new deposits and to revitalize the existing. Mineral raw materials (oil shales) have not been balanced due to uncertain economic and ecologically unacceptable technologies.

Most significant concentrations of uranium are connected to the granitoid complexes of Cer, Bukulja etc.

These are the key problems: too much relying on the use of fossil fuels, disproportion between geological and reserves of coal, oil and gas to be exploited. This points to possible uncertainty in disposal of these reserves in the oncoming period.

Sector objectives include:

exploitation of unsustainable natural resources in the manner that provides best long-term energetic security and least degrades environment not damaging health of people;

finding new deposits and sustainable use of non-renewable natural resources most effectively and in the most rational manner;

applying up to date methods when planning exploration of oil and gas in domestic area, also using best available technology for disposing of exploration waste material, modernization of refining capacities in order to satisfy present and planned demands as regards quality of products, distribution and selling oil derivatives, also applying all ecologic regulations that pertain to refining, distribution and selling of oil derivatives;

replacement of fossil fuels with sustainable resources of energy, applying certain economic measures.

It is necessary to develop long-term strategies in order to satisfy energetic needs, that is, exploitation of energetic mineral raw materials, to estimate influence on environment, cleaning the existing waste banks decontamination of water, reconstruction of damaged dams and collectors, and to revitalize the polluted soil.

Sustainable mining and world experiences

Trend in world production of mineral raw materials has for some time been moving in the direction of mass production and large capacities in deposits that in most cases are very poor. Such orientation cannot completely eliminate a certain role and significance of small deposits. Exploitation of small deposits in the world is known as "small-scale mining" or "small volume mining" and it still exists due to several reasons. Essential reasons that favor keeping up of exploitation of small deposits are connected partly with the genesis of these deposits, and on the other hand with exceptionally favorable technical, organizational and financial possibilities in the course of their exploration. Small deposits require relatively short time needed for exploration and modest investments during exploration and exploitation. Possibility to engage local labor and relatively fast manner to secure certain quantities of high quality raw materials are also in favor of keeping successfully up such a manner of exploitation in many countries in the world, especially developing countries. In Republic of Serbia during former explorations there have been discovered a large number of small deposits of various raw mineral materials. Some of the deposits are being subjected to some kind of exploitation, however a large number of deposits are partly or completely explored and if suitable economic analyses are to be applied, may start exploitation. Also, it is necessary that all problems belonging to the exploitation of small deposits be in agreement with legal regulations.

Today we hear very often a phrase “sustainable mining”. This seems to be contrasting in, the meaning as mining in its very nature involves the removal of a non-renewable resource. Nonetheless, sustainability and mining are not necessarily antithetical. We think that it may be a solid business case for good management of environmental and social issues, which often offers a more efficient operation while reducing the risk of legal action and helping companies to prepare for future regulatory changes. Meanwhile, investors are beginning to examine companies’ levels of social responsibility in an effort to reduce their own financial and reputational risks, MacDonald (2006) and Horowitz (2006) [1, 2]. Similarly, some customers have shown increasing interest in purchasing products from sources that have demonstrated good social and environmental practices. Governments are also showing concern about the long-term consequences of mining, as poor environmental or social performance can translate into economic and political problems. Another stakeholder group that has strong opinions about the mining industry is the general public. Pressure groups, including some non-governmental organizations, are increasingly using the internet to draw international attention to environmental incidents, while local communities may protest against and impede or even shut down mines Hilson (2002) and Hilson (2004) [3, 4].

In response to this trend, the mining industry has shown increasing interest in environmental and social sustainability in recent years. Within the framework of sustainable mining a very important part of mining industry may prove to be small scale mining.

Small scale mines: definition and characteristics

In present day literature we can find the following definitions by several authors, thus Artisanal and Small-Scale Mining (ASM) are formal or informal operations with predominantly simplified forms of exploration, extraction, processing and transportation. ASM is normally low capital intensive and uses high labor intensive technology. ASM can include men and women working on an individual basis as well as those working in family groups, in partnership or as members of cooperatives or other types of legal associations and enterprises involving hundreds or thousands of miners Chaulya (2004) [5, 6].

Artisanal and small-scale mining (ASM) is the oldest form of mining. It is estimated that up to 20 million people in at least 30 countries are active in ASM and a further 100 million people depend on the sector for their livelihood. In various countries, small-scale miners are known by terms such as galamsey, orpailleurs, ubeshi or wabeshi, panners, diggers, garimperos, pirquineros and pocket miners Quiroga (2002) [7]. The table 1. shows selected countries, number of mines and estimated employment rate.

Table 1

Small-scale mining operations and employment totals in selected developing countries Hilson (2002) [3]

Country	Number of mines	Estimated employment
Argentina	670	5,800
Bolivia	1000	70,000
Brazil	10,000	1,000,000
Burkina Faso	35–60	60,000
China	250,000	3,000,000
Colombia	9600	100,000 –200,000
Ghana	400–700	30,000
Guyana	3500	10,000–20,000
Haiti	50	4,500
India	10,000<	500,000
Indonesia	77,000	465,000
Mexico	2000	20,000– 40,000
Pakistan	2400	90,000–370,000

Peru	1550	20,000
Philippines	700	200,000
South Africa	5500	15,000–20,000
Tanzania	4000	450,000–600,000
Viet Nam	500–600	35,000 –40,000
Zambia	200	30,000
Zimbabwe	2000–5000	50,000–350,000

ASM is a production system that allows local people to earn cash income. However small, it provides an accessible livelihood for poor and marginalized peoples, often complementing other livelihood activities, such as agriculture, animal husbandry and hunting, and serving as a support operation in times of environmental or economic stress.

A number of attempts have been made to define 'small-scale mining' in an international context, according to criteria such as mine output, labor productivity, organization of the enterprise, and levels of technology, e.g. provide a broad definition of small-scale mines, suggesting that they are generally those mining operations that are both labor intensive and low-tech. Other authors, go one step further, arguing that small-scale mines, whilst low tech, can be placed into one of two broad categories: 1) high-value mineral extraction, in particular gold, silver, and precious stones; and 2) quarry mining or simply the removal of industrial minerals and construction materials on a small scale. More precise definitions have also been adopted defining a formal small-scale mining firm in terms of number of employees, size, earnings, and labor productivity and production capacity. In fact, some countries have even formulated their own definitions (see Table 2) for the purposes of including small-scale mining in national policies.

However, as Solomon (1997) [8] explains, none of these definitions has received universal recognition because:

Terms such as 'artisanal' (a label typically used for illegal mining) and 'small-scale' are used loosely in different contexts by different people.

The trade-off between capital employed and labor is generally not taken into account.

The relationship between production and value varies from sector to sector (e.g. high tonnage/ low value for commodities such as sand vs. low tonnage/ high value for diamonds, etc.).

The most easily recognizable distinction - the degree of formality - is not necessarily related to size.

Table 2

Definitions of small-scale mining in selected countries [3]

Country	Definition
Brazil	Individual or collective extractive work, using rudimentary methods, manual devices or simple portable machineries — for immediate exploitation of a mineral deposit which, by its nature, dimension, location and economic use, can be worked, independent of previous exploration work, according to criteria set by the National Department of Mineral Production.
Burkina Faso	Activities conducted on ore bodies or deposits by natural or legal persons using traditional techniques or low mechanization levels.
Chile	Mining operation by a person who works at a mine property or process plant by himself and with or without the family support, a maximum of five salaried workers, or by legal society with no more than six partners.
Ethiopia	Small scale mining means mining operations to be designated as such by the Minister of which the annual run-of-the mine ore does not exceed a certain limit, which differs from one mineral product to another and on the nature of mineral occurrence.
Ghana	Small-scale mining refers to operations of individual Ghanaians or organized groups of Ghanaians (4–8 individuals), or cooperative of 10 or more individuals, which are entirely financed by Ghanaian resources at certain limit, and carried out on full time basis using simple equipment and tools.
Mexico	Mines whose annual production values do not exceed US$3.0 million, provided that their daily production capacity is less than 200 tons per day (for metal mines) and 300 tons per day (for non-metal mines).
Suriname	The exploitation of mineral deposits which, due to their mode of occurrence and their size, can be mined economically by simple means and techniques.

On the other hand, Hilson (2002) [3,4] says that small-scale mining per se can be distinguished as mining activity involving the application of low, intermediate technology and universal prospecting methods, and requiring low initial investments and high employment per-unit output. More specifically, each operation exhibits, inter alia, the following:

An involvement with the extraction or processing of precious metals/gemstones on alluvial deposits or orebodies situated at or near the surface;

Intense labor activity with fewer than 15 workers per operation;

Remote and isolated location - situated well out of the reach of urban centers;

Rudimentary techniques and low technological aware- ness;

Low degree of mechanization and a chronic shortage of capital; and

Low levels of environmental, health and safety awareness.

Further, from a technological perspective, the activity encompasses a broad range of operations, from informal micro-scale mining that utilizes almost exclusively manual techniques to extract high value minerals from alluvial deposits and outcrops, to small organizations of semi-skilled entrepreneurs who employ mechanization strategies and semi-advanced mineral processing techniques.

Mining of small capacities, disregarding the differences in defining the mentioned criteria is mostly distinguished by the following characteristics:

relatively low degree of deposit prospecting and of the knowledge of mineral material quality,

nonsystematic exploitation due to lack of data on deposit,

low capital investments due to significant participation of living labor,

relatively low degree of utilization of the mineral material when exploiting and a high degree of dilution,

unfavorable working conditions, especially in underground exploitation,

inadequate social care and insufficient safety of workers,

low tax revenues for the government, etc.

However, it is also necessary to single out those characteristics of small capacities mining that are regarded as their advantages:

short prospecting period and investing of relatively meager financial means,

possibility to build fast mining capacities and installations for mineral processing, with rather small investments and relatively small energy consumption,

equipment is often light and simple, also exceptionally mobile which is a great advantage especially when exploiting silt deposits of gold, precious stones and semi-precious stones, etc.,

possibility to employ local labor which effectively reduces unemployment in undeveloped regions,

smaller quantities of needed deficient mineral material may be relatively quickly secured,

mineral materials from such deposits are mostly of a high quality, and that is secured by way of various procedures of their preparation,

these mines cause far less negative results on the environment.

All negative characteristics are subject to changes for the better by introducing more modern technology, and that mostly depends on economic factors, that is, the value of the mineral material.

Small-scale deposits: exploration and opening

The initial phase of mining activities in the process of underground exploitation is called opening of the deposit. It is characterized by making a system of mine rooms with basic objective to secure communication between ore deposit and the surface of the terrain Beljić (2014) [9].

Depending on the conditions in which the exploitation is taking place during the phase of opening development we can recognize: different types of room openings, organizing forms, as well as characteristic ways of using the same. Here will be presented some of the usual ones: classification of the opening system, influential factors, as well as the special objectives that are realized by this exploitation phase. Generally speaking, the fact that exploitation conditions are becoming drastically complex may serve as the basic characteristic of the opening, and that can be noticed in several aspects such as: utilization of the existing ore deposits, content reduction of useful components in ore, changeable market conditions when talking about exploitation of metallic mineral raw material.

The consequence of the mentioned is difficulties in business deals as well as aggravation of total economic effects of exploitation. It can be said that underground exploitation is taking place at greater and greater depths, especially in localities where there are, according to various criteria, rich ore deposits. On the other hand, there occurs increase in the quantity of mass in the existing deposits, and that has been made possible by application of new technologies.

There are more and more mine openings with small-scale and medium-scale annual production capacities. Thus established flexible production units have the possibilities to deal in their own way with problems caused by the changeable business conditions. Specific organization plans starting from those that make possible production of some ten million tons of ore annually, and then mining at the depths greater than 2,000 m to small-scale mines with few employed, practically at the level of the family manufacture, all these mean application of various technical and technological solutions. So the manner in which the mines are opened as well as preparations give a wide scope of solutions. What solutions are to be developed and used depend on a number of influential factors.

Mining practice knows general classifications of the opening systems. However, as much as these classifications are useful and applicable, the fact is that every mine or potential deposit are specific to a significant degree and the schematized approach for the solving of problems cannot always be applied. It seems necessary to point out that in literature there are very different classifications by which the system is described, but depending on the criteria taken into consideration. Also, very often the classifications given by various authors are in fact similar, or differ in details only. Criteria and classifications that have been pointed out represent specific selection and systematization and are based on a large number of data from literature.

Opening of ore deposits has to be in agreement with application of effective means for transport and mining, transport of people, pit servicing, drainage, ventilation etc. In other words, by opening system are secured functioning and exploitation of the mining mechanization.

From the viewpoint of application of transport mechanization, the mine may be opened and equipped in such a manner that transport and haulage are executed by one means of transport. In this case, as a rule, are used transport belts and pit trucks. Technological scheme is very simple and effective, namely there is no need for discontinuous transport and reloading of the ore. The construction of the entire system is extremely simple. The restrictions of such an approach are reflected in exploitation depth where it may be effectively applied, the depth is around 300-400 m.

Combined means are applied. One or more kinds of means of transport deliver material to main haulage rooms, where the reloading is done. Haulage is performed by another kind of means of transport. The scheme has wide application, it is flexible and there is no restriction by depth of occurrence of the deposit. Negative side of this is discontinuous transport, larger number of rooms to be opened and accordingly complex construction of the system.

A great number of factors have influence on the solving of problems during opening. In order to have a more effective insight into the problems they were classified according to their nature and characteristics. According to these criteria four groups have been formed and shown in the table 3 [9].

Table 3

Classification of factors by nature and characteristics [9]

Natural-geological factors	Technical technological factors	Infrastructural factors	Economic factors
Location of deposit in Earth's crust	building speed, term for exploitation start up	expenses for construction of opening objects	transport situation
Depth of occurrence	production capacity	expenses for equipping opening rooms	infrastructure of transport on surface
Strike of the deposit	mining methods	haulage expenses	energy transfer
Inclination angle of the deposit	efficiency of transmission of the object	maintaining expenses	population on the surface of terrain
Number of layers or ore bodies and their mutual position	form and quantity of available energy	ventilation and drainage costs	water supply
Morphology of the ore bodies	capacity and speed of haulage	transport costs	supplying material for underground mine operation
Deposit limit reserves, quality, quantity and distribution of useful component	ventilation system	ore losses as consequence of type of opening	
Special geological features, physical, Mechanical, hydro-geological, structural	drainage system	time needed for horizon preparation	
Tectonics of the terrain and of the deposit	manner of transport and haulage	value of the terrain over the pit	

Socio-economic benefits

Small-scale mining has brought both major problems and immeasurable socio-economic benefits to a number of developing countries. In recent years, however, the bulk of research has been devoted to analyzing the negative aspects of the industry. As documented in a now burgeoning literature, a number of environmental, health and safety problems persist, each of which adversely impacts human quality-of- life, mainly because most operations are low-tech and employ uneducated and poverty-stricken workers. Sufficient effort has been made to make the world aware of these problems, which include, inter alia, excessive pollution, chemical contamination, inadequate mine safety design, and disease, but in the process, the socio-economic importance of the industry is increasingly being overlooked [3].

We think that it might be very beneficial to take into consideration the impact of contribution of small scale mining in our country. Mostly because of the socio-economic significance of small-scale mining in developing countries that proved to be of good results in low and poor surroundings. Also, to outline some key measures that could help resolve many of its current problems and improve the sustainability of operations. It is important to clarify that for decades, the extraction and processing of minerals on a small scale has provided millions of people from a great number of developing nations with economic security, and in the process, has helped to alleviate poverty where other industries could not. Small- scale mining has also produced sufficient revenue and foreign exchange earnings for the governments of these countries, and continues to produce close to one-sixth of global mineral output. Xia Cao (2017) [8, 9, 10].

To refer to the situation in our country, we think that it is important to mention the following facts: According to the findings of the World Bank who financed the 'Study of the Master Plan for the Development of the Mining Industry in Serbia' (Japan International Cooperation Agency, 2007-2008), the mining industry of Serbia participated with about 2% in the gross national income. The opinion of the Japanese experts was, and they also published, that participation of the mining industry in the GDP could be about 10% [11].

One of the directions of the mining industry development in our country could be also the opening and operations of the so-called small-scale mines. Our country has at its disposal potentials for such exploitation. Ore mining in small-scale mines exists all over the world and we think that it could be more present even in Serbia. Of course, we mean that the activity should strictly respect regulations. Since a good institutional and legal framework is necessary in order to proceed with this type of mining, in this study we have given a short review of the place, role, significance as well as the controversies that go with this type of exploitation, as well as the review of the legal solutions foreseen by our legal regulations.

In order to clarify the socio- economic importance of small-scale mining in developing countries, we have to draw heavily from the published literature. Some of the major problems in the industry are then briefly examined to illustrate the challenges faced by governments and policy-makers in promoting a more sustainable small- scale mining sector. The article concludes by outlining some key steps that could lead to improved sustainability. For the purposes of the discussion, sustainable (small-scale) mining is recognized as activity in the sector that is continuously making improvements in social, economic and environmental areas Jenkins (2006) [12].

Conclusion

In the world of today where great natural resources have been mostly used up without great respect and regard for the future it has become clear that we have to turn to the small resources which until present have been considered as not “worthwhile” exploiting.

Although there is no strict international classification that defines the term small-scale mines, the significant potential can certainly be found in deposits that are not very interesting for the big mining companies. Also, as previously mentioned, in the Republic of Serbia the term 'small-scale mines' is not clearly defined, however the fact that there is a great number of such mines, as well as the potential deposits means that they could be classified into this category. If we take into account all necessary documentation which the current law demands, we may conclude, that it is not suitable for the scope and significance of different kinds of work that are being carried out in small-scale mines.

Thus, it is obviously of utmost importance to make some changes in the general overview as well as in the local policies of what are important and necessary steps to be taken in order to improve things.

However all steps that are of the utmost importance must be taken in connection with and relay on the National Strategy. This is necessary due to harmonization of national regulations dealing with resource management with EU legislature. All this refers to new deposits and rational use of the existing natural resources by applying clean technologies, preventing and controlling pollution.

Bibliography

1. **Karen MacDonald** Section 1: Environmental Management, Legal and Policy Issues in The Mining Industry, Journal of Cleaner Production 14 (2006) 227-229
2. **Leah Horowitz** Section 2: Mining and Sustainable Development, Journal of Cleaner Production 14 (2006) 307-308
3. **Gavin Hilson** Small-Scale Mining and its Socio-Economic Impact in Developing Countries, Natural Resources Forum 26 (2002) 3–13
4. **Gavin Hilson, Oliver Maponga** How has a Shortage of Census and Geological Information Impeded the Regularization of Artisanal and Small-Scale Mining? Natural Resources Forum 28 (2004) 22–33
5. Recent Developments in Small-Scale Mining, A Report of the Secretary-General of the United Nations, Natural Resources Forum Vol. 20. NO. 3. (1996) pp. 215-225
6. S. K. Chaulya Improving EHS Management in India’s Small-Scale Mining Sector, Environmental Quality Management, Wiley Periodicals Inc. (2004) 65-80
7. **Eduardo R. Quiroga** The Case of Artisanal Mining in Bolivia: Local Participatory Development and Mining Investment Opportunities, Natural Resources Forum 26 (2002) 127–139
8. **Solomon, M.H.** Small and mid-scale mining in South Africa: beyond the rhetoric. Raw Materials Report 12(3) (1997) 23–30.
9. **Beljić Čedomir** Mali rudnici sa podzemnom eksploatacijom, od ideje do realizacije, Univerzitet u Beogradu - Rudarsko-geološki fakultet, Beograd (2014)
10. **Xia Cao** Policy and Regulatory Responses to Coalmine Closure and Coal Resources Consolidation for Sustainability in Shanxi, China, Journal of Cleaner Production 145 (2017) 199- 208
11. **Gluščević Branko, Lutovac Suzana, Beljić Čedomir** Contribution to Improvement of the Legalization of the Work Process of Small-Scale Mines in The Republic of Serbia, Underground Mining Engineering 25 (2014) 11-17
12. **Heledd Jenkins, Natalia Yakovleva** Corporate Social Responsibility in the Mining Industry: Exploring Trends in Social and Environmental Disclosure, Journal of Cleaner Production 14 (2006) 271-284
13. Nacionalna strategija održivog razvoja, Službeni glasnik RS, br. 55/05, 71/05-ispravka i 101/07

INFLUENCE OF MINING AND CONCENTRATION WORKS ACTIVITY ON LAND RESOURCES

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Abstract. The research provides assessment of current and longer-term consequences of iron ore open pit mining for land resources of adjacent areas. There are applied methods of analysis of fund materials; comparison of topographic sheets and special maps, visual observation, soil testing, laboratory analyses and statistic processing of data obtained. It is revealed that facilities of iron ore mining and concentration waste accumulation (dumps and tailing ponds) are destructive factors for the local lithosphere, dust chemical contamination being the basic one. The steps aimed at reducing negative impacts of technogenic objects of the mining and raw material complex on the environment are under study.

Introduction. In terms of the environment, iron ore open pit mining is one of the most harmful and destructive. Consumptive use of Kryvyi Rih region's ecosystems and resources for the last 140 years has caused enormous destruction of the local landscape, litho- and hydrosphere. Extensive mining of Kryvyi Rih iron ore deposits through the Soviet times has escalated since the establishment of the market economy and private property reaching 5.5 bln t of raw iron ore [1]. Owners' irresponsibility for anti-environmental activities and low environmental abuse charges provide the basis for the region's continuous exploitation and reduce prospective investment of resource-saving technologies to be introduced here.

The research is aimed at determining consequences of mining and concentration works' (GOKs) activity affecting Kryvyi Rih region land resources. To achieve this aim, solution of the following tasks is envisaged:

- studying basic stages of formation of modern ideas concerning the role of the environment in Kryvyi Rih enterprises' economic activity in terms of iron ore mining;
- providing characteristics of primary factors and consequences of GOKs' activity affecting Kryvyi Rih region's landscape and environment;
- analyzing available data on GOKs' impacts on the environment;
- conducting field and laboratory investigations of the influence of waste accumulation areas of mining enterprises on land resources;
- developing recommendations on improving the environment of technologically disturbed and polluted lands.

Formation of modern ideas on the environment role in the region economic activity. As is known, there are two generalized models of the technogenic type of the economic development in terms of the environmental-economic policy - *frontal economy and the environmental protection concept*.

The frontal economy was widespread in the world and in Ukraine in particular in the 1980s. According to this concept, all lands and natural resources were considered unlimited and inexhaustible. Both in theory and practice, the economic growth was based on two factors only - labour and capital, without considering any natural resources, amounts of their consumption and potential restoration. This approach was justified by the low level of productive force development and great potential self-regulation in the biosphere that caused no global changes so far.

Consequences of this economic stage for Kryvyi Rih environment included significant destruction of the surface relief and withdrawal of hundreds of hectares of agricultural lands because of unsystematic creation of many iron ore open pits and underground mines and accumulation of millions of tons of rocks in overburden dumps of open pits and waste dumps of underground mining. The local rivers Salsahan and Inhulets, the regional underground hydrosystem and land resources were seriously damaged.

The first damages of Kryvyi Rih region landscape and environment were caused by the mining enterprises of Rakhmanovo-Kryvorizke, Almazne, Pivdenne and Novokryvorizke associations created at the end of the 19th century in 1885-1886. In the Soviet times, the same principles of the frontal economy were guiding in escalating rich iron ore mining accompanied by creation of the mine administration and several underground mines. In 1950s-1970s, there were built large-scale mining and concentration works (YuGOK in 1955, CGOK in 1956, SevGOK in 1958, NovoKryvokizkyi in 1959 and InGOK in 1965) oriented on "poor" low-grade iron ore mining and concentration to obtain marketable ore.

Newly established GOKs multiplied the destructive impact of mining on the regional landscape and environment, these changes becoming irrevocable. Huge open pits and dumps, landfill sites of concentration wastes (tailing ponds) and intensive dust-gas emissions turned hundreds of hectares of mining sites into dead zones and powerful sources of dust contamination for adjacent lands. The consumptive attitude to the environment on this stage of Kryvyi Rih region economic development did not provide any nature-saving and restoration steps at mining facilities as the increased iron ore output was the only top priority. The mentioned approach resulted in numerous destroyed and polluted areas and greatly affected the regional biogeocenose.

Awareness of exhaustibility of natural resources, escalating environmental instability in industrial regions and acknowledgement of hazards of further application of the frontal economy made many world countries change their attitude to the planet's environment at the end of the 1970s. In 1972, in Stockholm, the Declaration of the UN Conference on Environmental Issues was adopted declaring that maintenance and improvement of the environment is an essential problem affecting people's welfare and the economic development of all world countries [2].

Consideration of nature laws in solving economic problems have gradually encouraged the transition from the frontal economy to ***the concept of environmental protection*** that requires economic entities' taking account of environmental consequences of production. Since then, in many countries, including Ukraine, there have appeared state structures of nature protection and accelerated legal activity on the issues of regulating resource use standards and procedures. Active international cooperation on environmental issues has begun worldwide [3]. In Ukraine, the law “On Environmental Protection” has been valid since 1991 [4].

Under *the environmental protection concept,* Ukraine has reached some environmental stabilization, yet there has not been any qualitative improvement as **the general technogenic type ideology** of the environmental-economic development has not changed. Economic interests, industrial acceleration and application of scientific and technological achievements to increasing profits remain of primary importance.

The economic development of the technogenic type is characterized by ***the externality effect*** when some negative environmental and economic consequences of the economic activity occur and corresponding economic entities are not responsible for the damages [5]. An example of this is any occurrence of harmful emissions into the atmosphere and pollutant discharges into water reservoirs, their consequences being evident not only in places of discharges, but also along the whole dispersion front with the wind and water currents. Damages are normally not compensated to aggrieved parties.

In 1981, following the USSR initiative, the UN General Assembly approved the Resolution “On Historical Responsibility of States for the Preservation of Nature for Present and Future Generation”. A year later, on October 28, 1982, 111 UN General Assembly Members adopted the World Charter for Nature [6] that fixed the dependency of human life on natural systems functioning.

Further evolution of the nature preservation concept resulted into that of ***sustainable social and economic development*** when the heads of 178 world states including Ukraine signed “**Agenda 21”** during the UN Conference on the Environment and Development (Rio de Janeiro, June 3-14, 1992) [7]. The indicated ideas were approved on the World Environmental Summit of 2002 in Johannesburg (South Africa) that formulated the modern definition of sustainable development comprising three components - economic efficiency, social equality and environmental sustainability. It is defined that **sustainable social and economic development** *is the one under which optimal satisfaction of people’s needs is achieved under con-*

ditions of using all possible resources in the way that generations to come will be able to satisfy their needs accordingly [3]. Therefore, in the modern formula of industry, **nature** (the environment) should go first followed by **capital** (economy).

Certain intensification of Ukrainian state institutions, business and community activities aimed at introducing sustainability ideas started in 2010 when Euro-integration became a priority of the country's policy. The state declared **its full support of sustainable economic and social development** that was confirmed by the Law of Ukraine "On the Fundamental Principles (Strategies) of the State Environmental Policy of Ukraine for the Period until 2020" as of December 21, 2010 (№ 2818-VI) [8].

The Decree of the Cabinet of Ministers of Ukraine "The State Strategy of Regional Development for the Period until 2020" (August 6, 2014, № 385) also became a strategic document developed according to European standards [9].

After signing the Ukraine-EU Association Agreement, a new stage of Ukraine's economic development commenced as this document contained clear suggestions on implementing sustainable development principles in environmental, social and economic areas [10]. The Decree "On Strategy for Sustainable Development "Ukraine-2020" approved by President on January 12, 2015 (№ 5/2015) has become one of the steps aimed at introducing European living standards in Ukraine [11].

The Law of Ukraine "On Environmental Impact Assessment" of May 23, 2017 (№ 2059-УIII) is intended to encourage industrial greening [12].

Thus, the sustainable social and economic development concept has been adapted to Ukrainian conditions for over 10 years, yet permanent economic crises, absence of clear development strategy, recurrent changes of governments and their priorities could not enable proceeding from sustainability declaration to its implementation. Drafted legislative and regulatory documents on economy greening issues are neither efficiently implemented nor observed. The current low charges for natural resource use, harmful emissions/discharges and industrial waste disposal cannot compensate actual damages to the environment and people's health. They are also unable to provide industrial producers with required incentives to care about the environment to a greater degree than about their own profits.

The natural resource-intensive and destructive ***technogenic type of the economic development*** is still prevailing in Ukraine' economy, both in general and in that of Kryvyi Rih region in particular. This development type is characterized by large-scale and intensive use of nonrenewable resources (minerals) only, but also renewable ones (soils, water, etc.) with the rate exceeding their self-restoring capacity.

Privatization of mining enterprises has not resulted in increased investment in equipment and technology necessary for iron ore mining and concentration. The region's vital issues of concentration tailings re-treatment, application of oxidized ores, manufacturing of construction materials from waste rocks, introduction of internal dumping technologies and reduction of hazardous emissions into the atmosphere and water reservoirs. There is continuous intensive withdrawal of extra land for disposal of iron ore mining and concentration wastes. Operations on restoring mined and disturbed lands are not envisaged in deposit rent agreements and are usually underfinanced or financed randomly and slowly.

Characteristics of factors of mining and concentration enterprises' activity affecting Kryvyi Rih region landscape and environment. Kryvyi Rih landscape was damaged the most in the early 1960s because of introduced "poor" low-grade iron ore mining (ferruginous quartzite of 17-42 % iron content) by the open pit mining method accompanied by its subsequent concentration to produce a 65-67 % Fe concentrate. The five operating mining and concentration works (GOKs) of Kryvyi Rih are engaged in iron ore mining at nine open pits of over 300 m deep with the total area of about 6 thousand hectares. Mining and concentration of 1 ton of raw ore by current technologies results in 3-4 tons of wastes accumulating in enormous waste dumps and either multi-layered or flat tailing ponds (landfills) containing concentration wastes.

There are almost 4 bln m^3 of accumulated industrial wastes covering the area of almost 12 thousand hectares, 5 thousand hectares of which are occupied by waste dumps and over 7 thousand hectares - by tailing ponds. The total area of the city and suburban sites of disturbed after-mining lands makes about 34 thousand hectares, their restoration rates being extremely low (0.2-1.7 % per year) [1]. At the same time, waste dumps and tailing ponds are growing by 55-60 million m^3 of waste materials annually, tens of hectares being withdrawn additionally. Mining landscapes occupy almost 30% of the city area which is 431 m^2, this proportion constantly increasing. This figure should be supplemented by 70 % of adjacent lands including arable ones and suburban agricultural facilities disturbed under the action of dust and highly mineralized water filtrates from waste dumps and tailing ponds.

Thus, iron ore concentrate manufacturing at modern mining and concentration works of Kryvyi Rih results in formation of huge man-made formations of accumulated mining and concentration iron ore wastes.

Waste materials from dumps and tailing ponds contain high percentages of fine fraction components of the average particle diameter d_{av}= 0.089 mm [13], the latter becoming a source of intensive dusting. Besides, on mature surfaces of technogenic facilities, there are created *weathering crusts* of destroyed rocks with formed fine particles being an additional dusting sources. Under the action of wind, dust particles go up into the air and are transported as dust clouds over great distance and accumulated in topographic lows. Taking account of the fact that in Kryvyi Rih, northern, north-eastern and eastern winds (over 50 % of all river rhumbs) [14] prevail, it is evident that dust emissions of the mining and concentration works propagate along the wind plumes over the suburban villages and agricultural lands. Kryvyi Rih mining and concentration enterprises have been functioning for over 60 years, thus investigations into consequences of long-term dust impacts on the lands adjacent to the waste dumps and tailing ponds are of particular interest.

Consequences of long-term impacts of waste accumulation facilities of the mining and concentration works on land resources. Analysis of researches and publications on the issues of local GOKs affecting land resources reveals that investigations into dust and gas emissions of mining and concentration enterprises affecting the lithosphere indicate the greatest influence of the chemical composition of aerogenic pollutants on soil conditions. According to this, the majority of known works deal with the problem of accumulated heavy metals and the mechanism of their further translocation into plants and plant products [14-23].

The chemical composition of the dust on the GOK facilities is determined by the composition of rocks at waste accumulation places. According to V.D. Babushkin and his co-authors (1971), the primary pollutant substance of waste dumps and tailing ponds is dust containing from 20% to 70% of silicon dioxide [22]. The rest dust components are transitive and intransitive metals, some semimetals (metalloids) and non-metals. The charts of waste disposal sites of YuGOK and Novokryvorizkyi GOK indicate that a kilogram of tailings of "Voikovo" and "Obiednane I Karta" tailing ponds contains 112 g of Fe total, 15 g of magnetite quartzite (Fe_{mag}), 56 g of iron oxide (II) (FeO), 81 g of iron oxide (III) (Fe_2O_3), 614 g of silica dioxide (SiO_2), 39.8 g of magnesium oxide (MgO), 1.2 g of manganese oxide (MnO), 53.4 g of sodium and potassium oxide mixture ($Na_2O+ K_2O$), 1.02 g of sulfur (S), 1.71g of phosphorus oxide (P_2O_5) and 2.77 g of micro-components of nickel, copper, zinc, lead, cobalt, molybdenum, tungsten, chromium, mercury, thallium, etc. Rocks stored in waste dumps have almost the same chemical composition [13; 15; 17; 23-24]. It is determined that inside waste dumps and multilayered tailing ponds, under the action of atmospheric precipitation, seasonal temperature changes, highly mineralized waters, changeable alkalinity, etc. there occur some physical and chemical processes resulting in readily soluble salts (sulphate and chloride of K, Na, Ca, Mg, carbonate of alkaline and alkaline-earth metals). At the same time, there is hydrolysis of silicate and base leaching of KOH, $NaOH$, $Mg(OH)_2$, $Ca(OH)_2$, silica and $MnCO_3$ into moveable alkaline waters. The least soluble are compounds of Fe, Mn, P and heavy metals (Cr, Ni, Co, Cu, Zn, Pb, Ni, etc.) which are difficult to transport by water, yet they can migrate over large distances with dust [17; 21-22].

Concentration of admixtures of the mentioned metals and their compounds in dust samples from different facilities of certain GOKs can vary from traces to several milligrams, yet no element exceeds the current sanitary norms. At the same time, it is known that being deposited on the soil surface, dust components including heavy metals are capable of accumulating and due to the summing effect, local concentration of certain elements can considerably increase.

To determine the rate of escalation of chemical contamination of soils by certain dust components from waste dumps and tailing ponds and longer-term consequences of their influence on the whole range of agrochemical parameters of soils and the rate of their chemical contamination, special investigations into dynamics of agrochemical indicators of agricultural lands were conducted.

Research results and their discussion. The testing site is presented by a land lot of 10 thousand hectares in the northern part of Shyroke district of Dnipropetrovsk region. On its boundary, in the northern and north-eastern part, there are “Livoberezhni” (Left-Bank) dumps (in operation since 1969, 823 hectares, (from now on the area is given as of 2016)) and the multi-layer tailing dump “Voikovo” (in operation since 1977, 592 hectares) of the PJSC YuGOK. The multi-layer dump “Obiednane” (in operation since 1964, nearly 695 hectares) shared by the PJSC YuGOK and the mining and concentration works (GOK) of the Mining Division (MD) of ArcelorMittal Kryvyi Rih (AMKR) is in the east and dumps 2-3 of the MD AMKR (in operation since 1972, nearly 498 hectares) are in the west. So, technogenic facilities of two typical Kryvyi Rih GOKs functioning for over 60 years are in a semicircle around the chosen site.

The facilities situated to leeward are as high as the operation sites (dust formation sources) more than 140 m over the level of the surrounding landscape and continue growing.

The central and eastern parts of “Livoberezhni” dumps consist of oxidized ferruginous quartzite, the north-west part - of crystalline schist, non-metal and low-metal quartzite. Dumps 2-3 of the MD AMKR are made of overburden rocks (low levels) and at present oxidized ferruginous quartzite is being stockpiled there. The prevailing mineral of the tailings is quart (up to 65%), other minerals are magnetite, hematite, carbonate, clay silicate, calcium, ferric hydroxides, apatite, trace elements etc.

Results of agrochemical monitoring of soils were analyzed retrospectively on the basis of archives (1980-2003) of the state institution “Institute for Soil Protection of Ukraine”, Dnipropetrovsk branch.

To estimate the character and degree of agrochemical changes in the condition of land resources on the area under study, 115 samples of soil were analyzed. The samples were taken at substantiated points of the specially developed network of monitoring test sites the choice of which considered the character the technogenic pressure on the area under study. In most cases the size of monitoring sites made 500×500 m.

Each soil sample was further studied by laboratory methods (at laboratories of the state institution “Institute for Soil Protection of Ukraine”, Dnipropetrovsk branch) for contents of productive moisture, labile phosphorus and potassium (by Chirkov method); nitrogen mineral and easily accessible for plants organic compounds; humus (by Tiurin method); metabolic calcium, sodium, magnesium compounds; total carbonates. Other measurements included: moisture absorption capacity of soils; acidity, solid residue of water extract; content of total and labile (resulted from ammonium-acetate extracting at pH=4.8) forms of iron, manganese, lead, cadmium, mercury, copper and zinc; remains of pesticides (DDT, hexachloran and 2.4-D) and density of radioactive contamination (cesium-137 and strontium-90).

The investigation resulted in the conclusion that the dominating soil of the area under study is southern chernozem (69% of the studied monitoring sites). Other types of soils are alkaline chernozem common for terrace plains, divide lowlands, low old terraces of the Inhulets river and diluvium tails. Saline areas among these soils are the result of saline chloride-sulphate ground water flooding.

Analysis of the archive data on agrochemical observations of the above territory soils in 1988-1990 shows that the productive moisture level during that period fluctuated within 144-237 mm in the 0-100 mm layer that is considered to be very good according to the current criteria. In 2004 the amount of the productive moisture in the soils decreased to the “good” level and remained the same in 2016. According to the data of 1988-1996, the pH level of the water extract fluctuated within 6.7 to 7.6, in 2004 – within 7.2-7.5, in 2016 - within 8.4 – 7.2), i.e. this indicator changed from subacid to subalkali. Considering the fact that pH 8-9 is already characteristic of saline and alkali soils, it can be concluded that for the last 10-12 years the soils have undergone certain salinization due to filtrates of highly mineralized waters of the nearby tailing ponds.

Analysis of the 30 years’ observations of the humus content in agricultural soils of the area under study shows that the content is mostly mean (2.1-3.0 %) and elevated in some places (3.1-4.0 %). However, for the last 20 years (from1996 to 2016) the humus content has decreased by average 0.36% (in Ukraine for this period its content has decreased by average 0.22%, data as of 2014) resulting in corresponding land productivity decrease. The above mentioned is a negative phenomenon as restoring the humus content by 0.1 % in natural conditions requires 25-30 years [24]. Soil impoverishment may be caused by both the national-level trends of agricultural workers' violation of farming culture (commitment to exhaustive cropping, violation of crop rotation, insufficient mineral and organic fertilizer treatment) and technogenic factors (soil erosion and the above mentioned alkalization without plastering). As land productivity of the area under study has decreased by 0.14 % which is above the average national indices, this fact may be considered as the one caused by technogenic pressure.

In terms of nutrients, the soils under study are sufficiently supplied with nitrogen, phosphorus and potassium (as of 2016) and their agrochemical estimation is 100 points and more.

The conducted monitoring of contaminating and dangerous compounds accumulated in the soils under study (remains of pesticides and radiation contamination density) in the samples in 2016 and comparison of these data with the results of environmental and agrochemical examination of the area lands in 1996 and 2004 show that all arable lands do not contain pesticide remains (DDT and its metabolites, hexachloran and 2,4-D amine salt) and density of their radiation contamination with ^{137}Cs (cesium-137) and ^{90}Sr (strontium-90) is within the norm.

Estimation of contamination of the soils with chemical elements was conducted for the whole range of micro- and macrocomponents determining the total content and the content in labile compounds (ammonium-acetate extract from the soils). It is well-known that *the number of pollutants in labile forms* of compounds testifies to the extent to which corresponding chemical elements *are able to enter human trophic chains* through vegetable food and livestock products.

The results of monitoring in 2016 demonstrated excess of maximum allowable concentration (MAC) norms for labile forms of I and II hazard classes (lead, zinc and cadmium) on the area of nearly **188** hectares of the examined territory.

Soil of nearly 143.6 ha area are contaminated with labile forms of **zinc** (hazard class I element) compounds exceeding MAC 5.4-fold on average. The contaminated areas lie in the north-west of “Livoberezhni” dumps of YuGOK (about 83.5 hectares) and within 1 km distance to the south of the tailing pond “Obiednane I Karta” of YuGOK.

The labile forms of the element of the I hazard class **lead** exceeds MAC norms (6 mg/kg) on 4 monitoring sites: a 14.6 ha field in 0.9-1.1 km distance southwards from the tailing pond “Obiednane” (1.6-fold excess of MAC) and a 13.4 ha field 0.8 km southwards from the dumps “Livoberezhni”. The contaminated 0.8-2km wide zone of 83.5 hectares with the detected level of labile forms of lead exceeding MAC 1.8-fold is located on the above mentioned site polluted with zinc in the south-western direction from the dumps “Livoberezhni”. Another contaminated field of 16.3 hectares lies westwards from YuGOK tailing pond “Voikovo”. In general, the area of agricultural lands with an excessive level of labile forms of lead makes over **127.8** hectares (as of 2016).

Analysis of detecting labile forms of heavy metals of the II hazard class, particularly cadmium, shows that this element contaminates 83.5 hectares (already mentioned as one of the sites contaminated with lead and zinc) and is 2.8 times as much as MAC (0.7 mg/kg).

Considerable (exceeding MAC, 1.5 mg/kg) contamination of soil with labile forms of **manganese** is observed on sites impacted by dust from “Livoberezhni” dumps.

Contamination with **copper** (MAC 3 mg/kg) is detected on a small area and registered in only one sample of soil near the dumps “Livoberezhni” of YuGOK.

The above norm content of **iron** (MAC 12 mg/kg) is detected about 1.5-2 km southwards from the complex of technogenic facilities (the dumps “Livoberezhni”, tailing ponds “Obiednane” and “Voikovo”). The contaminated territory occupies the area of about 57 hectares.

Besides studying soluble forms of soil pollutants, contents of total of forms individual elements from dump and pond dust in soils under technogenic pressure have been analyzed. In this case, data of the background level of soil contamination with corresponding elements for Dnipropetrovsk region are taken as criteria of soil contamination occurrence [26].

Analysis of data on distribution of the content of *total forms* of **zinc** shows that the background level (30 mg/kg) on practically all the examined territory in Dnipropetrovsk region is exceeded. On 23 testing sites (20 % of the examined territories) the content of zinc is 2 and more times larger than the background level and makes 60.61 to 83.3 mg/kg. These areas are mostly located in the north-western part of the technogenically affected territories, i.e. they are in close neighborhood with the dumps and tailing ponds. The maximum level of zinc is registered in the south-western direction 0.8-2 km away from YuGOK dumps and makes 487.5 mg/kg, i.e. 16 times larger than the region background level.

Total forms of **lead** exceed the background level (10 mg/kg) in 50% of samples from the examined territory. These lands are mostly located in the south-western directions from dumps and ponds.

Analysis of the content of *total forms* of **cadmium** and **manganese** shows that their content on the examined territory exceeds the background level (1 mgr/kgr and 0.6 mg/kg respectively) on 6 monitoring sites whereas for **copper** it does not practically exceed the background level (20 mg/kg) in majority of studied samples. 3-fold excess of cadmium compounds and 10-32 % excess of manganese are detected on monitoring points of sampling westwards from the dumps “Livoberezhni” of YuGOK.

Iron compound content exceeds the background level (2-7 mg/kg) on 65 % of the territory under observation. On most sites, this excess makes 1.5-2 times but on the monitoring sites near the dumps “Livoberezhni” and on the south-western part of the observed territory impacted by the ponds it makes 7-10 times.

All the above data testify that due to accumulation, certain elements contained in dust create zones of above-norm concentration exceeding the current sanitary norms. Components of dust from dumps and tailing ponds of the operating GOKs, particularly the southern group of Kryvbas, enable accumulation of I (lead, zinc) and II (cadmium, manganese, copper and iron) hazard class (toxic) elements. Significant accumulations of chrome, strontium, mercury and nickel in soils are not detected.

The comparative analysis of the data on chemical contamination of the examined soil during 1996-2016 shows that soil contamination occurs in time and space with gradual acceleration. For instance, in

1996, content of manganese, copper and zinc in soils averaged 21, 0.44 and 0.21 mg/kg respectively, in 2004 - 23, 0.5 and 0.22 mg/kg respectively, in 2016 contamination reached on average 49.9, 1.37 and 4.91 mg/kg respectively (maximum for zinc – 89.17 mg/kg!), i.e. for the recent 12 years contamination has increased 2.5-fold, and for zinc - 22-fold. The dynamics of contamination accumulation like that testifies either to increased toxicity of dust or increased dust volumes.

Considering the location of contaminated soils relative to technogenic facilities, directions of prevailing winds and composition of dump and pond dust, *the following statement can be made*. Dump and pond dust spread with the wind (northern and north-eastern winds are known to prevail in the district under study) is the source of soil contamination with traces of heavy metals. This is a manifestation of the fact that *technogenic facilities are correlates of contamination*. Availability of land sites with exceeded MAC norms and regional background level for traces of **lead**, **zinc**, **cadmium** and **iron is manifestation** of, firstly, presence of these toxic elements in dust of the dumps and ponds that **increases significantly the hazard class** of the dust like that. Secondly, aerogenic contamination is happening gradually and accumulation of the dust compounds in soils happens with certain acceleration in 0-10 and 10-25 cm deep layers of soil.

The studies have determined that due to long-term (up to 60 years) aerogenic contamination of soils with dust emissions from GOK dumps and tailing ponds, the upper soil layer accumulates certain pollutants that are considered as traces in spot dust samples are not significantly concentrated. It has also been determined that in individual cases there are formed geochemical anomalies (centers) of heavy metals in the upper layer of zones of long-term contamination. In our investigation the center like that was formed in the zone of the direct impact of dust emissions from the dumps “Livoberezhni” of YuGOK under prevailing north-eastern winds, namely on the 83.5 ha site (2016) of agricultural lands. There, high (over MAC) simultaneous concentrations of zinc, lead, cadmium, manganese and partly copper are registered.

Considerable decrease of self-purification ability of soils is known to occur on sites with geochemical anomalies and physical and chemical conditions for migration of contaminating elements are radically limited.

Conclusions: On the basis of the given results of the investigation into soil conditions in the zone of aerogenic contamination with dust from GOK dumps and tailing ponds the following conclusions can be drawn:

1. Due to the effect of accumulation and summation, microelements of the GOK dump and pond dust create considerable over MAC norm concentrations of harmful substances on the soil surface.

2. The most harmful and capable of accumulating in soils of the adjacent to YuGOK and NKGOK territories dump and pond dust microcomponents are elements and compounds of zinc, lead, (I toxicity class), cadmium, manganese and iron (II toxicity class).

The class of environmental hazard of open pit mining and iron ore concentration wastes accumulated in dumps and tailing ponds of GOKs requires reconsideration as such components as heavy metals are able to migrate long distances (up to 3-5 km) with the wind and create zones of accumulation and over norm concentration in the upper layer of the soil.

4. Parameters of sanitary and protection zones (SPZ) around places of accumulation of potentially toxic wastes of iron ore mining and concentration require reconsideration. At present SPZ around mining and concentrating works are established according to "National Sanitary Rules for Planning and Development of Residential Areas" No. 173, June 19, 1996 and make only 300 m which is insufficient for multi-level technogenic facilities (dumps and tailing ponds) with dust-forming surfaces of over 100 m high.

5. To decrease pollution pressure on lands of territories next to dumps and tailing ponds, local and environmental control authorities should demand unconditioned observance of Point 5.13 of the Order of the Ministry of Health Care of Ukraine No. 173, June 19, 1996 "On Approval of National Rules for Planning and Development of Residential Areas" which provides landscaping of SPZ around all dumps and tailing ponds on the distance of not less than 60 % of their width.

6. Signs of chemical contamination of soils impacted by aerogenic pollution caused by dumps and tailing ponds start appearing 10-15 years after the beginning of such impact with further acceleration of

the effect. In 30-40 years it reaches the level of chemical degradation.

Recommendations. The current situation concerning prospects for implementation of the concept of sustainable social and economic development requires solving the following tasks:

1. On the national and legal level:

- considerable growth of financial responsibility of economic entities for violation of the environmental law of Ukraine and recommendations of international environmental programs;

- introduction of requirements concerning development of the chapter on landscape planning for all projects of building and reconstructing mining facilities into national building norms (NBN);

- making it obligatory to include not less than 10% of annual incomes of the designed production into cost estimates of any mining projects for land remediation and optimization of destroyed landscapes;

- cancellation of preferential taxation in the Tax Code of Ukraine for stockpiling each ton of mining wastes and raise of tax rates to the objective level of the III hazard class, which is conditioned by availability of highly toxic heavy metals in these wastes.

2. On the local authority level:

- development of a strategic plan of measures for optimizing the city’s landscape structure in cooperation with design companies and enterprises;

- introduction of concrete measures on phase implementation of the strategic plan of enhancing the city’s landscapes into Complex environmental programs and allocation of not less than 15% of the city’s environmental fund for this purpose;

3. On the level of mining enterprises:

- considerable intensification of investing in development of measures for enhancement of iron ore concentrate production, namely in technologies: re-treatment of concentration tailings, oxidized ores, creation of inside dumps in dead zones of open pits etc.

References

1. **Bobyr, O.V.** (2012). *Kryvyi Rih region environment*. Kryvyi Rih: Naukova biblioteka KNU.

2. Declaration of the UN Conference on Environmental Problems. Retrieved from: http://www.un.org/ru/documents/ decl_conv/declarations/declarathenv.shtml

3.Report of the international commission on the environment and development. (1989). Ed. by S.A. Yevteyeva and R.A. Perelet. Moscow: Progress.

4. **Law of Ukraine "On the Environment Protection"** No. 1264-XII of June 25, 1991. Bulletin of Verkhovna Rada of Ukraine (VVR), No. 41.

5. Zaverukha, N., Serbriakov, V., Skyba, Yu. (2006). Fundamentals of ecology: Training guide for higher educational institutions. Kyiv: Karavels.

6.World Charter for Nature. Retrieved from: http://www.un.org/ru/documents/decl_conv/ conventions/charter_for_nature

7. Agenda 21 and other documents of the conference in Rio de Janeiro. (1993). Geneva, Centre "For our mutual future".

8. Law of Ukraine "On the Fundamental Principles (Strategies) of the State Environmental Policy of Ukraine for the Period until 2020**"** as of December 21, 2010, No. 2818-VI.

9. State strategy for regional development for the period until 2020 as of August 6, 2014, No. 385.

10. Association Agreement between Ukraine, on the one part, and the European Union, the European Atomic Energy Community and their state-members, on the other side. (2017). Retrieved from: http://zakon4.rada.gov.ua/laws/show/984_011/page

11. Decree of President of Ukraine "On Sustainable Development "Ukraine-2020" of January 12, 2015, No. 5/2015.

12. **Law of Ukraine** "On Environmental Impact Assessment" of May 23, 2017 (No. 2059-УIII). Bulletin of Verkhovna Rada of Ukraine (VVR), 2017, No. 29, Article 31.

13. Charts of waste disposal sites (tailing ponds and waste dumps) of the PJSC SevGOK and the PJSC ArcelorMittal-Kryvyi Rih in 2000-2015.

14. **Antonik, V.I., Petrukhin, A.V., Antonik I.P.** (2017). Influence of waste dumps and tailing ponds of Kryvyi Rih concentration plants on the environment of adjacent areas. The Journal of KNU. Issue 44. Kryvyi Rih: DVNZ KNU, pp. 161-166.

15. **Dobrovolskiy I.A**. (1988). Some regularities of iron distribution in technogenic lanscapes of Kryvyi Rih region. Monitoring investigations into forest ecosystems of the steppe zone, their protection and efficient use. Dnepropetrovsk: DGU, pp. 69-72.

16. **Ilin V.B.** (2000). Evaluation of current environmental standards of heavy metals content in soil. Agrochemistry, 9, pp. 74-79.

17. **Savosko, V.N.** (2000). Content of moveable forms of heavy metals in soils adjacent to SevGOK. Journal of Dnipropetrovs University. Biology. Ecology. Issue 8, vol. 2, pp. 64-69.

18. Degradation and protection of soils. (2002). Ed. by H.V. Dobrovolskyi. Moscow: MGU.

19. **Shykula, M.K., Ihnatenko O.F., Petrenko, A.P.** (2004). Protection of soils. Kyiv: Znannia.

20. **Toxicity Criteria Database**. (2012). California Environmental Protection Agency (EPA). Retrieved from: http//www.oehha.org/risk/chemicalDB.index.asp.

21. **Hryshko, V.M., Syshchykov, D.V., Piskova, O.M., Mashtaler, N.V.** (2012). Heavy metals: reaching soils, translocation in plants and environmental danger. Donetsk: Donbas.

22. **Babushkin V.D.** (1971). Investigations into hydrogeological conditions of deposits. Moscow: Nedra.

23. **Beresnevych, P.V., Kuzmenko P.K., Nezhentseva N.H.** (1993). Environmental protection in tailing pond exploitation. Moscow: Nedra.

24. **Baklytskyi V.V.** (2013). Environmental monitoring of soils: complex analysis of impacts of waste disposal sites of PJSC "YuGOK" on the environment. Kryvyi Rih: TOV "Tsentr ekolohichnykh doslidzhen ta audytu".

25. **Sanitary Regulations and Norms 42-128-4433-87** (1988). Sanitary norms of admissible concentrations of chemical substances in soil. Moscow: B.i.

26. **Fateiev A.I., Pashchenko, Ya.V.** (2003). Background content of microelements in Ukraine's soils. Kharkiv.

27. Conducting a comprehensive analysis of the ecological state of the environment of the Novolatovsky village council and elaborating a comprehensive program for ensuring ecological safety of the Novolatovsky village council / Kryvyi Rih Research Ore Mining of Kryvyi Rih National University; head: **Petrukhin AV**; performers: Antonik V.I., Kulkova T.M., Grishko V.M., Chepurny V.I. and so on. - Kryvy Rih, 2016 – 630p. - DR 0116U006560

JUSTIFICATION OF TRANSFER PARAMETERS IN CONDITIONS OF DEEP ZONE DEVELOPMENT OF IRON ORE SURFACE MINES

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Abstract. *Subject of the research is* parameters of mining transport in-pit systems in conditions of mining steeply dipping iron ore sheet deposit by open method on big depth.

Objective of the research is parameters of in-pit reloading points, constructed in cramped conditions of opening deep horizons of iron ore open pit mines and mining depth zone of a mineral occurrence.

Tasks of the research are analysis of mining technical indexes of open pit mining iron ore in Ukraine and Kazakhstan and highlighting their typical values; cast of calculation of depth zone parameters while finalizing mining iron ore sheet deposits by open method; determination of the nature of the connection of the parameters of the deep zone of the mineral occurrence with the parameters of in-pit transport and loading points; justification of the parameters of loading points and their performance in conjunction with rail transport; assessment of transport schemes for truck-conveyor transport on the deep horizons of iron ore open pit mines in terms of energy efficiency; study of the parameters of conveyor transport taking into account the world experience of its operation.

Methods of the research are: analysis, systematization and abstraction in the study of mining and technical indicators of open pit mining iron ore in Ukraine and Kazakhstan; mathematical modeling in the development of methods for calculating the parameters of the deep zone of the mineral occurrence, the parameters of the reload of various types of transport; economic modeling in calculating the efficiency of transport schemes.

The developed method of calculating the parameters of the deep zone of the mineral occurrence allows calculating the contour and current overburden factors more accurately, as well as correct them by controlling the parameters of transport schemes and overload. The proposed scheme for the opening of deep horizons of an open pit mine saves more than 100 thousand USD / year by reducing the consumption of fuel and lubricants.

Introduction. Analysis of mining enterprises operation in Ukraine and Kazakhstan (Tabl. 1,2) shows that iron ores are mined by open pit mines with a design depth of up to 500 m, and in some cases, 700-800 m. The size of such open pit mines is 1,000×3,500 m and more over the surface, and their sizes along the bottom vary from 300 to 1240 m [1-3]. The number of marginal balance reserves of minerals in depth is 600-1000 million tons, most of which are located below the bottom of the open pit mine. The commissioning of these reserves will result in: first, an increase in the production capacity of the open pit excavation of overburden, which is characterized by an increase in the average and current stripping ratios; secondly, to the necessity of withdrawing objects protected by pillars: rivers, towns, waste dumps and poor ores, railways, factories, etc; thirdly, to expand the area of the mining allotment of an enterprise [4,5].

Table 1

Mining-technical indexes of open pit mining iron ores of Ukraine

Title of indexes	Open pit mine of InMEP	Open pit mine of SMEP	Open pit mine № 2-bis AMKR	Open pit mine № 3 AMKR	Unified open pit mine of SMEP and № 3 AMKR	Open pit mine № 1 CMEP	Open pit mine № 3 CMEP	Annov open pit mine NMEP	Open pit mine of Poltavsk MEP	Open pit mine of Yeristov MEP
Horizontal thickness of ore-shoot m_h, meters	70-550	135-400	45-90	260-540	135-540	95-595	300-350	300-650	110-200	240-550
Angle of dip of bank γ, degrees	60-70	40-70	60-85	55-70	40-70	55-70	45-85	55-85	55-90	70-85
Design depth of open pit mine H_d, meters	650	660	415	500	850	500	545	450	390	500
Design capacity: - by ore P_m, mln. tons										

- by overburden V_r, mln. tons	36,5 90,3	34 69,4	8,5 24,7	18 43	150 14 –16	9,5 31,7	9 24,8	18,5 87	34 133,3	9 65
Dimensions of an open pit mine on surface: - width *B*, meters - length *L*, meters	 2250 3600	 2550 3000	 1200 2200	 2000 2550	 5500 6750	 1630 4290	 1360 1700	 1500 7300	 2100 4460	 1500 3750
Dimensions of the open pit bottom: - width b_d, meters - length l_d, meters	 240 1000	 175 350	 100 400	 450 800	 250 500	 70 200	 110 126	 30 4200	 70 3640	 100 1880
Annual capacity of an open pit mine by ore A_m, mln. tons	35	35,56	9,7	13,8	37	9,8	4,8	15	32	9
Annual capacity of open pit mine by overburden A_r, mln. tons	67,6	73,4	26,1	46,7	58	37,8	13,9	77,8	96	65
Overburden transportation distance L_r, km	7	5	3	4	5	2	11	9	8	9

Table 2

Mining-technical indexes of open pit mining iron ores of Kazakhstan

Title of indexes	Kachar open pit mine	Sarbay open pit mine	South-Sarbay open pit mine	Sokolovsk open pitm ine	Kurzhunkul open pit mine	Sor open pit mine	Shagyrkul open pit mine
Open pit bottom level, meters	-570	-480	-340	-380	-215	80	-175
Open pit mine depth H_d, meters	764	680	530	570	405	148	440
Geological reserves of ore $V_{m.g}$, mln. tons	803,4	87,6	146,4	66,7	73,0	62,1	101,8
Iron content in ore: In subsoil, % on plant, %	 39,13 38,18	 38,96 35,5	 42,12 37,69	 34,8 28,06	 44,52 35,96	 41,66 37,18	 40,55 37,31
Ore reserves V_m, mln. tons	824,1	91,7	164,8	69,4	95,4	69,4	111,02
Overburden volume in open pit mine (including rocks) V_r, mln. m^3	956,3 (574,1)	74,3 (62,5)	504,7 (208,8)	34,8 (34,8)	113,1	93,0 (26,5)	262,77 (140,6)
Average stripping ratio k_a, m^3/tons	1,16	0,81	3,45	0,5	1,19	1,34	2,37
Open pit dimensions by surface: - width *B*, m; - length *L*, m	 2900 3000	 2500 3600	 1900 3300	 2000 3400	 1500 1500	 1200 2100	 1500 2500

Open pit dimensions by bottom:							
- width b_d, m	175	80	100	70	150	130	80
- lengths l_d, m	430	1000	175	200	200	200	120

It should be noted that the value of the resulting slope angles for non-operating pit sides significantly affects the maximum stripping ratio, the largest of which sets the boundaries and the efficiency of mining. At the same time, by increasing the slope angles of the non-operating sides and individual benches on them, the amount of over-burden rocks within the open pit field is significantly reduced, as a result of which the efficiency of iron ore mining is significantly increased. To ensure the stability of the sides, a special offset of the ledges is carried out when they are set in the limit position and the frill of stabbing along the plane of the blasting by excavators.

Depth parameters

The deep zone of the mineral occurrence is a part of the deposit of minerals and interlayers of waste rock that is not prepared for excavation and is below the current level of the bottom of the pit, for opening of which it is necessary to carry out the pit-side separation and extract part of the deposit in the marginal zone.

Volume of deep zone of the mineral occurrence V_{III} is using the following formula, m^2

$$V_{III} = \frac{S_{III}\left(H_d - H_c\right)\left(ctg\beta_1 + ctg\beta_2\right)}{2} + S_{III} l_d , \qquad (1)$$

where S_{III} - cross-sectional area of the deep zone of the mineral occurrence, m^2; H_d - project depth, m; H_c - current depth of the open pit mine, m; β_1, β_2 - the resulting slope angles of the pit in the opposite ends of the field in the projected position, degrees; l_d - the design length of the open pit mine at the bottom, m.

The cross-sectional area of the deep zone of the mineral occurrence S_{III} can be calculated from the geological sections data, as well as analytically. The figure, which is a section of the deep zone of the mineral occurrence (Fig. 1), is limited on the abscissa axis by the contours of the mineral occurrence, which are parallel straight lines at a distance m_h from each other, inclined at an angle γ to the positive direction of the abscissa axis, where m_h - horizontal mineral thickness, m; γ - dip angle, degrees. Based on the analysis of the parameters of open pit mining at iron ore open pit mines, the horizontal mineral thickness (m_h) is in the range of 100-650 m, and the dip angle γ is 40-90°. The values of these parameters are determined by natural factors.

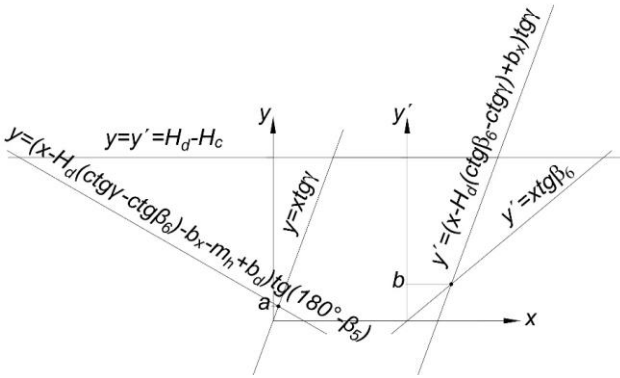

Fig. 1 Outline for determining depth parameters of mineral occurrence

The ordinate axis is limited by the level of the current level of the pit bottom, the level of the boundary mark of the pit bottom, the design position of the pit sides. Moreover, the distance at the level of the *x*-axis between them is the width of the pit at the bottom at the boundary position b_d. In this case, the angle of inclination of straight lines, which represent the design position of the pit sides, is (180° -$_5$) and β_6 to the positive direction of the x-axis. The pit width to the bottom in the boundary position b_d should be within $b_{c.\min} \leq b_d \leq m_h$, where $b_{c.\min}$ is the minimum value of the current pit width at the bottom, which is determined based on the technological parameters of the deep horizon of the open pit mine, m.

While using trucks, m

$$b_{c.\min.a} = R_a + 0{,}5b_a + 0{,}5l_a + c, \qquad (2)$$

where R_a - minimum radius o dump truck turn, m; b_a - width of a dump truck, m; l_a - length of a dump truck, m; c - clearance between the dump truck and the side of the cutting, m.

While using trucks, m

$$b_{c.\min.r} = 2R_s + e + 2e_1 + g + b, \qquad (3)$$

where R_s - excavator body rotation radius, m; e - the gap left between the body of the excavator and the lower edge of the side of the cutting, m; e_1 - the gaps between the truck and the excavator on the one side, and between the truck and side of the drainage ditch on the other side,m; *g* - way clearance, m; *b* - drainage ditch width, m.

Value of b_d varies between 70-450 m in the practice of open pit mining. The magnitude of the slope angles of the open pit sides in the top and flat walls in the design position (β_5 and β_6) on deep iron ore open pit mines vary between 28-32° and is determined by the formula

$$\beta = arctg \frac{n_b h_b}{n_t b_t + n_s b_s + n_b h_b ctg\alpha_b}\text{, degrees} \tag{4}$$

where h_b - bench height, m; n_b, n_t, n_s - number of benches, transport platforms and safety platforms accordingly, units.; b_t, b_s - width of transport platforms and safety platforms, m; α_b - bench slope angle of non-operating benches, degrees.

The magnitude of the project depth of the open pit depends on the economic feasibility of open-pit mining. The Institute GIPRODUDA recommends determining the final depth of the pit by the formula, m

$$H_d = \frac{m_h\left(\frac{\upsilon_s}{\upsilon_u}C_u - C_s\right)}{(ctg\beta_5 + ctg\beta_6)C_u}, \tag{5}$$

where: υ_s, υ_s - the output of the concentrate from minerals mined by open and underground methods; C_u, C_s - unit costs for the extraction of minerals by open and underground methods, USD/m^3.

The approach to the calculation of the cross-sectional area of the deep zone of the mineral occurrence varies depending on the current position of the level of the pit bottom expressed by the equation $y=y'=H_d-H_c$, and depends on following conditions:

$$\begin{cases} H_d - H_c \geq a \\ H_d - H_c \geq b; \end{cases} \begin{cases} H_d - H_c < a \\ H_d - H_c < b \end{cases} \begin{cases} H_d - H_c \geq a \\ H_d - H_c < b \end{cases} \begin{cases} H_d - H_c < a \\ H_d - H_c \geq b \end{cases} \tag{6}$$

Determine *a* from equation systems

$$a = \begin{cases} y = xtg\gamma \\ y = (x - H_d(ctg\gamma - ctg\beta_6) - b_x = m_h + b_d)tg(180° - \beta_5) \end{cases} \tag{7}$$

where β_5 - the resulting slope angle of the pit side from the top wall of the deposit in the design position, degrees; β_6 - resulting slope angle of the pit side from the flat wall of the deposit in the design position, degrees; b_x - parameter that determines the position of the open pit mine design contour in cross section is the distance from the design contour of the open pit mine in the flat wall to the intersection of the contour line of the mineral of flat wall and the surface, m

$$xtg\gamma = \left(x - H_d\left(ctg\gamma - ctg\beta_6\right) - b_x - m_h + b_d\right)tg\left(180° - \beta_5\right)$$

$$\frac{xtg\gamma}{tg\left(180° - \beta_5\right)} - x = H_d\left(ctg\beta_6 - ctg\gamma\right) - b_x - m_h + b_d$$

$$x\frac{tg\gamma - tg\left(180° - \beta_5\right)}{tg\left(180° - \beta_5\right)} = H_d\left(ctg\beta_6 - ctg\gamma\right) - b_x - m_h + b_d$$

$$x = \frac{tg\left(180° - \beta_5\right)\left(H_d\left(ctg\beta_6 - ctg\gamma\right) - b_x - m_h + b_d\right)}{tg\gamma - tg\left(180° - \beta_5\right)}$$

$$a = \frac{tg\left(180° - \beta_5\right)\left(H_d\left(ctg\beta_6 - ctg\gamma\right) - b_x - m_h + b_d\right)}{tg\gamma - tg\left(180° - \beta_5\right)}tg\gamma \quad (8)$$

Find b from equations system:

$$b = \begin{cases} y' = xtg\beta_6 \\ y' = \left(x - H_d\left(ctg\beta_6 - ctg\gamma\right) + b_x\right)tg\gamma \end{cases}$$

$$xtg\beta_6 = \left(x - H_d\left(ctg\beta_6 - ctg\gamma\right) + b_x\right)tg\gamma$$

$$\frac{xtg\beta_6}{tg\gamma} - x = H_d\left(ctg\gamma - ctg\beta_6\right) + b_x \quad (9)$$

$$x\frac{tg\beta_6 - tg\gamma}{tg\gamma} = H_d\left(ctg\gamma - ctg\beta_6\right) + b_x.$$

$$x = \frac{\left(H_d\left(ctg\gamma - ctg\beta_6\right) + b_x\right)tg\gamma}{tg\beta_6 - tg\gamma}$$

$$b = \frac{\left(H_d\left(ctg\gamma - ctg\beta_6\right) + b_x\right)tg\gamma}{tg\beta_6 - tg\gamma}tg\beta_6. \quad (10)$$

Thus, in general, the cross-sectional area of the deep zone of the mineral occurrence is determined based on the following expression, m^2

with $H_d - H_c \geq a, \quad H_d - H_c \geq b$

$$S_{III} = m_h \cdot (H_d - H_c) - S_V - S_{VI},\ \text{м}^2 \qquad (11)$$

with $H_d - H_c < a, \quad H_d - H_c < b$

$$S_{III} = b_d (H_d - H_c) + \frac{(H_d - H_c)^2 (ctg\beta_5 + ctg\beta_6)}{2}, \qquad (12)$$

with $a \le H_d - H_c < b$

$$S_{III} = (m_h + b_x)(H_d - H_c) + \frac{(H_d^2 - H_c^2)(ctg\gamma - ctg\beta_6)}{2} - S_V, \qquad (13)$$

with $a > H_d - H_c \ge b$

$$S_{III} = (b_d + H_d ctg\beta_6 - b_x)(H_d - H_c) - \frac{ctg\gamma (H_d^2 - H_c^2)}{2} + \frac{ctg\beta_5 (H_d - H_c)}{2} - S_{VI}, \qquad (14)$$

where: S_V - cross-sectional area of the marginal zone of the top wall of deposit, m^2; S_{VI} - cross-sectional area of the marginal zone of the flat wall of the deposit, m^2.

$$S_V = \frac{(H_d (ctg\gamma - ctg\beta_6) + b_x - b_d + m_h)^2}{2(ctg\gamma + ctg\beta_5)}, \qquad (15)$$

$$S_{VI} = \frac{(H_d (ctg\beta_6 - ctg\gamma) - b_x)^2}{2(ctg(180 - \gamma) + ctg\beta_6)}, \qquad (16)$$

Reloading while operating railway transport

The shift performance of the transfer point is determined by the formula in general case

$$Э = \frac{(T_c - t_n) \cdot n_д \cdot m_н}{\left(\dfrac{m_н \cdot n_{д.о}}{n_п \cdot Э_ч} + t_{в.о}\right)\left[\left(\dfrac{n_д}{n_{д.о}} - 1\right) + t_o\right]}, \qquad (17)$$

where T_c, t_n - respectively, the duration of the shift and regulated breaks in the work, hours; $m_н$ - carrying capacity of a wagon, tons; $n_{д.о}$ - the number of simultaneously loaded wagons (dumpcarts); $n_д$ -

the number of wagons in the railway transport; n_n - number of simultaneously operating loading machines; $Э_ч$ - technical performance of the loading machine, tons/hour; $t_{в.о}$, $t_о$ - the duration of the exchange, respectively, of trucks and railway transport while loading, hours.

The best conditions of operation, group use of feeders, the current supply of railway transport for loading can significantly improve the performance of reloading points in comparison with equipping them with open pit excavators.

The duration of loading railway transport has a straightforward character and decreases sharply with an increase in the productivity of handling equipment and the number of wagons in the railway transport. With an increase in the carrying capacity of the railway transport, the performance of the reloading point increases (Fig. 2). The performance of the reloading point mainly depends on the number of loading machines, their performance, the number of dump carts in the railway transport, the scheme of supply and exchange of railway composition. Open pit excavators have higher performance compared to overburden excavators and draglines, which explains their widespread use. The performance of conveyors, vibratory and plate feeders depends on the width of the blade and the speed of its movement. Thus, the technical performance of conveyors with a belt width of 1200-2000 mm varies from 1000 to 6000 t/h. For the VFR-4 and VFR-ZK vibrating feeders, it amounts to 1500-2000 t/h, plate feeders with a belt width of 1500-1800 mm - 2000 t/h.

In order to reduce the duration of railway composition delays, sometimes they are loaded with two excavators. The device of the same reloading points with simultaneous loading of 1-5 wagons and more group of feeders helps to reduce the duration of idle railway transport under loading to 8-15 minutes. The intensity of the rock mass intake should correspond to the performance of the transfer equipment to ensure the normal operation of the reloading point.

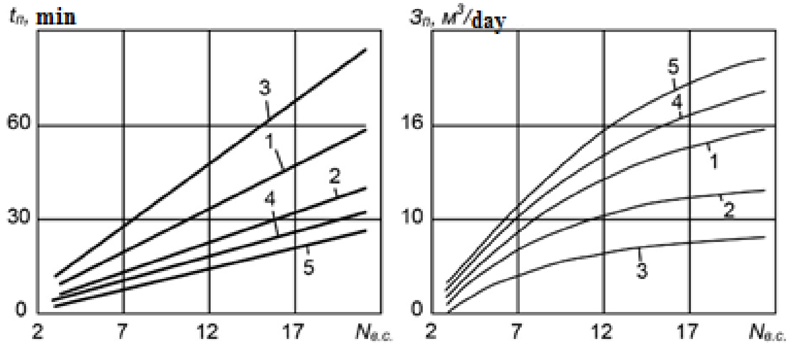

Fig. 2 - Dependences of change in duration of loading a railway transport t_n *a* - and capacity of reloading point $Э_n$; *b* - from the number of dump carts 2BC-105 $N_{в.с}$: 1,2,3 - loading a single dump cart simultaneously with one, to and three vibro feeders VFR-3K (VFR-4); *4* - loading four dump carts simultaneously with three vibro feeders each; 5 - loading excavators EKG-8I

Reloading warehouses occupy an area of not less than 50×250 m, that significantly increases the amount of work on the separation of the pit side. The warehouse height of 10-12 m does not provide sufficient safety for dump trucks discharging at the top of the site. The cost of reloading 1 ton of rock mass is comparable to loading it in the stope. At the same time, points equipped with high-performance reloading devices can significantly increase the speed of loading railways composition, free up excavators for their intended operation on open pit mines and dumps, increase the productivity of service personnel, and reduce energy and material consumption. Excavator-less reloading points are located on small sites, which reduces the volume of mining and construction work on the separation of the pit sides [6].

Justification of conveyor trasnport parameters

The main parameter of the conveyor transport, which most significantly affects the cost of mining, is the angle of inclination of the conveyor belt. Curves were constructed reflecting the dependence of the annual expenses for the depreciation of fixed assets, current costs and installation metal consumption from the height of the rock mass lift to determine the rational value of the slope of the route (Fig. 3-5). Economic indicators are taken based on experience in the design and construction of steeply inclined conveyors of Dos Santos International (USA) [7].

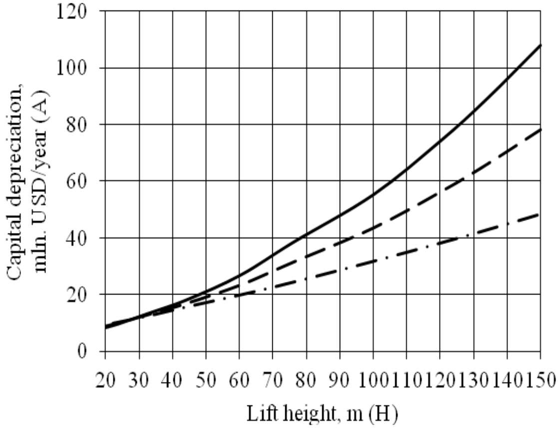

Fig. 3. Dynamics of capital depreciation sum increase with rock mass lift height increase during implementation of conveyor transport with track incline angle of: 15° – ————; 30° – – – – – – – – – – – – –; 45° – –·–·–·–·–·–·–

The curves in Figure 3.2 are convex quadratic functions that exist in the first coordinate angle, since the sum of the depreciation costs and the height of the lift are positive values. Equations of function *A=f(H)* for incline angles 15,30° and 45° look like the following

$$A_{15} = 0{,}0034\, H^2 + 0{,}18\, H + 3{,}94, \text{ mln. USD}, \qquad (18)$$

$$A_{30} = 0{,}0019\, H^2 + 0{,}21\, H + 4{,}18, \text{ mln. USD}, \qquad (19)$$

$$A_{45} = 0{,}0004\, H^2 + 0{,}23\, H + 4{,}41, \text{ mln. USD}. \qquad (20)$$

It can be seen from the graphs in Figure 3.2 that with a lifting height of 20-27 m, the annual depreciation during the operation of conveyors at an inclination angle of 45 degrees exceeds the cost of operating conveyors at an angle of 15 degrees. However, starting from 27 m, the use of steeply inclined conveyors is more economically feasible.

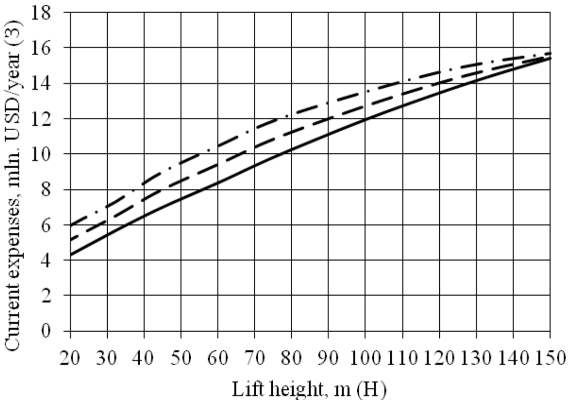

Fig. 4. Dynamics of current expenses sum increase with rock mass lift height increase during implementation of conveyor transport with track incline angle of: 15° – ————; 30° – – – – – – – – – – – – –; 45° – –·–·–·–·–·–·–

The curves in Figure 3 are concave quadratic functions that exist in the first coordinate angle, since the magnitude of the current costs and the height of the lift are positive values.

Equations of function *З*=*f*(*H*) for incline angles 15,30° and 45° look like the following

$$З_{15} = -0{,}0002\, H^2 + 0{,}12\, H + 2, \text{ mln. USD}, \quad (21)$$

$$З_{30} = -0{,}0003\, H^2 + 0{,}13\, H + 2{,}6, \text{ mln. USD}, \quad (22)$$

$$З_{45} = -0{,}0004\, H^2 + 0{,}15\, H + 3{,}15, \text{ mln. USD}. \quad (23)$$

It can be seen from the graphs in Figure 3.3 that with a lifting height of up to 150 m, annual operating costs while using conveyors at an inclination angle of 45 degrees exceed the costs of operating conveyors at an angle of 15 degrees.

However, starting from 150 m, the use of steeply inclined conveyors is more economically feasible.

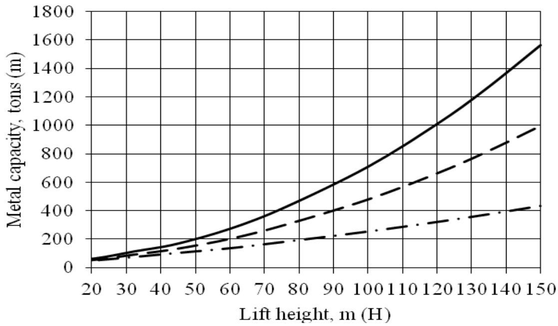

Fig. 5. Dynamics of metal capacity increase of conveyor installment with rock mass lift height increase during implementation of conveyor transport with track incline angle of: 15° – ————————; 30° – – – – – – – – – – – – –; 45° – –·–·–·–·–·–·–

The curves in Figure 3.4 are convex quadratic functions that exist in the first coordinate angle, since the mass of the conveyor system and the height of the lift are positive values. Equations of functions *m=f(H)* for incline angles 15,30° and 45° look like the following

$$m_{15} = 0{,}07\, H^2 + 0{,}31\, H + 43{,}8, \text{ mln. USD,} \tag{24}$$

$$m_{30} = 0{,}04\, H^2 + 0{,}64\, H + 28, \text{ mln. USD,} \tag{25}$$

$$m_{45} = 0{,}008\, H^2 + 1{,}6\, H + 12{,}24, \text{ mln. USD.} \tag{26}$$

It can be seen from the graphs in Figure 3.4 that the metal intensity of steeply inclined conveyors is lower than that of flat ones. This is explained by the fact that due to the greater angle of inclination of the conveyor belt, a smaller length of the conveyor gallery is achieved.

Energy efficiency assessment of transport schemes

The most common type of transport is truck and conveyor on the deep iron ore open pit mines of Ukraine and Kazakhstan. Due to the advantages of dump trucks, namely, the autonomy of the drive and maneuverability, they are implemented during the opening of the deep horizons of open pit mines and in conditions of intensive advance of stopes and a high rate of deepening of mining operations with different open pit mine capacity, from several hundred thousand to 70-100 million tons of rock mass per year and the transport distance of the rock mass to 4 km (in some cases 6-7 km), as well as during the construction of open pit mines.

However, the main disadvantage of the use of a truck is the high cost of transporting the rock mass. Thus, according to statistical data, the cost of transportation by dump trucks is about 0.28 USD / km, while transportation by rails costs 0.09 USD / km, conveyor transport costs 0.57 USD / km with transportation distance 3-4 times less than that of a truck [8].

A significant part of these costs is due to the cost of diesel fuel. In addition, their significant consumption while mining deep horizons of the open pit leads to the release of harmful exhaust gases and their accumulation in the in-pit space. Therefore, the search for ways to reduce the volume of fuel consumption, in particular, energy-saving transport schemes, is a topical task.

The rock mass moves along the mining front to the transport exit from the ledge after loading when using wheeled vehicles. In this case, there is a dead-end front, in which the movement of vehicles is carried out in the opposite direction, and a pass-through front, in which two or more specialized transport exits are used on the bench - separately for supplying empty and loaded vehicles for moving rock mass [6]. In addition, it is possible to unload into a bunker-loader with a dead-end reversal of dump trucks and with their through passage [9, 10].

The graph of dependence of the amount of diesel fuel consumption of dump trucks for the transport cycle, depending on the height of the lifting of the rock mass for the studied transport schemes is shown in Fig. 6, the dynamics of the decline in the efficiency of the studied transport schemes with a through front and dead-end unloading into a bunker, with a dead-end front and through passage over the bunker, with a through front and through passage over the bunker relative to the universally applied schemes - in Fig. 7.

The study of transport schemes has shown that the most effective, from the point of view of energy saving, is a scheme with a through front of work and a through passage of dump trucks when unloading into a bunker. Efficiency is achieved by reducing the time for maneuvering. The greatest effect is achieved for the height of the rock mass up to 45 m. The least effective is the scheme with a dead end of work front and a dead end reversal of dump trucks while unloading.

The dynamics of the growth of the efficiency of the studied transport schemes with the through front and dead-end unloading into the bunker, with a dead-end front and through passage over the bunker, with the through front and through passage over the bunker relative to the existing scheme is given in Fig. 8

The effectiveness of the proposed schemes increases with an increase in annual transportation. Annual savings in diesel fuel and fuel costs amount to 3.5-190 thousand USD, depending on the transport scheme and production capacity.

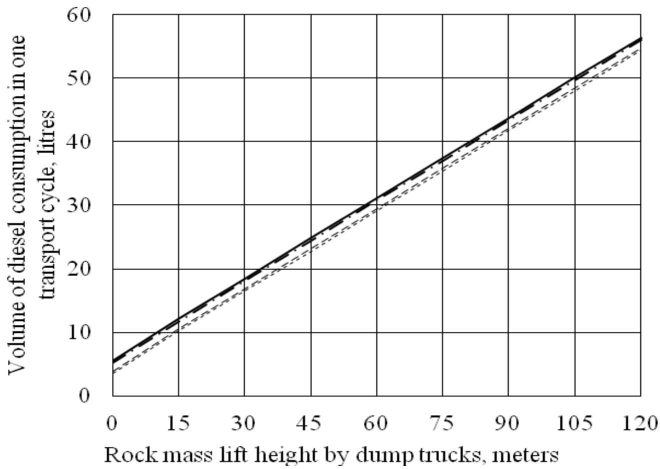

Fig. 6. Graph of dependences of diesel consumption of dump trucks in a transport cycle depending on height of rock mass lift during transport scheme with dead end front and dead end unloading (________________________), ith through front and dead end unloading into a bunker (_._._._._._._._._._._._), with dead end front and through passage above bunker (__ __ __ __ __ __ __), with through front and through passage above bunker (_ _ _ _ _ _ _ _ _ _ _ _ _ _)

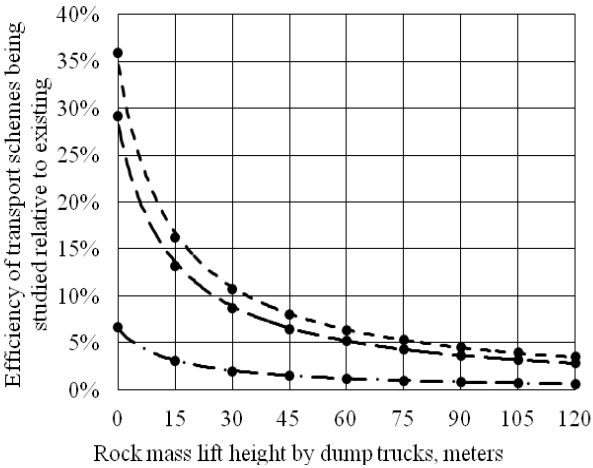

Fig. 7. Dynamics of efficiency decline of transport schemes being studied with through front and dead end unloading into a bunker (_._._._), with dead end front and through passage above bunker (__ __), with through front and through passage above bunker (_ _ _ _ _ _ _ _ _ _ _ _ _ _) relative to existing

Conclusions. The developed method of calculating the parameters of the deep zone of the mineral occurrence allows calculating the contour and current overburden factors more accurately, as well as correct them by controlling the parameters of transport schemes and reload. It is established that the parameters of the deep zone of the mineral occurrence, namely the volume and cross-sectional area, depend on the width of the transport platforms and the overall dimensions of the vehicles and reloading points.

It is proposed to introduce a transport scheme with a through operation front and a through passage of dump trucks when unloading them into the bunker during opening of the deep horizons of iron ore open pit mines, in terms of reducing the consumption of diesel fuel by dump trucks. At the same time, fuel consumption per transport cycle will be reduced by 2 liters. Thus, with an annual capacity of 10 million tons, the savings of diesel fuel will be 150 thousand liters.

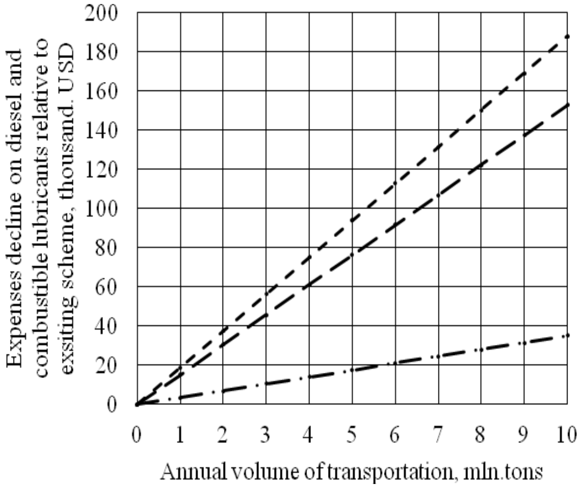

Fig. 8. Dynamics of efficiency of transport schemes being studied with through front and dead end unloading into a bunker (), with dead end front and through passage above bunker (__ __ __ __ __ __ __ __), with through front and through passage above bunker (_ _ _ _ _ _ _ _ _ _ _ _) relative to existing

The established dependences of the costs of operating steeply inclined lifts on the height of the lift indicate an increase in capital and operating costs with an increase in the transportation distance of the rock mass, as well as a decrease in capital costs with an increase in the angle of inclination due to a decrease in the metal capacity of a structure.

References

1. **Dryzhenko A.Y.** (2014). Open pit mining. Dnepropetrovsk: NMU, 590 s.

2. **Rysbekov K.B., Kalybekov T., & Soltabaeva S.T**. (2018) Study of the impact of standards of reserve preparedness on the stabilization of ore mining in open pit mining. KazNITU Newsletter, 4, pp. 101-107.

3. **Drizhenko A.Y., Shustov A.A., Adamchuk A.A., Nikiforova N.A.** (2017). Improving open pit mining technology of iron ore open pit mines during their deepening. Coll. Sc. works' NMU, issue 52. pp. 79-86.

4. **Kalybekov T., Sandibekov M.N., & Rysbekov K.B.** (2018) Management of land reclamation on opencast mining. *Resources and resource-saving technologies in mineral mining and processing. Multi-authored monograph.* Petroșani, Romania: UNIVERSITAS Publishing, 37-53.

5**. Kalybekov T., Sandibekov M.N., & RysbekovK.B.** (2018) Reclamation of lands disturbed by open pit mining. KazNITU Newsletter, 5, 273-279. Retrieved from http://kaznitu.kz/ru/research/vestnik-kaznitu/publications

6. **Dryzhenko A.Y.** (2011). Open pit mine technological mining transport systems. Dnepropetrovsk: NMU, p. 542.

7. **Dos Santos, J. A.** (2012, November 30). The Cost and Value of High Angle Conveying – 2012 (D. Stephan, Ed.). Retrieved from https://www.process-worldwide.com/the-cost-and-value-of-high-angle-conveying-2012-a-387531/

8. **Babets Y. K., Melnykova I.Y., Hrebeniuk S.Y., & Lobov S.P.** (2015). Investigation of technical and economic indicators of mining enterprises of Ukraine and their efficiency in conditions of the alternating world market of iron ore : monograph. Kryvoy Rog: Pub. R.A. Kozlov.

9. **Dryzhenko A.I., Adamchuk A.A., Shustov O.O., Moldabayev S.K. & Nikiforova N.A.** (2018) Adapters for unloading rocks from dump trucks into a bunker. Patent № 123290, Ukraine.

10. **Adamchuk A.A., & Shustov O.O.** (2018) System approach to selection of new vehicles for deep open pit mines. Collection of scientific works of NMU. Dnepropetrovsk: NHU, 54, pp. 8-18.

MATHEMATICAL MODELING OF A ROTARY DRILLING RIG DRILLING ROD TRANSVERSE OSCILLATIONS

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The operation of drilling rigs in the modes of increased vibration of drill rods increases the number of main unit breakdowns, increases the wear of the rods, reduces the technical and economic parameters of drilling, worsens the working conditions of operating personnel. Therefore, the choice of rational modes of rotary drilling rigs operation, which allow reducing oscillations of drill rods, is an actual problem that meets the requirements of their operation. Many reasons affecting the vibration resistance of the operation of rotary drilling rigs, indicate the expediency in the study to apply modern methods, which include the method of mathematical modeling. The paper considers the developing of a mathematical model of the transverse oscillations of the drill rod, taking into account the principal of physics. The development of such a model made it possible not only to distinguish the natural frequencies of the transverse oscillations of the drill rod, but also to obtain an analytical formula that relates the values of these frequencies to the parameters characterizing the operation of the drill rod. It is important that this formula managed to be presented in a dimensionless form, combining the parameters into complexes, which reduced the number of variables in the formula from five to two, thereby facilitating the study.

The problem and its connection with practical tasks.

Rotary drilling rigs are widely used when minerals are open-mined. The functioning of rotary drilling rigs in modern conditions is associated with the implementation of forced modes, which leads to increased vibration of the drill rods, related, in particular, to their transverse oscillations. Forcing the drilling mode, associated with the need to increase the productivity of drilling machines, in turn, leads not only to an increase in the oscillation of the drill rods, but also to the expansion of its spectral composition. The operation of machines in the modes of increased vibration of the drill rods leads to an increase in breakdowns of the main components, increased wear of the rods, a decrease in technical and economic indicators of drilling, deterioration of the working conditions of the staff. The choice of rational modes of rotary drilling rigs operation, which will reduce the oscillations of the drill rods, is an actual problem related to their operating conditions.

Therefore, by mathematical modeling of nonlinear dimensionless dependencies of frequencies and amplitudes of transverse natural oscillations of a drill rod, taking into account the physical laws associated with this process, it will further allow to study the effect of parameters not separately from the amplitudes of forced transverse oscillations, but in combination and reduce adverse conditions of the machine as a whole, is an urgent task and meets the requirements of their operation.

The simulation of oscillations of a drilling rod during the operation of a rotary drilling rig involves two stages. At the first stage, mathematical modelling of drilling rig oscillations is carried out, based on the corresponding equations of mathematical physics, the basis of which are the conservation laws. Naturally, mathematical modelling is an idealization of the studied processes.

Therefore, to establish the adequacy of solutions obtained by mathematical modeling, it is necessary to introduce the second stage, namely, testing on real objects. At the same time, such tests on a drilling rod under real conditions are impossible, since they lead to violations of the technological regimes of drilling and, as a result, to significant economic costs. As one of the possible ways to overcome this problem is a computer modeling of a drilling rod with the help of which the necessary experiments can be carried out.

Analysis of research and publications.

According to the author of the paper opinion [1], the main cause of vibration of rotary drilling rigs when blastholes drilling in open mining is the elastic oscillations of the drilling rod. Tensometric studies of stresses in the drilling rod have shown that the axial force at the bottom of the borehole is not constant; it changes periodically, with a constant component and a variable, the amplitude of which is approximately 40% of the constant component. Similar oscillatory phenomena are inherent in the torque on the drilling rod, where the variable component reaches 70-75% of the constant. The nature of the stress variation in the bar of the drilling rod is given in paper [1], which shows the oscillogram of mechanical stresses in the drilling rod bar at the speed n=50 min^{-1} and the axial force P=225 kN. In this case, the resulting stresses in the bar have the form: $\sigma=\sigma_{cm}+\Delta\sigma\cdot\sin\omega_1\cdot t$ - compression stress, $\tau=\tau_{cm}+\Delta\tau\cdot\sin\omega_2\cdot t$ - torsional stresses (tangential). Experimental studies conducted at the Central mining combine «Uralasbest» (inclined drilling machine 2RDR-200N) showed that the frequency of drilling increases with increasing speed of rotation of the drilling tool. When changing the rotational speed from 50 to 150 min^{-1}, the oscillation frequency of the variable component of the axial force is in the range of 0,8-1,2 Hz, the frequency of the variable component of the torque varies from 1,2 to 2 Hz. The nature of drilling rod fluctuations is even more complex. The use of natural vibrations of rod in rotary drilling rigs in open mining in order to increase their productivity requires the development of the issue of their vibration isolation. The authors declare that one of the ways to solve this issue is to replace the rigid connection of the drilling rod with the rotary drilling rig by an elastic connection with a relatively soft characteristic. However, the authors [1] do not provide any calculations or recommendations regarding the characteristics of the elastic connections of the drilling rod with the rotary drilling rig. While we [2], on the basis of calculations, have found that the cause of intense longitudinal oscillations of the rotator and drilling rod of rotary drilling rig is the resonant vibration of the rotator suspension on spring-damped cable pull rods of polyspast pulley block feedings to the bottomhole and the polyspast pulley blocks of the drilling rod removal from the drilled borehole. Since the polyspast pulley blocks of feed and removal of bar are pretensioned, the rotator suspension from the drilling rod is constantly spring-loaded from both sides by the ropes of the polyspast pulley blocks and has different natural frequencies of oscillations depending on the number of bars in the drilling rods. So, for example, the suspension of the rotator of the USBSH-250A machine with one weighed bar with a diameter of 219 mm and a length of 8000 mm has its own oscillation frequency f=8.8 Hz, with two screwed-on rods f=7.7 Hz, with three screwed rods -f=6.9 Hz.

Saroyan A.E. carried out research at the drilling of deep boreholes 2200-2500 m [3]. He notes that with the continuous contact of the drilling bit teeth with the borehole bottom in the string, elastic waves arise associated with both rolling of the drill bit roller cutter from a tooth onto a tooth, and with the rolling of the drill bit roller cutters like cones along a wavy of the face. However, how this waviness and the type of this waviness are recorded is not shown by the author.

In [3], it was also shown that another source of longitudinal vibrations is the rotation of the drill string. Heterogeneity of drilled rocks, changes in friction forces along the boreholes and other causes lead to uneven rotation of the drill string.

In [4], for the first time for rotary drilling rigs, the authors give a mathematical model of the longitudinal and torsional vibrations of a drill rod, as well as the dependence of the low frequencies of their own longitudinal and torsional vibrations on the length of the drill rods for the SBSH-250N and SBSH-250 MNA drilling rigs. It is shown that with increasing of borehole depth by increasing the drilling rod, natural frequencies of, both longitudinal, transverse and torsional vibrations of the rods decrease according to a non-linear law, while approaching each other in magnitude.

Simonov V.V., Yunin Ye.K. [5] and Saroyan A.Ye. [3] agree, on the basis of the tests carried out, the falling torque characteristic of the drill bit with increasing angular velocity of its rotation causes torsional and longitudinal vibrations during the drilling of deep (up to 3000 m) boreholes.

Sukhanov A.F., Kutuzov B.N., Schmidt R.G. [7] note that with an increase in the bit rotation speed, the vibration parameters also grow, and when drilling fragile monolithic rocks less intensively than when drilling strong, fractured rocks. With an increase in the speed of rotation of the drill rod over 120-150 min^{-1}, in drill rods with the cable-polyspast supply system, resonant phenomena often occur, precluding the further possibility of operating without changing the operating parameters. However, in the paper there is no data on the value of the frequencies and amplitudes of these resonant oscillations. In the paper [7] it is also indicated that when the rotary drilling rigs operate, the axial feed forces and the number of rotations of the rotator can reach such values at which the drilling rod loses stability. The authors have performed a theoretical definition of the vibration resistance of drill rods, as a result of which it is shown (Fig. 17, p. 48 [7]) that for rods of 10 m long with an outer diameter of

Ø 152 mm and a wall thickness h = 12 mm with an axial force P = 200 kN stability is lost when the number of rotations n=275 min^{-1}, and for P=500 kN - when n=80 min^{-1}. Experimental data (Fig. 20, p. 53 [7]), given by the authors on the bar Ø 152 mm, length 6 m (that is, more rigid than 10 m), obtained on the SBSH-200 drilling rig with a rigid cartridge feed scheme show that stability is lost when P=180-190 kN and the number of rotations n=150 min^{-1}, does not confirm the theory set forth in the same source, since the rigid bar loses stability with less by 5-10% efforts and 54.5% less rotations than according to theoretical calculations. In addition, it should be noted that currently the most common are the more powerful SBSH-250 MNA-32 drilling rigs, which use 8-meter thick drill rods ø215×51.5 and ø203×50. At the same time, in iron-ore open pits, for example, in the Kryvyi Rih iron-ore basin, they drill to a depth of up to 24 m, that is, with no more than 3 rods at a speed of n≤110 min^{-1} and supply efforts of P≤220 kN. In the well-known publications there are no data on the stability of such drill rods under these drilling conditions. In a later paper [17] Kutuzov B.N. with co-authors gave data on the loss of stability of the drill rod of the SBSH-250MN drilling rig P≥250 kN and the number of rotation n≥120 min^{-1}, taking into account the centrifugal force arising from the rotation of the axially bent drilling rod. Will a loss of stability of the drill rod occur, taking into account the centrifugal force arising from the rotation of the axially curved drill rod up to 24 m long under the conditions of the Kryvyi Rih iron ore basin, is unknown. To clarify these contradictions, it is necessary to carry out special studies on the stability of the drill rod in the range of real axial feed forces during drilling with rotary drilling rigs of the SBSH-250 type.

In paper [8], the design model is presented and the natural frequencies of the transverse oscillations of the drill rod are defined below -ω=61-59 1/s for various axial feed forces R in the range of 50-350 kN for the SBSH-250N machine of the Novokramatorsk plant without specifying the rod parameters. This paper presents recommendations for rotational frequencies of the drill rod, taking into account the forced resonant oscillations for the SBSH-250N drilling rigs with one rod equipped with a roller cutter with a number of teeth z=3.

However, the SBSH-250N drilling rig was a prototype that was not put into production. Therefore, it is not possible to verify the recommendations of the authors.

When describing the operating conditions of rotary drilling rigs, most of the authors, as the main source of vibration, define the frequency of rotation of the drill rod, longitudinal, torsional and transverse oscillations of the drilling rod pipe strings. However, there are no data on the amplitudes of these oscillations and the conditions for their transmission to the drilling rig, which makes it impossible to predict in advance the vibration of the bar and the whole rig and consciously control the modes of its operation, reduce or completely eliminate the extreme oscillations, which, as mentioned above, lead to the destruction of the metal structure masts and significant vibration in the workplace of the operator of the drilling rig.

Analysis of the processes that determine the transverse oscillations of the drill rods indicates both the number of them and the impossibility of taking them all into account. Therefore, we consider it expedient to carry out mathematical modeling of the transverse oscillations of the drill rod, taking into account the physical laws associated with these processes

Material presentation and findings.

In modeling, the drill rod is considered as a hollow rod of circular cross section, both ends of which are floated [9]. In this case, the bar takes compression from the feed force.

According to the scheme of the drill rod, shown in Figure 1, a mathematical model describing its transverse oscillations can be represented as a homogeneous partial differential equation [9]

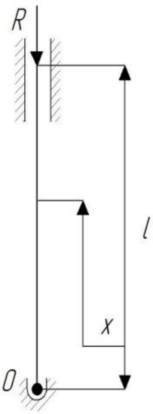

Fig.1. Drill rod scheme

$$EJ\frac{\partial^4 y}{\partial x^4}+R\frac{\partial^4 y}{\partial x^4}+m\frac{\partial^4 y}{\partial x^4}=0\ , \qquad (1)$$

where $y=y(x,t)$ transverse movement of the drill rod, m; E - the modulus of rod material elasticity, N/m^2; J - moment of inertia of the rod cross section, m^4; m - intensity rod mass, kg/m; R - rod feeding force, N.

De facto, at both ends of the rod, sliding fits, but with such a ratio of the length of the rod l and its diameter $D(l>>D)$ the rod behaves like a hinged beam, therefore the boundary conditions are written as

$$y(x,t)\big|_{x=0}=0\,,\ \frac{\partial^2 y(x,t)}{\partial x^2}\Big|_{x=0}=0 \qquad (2)$$

$$y(x,t)\big|_{x=l}=0\,,\ \frac{\partial^2 y(x,t)}{\partial x^2}\Big|_{x=l}=0 \qquad (3)$$

Initial conditions can be written as

$$y(x,t)\big|_{x=0}=\varphi(x)\,,\ \frac{\partial y(x,t)}{\partial t}\Big|_{x=0}=\psi(x)\,, \qquad (4)$$

where $\varphi(x)$, $\psi(x)$ - functions that determine the initial profile and the transverse speed of the rod.

The solution of the Cauchy problem (1),...,(4) will be made by the Fourier method [10] in the form of a product of functions depending on one variable,

$$y(x,t)=X(x)T(x)\,. \qquad (5)$$

Substituting (5) into the differential equation (1), we obtain

$$EJ\frac{d^4X}{\partial x^4}T+R\frac{\partial^2 X}{\partial x^2}+mX\frac{d^2T}{\partial t^2}=0\,. \qquad (6)$$

Next, we write equations (6) in the form of relations of functions of one variable. To do this, we transfer the third term to the right side

$$EJ\frac{d^4X}{\partial x^4}T+R\frac{\partial^2 X}{\partial x^2}=-mX\frac{d^2T}{\partial t^2}\,,$$

and divide both sides of the equation by the product of functions (5). After the reduction in the left side of the equality on *T*, and in the right side on *X*, we get

$$\frac{\frac{EJ}{m}\frac{d^4X}{\partial x^4}+\frac{R}{m}\frac{d^2X}{dx^2}}{X}=-\frac{\frac{d^2T}{\partial t^2}}{T} \qquad (7)$$

Since the left and right side of the equation (7) depend on various variables, for equality, they must be constant, i.e.,

$$\frac{\frac{EJ}{m}\frac{d^4X}{\partial x^4}+\frac{R}{m}\frac{d^2X}{dx^2}}{X}=\omega^2, \qquad (8)$$

$$-\frac{d^2T/\partial t^2}{T}=\omega^2, \qquad (9)$$

where - ω - circular frequency, *rad/s.*

The equations (8) and (9) of multiplication, respectively, by *X* and *T* are reduced to the form

$$\frac{EJ}{m}\frac{d^4X}{\partial x^4}+\frac{R}{m}\frac{d^2X}{dx^2}-\omega^2X=0, \qquad (10)$$

$$\frac{d^2X}{dx^2}+\omega^2T=0. \qquad (11)$$

Solution of equation (10) will be sought in the form

$$X=e^{\lambda\cdot x}. \qquad (12)$$

Substituting (12) into (10) we obtain the characteristic equation

$$\frac{EJ}{m}\lambda^4+\frac{R}{m}\lambda^2-\omega^2=0. \qquad (13)$$

Equation (13) is biquadratic and is solved by reducing the wall thickness, length, and load to a quadratic equation.

$$\frac{EJ}{m}\xi^2+\frac{R}{m}\xi-\omega^2=0, \qquad (14)$$

where $\xi=\lambda^2$

The solution of equation (14) is

$$\xi_1 = \frac{-\frac{R}{m} - \sqrt{D}}{\frac{2EJ}{m}}, \ \xi_2 = \frac{-\frac{R}{m} + \sqrt{D}}{\frac{2EJ}{m}}, \tag{15}$$

where $D = \sqrt{\frac{R^2}{m^2} + \frac{4EJ\omega^2}{m}}$ - discriminant of the equation (14)

The solution (15) can be reduced to the form

$$\xi_1 = \frac{-R(\sqrt{1 + \frac{4EJm\omega^2}{R}} + 1)}{2EJ}, \xi_1 = \frac{R(\sqrt{1 + \frac{4EJm\omega^2}{R^2}} - 1)}{2EJ}. \tag{16}$$

According to the change of a variable, we find four roots of bi-quadratic equations, two of which are complex-related, and two are real.

$$\lambda_1^{(1)} = \sqrt{\frac{R}{2EJ}\left(\sqrt{1 + \frac{4EJm\omega^2}{R^2}} + 1\right)} \cdot i,$$
$$\lambda_1^{(2)} = -\sqrt{\frac{R}{2EJ}\left(\sqrt{1 + \frac{4EJm\omega^2}{R^2}} + 1\right)} \cdot i, \tag{17}$$

where ($i = \sqrt{-1}$ - imaginary unit)

$$\lambda_2^{(1)} = \sqrt{\frac{R}{2EJ}\left(\sqrt{1 + \frac{4EJm\omega^2}{R^2}} - 1\right)},$$
$$\lambda_2^{(2)} = -\sqrt{\frac{R}{2EJ}\left(\sqrt{1 + \frac{4EJm\omega^2}{R^2}} - 1\right)} \tag{18}$$

We introduce notation to simplify further transformations, reducing the number of variables to two

$$\alpha = \sqrt{\frac{R}{2EJ}}, \ \beta = \sqrt{1 + \frac{4EJm\omega^2}{R^2}}. \tag{19}$$

Then formulas (17) and (18) take the form

$$\lambda_1^{(1)} = \alpha \cdot \sqrt{\beta + 1} \cdot i, \lambda_1^{(2)} = -\alpha \cdot \sqrt{\beta + 1} \cdot i, \lambda_2^{(1)} = \alpha \cdot \sqrt{\beta - 1}, \lambda_2^{(2)} = -\alpha \cdot \sqrt{\beta - 1}. \tag{20}$$

Taking into account (12), we obtain four linearly independent solutions

$$X_1 = e^{\lambda_1^{(1)} \cdot x}, X_2 = e^{\lambda_1^{(2)} \cdot x}, X_3 = e^{\lambda_2^{(1)} \cdot x}, X_4 = e^{\lambda_2^{(2)} \cdot x}$$

Since the original equations contain only real variables, the solution must also be expressed in terms of real variables. Considering that a linear combination of solutions is also a solution of a linear differential equation, we get

$$\overline{X_1} = \frac{X_1 + X_2}{2} = \cos\left(\alpha\sqrt{\beta+1} \cdot x\right), \overline{X}_2 = \frac{X_1 - X_2}{2i} = \sin\left(\alpha\sqrt{\beta+1} \cdot x\right), \quad (21)$$

$$\overline{X}_3 = \frac{X_3 + X_4}{2} = ch\left(\alpha\sqrt{\beta-1} \cdot x\right), \overline{X}_4 = \frac{X_3 - X_4}{2} = sh\left(\alpha\sqrt{\beta-1} \cdot x\right). \quad (22)$$

As a result, the general solution of equation (10) is written as

$$\begin{gathered} X(x) = C_1 \cos\left(\alpha\sqrt{\beta+1} \cdot x\right) + C_2 \sin\left(\alpha\sqrt{\beta+1} \cdot x\right) + \\ + C_3 ch\left(\alpha\sqrt{\beta-1} \cdot x\right) + C_4 sh\left(\alpha\sqrt{\beta-1} \cdot x\right). \end{gathered} \quad (23)$$

The boundary conditions taking into account the representation of the function $y(x, t)$ in the form (5) will take the form

$$X(x)\Big|_{x=0} = 0, \ \left.\frac{d^2 X(x)}{dx^2}\right|_{x=0} = 0 \quad (24)$$

$$X(x)\Big|_{l=1} = 0, \ \left.\frac{d^2 X(x)}{dx^2}\right|_{l=1} = 0\,. \quad (25)$$

First of all, let's calculate the derivatives of the total solution (23)

$$\begin{gathered} \frac{dX}{dx} = (\alpha(\sqrt{\beta+1}(-C_1 \sin(\alpha\sqrt{\beta+1} \cdot x) + C_2 \cos(\alpha\sqrt{\beta+1} \cdot x)) + \\ + \sqrt{\beta-1}(C_3 sh(\alpha\sqrt{\beta-1} \cdot x) + C_4 ch(\alpha\sqrt{\beta-1} \cdot x))) \end{gathered} \quad (26)$$

$$\begin{gathered} \frac{d^2 X}{dx^2} = \alpha^2((\sqrt{\beta+1})(-C_1 \cos(\alpha\sqrt{\beta+1} \cdot x) - C_2 \sin(\alpha\sqrt{\beta+1} \cdot x)) + \\ + (\beta-1)(C_3 ch(\alpha\sqrt{\beta-1} \cdot x) + C_4 sh(\alpha\sqrt{\beta-1} \cdot x))) \end{gathered} \quad (27)$$

Substituting (26) and (27) into the boundary conditions (24), we obtain

$$C_1 + C_3 = 0, \ C_1(\beta+1) + C_3(\beta-1) = 0$$

Given that the determinant of a system of linear equations is not equal to zero

$$\Delta = \begin{vmatrix} 1 & 1 \\ \beta+1 & \beta-1 \end{vmatrix} = \beta - 1 - \beta - 1 = -2 \neq 0$$

This system has the only zero solution, i.e.

$$C_1 = 0\,, C_3 = 0\ . \tag{28}$$

Substituting (28) into the general solution (23), we obtain

$$X(x) = C_2 \sin(\alpha\sqrt{\beta+1}\cdot x) + C_4 sh(\alpha\sqrt{\beta-1}\cdot x) \tag{29}$$

To find other constants, we use the boundary conditions (25)

$$\begin{aligned} &C_2 \sin(\alpha\sqrt{\beta+1}\cdot l) + C_4 sh(\alpha\sqrt{\beta-1}\cdot l) = 0 \\ &-C_2(\beta+1)\sin(\alpha\sqrt{\beta+1}\cdot l) + C_4(\beta-1)sh(\alpha\sqrt{\beta-1}\cdot l) = 0 \end{aligned} \tag{30}$$

The resulting homogeneous system of linear equations must have non-zero solutions, since otherwise differential equation (10) will have only zero solution.

For the existence of a non-zero solution of the system of linear equations (30), it is necessary that its determinant is zero, i.e.,

$$\Delta = \begin{vmatrix} \sin(\alpha\sqrt{\beta+1}\cdot l) & sh(\alpha\sqrt{\beta-1}\cdot l) \\ -(\beta+1)\sin(\alpha\sqrt{\beta+1}\cdot l) & (\beta-1)\cdot sh(\alpha\sqrt{\beta-1}\cdot l) \end{vmatrix} = 0 \tag{31}$$

Expanding the determinant, we obtain the transcendental equation

$$\begin{aligned} &(\beta-1)\sin(\alpha\sqrt{\beta+1}\cdot l)sh(\alpha\sqrt{\beta-1}\cdot l) + \\ &+(\beta+1)\sin(\alpha\sqrt{\beta+1}\cdot l)sh(\alpha\sqrt{\beta-1}\cdot l) = 0 \end{aligned}$$

or, after algebraic transformations,

$$2\beta \sin(\alpha\sqrt{\beta-1}\cdot l)sh(\alpha\sqrt{\beta-1}\cdot l) = 0\,. \tag{32}$$

In the future, for the convenience of calculations we introduce substitute

$$\gamma = \alpha \cdot l\,. \tag{33}$$

Taking into account (33), the equation (32) with the condition β>0 takes the form

$$\sin(\gamma\sqrt{\beta+1) = 0}\,. \tag{34}$$

Equation (34) admits the solution at values

$$\gamma\sqrt{\beta+1} = \pi\cdot n,\ \ (n = 1,2,...), \tag{35}$$

From equation (35) we find

$$\beta_n = \frac{\pi^2 n^2}{\gamma^2} - 1, \ (n = 1,2,...), \tag{36}$$

Then, we consider the substitute (19), we find the discrete values of the circular part ω

$$\omega_n = \frac{R}{2}\sqrt{\frac{\beta_n^2 - 1}{EJm}}, \ (n = 1,2,...), \tag{37}$$

We take into account (36), formula (37) is consistently converted into

$$\omega_n = \frac{R}{2\sqrt{EJm}}\sqrt{\left(\frac{\pi^2 n^2}{\gamma^2} - 1\right)^2 - 1},$$

$$\omega_n = \frac{R}{2\sqrt{EJm}}\frac{\pi \cdot n}{\gamma}\sqrt{\frac{\pi^2 n^2}{\gamma^2} - 2}, \tag{38}$$

$$\omega_n = \frac{\pi^2 n^2}{l^2}\sqrt{\frac{EJ}{m}}\sqrt{1 - \frac{2\gamma^2}{n^2\pi^2}}, \quad (n = 1,2,...).$$

Cyclic frequency is according to the formula

$$f_n = \frac{\omega_n}{2\pi}, \ (n = 1,2,...). \tag{39}$$

Considering that the value (35) nullifies the determinant (31) of system (30), to find the constants we have one equation with two unknowns

$$C_2 \sin \pi \cdot n + C_4 sh(\gamma\sqrt{\beta_n - 1}) = 0, \tag{40}$$

or, taking into account (32) i (36),

$$C_4 sh(\lambda\sqrt{\left(\pi^2 n^2\right)/\gamma^2 - 2}) = 0, \text{ i.e. } C_4 = 0.$$

As a result of the solution, equation (29) takes the form

$$X_n(x) = C_2 \sin\left(\pi \cdot n\frac{x}{l}\right), \ (n = 1,2,...), \tag{41}$$

At the same time, circular frequencies (38) are eigenfrequencies, and functions (41) are eigenfunctions that correspond to these frequencies. The time dependence of the solution of the differential equation (1) is found by solving equation (11). To solve this equation, we compose the characteristic equation $k_2 + \omega^2 = 0$, the solution of which has the form

$$k_{1,2} = \pm i \cdot \omega . \qquad (42)$$

Then, taking into account (42), the solution of equation (11) is written in the form

$$T(t) = A\cos\omega \cdot t + B\sin\omega \cdot t . \qquad (43)$$

Then, taking into account (38), the solution of equation (43) is written in the form

$$T_n(t) = A_n \cos\omega_n t + B\sin\omega_n t, \quad (n = 1,2,...), \quad (44)$$

is written in the form $y_n(x,t) = X_n(x)T_n(t), \ (n = 1,2,...),$ or, taking into account (41) i (44),

$$, y_n(x,t) = \sin\left(\pi \cdot n\frac{x}{l}\right)\left(c_n\cos\omega_n t + d_n\sin\omega_n t\right), \qquad (45)$$

where $c_n = C_2 a_n$, $d_n = C_2 b_n$, Then the solution of the differential equation (1) can be represented as a superposition of solutions (45)

$$y(x,t) = \sum_{n=1}^{\infty}\sin\left(\pi \cdot n\frac{x}{l}\right)\left(c_n\cos\omega_n t + d_n\sin\omega_n t\right). \qquad (46)$$

To find the constants included in the solution (46), it is necessary to use the initial conditions (4). According to the first initial condition, we get

$$\varphi(x) = \sum_{n=1}^{\infty} c_n\sin\left(\pi \cdot n\frac{x}{l}\right). \qquad (47)$$

To find the constant c_n, multiply both sides of equality (47) by $\sin(\pi \cdot n(kx/l))$and integrate over the interval [0, l], that gives

$$\int_0^1 \varphi(x)\sin\left(\pi k\frac{x}{l}\right)dx = \frac{l}{2}\sum_{n=1}^{\infty} c_n\delta_{kn} = \frac{l}{2}c_k , \qquad (48)$$

where $\delta_{kn} = \begin{cases} 0, k \neq n \\ 1, k = n \end{cases}$ - Kronecker symbol. Thus, according to (48) we can write

$$c_n = \frac{2}{l}\int_0^1 \varphi(x)\sin\left(\pi \cdot n\frac{x}{l}\right)dx\,. \tag{49}$$

To find the second constant, we first pre-differentiate the solution (46) with respect to time

$$\frac{\partial y(x,t)}{\partial t} = \sum_{n=1}^{\infty}\sin\left(\pi \cdot n\frac{x}{l}\right)(-\omega_n c_n \sin\omega_n t + \omega_n d_n \cos\omega_n t). \tag{50}$$

Then, according to the second initial condition, we get

$$\psi(x) = \sum_{n=1}^{\infty}\omega_n d_n \sin\left(\pi \cdot n\frac{x}{l}\right). \tag{51}$$

After multiplying both sides of equation (51) by sin ($\pi \cdot n(kx/l)$) and integrating on the interval [0, l], we obtain

$$d_n = \frac{2}{\omega_n l}\int_0^1 \psi(x)\sin\left(\pi \cdot n\frac{x}{l}\right)dx. \tag{52}$$

The solution of the Cauchy problem (1), ... (4) taken into account (49) and (52) is written as

$$\begin{aligned} y(x,t) = \frac{2}{l}\sum_{n=1}^{\infty}\sin\left(\pi \cdot n\frac{x}{l}\right)(\cos\omega_n t\int_0^1 \varphi(\xi)\sin\left(\pi n\frac{\xi}{l}\right)d\xi + \\ + \frac{1}{\omega_n}\sin\omega_n t\int_0^1 \psi(\xi)\sin\left(\pi n\frac{\xi}{l}\right)d\xi). \end{aligned} \tag{53}$$

To simplify research, we will bring formula (38) to a dimensionless form.

$$\tilde{\omega}_n = n^2\sqrt{1-\frac{\delta^2}{n^2}},\ \ (n = 1,2,...), \tag{54}$$

where $\tilde{\omega}_n = \dfrac{\omega_n}{\overline{\omega}}$, $\overline{\omega} = \dfrac{\pi^2}{l^2}\sqrt{\dfrac{EJ}{m}}$, $\delta = \dfrac{l}{\pi}\sqrt{\dfrac{R}{EJ}}$

In formula (54), the unit of measurement of the circular frequency is $\overline{\omega}$, which is determined by the properties of the studied drill rod, and the effect of the load on the rod is determined by the complex δ. Such a record of formula (54) allows one to study the effect of parameters not separately, but in a complex, reducing their number from five (R,E,J,m,l) to two $(\tilde{\omega}, \delta)$.

Table 1 presents the results of calculations by the formula (54). Analysis of the results calculation shows that for the first harmonic (n=1), with increasing parameter δ, the circular frequency sharply decreases.

For further harmonics (n=2.3), there is no such a change - the magnitudes of the circular frequencies are larger, but they vary considerably less depending on the parameter δ Therefore, we can conclude that the first harmonic makes the main contribution to the vibration of the drill rod.

Table 1

The dependence of the angular frequency of the load for different harmonics in a non-dimensional form

δ \ n n	1	2	3
0,2	0,98	3,98	8,98
0,4	0,92	3,92	8,92
0,6	0,8	3,82	8,82
0,8	0,6	3,67	8,67
1	0	3,46	8,49

Below are the results of numerical simulation. According to the initial data, the parameters of the drill rod are characterized by

$$R = 200\ kN;\ m = 206{,}3;\ E = 2 \cdot 10^{11} Pa;\ J = 9{,}72 \cdot 10^{-5} m^4;$$

$$d_1 = 9{,}112\ m;\ d_2 = 0{,}215\ m.$$

Then, according to the formula (54), we find, rad/s

$$\delta = \frac{l}{\pi}\sqrt{\frac{R}{EJ}} = \frac{l}{3{,}14159}\sqrt{\frac{200000}{2 \cdot 10^{11} \cdot 9{,}72 \cdot 10^{-5}}} = 0{,}032 \cdot l,$$

$$\overline{\omega} = \frac{\pi^2}{l^2}\sqrt{\frac{EJ}{m}} = \frac{3{,}14^2}{16^2}\sqrt{\frac{2 \cdot 10^{11} \cdot 9{,}72 \cdot 10^{-5}}{206{,}3}} = \frac{3{,}03 \cdot 10^3}{l^2},$$

$$\tilde{\omega}_n = n^2 \cdot \sqrt{1 - \frac{\delta^2}{n}} = \sqrt{1 - 1{,}042 \cdot 10^{-3} l^2}.$$

Formulas for circular and cyclic frequencies take the form

$$\omega_n = \overline{\omega} \cdot \tilde{\omega}_n = 3{,}03 \cdot 10^3 \cdot \frac{n^2}{l^2} \sqrt{1 - 1{,}042 \cdot 10^{-3} \frac{l^2}{n^2}};$$
$$f_n = 482{,}239 \cdot \frac{n^2}{l^2} \sqrt{1 - 1{,}042 \cdot 10^{-3} \frac{l^2}{n^2}}. \quad (n = 1{,}2{,}...). \tag{55}$$

Table 2 presents the results of calculations according to the formula (55) of circular and cyclical natural frequencies of transverse oscillations of the drill rod of the first three harmonics for different lengths of the drill rod.

Table 2. The calculation results for the three harmonics of the natural frequencies of oscillations for different lengths of the drill rod.

l, ì	8			16		
n	1	2	3	1	2	3
ω_n, rad/s	45,74	187,79	424,51	11,37	45,74	104,93
f_n, Hz	7,28	29,89	67,56	1,81	7,28	16,70

Checking the adequacy of the mathematical model was performed using the SolidWorks software package [11-15].

On the linear dimensions of two heavy drill rods, taking into account the requirements of the COSMOSWorks program [13], a computer model of the drilling rod was built: material - steel 45; connection of two rods - threaded coupling; axial force P = 220 kN; end fixing - the upper part in the form of a sliding fit of the spindle sleeve in the support node, the lower part - a dril bit in the form of a ball five.

The specified operating (excitation) frequency range is from 0 to 106.8 rad/s (0-17 Hz); according to the COSMOSWorks program, the modal damping factor was chosen, corresponding to the “metal structure with connections” - 0.03. The calculation of the amplitudes of oscillations in a given frequency range was carried out every 0.2 Hz, and near the resonant frequencies - every 0.05-0.1 Hz. Further, using SolidWorks, and FFiplus applications are performed calculations presents table 3.

Table 3

List of modes of rotation of the drill rod.

Mode №	Frequency (Rad/sec)	Frequency (Hertz)	Period (Seconds)
1 – x-axis	11.842	1.8847	0.5306
1 – y-axis	11.843	1.8849	0.53054
2 – x-axis	47.296	7.5274	0.13285
2 – y-axis	47.319	7.5311	0.13278
3 – x-axis	106.17	16.897	0.059183
3 – y-axis	106.29	16.916	0.059114

The visualization of the oscillation amplitudes of the drilling rod by the COSMOSWorks program is performed in a stylized way. The half-cycles of vibration amplitudes are shown on one side of the axis of rotation of the drilling rod. This indicates their symmetry. In the first mode, one half-period is the length of the drilling rod, in the second mode - one full period, in the third mode - 1.5 periods of oscillation.

The theoretical calculations in the first mode differ from the computer experiment in circular frequency by 0.75% and in amplitude by 0.04%, which can be considered a good confirmation of the theoretical calculations.

The obtained calculation results are in good agreement with both experimental data and modeling performed in the SolidWorks environment.

The findings, the task of further research.

Mathematical modeling of the transverse oscillations of the drill rod, based on physical patterns, allowed us to establish the functional dependence of the natural frequencies of the transverse oscillations of the drill rod on the main parameters of the rod: mass intensity, elastic modulus, diameter, wall thickness, length and axial load.

Bringing the formula that determines the frequency dependences of the bar parameters to a dimensionless view allowed grouping these parameters into complexes, reducing the number of variables from five to two, and thereby greatly simplifying the study of the resulting dependence.

Analysis of the dependence of the drill rod transverse oscillation frequency on the load showed that the first harmonic plays a significant role in the transverse oscillations. The frequencies of the following harmonics are much higher, but depend little on the load.

The task of further research is to implement mathematical modeling of the amplitudes of the forced transverse oscillations of the drill rod and, due to scale invariance or scaling, will allow, based on the similarity theory and dimension analysis, to study the effect of parameters not separately from the amplitudes of the forced transverse oscillations but in the complex, which significantly reduce the total amount of research.

References

1. **Marasanov Yu.P., Borovkov V.A., Stromwasser P.C.** (1972). *Elastic oscillations of a drill rod when drilling directional wells with a roller bit.* Moscow: News of higher educational institutions. Mining Journal. P. 132–140.

2. **Gromadskyi A.S., Gromadskyi V.A., Aksenov A.V.** (2011, May 25–28). *Damping of longitudinal oscillations of the rotary and drilling rod of rotary drilling rigs.* Kryvy Rih: Sustainable development of the mining and metal industry. International Sci.-Tech. Conf. P. 133

3. **Saroyan A.Ye**. (1979). *Drillstrings in deep drilling* Moscow: Nedra.

4. **Beshta A.S., Khilov V.S., Plakhotnik V.V**. (2004). *Mathematical model of longitudinal and torsional oscillations of a drilling rig.* Mining mechanics and automation. Collection of scient**ific papers. Issue 73.**

5. Simonov V.V., Yunin E.K. (1977). *The influence of oscillatory processes on the operation of the drilling tool*/Moscow: Nedra, 212 p.

6. **Kantovich L.I., Babarika S.D**. (1986*). Comprehensive assessment of the effectiveness of the stabilization of the drilling rod at rotary drilling.* Mining Journal. - № 2. - P. 50–51.

7. **Sukhanov A.F., Kutuzov B.N., Schmidt R.G**. (1969). *Vibration and reliability of rotary drilling rigs operation.* Moscow: Nedra. 123 p.

8**. Khilov V.S., Plakhotnik V.V**. (2004). *Evaluation of the natural frequencies of oscillations of the drill rod in non-stationary modes.* Collection of scientific papers of the National Mining University. –№ 19, v. 4. - p. 145–150.

9. **Timoshenko S.P., Young D.H., Weaver U.** (1985) *Variations in engineering*. Moscow: Mechanical engineering – 472p.

10. **Beshta A.S., Khilov V.S., Plakhotnik V.V. (**2004). *A mathematical model of the longitudinal and torsional vibrations of the drill rod.* Mining mechanics and automation. - Collection of scientific papers. - Issue 73.

11. *Zhupiev A.L., Bezpalko T.V., Zinoviev S.N*. (2005). *Methods of using the package of SolidWorks Education in the process of training of mechanical engineers.* Science Bulletin of the National Minig University - № 11. - P. 26–31.

12. **Kuiva Lee. (**2004). Basics of CAD/CAM /CAE. - S.-Pb .: Petersburg. 560 p.

13. Company SolidWorks Russia. The composition and purpose of the program complex of educational process SolidWorks Education. http://www.solidworks.ru/swr-academy/.

14**. Dunaeva N.Yu., Zagayko S.A.** (2007). SolidWorks-2007. S.Peterburg. S.Pb .: BHV - Petersburg, 1328 p.

15. **Alyamovsky A.A**. SolidWorks-2007. *Computer modeling in engineering practice*. S.Pb .: BHV - Petersburg, 2007. - 1040 p.

IMPROVING COST EFFICIENCY OF IRON ORE PREPARATION BY MEANS OF CONCENTRATE YIELD MAXIMIZATION

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Abstract

Metallurgical industry is the main consumer of ore preparation products; it sets the quality indices that the concentrate should meet. The amount of concentrate with the specified quality should be as large as possible; therefore, yield maximization is the main goal of the preparation process. In terms of post-Soviet countries, it was considered that averaging of the initial indices of the ore flow made it possible to compensate for all significant deviations and to simplify the preparation process control. However, it turned out that such an approach reduced the concentrate yield. There were no evidences of that fact, but the phenomenon was noticed. For the first time, an attempt of theoretical substantiation of that phenomenon was made in the works dealing with coal preparation. We have applied that well-known approach and got a graphic solution confirming the thesis as for reduction in the yield of iron-ore concentrate with the specified quality during the mixture treatment the beneficiation of the mixture of certain ore grades with different features.

Considering the fact that the best operating conditions for the separators are met when the initial content of the valuable mineral and the inflection point of the separation characteristic of the separation block have the same abscissas, the second possible solution to maximize yield has been proposed. The solution was also implemented graphically confirming the conclusion about the fact that the greater the differences between the preparation features of the mixed grades are, the greater the concentrate yield decrease is.

Finally, an attempt have been made to examine analytically the phenomenon of yield decreasing. Having described the curves of attachments distribution (prepared

material) and while comparing the expected concentrate yields, we have obtained an expression that indicates specific difference varying from zero (in terms of similar grades mixing) up to certain values (along with the increasing differences in the preparation features).

Introduction. Ore concentrate is the main commercial product of a preparation plant. Thus, the greater the yield of the specified-quality concentrate is, the higher the income of the enterprise is. The accounting documents in this case are material and commodity balances. Those documents should contain no discrepancies along with the explicit conclusions. While operating, it was determined that during the preparation of each ore grade and further averaging (mixing) of concentrates a greater yield was obtained comparing with the preparation of the mixture of those grades. However, no evidences of that fact were found. Accordingly, the problem arose to substantiate such discrepancies. Graphic-analytical constructions and analytical calculations made it possible to find regular discrepancy between the yields.

Method one to solve the problem of concentrate yield maximization. Paper [1] indicates possibility to increase coal concentrate yield during the coal mass preparation. That requires separate preparation of the grades which make up the mixture. That statement is called Reinhardt theorem.

Apply Reinhardt's technique [1] in the context of ore preparation on the basis of numerical analysis. Since theoretical search is being carried out, we will take average values of ores processed at "INGULETS GOK" PJSC for the averaged operating conditions of technological processes.

Reinhardt's technique is as follows:

Release of the valuable mineral is studied being the basis to determine attachment*-distribution function $F(\alpha)$ (* – attachments of iron ore to quartz).

Dependence of the processed product quality upon the location of the separation characteristic is determined by equation:

$$\beta = f\left(\alpha_{ip}\right),$$

where α_{ip} is abscissa of the inflection point of the separation characteristic.

In order to describe separation characteristic $P(\alpha)$ using single value α_{ip}, it is required that its initial coordinates will be (0, 0) and final coordinates will be (1, 1). Certain set (e.g., 5) of such characteristics with $0 < \alpha_{ip} < 1$ is specified. Then, the expected quality of the processed product for each separation characteristic is calculated.

After that, dependence $\beta = f(\alpha_{ip})$ with the attachments-distribution function $F(\alpha)$ are plotted on the same figure. Point 2 is performed for all grades being mixed (let it be two grades, equally represented in the mixture), and for their mixture

$$\beta_1 = f_1(\alpha_{ip});$$
$$\beta_2 = f_2(\alpha_{ip});$$
$$\beta_m = f_m(\alpha_{ip}).$$

After that, following graphical actions are performed in the figure illustrating the mixture distribution indices. Horizontal line is drawn from the point with ordinate corresponding to the specified value of the concentrate quality – β_{cs}. Section of that straight line between the intersection points with $F(\alpha)$ and $\beta = f(\alpha_{ip})$ (A, B) serves as a measure to find the specified concentrate quality during the separation of different grades. A vertical line is drawn from point A to the intersection with function $F(\alpha)$ (point C). The ordinate of this point will determine the concentrate yield (count from the top, i.e. $\gamma = 1 - C$).

Further, the technique is the same for all grades, i.e.:

release function for certain grades $F_i(\alpha)$ is determined;

functions $F_i(\alpha)$ and $\beta = f_i(\alpha_{ip})$ for each mixture grade are plotted on a figure;

line segment AB is drawn between curve $\beta = f_i(\alpha_{ip})$ and vertical $\alpha = 1$. Point B will indicate the specified concentrate quality for the particular grade – β_i. A vertical line is drawn from point A to the intersection with function $F_i(\alpha)$. The ordinate of this point will determine the concentrate yield obtained during the separation of each separate ore grade (count from the top, i.e. $\gamma_i = 1 - C_i$).

A mixture of concentrates obtained during the separation of each ore grade, gives a concentrate of a specified quality; its total yield will be

$$\gamma = \sum_n \gamma_i P_i \,.$$

To perform quantitative assessment of the represented theoretical considerations, take the mixture of separate ore grades with different features (*ore*-1, *ore*-2, *their mixture*), which are typical for the "INGULETS GOK" PJSC open pit.

Consequently, there are two ore grades with following valuable component contents: *ore*-1 $\alpha_1 = 0.4$; *ore*-2 $\alpha_2 = 0.25$. Sizes of valuable mineral inclusions are as follows: *ore*-1 $d_{in1} = 0.25$ mm; *ore*-2 $d_{in2} = 0.15$ mm. Ores are mixed in 1:1 ratio and ground to the average particle size of $\bar{d} = 0.08$ mm. Specified quality of the obtained concentrate is $\beta_{cs} = 0.8$. Average content of valuable mineral in the mixture is $\bar{a}_m = (0.4 + 0.25)/2 = 0.325$. Average size of valuable mineral inclusions in the mixture is $\bar{d}_{inm} = (0.15 + 0.25)/2 = 0.2$ mm.

Calculate the washability curves according to the methodology described in [2]

$$P_{og} = \frac{\alpha_{init}}{\bar{\bar{d}}} \cdot \int_0^{d_{in}} \left(1 - \frac{d}{d_{in}}\right) \cdot \exp\left(-\frac{d}{\bar{\bar{d}}}\right) \partial d;$$

$$P_{nmg} = \frac{1 - \alpha_{init}}{\bar{\bar{d}}} \cdot \int_0^{r_{in}} \left(1 - \frac{d}{r_{in}}\right) \cdot \exp\left(-\frac{d}{\bar{\bar{d}}}\right) \partial d;\,;$$

$$r_{in} = d_{in} \cdot \left(\sqrt[3]{\frac{0.67}{\alpha_{init}}} - 1\right)$$

where P_{og} is probability of ore grains recovery; P_{nmg} is probability of nonmetallic grains recovery; α_{init} is initial valuable mineral content; d_{in} is size of ore grains inclusions; r_{in} is size of nonmetallic grains inclusions; $\bar{d}$ is average particle size.

According to the initial data, attachments-distribution functions $F(\alpha)$ are shown in the following way: in Fig. 1 - for *ore-1*; in Fig. 2 - for *ore-2*; and in Fig. 3 - for *their mixture*.

Separation of various ore grades and their mixture on separators with different separation characteristics was simulated to obtain dependencies of the quality of the processed product on the abscissa of the inflection point of the separation characteristic: $\beta = f(\alpha_{ip})$. The curves are shown in Fig. 1, 2, 3 respectively.

$$\gamma = \int_0^1 P(\alpha)\cdot f(\alpha)d\alpha;$$

$$\beta = \frac{1}{\gamma}\int_0^1 \alpha \cdot P(\alpha)\cdot f(\alpha)d\alpha;$$

$$\upsilon = \frac{1}{1-\gamma}\int_0^1 \alpha \cdot (1-P(\alpha))\cdot f(\alpha)d\alpha; \qquad ;$$

$$f(\alpha) = \frac{dF(\alpha)}{d\alpha}.$$

Continue with the determining the required qualitative and quantitative indices of the ore grades preparation.

Draw a horizontal line through $0.8 = \beta_m$ point (Fig. 3). Drop a perpendicular line from the intersection point A of the horizontal with curve $\beta_m = f_m(\alpha_{ip})$. Obtain operating point of the separation characteristic on the abscissa axis; by drawing a horizontal line to the ordinate axis, we will have the value of concentrate yield obtained from the mixture of separate grades ($\gamma_m = 0.3$) from the point of intersection of the vertical line with the washability curve (point C).

Do the same with all the separate grades forming the mixture.

In terms of *ore grade #1*, plot horizontally section AB (Fig. 1) in such a way that it touches curve $\beta_1 = f_1(\alpha_{ip})$, as a result, section

A_1B_1 is obtained. Specified quality for the concentrate obtained from ore *grade #1* is $0.82 = \beta_1$. Drop a perpendicular line from the intersection point A_1 of the horizontal line with the curve. On the abscissa axis, obtain the operating point of the separation characteristic; by drawing a horizontal line to ordinate axis, from the point of intersection of the vertical with the washability curve (point C_1), we have the value of concentrate yield obtained from *ore grade #1*. It is $\gamma_1 = 0.41$.

In terms of *ore grade #2*, plot horizontally segment AB (Fig. 2) in such a way that it touches curve $\beta_2 = f_2(\alpha_{ip})$, as a result, segment A_2B_2 is obtained Specified quality for the concentrate obtained from *ore grade #2* is $0.79 = \beta_2$. Drop a perpendicular line from the intersection point A_2 of the horizontal line with the curve. On the abscissa axis, obtain the operating point of the separation characteristic; by drawing a horizontal line to the ordinate axis, from the point of intersection of the vertical with the washability curve (point C_2), we have the value of concentrate yield obtained from *ore grade #2*. It is $\gamma_2 = 0.24$.

Share of each separate ore grade is determined in advance. We have two specific ore grades in equal shares, so the yield will be: $\gamma = (0.24 + 0.41)/2 = 0.325$, which is more than 0.3 for the mixture of the same grades.

Thus, if, in terms of different ore grades being processed at a preparation plant, working points of the separators and the concentrate quality are specified, then the concentrates mixing will result in a greater total yield comparing to the beneficiation of those separate grades at the same value of the specified quality.

Now, if the concentrates obtained as a result of the separate preparation of specific grades are mixed, we obtain total concentrate with quality

$$\beta_m = \frac{(0.82 \cdot 0.41 + 0.79 \cdot 0.23)}{(0.41 + 0.23)} = 0.81.$$

Thus, the correct solution has been obtained. Consequently, we can draw a conclusion about the fact that Reinhardt theorem is also valid for the case of ore preparation. However, numerous graphical constructions result in the increased probability in the measurement error. Therefore, in terms of the slight differences in the preparation features of the mixture components, the yield increase can be comparable or related to the measurement error.

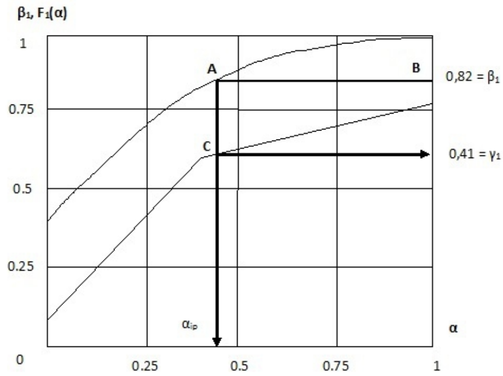

Fig. 1 - Graph to determine qualitative and quantitative indices of the ore *grade* #1 preparation

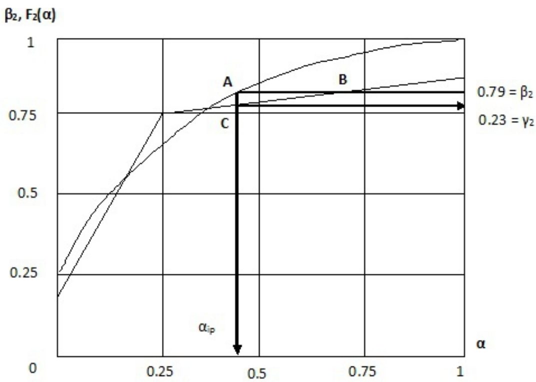

Fig. 2 - Graph to determine qualitative and quantitative indices of ore *grade* #2 preparation

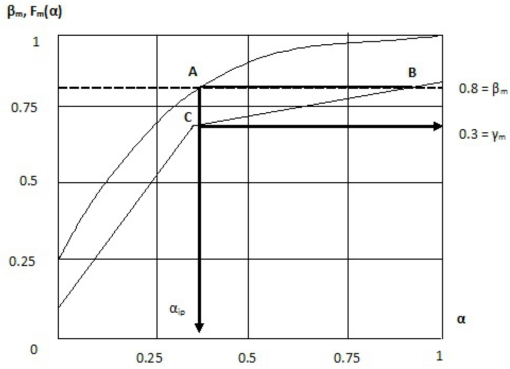

Fig. 3 - Graph to determine qualitative and quantitative indices of the *mixture* preparation

Method two to solve the problem of concentrate yield maximizing. Analysis of the solution of the previous problem has allowed outlining possible ways to reduce graphical constructions for its solution, which makes it possible to increase reliability of the calculated indices.

Since all the preparation features are planned and a mining enterprise fulfills the production plan, a company knows all the indices of the mixture and its components during the deposit mining. Specified indices for the preparation of separate grades are defined as follows.

All the grades are ground to the size planned for the mixture.

Rates of valuable mineral release are calculated being the basis for plotting of washability curves $F_i(\alpha)$ for each ore grade.

Furthermore, $F_i(\alpha)$ is used to develop functions of dependences of the enriched product quality upon the location of inflection point α_{ip} of the separation characteristic. The separation characteristic is plotted on the graph so that its beginning will have coordinates (0,0), and the end point will be (1,1). Abscissa of the inflection point corresponds to ordinate 0.5. While changing the position of the abscissa from 0 to 1 and calculating the value of the quality of the enriched product, find the required dependence

$$\beta_i = f_i(\alpha_{ip}).$$

Thus, the separation characteristic is identified by one parameter – abscissa of the inflection point.

The abovementioned solution points are the same as in method one (points 1, 2).

First, it is necessary to calculate the washability curves for each separate ore grade as well as for their mixture.

Washability curves, calculated in accordance with the methodology described in [2] are represented in Fig. 4.

According to the abovementioned methodology, functions $\beta_i = f_i(\alpha_{ip})$ for each ore grade and for their mixture were plotted (Fig. 5).

Further solution of the problem is as follows.

In Fig. 5, we draw a horizontal line from the point corresponding to the specified value of the concentrate quality; then, we drop the verticals to the intersection with the abscissa axis and from its intersection points with curves. Those will be the identification points of separation characteristics to separate corresponding ore grades.

In Fig. 4, we drop perpendiculars to the intersection with corresponding washability curves from abscissas corresponding to the inflection points of separation characteristics; then, we draw horizontals to the intersection with the ordinates axis and from the intersection points. Top-bottom counting along the vertical axis will indicate the concentrate yield of the corresponding grade. Total concentrate yield will be determined as a weighted average value depending on the ratio of separate ore grades in the mixture.

Assume that there are two ore grades with following valuable component content: *ore*-1 $\alpha_1 = 0.4$; *ore*-2 $\alpha_2 = 0.25$. Sizes of valuable mineral inclusions are as follows: *ore*-1 $d_{in1} = 0.25$ mm; *ore-2* $d_{in2} = 0.15$ mm. Ores are mixed in 1:1 ratio. (See conditions of the previous problem). Specified quality of the obtained concentrate is $\beta_{cs} = 0.8$. According to the initial data, washability curves $F_i(\alpha)$ (Fig. 4) and separation characteristics $\beta_{ki} = f_i(\alpha_{ip})$ were obtained (Fig. 5).

Draw the horizontal and fix the points of its intersection with the curves $\beta_i = f_i(\alpha_{ip})$, $i = 1,2,3$ from the point of ordinate (Fig. 5) which corresponds to the specified concentrate quality $\beta_{cs} = 0.8$. From the points of intersection, drop the verticals to the abscissa axis and determine the abscissas of the inflection points of the separation characteristics of separators which should be applied for corresponding grades processing. Taking into consideration certain errors in curves plotting, we obtain following figures: $\alpha_{ip1} = 0.4$; $\alpha_{ip2} = 0.3$; $\alpha_m = 0.325$.

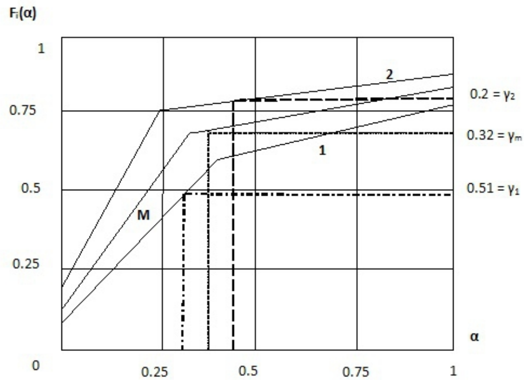

Fig. 4 - Attachments-distribution functions in ground separate ore grades and in their mixture (washability curves): *1 - ore grade #1*; *2 - ore grade #2*; M - *mixture*

Drop verticals to the intersection with washability curves of corresponding ore grades from those points in Fig. 4; draw horizontals to the ordinate axis from the intersection points. Sections on the ordinate axis, counted from the top, will determine the yields of processed products in case of their separation. Those values will be as follows: ore sort #1 $\gamma_1 = 0.51$; ore sort #2 $\gamma_2 = 0.2$; mixture $\gamma_m = 0.32$.

Since the ores are mixed in 1:1 ratio, the concentrate yield obtained in case of separate preparation of separate ore grades (i.e. when different ore concentrates are mixed after separation) is

$$\gamma_{m1} = (0.51 + 0.2)/2 = 0.35.$$

At the same time, the concentrate yield obtained in case of joint preparation of separate ore grades (i.e. when different ores are mixed before separation) is:

$$\gamma_{m2} = 0.32 .$$

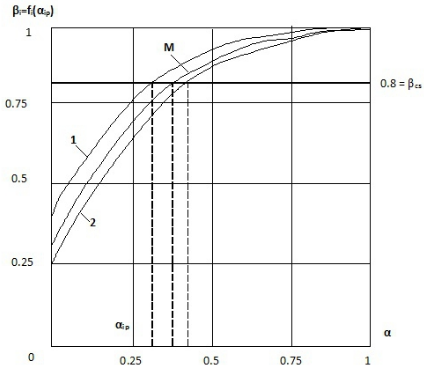

Fig. 5 - Graph to determine qualitative and quantitative indices of separate ore grades: *1 – ore grade #*1; *2 – ore grade #*2; M – *mixture*

Thus, the concentrate yield obtained in case of separate preparation of ore grades is greater than the yield obtained in case of the preparation of grades mixture.

Determine the concentrate quality indices in case of separate preparation.

Attention should be paid again to the fact that the sections on the ordinate axis, counted from the top, will determine the yields of processed products in case of their separate preparation; in terms of release indices they correspond to:

$$\gamma_1 = 0.51 = P_{og} + P_{att} + P_{nmg} .$$

The released ore grains content corresponds to the discontinuity line of the first kind of washability curve at α=1, and the other part of the section corresponds to the number of recovered high-grade attachments. Thus, we obtain following expression

$$\gamma_1 = 0.51 = 0.24 + P_{att1}$$

$$\gamma_2 = 0.2 = 0.172 + P_{att2};;$$

$$\gamma_3 = 0.3 = 0.177 + P_{attm}.$$

Hence, we obtain:

$$0.27 = 0.51 - 0.24 = P_{att1} ;$$

$$0.028 = 0.2 - 0.172 = P_{att2};$$
$$0.123 = 0.3 - 0.177 = P_{attm}.$$

Valuable mineral content in attachments of corresponding ore grades is as follows

$$\alpha_{att1} = 0.7;\ \alpha_{att2} = 0.625;\ \alpha_{attm} = 0.66.$$

Thus, quality of concentrates obtained from separate ore grades will be:

$$\beta_1 = \frac{P_{og1} + \alpha_{att1} \cdot P_{att1} + \alpha_{nmg1} \cdot P_{nmg1}}{P_{og1} + P_{att1} + P_{nmg1}} =$$
$$= \frac{0.24 + 0.16 \cdot 0.7 + 0.1 \cdot 0.1}{0.51} = 0.724.$$
$$\beta_2 = \frac{P_{og2} + \alpha_{att2} \cdot P_{att2}}{P_{og2} + P_{att2}} = \frac{0.172 + 0.28 \cdot 0.625}{0.2} = 0.947;$$
$$\beta_{\mathrm{m}} = \frac{P_{ogm} + \alpha_{attm} \cdot P_{attm}}{P_{ogm} + P_{attm}} = \frac{0.177 + 0.123 \cdot 0.65}{0.32} = 0.807.$$

Mixing separate ore grades after their separate preparation gives following total quality

$$\beta_{mixture} = (0.724 \cdot 0.5 + 0.947 \cdot 0.2)/0.7 = 0.79,$$

which does not differ significantly from the specified value (since the graphic-analytical plotting was performed).

Analysis of the obtained solution shows, that the greater the difference of indices of the mixture components preparation features is, the higher the expected increase in concentrate yield in case of their separate preparation is.

Confirm the validity of this statement. To prove this, consider ores with sharp divergences in the preparation features.

Ore grade #1: valuable mineral content $\alpha_1 = 0.9$; size of valuable mineral inclusions - 0.3 mm. Ore grade #2: valuable mineral content $\alpha_2 = 0.15$; size of valuable mineral inclusions - 0.1 mm.

We do not represent here all the calculations for the plotting of separation characteristics and $\beta_{ki} = f\left(\alpha_{ip}\right)$. Figures show the final results to determine the expected yields. Plotting was performed in accordance with the simplified method (Fig. 6, 7, 8).

Then

$$\Delta\gamma = (1+0.1)/2 - 0.4 = 0.15.$$

Now, if separately prepared ore grades are mixed, we obtain:

$$\beta_m = \frac{0.82 \cdot 0.41 + 0.79 \cdot 0.23}{0.41 + 0.23} = 0.82.$$

Thus, the obtained solution is valid. The difference in concentrate yields is 15%! (Fig. 6-8).

On the other hand, consider ore grades being close in their preparation features,e.g.: *ore sort* #1: valuable mineral content $\alpha_1 = 0.35$; the size of valuable mineral inclusions – 0.2 mm; *ore sort#2*: valuable mineral content $\alpha_2 = 0.25$; size of valuable mineral inclusions - 0.15 mm. Increase in the yield will be as follows

$$\Delta\gamma = (0.3+0.15)/2 - 0.2 = 0.025.$$

Thus, the statement has been confirmed as for the fact that the greater the divergence of the mixture components features is, the higher the increase in concentrate yield in case of separate preparation of the ore grades is.

It also follows that averaging of separate ore grades with sharp divergences in their preparation features reduces significantly the concentrate yield; thus, it is not expedient.

This study was not supported by theoretical substantiation, but it reveals one of the rules of theoretical calculations carried out in case of the analysis of preparation processes.

Valuable mineral release and grinding coarseness of ore are interconnected nonlinearly with the help of functionals. That results in the following.

Preparation features are random variables and vary within certain limits with known dispersion for each deposit. Process calculation involves average indices of preparation features.

After their transformation by the processing line operator, certain initial index β_1 (yield, valuable mineral content) is obtained which is considered to be average as well.

If we take a range of random values of preparation features and transform them with the help of processing line operator (e.g. Monte Carlo method), we will obtain a range of initial indices β_i, $i = 1,2,\ldots, N$.

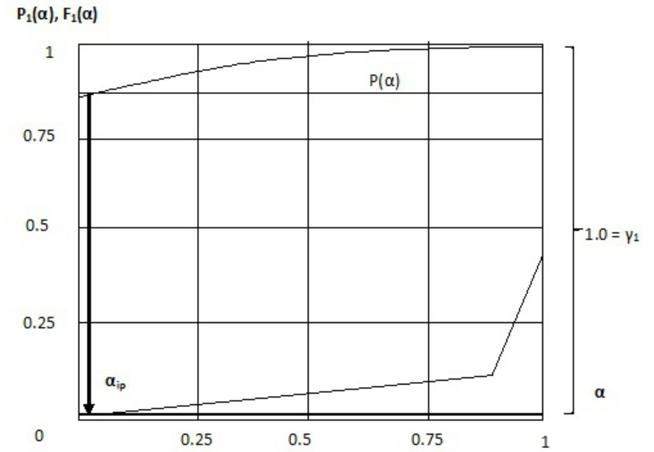

Fig. 6 - Graph to determine qualitative and quantitative indices of *ore grade* #1 preparation

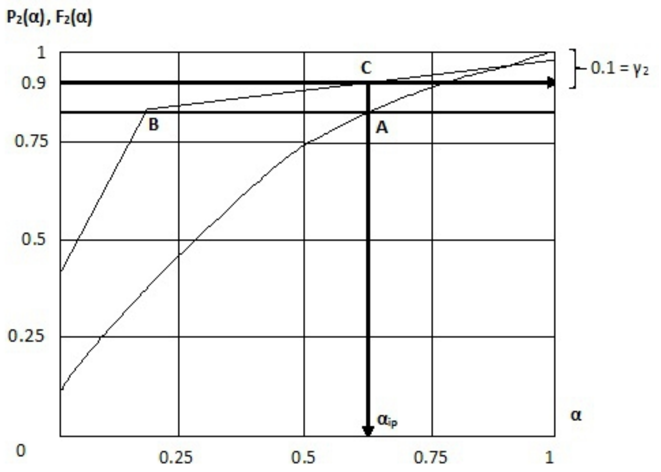

Fig. 7 – Graph to determine qualitative and quantitative indices of *ore grade #2* preparation

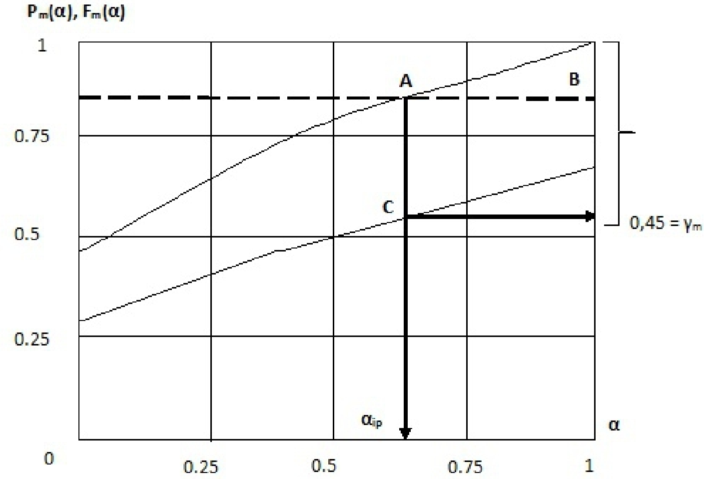

Fig. 8 – Graph to determine qualitative and quantitative indices of *mixture* preparation

After averaging the initial indices

$$\overline{\beta} = \frac{1}{N} \cdot \sum_{i=1,N} \beta_i \ ,$$

we obtain relation

$$\overline{\beta} > \beta_1 .$$

Summing up, it should be said that averaging of the initial indices does not provide the average value of the initial index while performing the actions proposed by the object transformation operator.

Conditions to obtain maximum concentrate yield during mineral processing. Mineral processing always involves random variables. Therefore, if it is necessary to replace a set of the variable values with a single value – we take into account only the value equal to mathematical expectation. If it is necessary to assess possible deviations, then the dispersion is determined as well. Typically, we operate with mathematical expectation; however, it is assessed as an average value.

One of the tasks is to plan the mining volume in order to form ore flow with specified beneficiation features to a beneficiation plant.

For example, it is supposed to mine three open pit faces with different preparation features. First, assess their average values. Further modeling helps determine the expected concentrate quality. All the calculations are performed by means of linear proportions. However, raw materials transformation into a concentrate with a specified quality involves a series of separation processes, in which direct proportionality is disturbed. Consequently, mixing of different ore grades does not allow obtaining the required result. Consider that process by numerical simulation of both single-stage separation of separate ore grades and their mixture.

The simulation sequence is as follows.

Following values of preparation features are preset: size of inclusions d_{in}; initial valuable mineral content α_i; and ore grindability being the average grinding coarseness $\overline{d}$.

To perform the simulation, we need distribution functions of those variables which are distributed in a certain way between the minimum and maximum values. Each mining enterprise is characterized by its own values. Then, by means of generating random numbers distributed uniformly within the interval from 0 to 1, turn them into the values of the required variables (Monte Carlo method).
The release indices are calculated being the basis to construct function of attachments distribution; attachments are obtained by grinding to $\overline{d}$.

To do that, content of the released grains is determined:

- content of released ore grains [1]

$$P_{og} = \alpha_{init} \cdot \sum_{d=0}^{d_{in}} \left(\left(1 - \frac{d_i}{d_{in}} \right) \cdot \Delta F(d_i) \right);$$

- content of released nonmetallic grains

$$P_{nmg} = (1 - \alpha_{init}) \cdot \sum_{d=0}^{r_{in}} \left(\left(1 - \frac{d_i}{r_{in}} \right) \cdot \Delta F(d_i) \right);$$

$$r_{in} = d_{in} \cdot \left(\sqrt[3]{\frac{0.65}{\alpha_{init}}} - 1 \right).$$

where

$$\Delta F(d) = \exp\left(\frac{d_i}{\overline{\overline{d}}}\right) - \exp\left(\frac{d_{i+1}}{\overline{\overline{d}}}\right).$$

Content of attachments is determined from

$$P_{oatt} = \alpha_{init} - P_{og};$$

$$P_{nmatt} = 1 - \alpha_{init} - P_{nmg}.$$

Content of narrow fractions is determined on the basis of approximation of the abovementioned dependences by straight line sections

$$F_{nmatt}(\alpha) = P_{nmatt} \cdot \frac{\alpha_i - \alpha}{\alpha_i} + \alpha \cdot \frac{1 - \alpha_i}{\alpha_i} \text{ if } 0 < \alpha < \alpha_i;$$

$$F_{oatt}(\alpha) = 1 - \alpha_i + P_{oatt} \cdot \frac{\alpha - \alpha_i}{1 - \alpha_i} \text{ if } \alpha_i < \alpha < 1.$$

Next, set some separation characteristic of the separation process $P(\alpha)$, and determine the qualitative and quantitative separation indices:

yields:

$$\gamma = \sum_{\alpha=0}^{\alpha=1} P(\alpha_i) \cdot \Delta F(\alpha_i);$$

$$1 - \gamma = \sum_{\alpha=0}^{\alpha=1} (1 - P(\alpha_i)) \cdot \Delta F(\alpha_i),$$

;

;

and quality indices:

$$\beta = \frac{1}{\gamma} \cdot \sum_{\alpha=0}^{\alpha=1} \alpha_i \cdot P(\alpha_i) \cdot \Delta F(\alpha_i);$$

$$\upsilon = \frac{1}{1-\gamma} \cdot \sum_{\alpha=0}^{\alpha=1} \alpha_i \cdot (1 - P(\alpha_i)) \cdot \Delta F(\alpha_i),$$

;

where

$$\Delta F(\alpha_i) = F(\alpha_i) - F(\alpha_{i-1}).$$

That is the end of the simulation cycle.

Next, repeat the steps according to that cycle from 10 to 15 times depending on the necessity.

Average the initial indices of the ore grade features and carry out a simulation cycle according to the features; further, find the separation indices of the mixture.

After performing a sufficient amount of simulation cycles, determine average values of yield $\bar{\gamma}$ and quality $\overline{\beta}$ of the concentrate obtained in case of separate beneficiation of each ore grade.

Then, having averaged the beneficiation features and performed a simulation cycle with those averages, determine the yield of the same quality concentrate $\overset{=}{\gamma}$.

Repeated simulations have shown that inequality $\overline{\gamma} > \overset{=}{\gamma}$ is always fulfilled.

Moreover, that inequality grows along with increasing difference in the beneficiation features values, e.g. when the distribution functions of indices differ slightly from each other, then, if $\overline{\beta} = 0.635$, we obtain $\bar{\gamma}$ =0,4 and $\overset{=}{\gamma} = 0.38$.

Consider the conditions of the yields balance using analytical ratios.

In addition to the released mineral, high-grade attachments are also recovered to the concentrate. Quantity of the attachments depends upon the inclination angle of high-grade attachments line (Fig. 4) characterized by its inclination coefficient. It is a matter of common knowledge that preparation specialists are always interested in the yield being formed at the expense of attachments recovery.

It follows from the Fig. 4, that the higher the valuable mineral content and the larger the size of its inclusion are, the greater the number of attachments and the higher the expected yield of the beneficiated product are.

Suppose that two ore grades are mixed: *ore grade* #1 with the initial valuable mineral content α_{i1} and inclination angle of the attachments content line k_1; *ore grade* #2 - α_{i2} and k_2 respectively. In addition, we have a mixture composed of those two ore grades with α_m and k_m respectively.

Equations of the sections of the integral distribution functions of attachments are as follows

$$F_1 = k_1 \cdot \alpha; \qquad F_2 = k_2 \cdot \alpha; \qquad F_m = k_m \cdot \alpha.$$

When the mixture is analyzed at an enterprise, it is taken into consideration by default tha:

$$k_1 > k_m > k_2.$$

Content of the separate ore grades is

$$C_1 + C_2 = 1.$$

According to the rules of matching of preparation indices and separation characteristics, expected yields γ_i will make up following expressions

$$\int_{\alpha_{i1}}^{1} k_1 \cdot \alpha^2 d\alpha = \gamma_1 = \frac{k_1 \cdot \alpha_{i1}}{2} + P_{og1};$$

$$\int_{\alpha_{i2}}^{1} k_2 \cdot \alpha^2 d\alpha = \gamma_2 = \frac{k_2 \cdot \alpha_{i2}}{2} + P_{og2};$$

$$\int_{\alpha_{m}}^{1} k_m \cdot \alpha^2 d\alpha = \gamma_m = \frac{k_m \cdot \alpha_{m}}{2} + P_{ogm}.$$

Further, following the rules of the mixture makeup, the equality must be observed

$$\left(\frac{k_m \cdot \alpha_m}{2} + P_{ogm}\right) = \left(\frac{k_2 \cdot \alpha_{i2}}{2} + P_{og2}\right) \cdot C_2 + \left(\frac{k_1 \cdot \alpha_{i1}}{2} + P_{og1}\right) \cdot C_1;$$

$$k_m = C_2 \cdot k_2 + C_1 \cdot k_1; \quad \alpha_m = C_2 \cdot \alpha_2 + C_1 \cdot \alpha_1; \qquad k_1 = \frac{\gamma_1}{1-\alpha_1};$$

$$(C_2 \cdot \alpha_2 + C_1 \cdot \alpha_1) \cdot (C_2 \cdot k_2 + C_1 \cdot k_1) \equiv \gamma_m; \quad k_2 = \frac{\gamma_2}{1-\alpha_2}$$

Basing upon graphical solutions performed earlier (see above), we have following numerical data

$$\alpha_1 = 0.35; \qquad \alpha_2 = 0.25; \qquad \gamma_1 = 0.51; \qquad \gamma_2 = 0.2.$$

It is also assumed that

$$C_1 = C_2.$$

Taking into account those relations, we have identical transformations

$$C_2^2 \cdot \alpha_2 \cdot k_2 + C_1^2 \cdot \alpha_1 \cdot k_1 + C_1 \cdot C_2 \cdot \alpha_1 \cdot k_2 + C_1 \cdot C_2 \cdot \alpha_2 \cdot k_1 \equiv \gamma_m;$$
$$C_2^2 \cdot \alpha_2 \cdot k_2 + C_1^2 \cdot \alpha_1 \cdot k_1 = \gamma;$$
$$C_2^2 \cdot \alpha_2 \cdot k_2 + C_1^2 \cdot \alpha_1 \cdot k_1 -$$
$$-\left(C_2^2 \cdot \alpha_2 \cdot k_2 + C_1^2 \cdot \alpha_1 \cdot k_1 + C_1 \cdot C_2 \cdot \alpha_1 \cdot k_2 + C_1 \cdot C_2 \cdot \alpha_2 \cdot k_1\right) = \Delta\gamma$$

While subtracting one equation from another, we obtain

$$\Delta\gamma = C_1 \cdot (1 - C_1) \cdot (\alpha_1 \cdot k_2 + \alpha_2 \cdot k_1) =$$
$$= C_1 \cdot (1 - C_1) \cdot \left(\alpha_1 \cdot \frac{\gamma_2}{1-\alpha_2} + \alpha_2 \cdot \frac{\gamma_1}{1-\alpha_1}\right) =$$
$$0.5 \cdot (1 - 0.5) \cdot \left(0.35 \cdot \frac{0.2}{1-0.25} + 0.25 \frac{0.51}{1-0.35}\right) = 0.07\,.$$

When process links between beneficiation indices are not linear, then the simulation will be correct in case of final indices averaging (i.e. multiple simulation results). In other words, Monte Carlo method is still the only correct way to complete the process tasks in mineral processing.

Conclusions

It has been proved that there is a difference in the yields in cases of joint and separate preparation of certain ore grades. Moreover, that difference grows along with increasing convergences in the beneficiation features of the mixed ore grades.

It is recommended to perform separate preparation of different ore grades in the processing schemes aimed at obtaining specified quality indices as a result of ore concentrates mixing.

References

1. **Mladetskyi I.K.** (2006). Sintez tekhnologiy obogashcheniya poleznykh iskopayemykh [Synthesis of mineral processing technologies]. Dnipropetrovsk: National mining university. - 154 p.

2. **Artiushyn S.P.** (1966) Sbornik zadach po obogashcheniyu ugley [Problem book in coal enrichment]. Moscow: Nedra. – 223 p.

PRIORITY DIRECTIONS OF THE STATE MANAGEMENT OF DEVELOPMENT OF MINERAL RESOURCES BASE OF WESTERN POLISSYA

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Abstract

Postgraduate student of the Department of Ecology, Technology of Environmental Protection and Forestry of the National University of Water Management and Nature Management, Ukraine One of the main directions of development of economic potential of Ukraine is the development of the mineral raw materials complex and enterprises - users of the subsoil, which make up its basis. Prolonged intensive exploitation of mineral resources has led to deterioration of mining and geological conditions for the development of deposits, significant depletion of the quality reserves of mineral raw materials, reducing its competitiveness in the world market, the formation of the structure of industry, shifted towards heavy industries, accumulation of long-term environmental effects. Therefore, rational nature management in the management of the users of the interior is an urgent problem of constructing a modern economy, focused on the principles of sustainable development.

Ukraine has already entered the stage of depletion of the subsoil. Wells for hydrocarbon raw materials reached a depth of 5 - 6 kilometers. There are almost no rich iron ore in Ukraine. Coal mining is conducted on average at depths of more than 700 meters. Notwithstanding all of the above, the Ukrainian economy continues to form under the influence of exploitation of the mineral raw materials complex, which remains the main element of its structural adjustment and significantly influences the increase of living standards of the population and the formation of environmental conditions of existence. This form of ecologization in the management of the activities of enterprises - subsoil users as their integration into the system of ecological services - has become increasingly important, which has caused the relevance of this article.

Introduction

The purpose of this study is to substantiate the directions of increasing the efficiency of mining activity of mining enterprises taking into account the principles of state regulation of the creation of the mineral raw material base of the region and consumption of natural resources.

The subject of research is theoretical and methodological principles of management of rational nature use of subsoil users on the basis of ecological services.

The theoretical and methodological grounds of this scientific work are the fundamental provisions of the science of state administration, general economic principles and methods of analysis of the laws of social production on market principles, as well as the work of domestic and foreign scientists on the development of state policy of rational use of mineral resources. Historical, systematic and logical-dialectical approaches are used in this work.

Therefore, in our opinion, at the present stage, the issue of substantiation and establishment of priority directions of the state management of mineral resources development in Ukraine at the regional level and application of the principles of public administration and decision-making at certain stages of the process of using the mineral-raw material base in the region is topical.

The essence and institutional framework for managing the rational use of natural resources by subsoil users

Activities in the field of study, use and protection of mineral resources are institutional activities based on the legislative and legal norms of the activity of the relevant bodies of the Ukrainian state on the organization of the study of the rational use of mineral resources to meet the needs of mineral raw materials and other needs of the economic complex, the protection of mineral resources in their close interconnection' with other natural objects, ensuring the safety of work when using subsoil, and also protecting the rights of enterprises, organizations, institutions and citizens in this area [1].

Relations that arise in connection with the study, use and conservation of mineral resources and the use of waste from the mining complex and related processing industries (peat, sapropel and other specific mineral resources, including groundwater, a rock of salt lakes and sea gulfs), called mining relations. They are regulated by the Constitution of Ukraine, decrees of the President of Ukraine, as well as by the Decrees of the Cabinet of Ministers of Ukraine on the study, use and protection of mineral resources, normative acts of the Ministry of Environmental Protection of Ukraine, the State Committee of Ukraine for Industrial Safety, Labor Protection and Mining Supervision, the Law "On Protection the Environmental Code of Ukraine, the Code of Ukraine on Subsoil, the Mining Law of Ukraine, the Laws of Ukraine "On the State Geological Survey of Ukraine", "On Concessions", "On Production-Sharing Agreements", "On Oil and Gas", "On Rent Payments for Oil, Natural Gas and Gas Condensate", "On State Regulation of Extraction, Production and Use of Precious Metals and Precious Stones and Control on operations with them", "On mining and processing of uranium ores, "as well as other legislative acts of Ukraine [2].

The main task of the institutional management of the relations of subsoil use is to ensure the reproduction of the mineral-raw material base, its rational use and the protection of mineral resources.

The main tasks of public administration in the opinion of domestic scientists in this area are:

- determination of volumes of mining of basic types of minerals for the current period and for the future in Ukraine as a whole and in regions;
- ensuring the development of the mineral raw material base and preparation of reserves of subsoil plots used for the construction of underground structures that are not related to the extraction of minerals;
- establishment of quotas for the supply of mined minerals;

- introduction of fees (fees) associated with the use of subsoil, as well as the regulation of prices for certain types of mineral raw materials;

- establishment of standards (norms, rules) in the field of geological study, use and protection of subsoil, safe conduct of work related to the use of subsoil [4].

The institutional system for managing the activities of subsoil users is based on solid scientific research conducted in different regions of Ukraine and has its own specific features and features specific to these regions. Among the scientific community who are studying the institutional principles and priorities for improving the management of subsoil use, one should note the scientific school that was formed in Dnipropetrovsk on the basis of the National Mining University and the Dnipropetrovsk National University named after
Oles Honchar.

Scientists of Dnipropetrovsk region Pivnjak G.G., Pavlenko I.I., Galushko OS, Grin'ko T.V., Yelisieva O.K., Meshko N.P. in their scholarly works consider issues related to the conceptual approaches to the implementation of the doctrine of sustainable development on the territory of Ukraine, mainly based on the materials of the coal industry of Ukraine. They provided the economic and mathematical justification for the sustainable development of socio-economic systems, the financial basis for ensuring sustainable development and the realization of the opportunities of coal enterprises for the implementation of social and environmental institutions [6].

Organizational mechanism of rational nature use of interior users is shown in Figure 1.

Scientists of this scientific center traditionally concentrate their attention on the issues related to the environmentalization of processes in the water supply, drainage and water treatment, but the scientific schools of professors Hrytsyuk PM, Kushnir NB, Malchik MV, Pavlova VI Sazonets IL, Skrypchuk PM, analyze and investigate a wider range of processes of enterprises in the field of nature management, including taking into account the activities of subsoil users. These scientists have made a significant contribution to the study of financial capacity of enterprises in the field of nature management, the implementation of national environmental standards to the standards of the European Union, harmonization of the system of environmental standards of Ukraine and EU standards, the socialization of Ukrainian corporations, including on the basis of sustainable development principles [9].

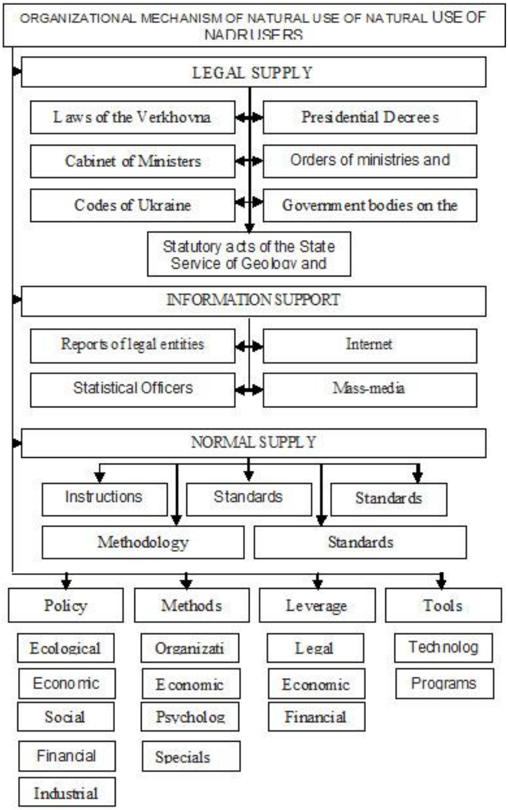


Fig. 1

The overcoming of the crisis situation in the economy of Ukraine on the basis of its structural adjustment can be carried out in a short time only on the basis of the resources of the state: labor and natural, basic production funds, communications, etc. The regulatory mechanism in the field of subsoil use and environmental protection is a system of management measures, environmental legislation and economic incentives aimed at sustainable management of nature.

Regulation of subsoil use is a real mechanism for the inclusion of environmental protection policies in the functioning of the economic system. Such regulators can be distinguished several: regulatory; organizational and managerial; economic (fig. 2)

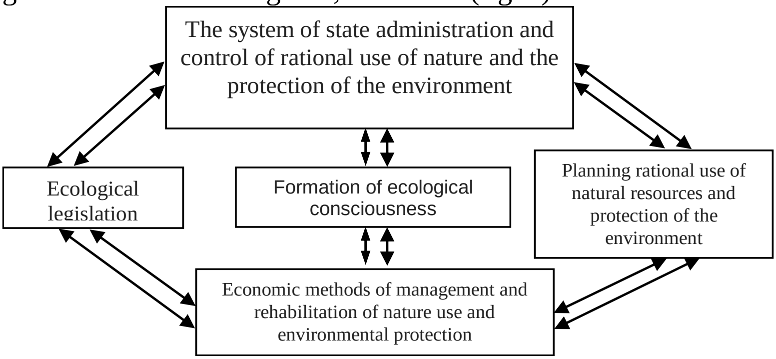


Fig. 2. The main levers of regulation of the process of rational nature management and protection of subsoil [3]

An important direction in improving the efficiency of management activities in the field of nature management and environmental protection is the harmonization of economic and environmental interests of enterprises, institutions, organizations, society as a whole and individual individuals. To ensure the economic and ecological interests of society, the state should create the necessary and optimal conditions for combining economic development with rational nature management and environmental protection, which is possible only through a combination of measures of administrative legal influence on nature users and measures of economic regulation of nature use and protection of the environment [8].

Publicity and public associations and organizations are also an integral part of the institutional system of environmental management of subsoil users. Citizens and their associations promote local councils of people's deputies and specially authorized bodies of state executive power in carrying out measures on rational use and protection of mineral resources. Subsoil users may be enterprises, institutions, organizations, citizens of Ukraine, as well as foreign legal entities and citizens. Active cooperation with national users of the subsoil and international organizations, which are an integral part of institutional management.

However, the activities of international environmental and social organizations are still aimed at creating a "green" ideology. An important function of international organizations is participation in the process of harmonization of norms and standards of mining products of Ukraine with EU countries, but harmonization of ecological activities of users of subsoil is not carried out to the full extent at present.

In accordance with Article 4 of the Code of Ukraine on Subsoil, subsoil is the exclusive property of the people of Ukraine and is provided only for use [9]. Agreements or actions that, in direct or indirect form, violate the right of ownership of the people of Ukraine to the subsoil, are null and void. The people of Ukraine exercise ownership of the subsoil through the Verkhovna Rada of Ukraine and local Soviets of People's Deputies. Separate powers regarding the disposal of bowels by the legislation of Ukraine may be granted to the relevant state executive authorities.

The main task of state regulation of the relations of subsoil use is to ensure the reproduction of the mineral-raw material base, its rational use and protection of mineral resources.

Violation of the legislation on subsoil entails disciplinary, administrative, civil and criminal liability. Almost all violations of the legislation in the area of the interior are in one way or another obscure the problems of ecology.

Under conditions of overcoming the consequences of the economic crisis in Ukraine, the effective use of super-utilization becomes of fundamental importance. Ukraine belongs to the few states of the world, which have their own natural resources, and the vast majority of the necessary minerals is concerned. However, so far there is no reason to assert it is about all the resources, perhaps not so much about the already explored deposits, but about the potential reserves. For example, the presence of native copper in the Rivne-Volyn region, which is reasonably predicted on the territory of Polissya. Activating these resources by identifying specific fields and organizing their development is an extremely urgent task of the present. Scientists have defined the content of relations between state authorities that take and implement decisions, and consumers of subsoil resources.

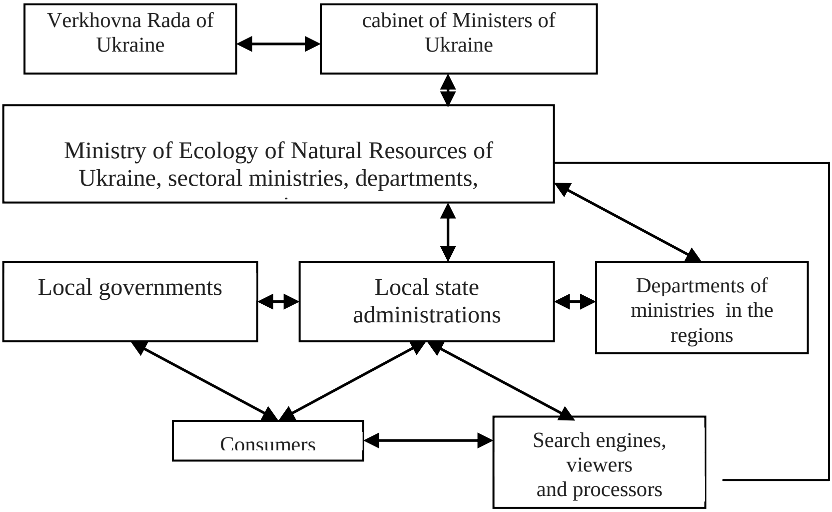


Fig. 3. Interaction of users of subsoil with the authorities

Implementation of managerial decisions is carried out at the regional level, which determines the need to increase responsibility and certain independence of the territorial authorities. The regional level of use of MCP (mineral resources) is largely determined by the implementation by the actors of their management of the achievement of strategic goals through the implementation of operational tasks and types of work [11].

In the management of subsoil use, scientists consider typical methods of administrative activity: legal, economic, administrative. The expediency of using social-psychological, propaganda methods as forming the ideology of economical nature management at the stages of the process of extraction and use of MCP is determined.

Bodies of state administration in the field of use and protection of mineral resources are divided into bodies of general and special state administration. The bodies of general government in the field of use and protection of subsoil are authorized bodies of state executive power, which, along with general powers in the field of socio-economic development of the state, also provide functions for ensuring the study, effective use and protection of mineral resources. Such bodies include, in particular: the President of Ukraine; National Security and Defense Council of Ukraine; Cabinet of Ministers of Ukraine; oblast, rayon and city state administrations.

The special services responsible for the regulation of mining relations include the State Service for Mining Supervision and Industrial Safety of Ukraine, which is a specially authorized central executive body, which carries out state regulatory regulation of issues of ensuring industrial safety in the territory of Ukraine, as well as special permitting, supervision and control functions.The main task of this body is: organization and implementation of industrial safety on the territory of Ukraine and state supervision of all sub-users and compliance with the requirements for the safe conduct of work in industry; Mining supervision; development and implementation of measures to prevent occupational injuries, etc.

State control over rational use and protection of mineral resources is aimed at ensuring compliance of all subsoil users with the established procedure for the use of mineral resources, legislation, approved in accordance with the established procedure standards, norms and rules in the field of geological study, use and protection of mineral resources, rules of state accounting and reporting. It is carried out by bodies of state geological control in close cooperation with the bodies of state mining supervision, environmental protection and other control bodies [11, 12].

Bodies of state geological control control the implementation of state programs of exploration works, the use of solutions on the methodological provision of works on geological study of subsoil, the validity of the application of techniques and technologies, quality, complexity, efficiency of works on geological study of subsoil, completeness of initial data on the quantity and quality of stocks of basic and the co-occurrence of minerals, the timeliness and correctness of state registration of works on geological study of subsoil.

Availability of special permits (licenses) for the use of subsoil and fulfillment of the conditions provided by them and implementation of decisions of the State Commission of Ukraine for mineral resources; compliance with the exploration exploitation of mineral deposits of technologies that would provide the necessary study of them. Preservation of exploratory mines and wells for the development of mineral deposits, as well as geological documentation, rock samples, duplicates of samples that can be used during further study of subsoil [10].

The bodies of state geological control in accordance with the legislation of Ukraine may also be granted other rights for the prevention and termination of violations of rules and norms of geological study of subsoil. The task of state supervision over the safe conduct of work related to the use of subsoil is to ensure compliance with all subsoil users of legislation approved in accordance with the established procedure of standards, norms and rules for safe conduct of works, prevention and elimination of their harmful effects on the population, the environment, buildings and structures, as well as for the protection of the subsoil [5].

State supervision over the safe conduct of work related to the use of subsoil is the responsibility of the bodies of state supervision of mining, which carry out their activities in cooperation with state geological control bodies, environmental and other control bodies, trade unions. In addition, the industrial control over the use and protection of the subsoil is carried out by enterprises, institutions and organizations (sub-users), which are in charge of the relevant authorities.

The correctness of the development of mineral deposits is controlled by surveying, geological and other services. But the most extensive and comprehensive surveillance over the proper operation of the subsoil and its protection, which includes the supervision of all types of use of the subsoil, is state mining supervision.

Each region (region) of Ukraine should have a "Concept of integrated industrial development of natural resources attributed to the region", since after the collapse of the USSR, the established legal regime of natural resources was violated, which caused significant damage to the economy of the state and the mineral-raw dependence of Ukraine.

Theoretical approaches to the definition of the components of rational nature management and corporate social responsibility

The process of nature use develops on the basis of the interaction of nature and society. The object of nature management as a science is the complex of relationships between natural resources, natural conditions of society and its socio-economic development.

It should be noted that humanity actively uses about 55 percent of land, 12 percent of annual water, half of the annual growth of the forest. Every year around 100 billion tons of ore are extracted from the earth and 7 billion tons of conventional fuel are burned.

In Ukraine, agricultural land occupies 41.84 million hectares (69.3 percent of Ukraine's territory), land cultivation has reached 56 percent of the country's territory and is the highest in the world. In the system of water management, 1087 reservoirs with a total volume of more than 55 billion m3 were built, 7 large channels with a length of about 2000 km, supplying them over 1000 m3 of water per second, producing about 5 per cent of the world volume of mineral resources, the total volume of forest use is 14.4 million m3 [31]. Over the past 100 years, 360 billion tons of carbon dioxide have been thrown into the atmosphere. The area of land occupied by various kinds of waste is about 160 thousand hectares.

If with such processes as "extraction", "use", "recycling" of natural resources mankind is familiar for a long time, then with "reproduction" it has collided only recently.

The subject of the study of environmental processes and environmental processes can be considered optimization of these relationships, aspiration for conservation and reproduction of the environment. AM Marinych distinguishes the following types of natural resources: - industry - water use, land use, forest management, use of mineral resources and others; - complex-territorial (regional): planetary, interstate, state, republican, local, as well as nature use in certain industries - in industry, agriculture, construction, land reclamation, health care and others [26]. The criteria for determining the environmental liability of enterprises are given in Table. 1

Table 1

Criteria for determining environmental liability of enterprises

Criteria	Signs of environmental compatibility of enterprises
Compliance with environmental obligations	- the corporate vision of the company is fully consistent with the concept of sustainable development; - protection and restoration of the natural environment are defined by strategic priorities; - is aware that the economic system operates within the ecosystem that is limited; - the company adheres to and acts in accordance with the requirements of environmental legislation; - the company is fully responsible for the damage caused by the environment; - Encouraged corporate culture based on environmental values.
Energy and raw material management	- effective use of natural resources; - creation and use of renewable energy and materials; - the company is guided by system thinking in its activity; - The company is trying to minimize carbon footprint emissions; - there is a constant analysis of environmental achievements and the search for new environmental solutions; - There is an ongoing analysis of environmental costs and benefits.
Effective involvement of stakeholders	- the company informs local communities and authorities about the environmental consequences of their activities; - the company is responsible to the community and other stakeholders for their current and future activities, as well as for actions committed in the past; - the company takes into consideration the opinions and wishes of stakeholders in the development and implementation of their own projects; - the company's activities are transparent, including information on the impact of its activities on the environment; - The company constantly analyzes and regularly collects the impact of its activities on the environment.

Considering it through the prism of rational nature use, we see that it is increasingly becoming an economic process, which includes, firstly, the restoration of nature as a source of objects and means of labor (soil reclamation, forestry, etc.); and secondly, the restoration of nature, as a spatial basis (the landscape of the territories, broken by the construction, etc.); thirdly, the restoration of the human environment (purification of the atmosphere, reservoirs, restoration of forests, etc.). Reproduction of non-reproductive resources should take place in the form of the growth of their explored reserves, as well as the economical use of available at the expense of better processing, replacement of some types of raw materials by others [11]. It can be argued that the use of nature is an objective process that takes place between society and nature and reflects the development, use, reproduction of natural resources, as well as the impact on nature in the process of economic and other human activities, transformation and protection of nature in the interests of society. All this is confirmed by the formula of nature use (for T. Yu.Yu.), given [42] in Fig. 4:

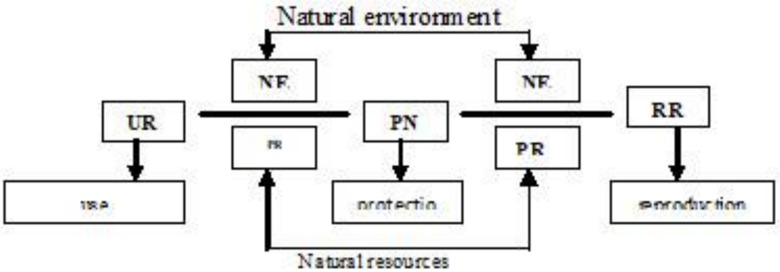


Fig. 4. Formula of preservation of natural resource potential of development of society: PS - natural environment; PR - natural resources; UR - use of resources; RR- reproduction of resources, PNE - protection of the natural environment

It was determined that the mineral raw materials complex in the period from 2000 to 2012 provided 23-25 percent of the gross national product. With extraction and use of minerals, 48 percent of Ukraine's industrial potential and up to 20 percent of its labor resources are connected. These indicators are close to the indicators of developed countries with a strong mining industry, which concentrates from 20 to 40 percent of total investment and up to 20 percent of labor resources [3].

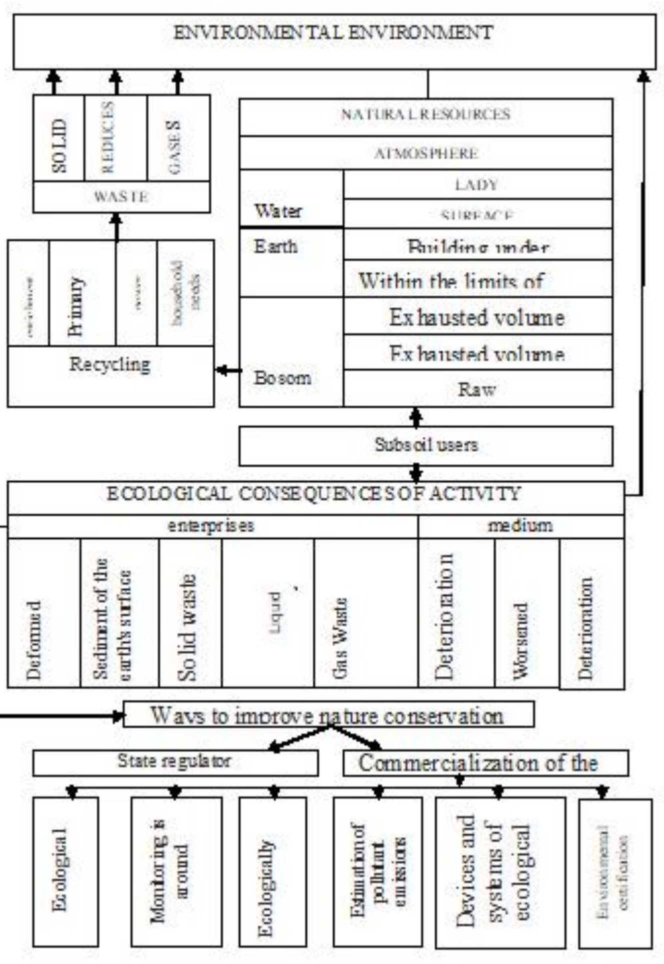
As of January 1, 2013, the state balance of mineral resources accounted for about 8 thousand deposits of 96 types of minerals, 3349 deposits are mastered by industry, and more than 2 thousand of mining enterprises are operating on their basis. The cost of explored stocks per capita in Ukraine is about $ 150,000, and according to Western experts, more than $ 200,000. More than a third of Ukraine's export earnings from the sale of mineral raw materials. Some minerals in Ukraine are represented by unique reserves and quality of raw materials deposits, which are located in rather favorable conditions for the creation of mining complexes (for example, copper mining in the Rivne and Volyn regions) [13].

However, in the current conditions, the pace and scale of reproduction of its own mineral-raw material base does not satisfy the needs of the state. Due to lack of funds, the volume of exploration works decreased by 3-4 times. Therefore, since 2004, the growth of explored reserves of most of the major minerals does not offset their production. The consequences of an unweighted policy of the past have already negatively affected the efficiency of the economy. The analysis of the state of affairs and projections suggest that in the near future the situation may become even more complicated. Lack of certain types of own raw materials will progress, unless already taking decisive action. In addition to the traditional import of some non-ferrous and rare metals, coking coal, magnesite, and fluorspar, there may be a need to import raw materials that were previously even exported from Ukraine (native sulfur, high-quality fluxes, etc.) [3].

In recent years, real opportunities have been confirmed for further growth of hydrocarbon reserves, opening and exploration of new deposits for Ukraine of minerals - gold, chromium, copper, lead, zinc, rare and rare earth elements. It is in them that there is an urgent need, connected with the need to create conditions under which the export potential of the state will increase.

Taking into account global trends in the use of minerals, the main issues of the mineral-raw material base are associated with the following factors: the value and non-renewal of natural mineral resources determine the need for their rational and economical use.

Intensive methods of extraction, processing and consumption of minerals on the basis of the latest advances in science and technology are an integral part of the worldwide technical revolution. Influence of enterprises - subsoil users on the environment is shown in Fig. 5



However, in today's conditions, the pace and scale of reproduction of its own mineral-raw material base does not meet the needs of the state. Due to the lack of funds, the volume of geological exploration decreased by 3-4 times. Thus, since 2004, the growth of proven reserves of most major minerals does not offset their production. The consequences of the past policy in a negative condition already had a negative impact on the efficiency of the economy. In recent years, real opportunities have been confirmed for further growth of hydrocarbon reserves, opening and exploration of new deposits for Ukraine of minerals - gold, chromium, copper, lead, zinc, rare and rare earth elements. It is in them that there is an urgent need, connected with the need to create conditions under which the export potential of the state will increase.

Efficient use of mineral wealth on the basis of modern technologies that combine high economic efficiency of extraction and processing of minerals with minimal impact on the environment can become the thread that will unlatch the whole tangle of complex economic, social and economic problems of our present. In the said document it is planned to solve urgent problems of mineral complexes (MSCs) in the near future (until 2015-2020).

From this perspective, the "Concept of building the mineral-raw material base as the basis for stabilizing the Ukrainian economy for the period up to 2025" was formed, approved by the decision of the Cabinet of Ministers of Ukraine of March 9, 1999, № 338.

At the same time, a system of complex (geological, engineering-geological, seismological, ecological-geological, etc.) study of the territory of Ukraine and its individual regions is foreseen for the development of scientific principles of nature protection policy of the state and counteracting dangerous natural and man-made catastrophic phenomena and processes [7].

Applying effective measures that can accelerate the solution of the problems of subsoil use is necessary now, not from some "hot" issues, but in a complex, scientifically grounded system. The tasks are extremely important and complex, and their implementation requires further fundamental research. So it is not surprising that various groups of researchers are attempting to bring the theoretical foundation to these pressing tasks.

One of the first such attempts was the publication of the book by MM Korzhnev and V.S. Mishchenko entitled "The geological branch of Ukraine: ways of eliminating developmental imbalances" issued by the Publishing House "KM Academy" [66]. The authors of this book - scientists in the field of economics of mineral raw materials and geoecology - correctly put and solve some important issues of the state geological service. First of all, it concerns the thesis that the study and development of natural mineral wealth should be accompanied by a significant improvement in the ecological situation throughout the territory of Ukraine.

At the same time, the main conclusion drawn in the book, can not but cause decisive objections. It is reduced to the fact that to eliminate the "main imbalance" in the industry should abandon the further development of new mineral deposits. To substantiate their position, the authors resorted to a formal statistical analysis of the security of the extractive industries by explored reserves of minerals without attempting to deal with the merits.

Determining the terms by which Ukraine will fix each of the types of minerals, they fall into a conflict situation: instead of the active stock (real for the form) consider the general issues. Their usual comparisons are from a uniform standard of living in 1997 - one of the most critical for the economy, when most of the mining and processing complexes, as they say, "lay". But do we have the right to predict such a situation in the future? Then decide to identify any unnecessary business activity, not the geographic area of Ukraine.

The analysis of the whole situation in the industry convinces that the scientific strategy for the mineral raw materials complex and further geological industry should be based not on general but on active measures of minerals and perspective resources of the best communities prepared for intelligence. Without a constant improvement of the stock base, without the constant opening of new types of quality and with simple conditions of origin, it is impossible to achieve significant progress in the mining and metallurgical, mining-chemical, agro-industrial and fuel-energy complexes.

In addition to the natural features of the deposit, the result of the economic assessment of reserves significantly affected by various external conditions: the volume of raw material needs; its price; the price of goods and services necessary for its extraction and processing; the price of land; availability of resources in the area of labor, energy, water, etc.

It should be noted that in stable conditions of management such indicators did not remain unchanged for a long time. Particularly often, they are changing now, in the transition to a market economy. Consequently, stocks that previously were balance sheets may become off-balance sheet and vice versa. It all depends on social relations in the process of using the subsoil.

It can be stated that the current legislation on the earth's subsoil of Ukraine is in a state of development, and therefore it has features such as inconsistency, incompleteness, some inconsistency with other branches of law, lack of clear legal definitions and guarantees. Such unsatisfactory state of legislation in a crisis of technogenic ecological safety in the conditions of the pace of the process of closure of mines will lead to the emergence of serious emergencies of emergency situations of technogenic and environmental nature. To avoid this, an effective legal framework for improving the mechanism of regulation, management and control of public relations in the process of use and protection of subsoil is necessary [10]. One form of such social relations is the system of environmental responsibility, which is an integral part of a wider corporate social responsibility system.

The concept of rational nature management and environmentalization of the activities of enterprises in Ukraine is only emerging, although in the West it is in the flourishing stage. The reasons for underestimation of the environmental component in domestic enterprises are as follows: first, in Soviet times, economic growth was extensive - the post-production of minerals increased. Second, Ukrainian buyers did not pay attention to whether the product is environmentally friendly or not. Third, society has not yet established itself as a collective social responsibility.

The main obstacles to the environmental development of enterprises in Ukraine are imperfect environmental legislation, the lack of proper environmental standardization and certification system, the slow development of ecological safety of production institutes, and the low level of environmental consumption culture.

Not only is the legislative regulation of the process of environmentalizing the activities of enterprises, but also the strict observance by the enterprises and citizens of environmental norms and standards.

Thus, most Ukrainian enterprises at best recognize only legal ecological liability, that is, they organize their activities in accordance with domestic environmental legislation. However, from year to year, there is a growing number of companies whose leadership recognizes the acuteness of the global environmental crisis and is trying to contribute to the development of the environment. The ecological component of social responsibility is one of the key requirements for the Ukrainian companies to enter the world market.

Export-oriented Ukrainian companies have to produce products that meet European standards, in particular environmental ones, which are more stringent than domestic ones.

Conclusions

Consequently, we can conclude that in the process of studying the essence and institutional framework for management of rational nature use by subsoil users, the article concludes that the current legislation on the depths of Ukraine is in a state of development, and therefore it has features such as inconsistency, incompleteness, some inconsistency with other branches of law, lack of clear legal definitions and guarantees. To prevent this, an effective legal framework for improving the mechanism of regulation, management and control of public relations in the process of use and protection of mineral resources is necessary.

Determining the criteria of rational nature management on the basis of preservation of natural resource potential, it has been established that in order to prevent the negative effects of the users of the subsurface resources, a system of environmental responsibility is required that is an integral part of a broader system of corporate social responsibility.

The analysis of world experience in institutional regulation of subsoil users on the basis of rational nature management has determined that the main factor in the efficient use of the entire potential of the mining industry of the European Union and individual corporations is the formation of a national, international economic and environmental strategy, which sets as its goal the creation and efficient functioning of necessary and sufficient institutional mechanisms for environmental and economic policies to ensure sustainable development, which is due to the progressive aggravation of global, national and regional environmental and social problems that can not be solved within the framework of traditional socio-economic approaches.

References

1. **Amosha A.I.** (2004). Problems of the domestic coal industry in the context of Ukraine's accession to the WTO and EU integration. Coal of Ukraine. - № 2. - p. 3-5.

2. **Golub A.A. & Trukova E. B.** (2008). Economics of Natural Resources - M .: Aspect Press, - 318p.

3. Report on the state of the environment in Ukraine in 2012 in the Rivne region. [Electronic resource]. - Mode of access: http://www.menr.gov.ua/dopovidi.

4. **Yu.Yu. Tunic**. (2005). Ecological Constitution of the land. Idea. Concepts. Problems. Bulletin of Khmelnitsky National University. - Lviv, - №11. - Part 1. - P. 32-42.

5. On Environmental Protection [Electronic Resource]: Law of Ukraine. № 1264-XII dated 25.06.1991. - Access Mode: http://zakon2.rada.gov.ua/laws/show/1264-12/page.

6. The Land Code of Ukraine [Electronic resource]: Law of Ukraine № 2768-III dated 25.10.2001 - Mode of access: http://zakon4.rada.gov.ua/laws/show/2768-14.

7. Makarenko O.Yu. (2010). On Subsoil Use in Ukraine. State and Law. Legal and political sciences: Sb. sciences works - K .: Institution of State and Law of. V. Koretskyi, NAS of **Ukraine. - Vip. 48. - pp. 424-429.**

8. Makarenko O.Yu. (2006). Legal grounds for the development of mineral deposits. Scientific potential of the world: materials of international relations. sci. pract. conf. - Dnipropetrovsk: Science and Education. - T. 15. - P. 47-52.

9. **Malanchuk L.O**. (2014) Principles of Public Administration and Control in the Field of Exploration and Use of Subsoil at the Regional Level. Economy and the State. - No. 5. - P. 124-1**28.**

10**. Malanchuk L.O**. (2011). Topical issues of subsoil use in the Rivne-Volyn region. Materials of interludes. Industrial Conference "Efficiency of Realization of Scientific Potential in Modern Conditions" (February 10-14, 2011). - P. Plain, Carpathians. - P. 162-163.

11. Program for development and industrial development of mineral resources of Rivne region for the period until 2015. - Rivne, 2010. – 21p.

12. Program of development of mineral resources of Ukraine for the period of 2010-2013 and till 2020. - Kyiv, 2009. - 45 p.

13. About the approval of the Concept of the National Environmental Policy of Ukraine for the period till 2020 [Electronic resource]: Order of the Cabinet of Ministers of Ukraine №880-r of October 17, 2007 - Access mode: http://zakon4.rada.gov.ua/laws / show / 880-2007-p.

SUSTAINABLE USE OF WATER IN MINING AND MINERAL PROCESSING

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Abstract. Clean water is one of the most valuable natural resources. Its amounts are dramatically decreasing worldwide and mining and mineral processing industry takes a significant share in this process. This chapter presents briefly (a) negative effect of mining and mineral processing on the water consumption and natural water bodies pollution, (b) the major worldwide legislation measurements already in force and still needed for preventing water overconsumption and pollution by the mentioned industries, and (c) the technologies available and under development for minimization of clean water use and for combating the water pollution by mining and mineral processing industry.

1. Introduction

Water is very important for the socio-economic progress, healthy ecosystems and for the human survival. The biodiversity loss in freshwater systems is occurring at twice the rate of other natural systems. Thus, their ability to provide ecosystem services declines, resulting in negative consequences for human well-being (MEA, 2005). It is estimated that 3.6 billion people live in areas that are potentially water-scarce at least one month per year, and this population could increase to 4.8–5.7 billion by 2050. Water demand for goods manufacturing is expected to increase by 400 % between 2000 and 2050 globally (WWAP, 2018).

About 71 % of the Earth's surface is water-covered but the salty water represents about 96.5 % of all Earth's water. Freshwater is indispensable for sustainable life and development on our planet. However, in all its forms including ice caps, glaciers and permanent snow it represents < 3.454% of the global water (USGS, 2016). Freshwater is a finite and irreplaceable resource if it is not well managed. The road to supply additional fresh water is to purify the wastewater for reuse in industrial facilities or purify sea water. The other possibility is to minimize water use. Neither of these frontiers have been conquered cost effectively with existing technology.

Mining and mineral processing industry, as a global industry, contributes to water consumption and natural water bodies' deterioration. The aim of this chapter is to present briefly the water pollution, caused by this industry, the relevant legislation and the technological measures aimed at the problem mitigation.

2. Mining and mineral processing - as water consumer and polluter

2.1. Mining activities and leaching in place

Polluted water can appear from active mining operations dewatering, flooding of closed mine voids and discharge of untreated naturally formed mine water. Formation of acid rock drainage is a natural process of sulfuric acid production when sulfides in rocks are exposed to air and water

$$FeS_2+H_2O+3.5\ O_2 \rightarrow FeSO_4+H_2SO_4.$$

Production of acid mine drainage (AMD) is the same process in its nature, however greatly magnified when mining exposes the rocks, that have lain unexposed for geological eras, to air and water. AMD can be formed both in underground mines and in the rocky material pilled on the earth surface as a result of open pit mining. In rock dumps, overburden piles, and other mine materials piles, AMD may start to form immediately. The acid generation potential and the potential for release of other constituents is increased in these units compared to the in-place ore body due to the fact that the rock is ground or crushed, thus presenting greater particle surface area, and it is in an oxidizing environment. Acid rain drainage can result also from the oxidation of sulfide-containing waste rock used in road construction in mining areas. Often, when the water reaches a certain level of acidity, a naturally occurring bacteria *Thiobacillus ferroxidans* may appear, accelerating the oxidation and acidification processes. Acidified water facilitates leaching of heavy metals (such a cobalt, copper, cadmium, lead, silver, zinc) and arsenic, contained in the excavated rock or exposed in an underground mine and contacting with water. Even trace metals can be leached.

Natural underground or surface drainage and rainwater carry out the acidified water from the mine site and polluted water enters into nearby streams, rivers, lakes and groundwater, as well nearby soils.

Formation of AMD is not the only way of water pollution by mining activities. Some metals and metalloids can become mobile in neutral pH conditions. In uranium underground mines after blasting the rock comes into contact with water. Water in this environment contains a mix of ions, some of which are capable of forming soluble uranium compounds, such as uranyl sulfate, carbonate and nitrate Thus water that is pumped away from the site during mining operations can contain low levels of radiation and therefore contaminate local rivers and lakes. Contaminated with radioactivity and heavy metals water from flooded abandoned uranium mines can seep into groundwater or discharge in surface water bodies. The run-off from the mine stockpiles can be also polluted with radioactive compounds formed by the same mechanism and thus may cause contamination of the surrounding land and local rivers and lakes.

Oils and greases from the equipment in use can enter the adjacent water bodies, if adequate protection measures have not been taken. As a result of erosion of the exposed material, the on-site formed water may carry substantial amounts of sediment into streams, rivers and lakes. The result is clogging of riverbeds and suffocating watershed vegetation, wildlife habitat and aquatic organisms.

Mining activities use relatively large quantities of water, thus depleting freshwater supplies in the region surrounding the mine.

In heap or dump leaching most often dilute sulfuric acid is used for in situ leaching (ISL) of ores of copper, nickel, uranium. Alkaline cyanide solution is applied for precious metals.

Acids applied to dissolve the ore body usually dissolve metals in the host rock as well. The fluids remaining after the leaching process in the pores of the rock leached commonly contain elevated concentrations of toxic elements (such as cadmium, selenium, vanadium, lead, etc.) and radioactive isotopes, posing risk to nearby ground and surface water sources. In addition, the low pH of ISL wastewater can result in acidification of the surrounding environment. In some technologies uranium deposits are leached with ammonium carbonate-based solutions. In this case the level of radionuclides, such as radium, mobilized from the uranium ore into processing solutions tends to be higher than in acidic solutions.

Environmental problems related to heap or dump leaching are mainly due to the failure to keep process solutions within the leaching circuit. Most of the problems are caused by leakage, spillage or seepage of leaching solution at various stages of the process. Potential problems include: a) Infiltration of leaching solutions through pile or collection pond liners; b) Release of solutions due to failures in the pile or pond liners and associated solution transfer equipment; c) Leakage from solutions' transfer equipment or spills from broken pipes; d) Overflow of solutions containing toxic concentrations of heavy metals and / or cyanide after a heavy rainfall or rapid snowmelt. Any escape of leaching solutions outside the ore zone can lead to contamination of surrounding groundwater.

During gold leaching operation, most of the barren cyanide solution is recycled to leaching activities. However, the technology requires a portion of the solution to be bled off and disposed of. The barren cyanide must be disposed of following operations closure. These solutions have to be treated and discharged to tailings impoundments. Improper treatment may lead to pollutants mobilization by leaching of metallo-cyanide complexes of copper, iron, nickel, zinc, as well as other impurities, such as arsenic.

Heap or dump leaching generates piles of spent ore which has been in contact with the leaching solution. Spent ore may contain residual leaching solution prior to initiation of washing/ detoxification procedures. The spent ore typically contains unleached metals and other minerals characteristic for the ore body. Uncollected leachate from disposed material is a potential source of contamination of groundwater, surface water and soil. In addition, over time, other contaminants (arsenic, selenium, mercury and many other heavy metals), which are present in the spent ore may be mobilized in the leachate. Oxidation of sulfide ores in the spent material can generate acidic water, which additionally dissolves available heavy metals. Especially problematic may be precious metals leaching. Some residual cyanide may remain complexed with other constituents even after detoxification and disposal of spent ore. All above described events could lead to contamination of surrounding water bodies.

After the operation has been closed or reclaimed, runoff from the spent ore may occur if proper design and construction measures are not taken. This runoff may contain constituents associated with the ore, such as heavy metals, and total suspended solids. If sulfide ores are present, they may generate acidic leachate which may mobilize the metals that are present in the ore. The constituents associated with the leachate (metals and arsenic) can cause degradation of ground and surface water quality.

2.2. Mineral beneficiation and leaching in vessels

Different chemicals are added to the mined ores in the beneficiation process. In most cases, the added flotation reagents settle, neutralize and adsorb on the surface of mineral particles, but sometimes, some of them remain dissolved in wastewater, thus being a prerequisite for the environment pollution. Often the water is polluted with organic reagents: collectors (fatty and some aromatic amines, xanthates, dithiophosphates, dithiocarbamates, etc.); pH modifiers; additives - mercaptans (thiols and thiophenol); frothers - alcohols, compounds containing carboxyl, carbon, amino, sulfo and other groups. Usually wastewater is neutral, but there are also cases of release of weakly acidic (pH 4.0-4.5) or slightly alkaline (pH 8.0-8.5) waters. Generally, the wastewater is with high content of suspended solids. The type and concentrations of inorganic pollutants in wastewater from the flotation depends on the type of the material subjected to processing - some examples are presented in Table 1.

Most mining companies dispose of tailings under the form of slurry in a large wet tailings ponds. The slurry contains many of the chemicals used in the process. Tailings produced from the milling of sulfide ores may have concentrations of pyrite that are higher than those in waste rock. Since tailings contain small mineral particles, they can react with air and water more easily than waste rocks. Therefore, the potential to develop acidic conditions in pyrite-rich tailings is high, especially when tailings are not rich in lime or soda ash (as a result of the applied flotation flow-sheet). If it is not prevented or controlled, acidic waters can seep from the pond.

Table 1

Main inorganic pollutants in wastewater from flotation of ores of non-ferrous metals

Process type	Main inorganic pollutants
Flotation of Cu ores	As,Sb,Cd,Cu,Co,Mn,Fe,Mo,Pb,Hg,Ni,Se,Zn,Ag,CN^-
Flotation of waste from Cu metallurgy	As, Cd, Cu, Fe, Pb, Hg, Ni, Se, Zn, CN^-
Flotation of Pb ores	Pb,Zn,Hg,Cd,Cu,Cr,Mn,Fe,CN^-
Flotation of Zn ores	Pb,Zn,Hg,Cd,Cu,Cr,Mn,Fe,CN^-

During heavy precipitation periods, more water may enter in a tailings pond than its capacity, necessitating the release of tailings pond effluent. This effluent can contain toxic substances and its release may seriously degrade water quality of surrounding rivers and streams and impact negatively downstream habitats and groundwater, particularly if the effluent is not treated prior to discharge. Dam breaks at wet tailings ponds have created some of the worst environmental consequences of all industrial accidents. Failed wet tailings ponds release large amounts of toxic waters that can kill aquatic life and poison drinking water supplies for many miles downstream of the pond.

On completion of the operation, the tailings pond is covered permanently. Leaching and leachate leakage at abandoned or poorly closed tailings ponds and improperly stored waste can pollute groundwater, surface water, and agricultural soil.

Mineral beneficiation activities use relatively large quantities of water, thus sometimes depleting freshwater supplies in the region. In beneficiation plants, mineral treatment involves crushing and grinding of the material, followed by flotation, classification and thickening. The most significant water consumption is in flotation, transportation of concentrates and tailings and the evaporation and infiltration in tailings ponds. Flotation is carried out normally at a rate that varies between 25% and 40% of solids. Thus, the water requirements during flotation can vary between 3 and 1.5 m^3/t of mineral. Once the flotation is finished, the pulp concentrate is taken to thickening, where the percentage of solids is increased to between 40% and 60%, and some water is recovered. Finally the pulp concentrate is taken to filtration, where some water is again recovered, leaving the concentrates with moisture percentages of around 10%. Water from the flotation process is also used to transport the concentrates and the residues to the tailings ponds. Depending on the distance between the concentrator plant and the filtration and storage installations, the residual water may or may not be recirculated to the process.

Potential problems occurring at leaching in vessels (vats with false bottom, Pachuca tanks, Dorr agitators, tanks, autoclaves, digesters) include leakage from solutions' preparation and transfer equipment or spills from broken pipes.

Treatment of ores by wet methods, carried out in different vessels, beside the production solution, produces residues and waste solutions. Residues are disposed of in a tailings pond. Liquid effluents, containing toxic reagents, must be treated before being discharged. A secure permanent tailings pond is needed with adequate capacity for the life of the production site. Residues filtered off from aqueous solutions usually contain soluble ingredients. Seepage of contaminated water through the bottom or sides of the pond can lead to contamination of groundwater in the area. When the tailings pond is not planned with adequate capacity, or not properly constructed, an overflow is possible of solutions containing toxic concentrations of heavy metals and other dangerous pollutants after a heavy rainfall or rapid snowmelt. This causes pollution of surroundings and of downstream water. The problems are heavier at a break of the dike of a tailings pond.

3. Sustainable use of water in mining and mineral processing activities - examples of legislation measures in force in different continents

Sustainable development is a development that meets the needs of the present generations without compromising the ability of future generations to meet their own needs (Blewitt, 2012). To achieve a sustainable development, it is crucial to harmonize three core elements: economic growth, social inclusion and environmental protection. These elements are interconnected and all are crucial for the well-being of individuals and societies.

The society development depends on the use of an increasingly wide range of metals. Demand for all raw materials has risen and will increase in future. Substitution, recycling and usage efficiency improvements will not be enough on their own. The demand for all raw materials will rise and the mining and mineral processing activities will be left as a major source of raw materials in future.

The more obvious deposits have been already discovered and exhausted and nowadays lower grade deposits are being processed which is related to increased water consumption. Mining is increasing in moderate to high water risk countries with respect to water scarcity. Two-thirds of the “Big Six’s” Mining projects are in such countries - Australia, India, South Africa (with high risk), Chile, Peru, Mongolia and the USA (with moderate risk) (Metcalf, 2013).

In addition significant mining and mineral processing activities are being carried out in Angola, Namibia, Botswana, Zimbabwe, China - countries with high to moderate risk of water scarcity and in Northern African countries – with extremely high water shortage risk. According to Dr. Michael Neumann (2018), Chair MWG-UNECE and Vice President EU Federation of Geologists "a quarter of mining production, representing up to US$ 50 bn in annual revenue, could be exposed to water shortages and drought by 2030".

Sustainable use of water requires implementation of both legislative and technological measures. Most of the mining countries are trying to cope with the problem of high water consumption and water pollution by mining and mineral processing actives through their national legislation. Here only some examples, representative for the different continents, are briefly presented.

3.1. Africa

No reliable public sources are available on the mining, mineral processing and water use legislation in the North African most threatened countries.

From the other countries with big mining projects, mining and mineral processing in *Guinea* and *Mozambique* are governed by the corresponding country Mining Codes or Mining Law and the Environment protection laws, requiring EIA before and during the work of the mine or mineral processing plant and by water protection code/law. *South Africa*, as one of the biggest mining countries is considered as an example here.

South Africa is a federal state with three-levels of government: the national, provincial and local levels. The national and provincial levels have concurrent competence to regulate the environment, nature conservation, and pollution control.

The national, provincial and local levels have competence to regulate water.

Mining is regulated at the national level. Legislation governing water issues in the mining and mineral processing sector in South Africa is presented in Table 2 (Capones, 2016; La Fleche, 2017).

Table 2

Legislation (policies, laws, and regulations) governing water issues in the mining and mineral processing sector in South Africa

Constitution of the Republic of South Africa - Act 108 of 1996	Section 24 entrenches a right to a clean environment. Mining and water legislation with a bias towards environmental protection is derived from the constitutional obligation.
National Water Act of 1998	This is the main instrument regulating water usage including mine water use. Regulates licensing for water use in mineral processing.
National Environmental Management Act, 1998	Regulates environmental protection and preservation across a broad spectrum including mining and mineral processing.
Mineral and Petroleum Resources Development Act (2002) and corresponding Regulations	Regulate all mining and mineral processing activity including licensing for mining, processing, site closure.
Regulation on Use of Water for Mining and Related Activities Aimed at the Protection of Water Resources (Regulation 704 of 1999)	Details the regulatory framework governing water quality in mine usage. It requires mines to recycle water to the extent possible.
National Water Policy	It is underpinned by three fundamental principles for managing water resources: equity, (environmental) sustainability and efficiency.

3.2. Asia

The main mining countries are China, India and Mongolia. In *Mongolia* all minerals are owned by the state. Mineral exploration and production may only be carried out under a license validly issued by the Mineral Resources and Petroleum Authority of Mongolia to a

Table 3

Legislation (policies, laws, and regulations) governing water issues in the mining and mineral processing sector in Mongolia

Minerals Law of Mongolia (2006)	Provides a regulatory and administrative framework for the prospecting, reconnaissance, exploration and development of most types of mineral resources (excluding uranium, 'common minerals', petroleum products (conventional and unconventional), water or 'artesian mining' or 'micro mines' which are all regulated by their own separate laws.
Law on Licensing of Mongolia (2001)	Governs certain aspects of the mineral exploration and production licensing regime.

Subsoil Law of Mongolia (1988)	Regulates the use and protection of subsoil, including in the construction of underground mining operations and facilities.
Environmental Protec tion Law of Mongolia (1995)	Sets out the administrative framework and general obligations relating to environmental matters.
EIA Law of Mongolia (2012)	Sets out the framework and obligations relating to EIA of industrial projects.
Law on Water (2012)	Mine and mineral processing facilities are considered a 'water consumer' and must obtain a water permit.

Mongolian-registered legal entity. The main Mongolian legislation is summarized in Table 3 (La Fleche, 2017).

In *China* the authorities at the county level or the other government levels (i.e. the prefecture level or the provincial level - provinces, autonomous regions, municipalities, and special administrative regions) regulate mining, water, and environmental issues according to the relevant laws, issued by the National People's Congress, and the corresponding regulations.

China is perhaps the state with the highest degree of regulation in the field of extraction and processing of mineral resources - Table 4 (Jia, 2016; La Fleche, 2017).

The *Indian* mining sector is highly regulated with strong legal and regulatory mechanisms - Table 5 (Indian Chamber of Commerce, 2017).

3.3. Australia

Australia is a Commonwealth federation comprising of six states and two self-governing territories.

The Commonwealth Constitution sets out which competences are governed by the Federal government (Commonwealth) and which are in the purview of the states.

Minerals and mining activities are regulated at the state, rather than the federal level.

Table 4

Legislation (policies, laws, and regulations) governing water issues in the mining and mineral processing sector in China

Mineral Resource Law of the People's Republic of China (2009)	Regulates the approval and registration procedure of exploration and mining of mine resources.

Water Law of the People's Republic of China (2002)	Regulates allocation and protection of water resources, their monitoring, and the enforcement of violations of the Water Law.
Water and Soil Conservation Law of China (2010)	Prevents and controls water erosion, protects and ensures the reasonable utilization of water.
Water Pollution Prevention and Control Law of China (2008)	Prevents and controls water pollution, ensures the effective utilization of water resources.
Regulation on the Administration of the License for Water Drawing and the Levy of Water Resource Fees (2006)	Regulates permitting procedures for water rights allocations of underground and surface water.
Notice of the State Council on Issuing the Action Plan for the Prevention and Treatment of Water Pollution (2015)	The Action Plan aims to reduce pollutants and promote water saving.
Environmental Protection Law of China (2014)	Aimed to prevent and control pollution.
Law on Appraising of EIA (2003)	Provides for the assessment of the environmental impacts of investment projects.
Cleaner Production Promotion Law of China (2012)	Aimed at: promoting cleaner production, raising the efficiency of utilization of resources, minimizing the generation of pollutants, promoting the sustainable development of the economy and society.
Circular Economy Promotion Law of China (2009)	Aimed at improving resource utilization efficiency, conducting stringent monitoring of high water consumption and high-emission industries, including non-ferrous metal production and realization of sustainable development.
Integrated Water Discharge Standard (GB 8978-1996); Environmental Quality Standards for Surface Water (GB 3838-2002); Quality Standard for Ground Water (GB/T14848-93)	Set to control water pollution and protect water quality.
Emission Standard for Pollutants from Coal Industry (GB 20426-2006)	Aimed to pollution prevention and control in all coal mines, coal washing factories and their coal gangue dumping sites.
Emission standard of pollutants for copper, nickel, cobalt industry (GB 25467 – 2010)	Applies to management of wastewater discharges, EIA related to copper, nickel and cobalt mining and mineral processing projects in all their stages.
Environmental Protection Tax Law (2018)	Sets specific protection taxes on industry, including on water pollution.

Table 5

Legislation (policies, laws, and regulations) governing water issues in the mining and mineral processing sector in India

Mines Act, 1952; Mines and Minerals Development & Regulation Act (MMRD), 1957 and MMRD Amendment Act, 2015	The main acts that govern entire mineral sector of India

National Mineral Policy of 1993	The key reference document of rules, regulations, principles and procedures for regulating, developing and controlling the mineral sector (excluding coal, petroleum and atomic minerals).
The Mineral Concession Rules (MCR), 1960; The Mineral Conservation and Development Rules (MCDR), 1988	Most important rules under the MMDR-1957 for ensuring sustainable mining and mineral processing – amended 1994, 1999 and 2015.
National Mineral Exploration Policy, 2016	Provides for an action plan to ensure comprehensive exploration of mineral resources (non-fuel and non-coal).
The Offshore Areas Mineral (Development and Regulation) Act 2002	Regulates the development of mineral resources in territorial waters, continental shelf, exclusive economic zone and other maritime zones of India.
The Offshore Areas Mineral Concession Rules, 2006	Prescribe for measures for protecting the marine environment.
Mineral Conservation and Development Rules, 2017	Prescribe guidelines for conservation and development of minerals.
Environment Protection Act (EPA) 1986; Environment Protection (Amendment) Act (2006)	The main policies that have specific clauses for EIA, monitoring mining activities for the protection of the environment.
Forest (Conservation) Act, 1980 (FCA 1980), amended 2014	
Water (Prevention and Control of Pollution) Act 1974	Aimed to curtail the impacts of mining processes on the environment.
The Coastal Zone Regulation, 2011.	

As and example, the legislation of one of the most developed mining states (Western Australia) is presented in Table 6A (Capones, E., Anede, C.E., 2016). However, in several areas, including the environment, the Commonwealth has some regulatory powers which take precedence over any inconsistent state legislation - Table 6B.

Table 6A

Western Australia legislation governing water issues in the mining and mineral processing sector

Mining Act 1978	The primary legislation regulating mining and mineral processing activities in WA.
Mining Regulations 1981	Give effect to the provisions of the Mining Act 1978.
Mines Safety and Inspection Act (1994)	Law relating, among the others, to the environmental safety.

Mines Safety and Inspection Regulations 1995	Lays down environmental safety standards for the operation of mines and mineral processing facilities.
Environmental Protection Act 1986	Provides for the prevention, control and abatement of pollution and environmental harm, for the conservation, protection, and management of the environment, and for incidental matters.
Environmental Protection Regulations 1987	Provides for the regulation of prescribed premises.
Environmental (Unauthorised Discharges) Regulations 2004	Regulates prohibited discharge of specified contaminants in the environment.
Contaminated Sites Act 2003 (WA)	Provides for the identification, recording, management and remediation of contaminated sites.
Contaminated Sites Regulations 2006 (WA)	The Regulations give effect to the provisions of the Contaminated Sites Act 2003.
Rights in Water and Irrigation Act 1914	Provides for the regulation, management, use and protection of water resources. It contains the framework for licenses to take surface water, groundwater, or disturb waterways.
Rights in Water and Irrigation Regulations 2000	Sets out the procedural steps and requirements for licensing and other related issues.
Waterways Conservation Act 1976	Makes provision for the conservation and management of waters and of the associated land and environment.
Country Areas Water Supply Act 1947	Makes provisions to safeguard the supply and sources of water.

Table 6B

Australian Commonwealth legislation governing water issues in the mining and mineral processing sector

The Australian Constitution	Sets out all of the matters that form the Commonwealth (federal) government's exclusive jurisdiction and all other matters are taken to be part of the jurisdiction of the State legislatures.
Environment Protection and Biodiversity Conservation Act 1999 (the “EPBC Act”)	Most mining and mineral processing projects require assessment and approval as a "controlled action" for the purposes of the EPBC Act.
Environment Protection and Biodiversity Conservation Regulations 2000	The Regulations give effect to provisions of the EPBC Act.

3.4. Europe

All countries in the European Union obey the common legislation. The major legal documents related to the sustainable use of water in mining and mineral processing industry are presented in Table 7 (OJ, 1991; OJ, 1998; OJ, 2000; OJ, 2006a; OJ 2006b; OJ, 2006c; OJ, 2008; OJ, 2009a; OJ, 2010; OJ, 2010; O.J., 2015; EC, 2012).

3.5. North America

In the North America both Mexico and the USA are countries with risk of water scarcity. Mining activities in *Mexico* are subject of the federal jurisdiction as provided in the Mexican Constitution, therefore the same federal legal framework is applicable to all states. The minerals belong to the Mexican State, and the mining and mineral processing activities are subject of concessions granted by the federal government to Mexican citizens or companies. In the *USA* no person may engage in mining operations without obtaining a permit from the appropriate state authority. Issues of socio-economic impact, cumulative effects and environmental impact on water use are addressed during a NEPA review. Both countries have well-developed legislation aimed at water protection and its use in various areas of the economy, including mining and mineral processing. Their main laws are presented in Tables 8 and 9 (GlobalMine™, 2016; La Fleche, 2017).

Table 7

Water in minerals mining and processing – legislative approach for sustainable solutions - Europe

Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action (WFD)	WFD established a legal basis to protect and restore clean water across Europe and to ensure its long-term, sustainable use.
The Groundwater Directive 2006/118/EC	Developed in response to the requirements of Article 17 of the WFD.
Drinking Water Directive (Council Directive 98/83/EC), amended by Commission Directive (EU) 2015/1787 of 6 October 2015	Aimed at ensuring sustainable use of drinking water.

Continuation of table 7

Directive 2009/54/EC of 18 June 2009 on the exploitation and marketing of natural mineral water	Aimed at ensuring sustainable use of mineral water.
Council Directive 91/271/EEC concerning urban wastewater treatment	Under evaluation - with the aim to better guard natural water bodies.
The Marine Strategy Framework Directive - Directive 2008/56/EC of the European Parliament and the Council of 17 June 2008	Adopts a coordinated approach to managing human activities that have an impact on the marine environment.
Blueprint strategy for safeguarding Europe's water resources to 2020	The “Blueprint” outlines actions that concentrate on better implementation of current water legislation, integration of water policy objectives into other policies, and filling the gaps in particular as regards water quantity and efficiency.
Directive 2010/75/EU on industrial emissions (IED) (integrated pollution prevention and control)	Includes requirements aimed to preventing water pollution from metal ores processing.
Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH)	Dealing with all chemical that are used in mining and mineral processing.
Directive 2006/21/EC on the management of waste from the extractive industries (the mining waste directive) + Reference Document on Best Available Techniques	Aimed at sustainable management of tailings and waste-rock in mining and mineral processing activities.

Table 8

Legislation (policies, laws, and regulations) governing water issues in the mining and mineral processing sector in Mexico

Mexican Constitution, article 27	Provides the fundamental notions of the mining regulation.
Mining Law - June 26, 1992 and last amended on June 26, 2006	Represents a key legislation governing mining and mineral processing activities.
Regulations of the Mining Law, October 31, 2014	Mining concessionaires may use water obtained directly from the mine.
Federal Law of Waters, December 1992	Mining and mineral processing companies must obtain concessions from the National Water Commission or purchase concessions

	previously granted.
General Law on Ecological Balance and Environmental Protection (28 January 1988) and relevant Regulations	Requires that in order to start operations the mining and processing activities should be subject to a previous environmental authorization. In order to obtain such authorization, the companies must submit an environmental impact statement.
Federal Law on Metrology and Standards (1 July 1992)	Provides standards for water use and quality.
Federal Law of Environmental Responsibilities (7 June 2013)	District courts may receive and in this case must follow up a liability action on damages to the environment for purposes of restoration or compensation.

3.6. South America

The three countries in South America with well developed mining industry, namely Argentine, Chile and Peru fall into a water scarce area. In *Argentine* the mining activities are regulated by the Argentine Constitution, the Mining Code, federal laws and regulations, as well as local legislation by the provinces in accordance with the federal legislation (GlobalMine™, 2016; La Fleche, 2017). The Constitution provides the fundamental notions of the mining regulation. The Mining Code rules that the State (National and Provinces) is the original owner of the minerals. It stipulates that the mining rights are divided into exploration permits and exploitation concessions which must be granted by the State to individuals or companies incorporated under Argentine law. The mining concessions confer the rights to use the water for exploration and exploitation activities granting an easement for water or authorizations by local authorities to use the water. The Environmental Law 24.585/95 is incorporated in the Mining Code.

Table 9

Legislation (policies, laws, and regulations) governing water issues in the mining and mineral processing sector in the USA

General Mining Act of 1872	Regulates the whole sector - governs mineral ownership, operations and environmental compliance.
Mineral Lands Leasing Act of 1920	Provides US citizens the opportunity to obtain a prospecting permit or lease for coal, gas, oil, oil shale, phosphate, potassium and sodium deposits on federal lands.
Surface Mining Control and	A permit from the appropriate state authority or the U.S. Department of the Interior's is obligatory; requires

Reclamation Act (SMCRA)	operators to restore the environment affected by the mining and mineral processing activities.
Clean Water Act (CWA)	Requires water pollution permits (pollutant discharge elimination system permit, storm water pollution prevention plan, spill prevention control and countermeasure plan); dam safety permits; artificial pond permits; and water rights to be obtained before starting mining and/or mineral processing activities.
Resource Conservation and Recovery Act (RCRA)	Provides for reclamation plan and permits.
National Environmental Policy Act (NEPA)	Requires federal agencies to prepare an environmental impact statement (EIS) for all major federal actions significantly affecting the quality of the human environment – mining and mineral processing are classified among them.

The law regulates all the stages of the mineral extraction process and requires a previous environmental study of the each one of the prospection, exploration and exploitation stages, including the mine closing process. Before beginning mining activities the concessionaire must submit an environmental report to be approved by the authorities; the report includes among the others description of eventual modification of water, mitigation and compensation plans.

The major legal documents related to the sustainable use of water in mining and mineral processing industry in *Chile* are presented in Table 10 (GlobalMine™, 2016; La Fleche, 2017).

The law in ***Peru*** stipulated that all natural resources including metal and non-metal minerals are property of the nation and the state is sovereign over the exploitation of natural resources. The state sets the conditions for their use and for granting concessions. Through the mining concession, individuals have the right to explore and exploit the mineral resources of soil, subsurface and sea located within the area granted by the concession.

Table 10

Legislation (policies, laws, and regulations) governing water issues in the mining and mineral processing sector in Chile

Chilean Constitution (1980), article 19, no. 24	Provides for the absolute and exclusive ownership by the State of Chile of all mines and minerals.
The Mining Organic	Regulates the mining concession concept and

Constitutional Law on Mining Concessions, Law No. 18.097 of January 21, 1982	contemplates the characters and requirements of the two mining concessions under the Chilean Law: the exploration and exploitation mining concessions.
Mining Code, (Law No. 18.248, 1983) and corresponding Regulation, 1987	Elaborates on the provisions of the Constitution and of the Mining Organic Constitutional Law; provides that the owner of a mining concession is entitled to use waters found in the works within the limits of the concession, to the degree said waters are required for exploratory work, exploitation and processing, according to the type of concession said owner might engage in.
Law 19,300 General Environmental Bases (GEB), 1994	Established the Environmental Impact Assessment System (SEIA); mining and mineral processing projects or activities that have to be submitted to the SEIA must be awarded an Environmental Qualification Resolution (RCA) before being executed. The concession owners must respect third parties´ water rights.
Law 20,417 amending the GEB, 2010	Makes modifications for overseeing compliance with environmental standards and increasing applicable fines.
The new policy and governance of lithium brines, January 2016	Establishes a new regulatory framework defining operating conditions.

Applicants for a mining concession have the obligation to obtain the approval of the appropriate environmental certification, which varies according to the level of impact of the activity to be performed. In order to use water, mining concessionaires shall obtain water rights from the competent authority, the National Water Authority. It is also necessary to obtain the corresponding authorization for the discharge of sewage (GlobalMine™, 2016; La Fleche, 2017).

4. Worldwide legislation - in force and proposed measures

As it can be concluded from the above-described, the major mining countries are trying to cope with the water shortage and water pollution problems. However, these persistent problems are transborder and require pooling efforts of all stakeholders. Some examples are already available. At bilateral lever we can mention the United States - Canada Great Lakes Water Quality Agreement (Great Lakes Water Quality Protocol, 2012) that is applied to mining and mineral processing in one country which causes pollution in the other. Another example is the Resolution of the Euro-Latin American Parliamentary Assembly that is aimed at coordinating efforts for sustainable mining development at international level (Euro Latin American Parliamentary Assembly, 2015).

It has been realized that worldwide efforts were necessary. The need for the integration of economic development, natural resources management and protection, and social equity and inclusion was introduced for the first time at worldwide level by the 1987 Brundtland Report. The Convention on Environmental Impact Assessment (EIA) in a Transboundary Context (Espoo Convention) was signed in 1991 and its Protocol on Strategic Environmental Assessment (SEA), signed in 2003 (www.unece.org - a). They both include major mining and mineral processing activities in their scope, thus requiring impact assessment, opportunities for public participation, and other elements of environmental assessment. Further the Convention of the Transboundary Effects on Industrial Accidents was signed in 1992 (in force since 2000) – it promotes effective management of tailings management facilities (www.unece.org - b). The World Summit on Sustainable Development, held in 2002, advanced the mainstreaming of the three dimensions of sustainable development in development policies at all levels through the adoption of the Johannesburg Plan of Implementation. At the Rio+20 Conference (2012) the international community decided to establish a High-level Political Forum on Sustainable Development which held its first meeting in 2013. In September 2015 the United Nations General Assembly adopted the universal “2030 Agenda for Sustainable Development", along with a set of 17 Sustainable Development Goals (SDGs) and 169 associated targets - paragraph 54 of the United Nations Resolution A/RES/70/1 of 25 September 2015 (https://sustainabledevelopment.un.org, 2015).

Water use by mining and mineral processing industries directly tackles 3 SDGs (Columbia Center on Sustainable Investment, 2016):

- SDG6 - Clean Water and Sanitation, and SDG15 - Life on Land: Mine development needs access to land and water, presenting significant adverse impacts on lands and natural resources that can be mitigated or avoided.

- SDG12 – Responsible Consumption and Production: Mining can help to drive economic development through spurring the construction of new infrastructure for transport, communications, water and energy. Mining also provides materials critical for renewable technologies and the opportunity for companies to collaborate across the supply chain to minimize waste, and to reuse and recycle.

An UN Environment‘s Freshwater Strategy - 2017-2021 was developed that aimed at protecting, managing and restoring freshwater in support of human well-being and sustainable development. International Decade (2018-2028) for Action, “Water for Sustainable Development” was proclaimed by the Resolution 71/222 of the General Assembly of the UN (2017) that includes also the water use in mining and mineral processing industry.

Sustainable water use in mineral processing can be promoted and enforced through taxes and royalties, but also through incentives. All those legal measures require worldwide concerted actions that could be raised through the UN Economic and Social Council. They should be proposed and defended by the international mining and mineral processing communities which best know the industry needs and capabilities.

As already mentioned, the sustainable use of water requires implementation of not only legislative but also technological measures for water use minimization and water treatment and reuse.

5. Technologies for water use minimization

5.1. Mining activities

With existing technologies, the generation and leakage of the AMD is almost impossible to be stopped once the reactions begin. As a result, in the long run, it is necessary to implement measures for the AMD treatment. The first and best line of defense against AMD is to significantly prevent / reduce its generation by contacting sulfide-containing ores with air and water. For mining waste with high pyrite content, the basic principle is to reduce the flow of oxygen. In this context, passive prevention refers to covering the waste with a water or a dry mass layer. The dry covering material is typically waste material dug before reaching the sulfide ore. The water coating is essentially a lagoon that can contain tailings material. The purpose of the dry coating is to prevent (or at least reduce to negligible levels) weathering of sulfide minerals (which is the main cause for the AMD formation). The water-saturated barrier limits the amount of oxygen that would be involved in the sulfide oxidation process. Only the oxygen dissolved in water, whose water solubility is controlled by the partial pressure of oxygen (which is considerably lower than in the case of uncovered ores / waste), is involved in the process, according to Henry's law. The storage of sulfide -containing materials under water reduces the microbial population with oxidizing properties, decreases their oxidative activity and allows the development of sulfate-reducing bacteria (SRB). These bacteria contribute to the reverse process - the reduction of sulfate ions to sulfide ions, which help to precipitate the mobile metals in the form of metal sulfides. From the point of view of environmental protection, the construction of an artificial pond or dam to pile and cover sulfide mining waste is more appropriate than the filling of natural water bodies. On the other hand, ponds or dams are more susceptible to leakage, overflow, demolition, and require permanent, long-term maintenance.

Dry covering layers are particularly suitable for abandoned piles of waste material and tailing ponds. The objective is to provide a long-term barrier that will prevent oxygen access in areas rich in sulfide minerals, thus preventing the generation of AMD.

Already formed AMD is drained through canals or underground drains. To collect the drained wastewater, a drainage wreath is built around the heap. A suitable coagulant may be added to precipitate the coarse pollutants directly into the drainage wreath.

The quantity of contaminated mining water is also reduced by increasing the use of circulating water. For example, wastewater, after suitable filtration and treatment, can be used in the mining process to reduce dusting. Water with a relatively high mineralization and concentration of metal ions can be used in preparing leaching solutions for in place leaching.

5.2. Mineral processing

In general, one or more of the following mechanisms for the effective use of water at the operational level can be selected:

In the minerals beneficiation plant: - Installation of thickeners to obtain a high density concentrate; - Installation of filter presses; - Priority water transport of the concentrate, with subsequent recove-ry of water.

On tailings ponds: - Filtration of the waste slurry feed from the beneficiation plant to the tailings pond; - Additional dosage of flocculants and/or alkalizing agents (lime milk) in order to accelerate flocculation and precipitation;

- Improvement of the tailings pond design to achieve a higher rate of water recovery as the largest losses of water in the tailings pond are due to evaporation and infiltration;

- The bottom and walls of tailings pond must be covered with waterproof material, such as clay or spent ore after leaching. Further, a fine waterproofing material must be deposited at the bottom and the walls of the tailings pond to prevent or reduce the infiltration of contaminated water into ground or surface water; - Installation of tailings drainage to reduce filtration losses; - Installation of thickeners for the tailings slurry to increase the solids concentration prior to being transported to the depot; • Other practices for increasing the efficiency of water use are: - Covering the vessels used to store different reagents in the process with floating lids to avoid evaporation; - Automating the operation of pumps and mills; - Installation of leakage detection systems; - Filling tanks and installations using appropriate procedures to avoid spills;
- Use of valves to interrupt water supplies to avoid losses in case of emergency.

As an example, the best practices for the efficient use of water in the mining industry proposed by the Chilean State Commission on Copper are summarized in Table 11 (Brantes, 2008).

5.3. Hydrometallurgy

To prevent / reduce pollution from hydrometallurgy, a major measure is to minimize discharges from the areas where the metals are extracted. Leaching facilities must be properly designed. Waste ore repositories should be away from ground and surface water. Leaching facilities must be designed and built to operate as stand-alone systems that pump the depleted leaching solution back to top of the heap in order to be used again for leaching.

6. Technologies for water treatment and recycling

6.1. Wastewater from mining activities

Classical approaches to treat wastewater from mining activities include physical, chemical and physicochemical methods.

Physical methods make use of large shallow sedimentary lakes in which the water stays long enough for oxygen dissolved in the water to promote the formation of iron hydroxides that settle down. Other heavy metals are adsorbed on the hydroxides. The lakes must be large enough to provide enough space for sludge accumulation.

The *chemical treatment* is mainly used to remove dissolved metals. The most widely used process is neutralization, followed by chemical precipitation. Lime, slaked lime, limestone, caustic soda, magnesium hydroxide are used as reagents. The process is relatively expensive, multi-stage, comprising the following steps: a) pumping of contaminated water into the treatment facility, which may be a tailing pond or a tank built for that purpose; b) addition of neutralizing reagents and subsequent alkalization of the water to pH ~ 9, where most toxic metals precipitate as hydroxides; (c) aeration-moving the treated water to another pool where it is in contact with air. This allows the formation of iron hydroxides and their further oxidation and the formation of low soluble stable compounds that precipitate at the bottom of the pool. In general, the solid phase contains gypsum (formed in the neutralization) and unreacted lime, which facilitate precipitation and counteract eventual acidification and mobilization of the heavy metal ions. The precipitate contains most of the pollutants previously dissolved in the water. It accumulates at the bottom of the tank and can be removed for disposal.

Table 11

Technologies to optimize the use of water resources in copper production

Technology	General description
Automatic control of the compression system	Optimizes water recovery through an intelligent controller that increases the density of the tailings and thus reduces water consumption.
Permanent control of the water consumption	Controlling water consumption in the enterprise, performing internal audits and imposing fines on excessive water consumption.
Recirculation of waters from remote tailings ponds and waste disposal sites	Recycling of clean water from tailing ponds and waste disposal sites.
Bioremediation treatment of contaminated wastewater	Use of bio-hydro-metallurgical treatment for sedimentation of pollutants in wastewater from hydro-metallurgical processes, stabilization of sediments, at simultaneous recovery of water in these processes by means of filter presses.
Drainage control of the leaching systems	Use of appropriate software and materials to plan drainage of leach systems, to reduce infiltration

	losses, leakage, or the formation of saturated "mineral pockets".
Filtering the tailings	Using belt filter presses, drying the waste, increasing the amount of solids to 75% and sending the waste to the depot by means of a conveyor belt or truck.
Extreme compression	Use of more powerful thickeners and centrifuges for the production of hyper-concentrated waste from tailing ponds, recovery of larger quantities of water and the waste material depositing through the inclined dike method.
Dry milling and use of pneumatic centrifuges	Minerals grinding to optimal size so they can be separated by dry classification before flotation.
Retrieving additional quantities of water from the aquifer	Extraction of water from the saturated area of tailing ponds in operation or abandoned by drainage wells.
Using drainage pipes	Use of a system similar to those used in reservoirs and irrigation of farmland to capture water from the tailings pond.

Purified water is separated. These systems produce large volumes of sludge, which often requires drying facilities to be densified. Sludge disposal is the most expensive and the most difficult part of this mode of treatment of AMD. Because it contains heavy metals, the sludge requires careful handling to prevent the metals from dissolving and entering into the environment. The dry sludge can be transferred to an appropriate safe place for long-term storage or disposal. Although very commonly used in the mining industry, this method of treatment has the disadvantage that even dry sludge can pose a problem in disposal, and is also a likely permanent environmental hazard. For this reason, the method is best suited for waters that contain high levels of iron or aluminum because the precipitates of these metals do not normally pose a serious threat to human health.

The AMD may be neutralized and heavy metals immobilized from polluted water by means of reactive barriers placed in the water flow path, for example limestone, bentonite, zeolite, volcanic tuffs.

Although less widely applied, such as alkaline reagent treatment, sulphide chemical treatment (H_2S or NaHS) has also been used to remove metals from mine waters. Under suitable process parameters, the individual metals can be selectively precipitated in the form of metal sulfides. Purified water (which does not contain heavy metal ions) is separated from the solid phase and can be discharged directly into natural water bodies or reused in the mining process. Solid metal sulphides can be refined and sold to generate revenues that offset the cost of wastewater treatment.

Waters contaminated with cyanides are treated by chemical oxidation or complexation. Arsenic contaminated waters are treated by precipitation as iron arsenates or by applying oxidation-reduction processes. Molybdenum is removed by adsorption on iron hydroxides.

Physicochemical methods of mine water treatment comprise mainly flocculant and coagulant addition, use of ion exchange and membrane processes. Membrane processes for treatment of wastewater include ultrafiltration, microfiltration, nanofiltration and reverse osmosis and they are increasingly being applied in mining projects. They are used to reduce the concentration of dissolved substances and are usually applied after chemical treatment.

Biological treatment can be applied in three manners.

The first is a biological production of hydrogen sulphide to precipitate metals like sulphides. It is generally applicable in cases where the metals are in concentrations having an economic value. The second is for selenium removal (anaerobic treatment) or nitrogen-containing compounds such as cyanide, ammonia or nitrate (a combination of aerobic and anaerobic treatment). The third case is the use of passive biological treatment by the construction of facilities (wetlands) enabling the natural removal of pollutants. This treatment is suitable for very small volumes of water with low concentrations of metals.

Passive systems can purify water varieties and typically require lower capital and operating costs, as well as minimal human interference compared to widely applied conventional chemical and physicochemical methods. Passive systems are designed to optimize the realization of natural biogeochemical processes associated with the removal of pollutants. This is done by precipitating the metals in the form of hydroxides, sulphides and carbonates, and by appropriately changing the pH of the medium. Water and soil chemistry, as well as oxygen content, determine whether the processes will take place in oxidative (aerobic) or reductive (anaerobic) conditions. Typically, the effluent from the passive system is well buffered at pH 6.5-7.0 and can be discharged directly into a natural water source. Some of the metal sludges are unstable in the presence of oxygen and that is why the wet sludge should remain to a high extent or permanently submerged.

There are various versions of passive systems. Often they are most effective in their combined use. The choice of the appropriate treatment scheme depends on the volume of the flow, the type and content of the pollutants present, the local topography, the way of collecting and distributing the streams, etc. Passive systems are cheaper than conventional technologies for treating the wastewater from mining, but there are still some problems with the hydrology and the service life of the facility. Passive systems are suitable for treating AMD from already closed mines.

6.2. Wastewater from mineral processing

Waste water from flotation can be treated in many different ways:

- In-situ immobilization of heavy metals by converting them into low soluble compounds by chemical precipitation. The wastewater is alkalized to a pH of about 9.5-10.0, so heavy metal cations are converted into practically insoluble oxides and / or hydroxides. This should be done with environmentally safe agents and at a lower cost (for example, lime, fly ash, limestone). Chemical precipitation is still the most widely used method for removing heavy metal ions from wastewater from the minerals beneficiation. It applies to metals that precipitate in the form of hydroxides, carbonates, basic carbonates.

In some cases, after precipitation, the clear water is passed through an anion exchange column to remove the anions. The last operation is to neutralize the treated water to pH 7 - 8.5.

Although the chemical precipitation is a widely used treatment method, it has a number of drawbacks, such as the generation of bulky sludge, which must be further treated to meet the disposal criteria, as well as the loss of precious metals.

- Chemical oxidation of certain metals, anions (e.g. cyanides) and organic reagents - by aeration, treatment with chlorine, calcium hypochlorite, ozone, hydrogen peroxide, Fenton reagent.

- Adsorption of metals and some of the organic pollutants (e.g. xanthates) from the wastewater onto different materials: sand covered with ferric hydroxide, alumina, natural and modified zeolites, organic polymers, etc., or on solid wastes from various processes, such as fly ash, sludge from the production of aluminum ("red mud") and biological materials.

- Solvent extraction, followed by electrodeposition, can be used to extract metals from waste streams at high concentrations of those metals. Due to higher costs, the method is most suitable for small volumes of water with large amounts of dissolved metal.
- Ion exchange, cementation, membrane processes are also used to recover metals from the waste effluents. When membrane processes are applied, the treated water is sufficiently purified to be returned to the flotation process.
- The destruction of stable complexing reagents, cyanides, organic pollutants is achieved by anodic oxidation, and often simultaneously useful metals are electrowon at the cathode.

6.3. Wastewater from hydrometallurgy

Neutralization and subsequent alkalinisation with lime is generally carried out to treat waste fluids from in place hydrometallurgical extraction of copper or nickel. Thus the dissolved heavy metals are also precipitated. The treatment is usually done in special tanks.

When leaching is carried out into reactors, the waste acidic solutions are disposed of within the plant for wastewater treatment of the enterprise concerned.

Disposal of residual cyanide solutions and metallic cyanide complexes from precious metals leaching heaps is usually done by washing with fresh or recycled process water. The rinse continues until the wastewater containing a predetermined concentration of cyanide is obtained. There are a number of methods for cyanides treatment before disposing:

Oxidation by various oxidants: chlorine, sodium and calcium hypochlorites, ozone, hydrogen peroxide, electro-oxidation.

Adsorption of cyanide complexes onto ion exchange resins or activated charcoal.

Conversion of cyanide into less toxic thiocyanate (CNS^-) or ferro-cyanide $[Fe(CN)]_4^-$ and subsequent removal of ferrocyanide by oxidation or precipitation with heavy metals.

Flotation by forming complexes of cyanide with base metals and recovery the latter with special collector reagents.

Biological oxidation.

Deposition in shallow lakes (lagoons), where cyanides are degraded by photochemical processes, acidification by CO_2 and oxidation by air, dilution, adsorption, biological processes, metals precipitation.

Usually there is no single technology which can satisfy all the diverse requirements. A set of technologies has to be opted. Key considerations to the selection of appropriate and reliable treatment technologies for purifying and recycling of wastewater from mining and mineral processing activities are: proven performance; low energy usage, capital cost, operations and maintenance cost; ease of operations; robust processes able to deal with fluctuating water flow/quality, waste generation and its handling; water recovery; and reliance on different chemicals.

7. Conclusions

The long term sustainable use of water in mining and mineral processing industry is a mission possible. It is based on three pillars:

- Technical and financial aspects, such as progressive optimization and refinement of treatment technology, converting waste into saleable byproducts, financial resources to undertake the needed projects, and creating competent and adequate staff resources to deal with the task of sustainable water use.

- Environmental aspects, such as continuous improvement in terms of emissions to the environment, raw materials and energy efficiency.

- Social and regulatory aspects, such as enabling proper legislation and associated regulations that support sustainable water use - at national and international levels, and public/private and society/industry partnerships. Good practices implementation and further development require consultation and dialogue of all stakeholders - private industry investment, governments, policymakers, bank investment, environmentalists, scientists and local communities.

The hierarchy of mine water management should be strictly observed, namely:

- Pollution prevention at all potential sources on the mine and mineral processing sites;

- Minimization of potential impacts by mitigation measures;
- Recovery and beneficial use of water on mine complex;
- Treatment of mine water for beneficial use and discharge - the last option.

References

1. **Blewitt, J.** (2012). *Understanding sustainable development*. London: Taylor & Francis Group.

2. **Brantes R.A., Olivares G.** (2008). *Best practices and efficient use of water in the mining industry*. Chile: Quebecor World.

3. Capones, J.E. (2016). *Water Risks in the Mining Sector: South Africa.* Columbia: Columbia Center on Sustainable investment.

4. **Capones E., Anede,C.E.** (2016). *Water Risks in the Mining Sector: Australia.* Columbia: Columbia Center on Sustainable investment.

5. Columbia Center on Sustainable Investment. (2016). *Mapping Mining to the Sustainable Development Goals: An Atlas*. Switzerland: World Economic Forum.

6. EC. (2012). *A Blueprint to Safeguard Europe's Water Resources*. COM/2012/0673.

7. EPA, EC. (2012). *Great Lakes Water Quality Protocol of 2012*. Canada: EPA, EC.

8. Euro Latin American Parliamentary Assembly. (2015). *Resolution: 21st century mining, based on responsible and sustainable development.* Brussels: EP.

9. GlobalMine™. (2016). *Basics of Mining Law – Selected Jurisdictions*. Brussels: Globalaw™. https://sustainabledevelopment.un.org/post2015/transformingourworld Indian Chamber of Commerce. (2017). *Sustainable mining in India.* Geneva: CUTS.

10. **Jia S.** (2016). *Water Risks in the Mining Sector: China.* Columbia: Columbia Center on Sustainable investment.

11. **La Fleche, E.R.** (2017). *The Mining Law Review*. London: Law Business Research Ltd.

12. MEA, Millennium Ecosystem Assessment. (2005). *Concepts of Ecosystem Value and Valuation* ***Approaches*****. Washington DC: Island Press.**

13. Metcalf A. (2013). *Water scarcity to raise capex and operating costs, heighten operation risks*. Report No 149714, Special Comment: Moody's Investor Service.

14. **Neumann M.** (2018). *Challenges and opportunities in the path towards sustainable development of mineral resources*. Geneva: EGRC 9th session - UNECE.

15. OJ. (1991). Council Directive 91/271/EEC concerning urban wastewater treatment. *O. J. of the EU,* L 135/40-52, 30.5.1991.

16. OJ. (1998). Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption. *O. J. of the EU,* L 330/32-54, 5.12.1998.

17. OJ. (2000). Directive 2000/60/EC of the EP and of the Council of 23 October 2000 establishing a framework for Community action. *O. J. of the EC,* L 327/1-72, 22.12.2000.

18. OJ. (2006a). The Groundwater Directive 2006/118/EC. *O. J. of the EU,* L 372/19-31, 27.12.2006.

OJ. (2006b). Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH). *O. J. of the EU,* L 396/1-520, 30.12.2006.

19. OJ. (2006c). Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries. *O. J. of the EU,* L 102/15-34, 11.4.2006.

20. OJ. (2008). Directive 2008/56/EC of the EP and the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy. *O. J. of the E U,* L 164/19-40, 25.6.2008.

21. OJ. (2009). Directive 2009/54/EC of 18 June 2009 on the exploitation and marketing of natural mineral waters. *O. J. of the EU,* L 164/45-58, 26.6.2009.

22. OJ. (2010). Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control). *O. J. of the EU,* L 334/17-119, 17.12.2010.

23. OJ. (2015) Commission Directive (EU) 2015/1787 of 6 October 2015 amending Annexes II and III to Council Directive 98/83/EC on the quality of water intended for human consumption. *O. J.of the EU,* L 260/6-17, 7.10.2015.

24. United Nations, General Assembly. (2017). *Resolution adopted by the General Assembly on 21 December 2016, A/RES/71/222.* Geneva: United Nations Environment Programme.

25. USGS. (2016). Water Science School. Retrieved from *https://water.usgs.gov/edu/earthhowmuch.html*.

26. WWAP - United Nations World Water Assessment Programme. (2018). *The United Nations World Water Development Report 2018: Nature-Based Solutions for Water*, Paris: UNESCO.

27. www.unece.org - a, ww.unece.org/fileadmin//DAM/env/eia/welcome.html.

28. www.unece.org - b, www.unece.org/environmental/policy/conventions/industrial-accidents/about-us/envteiaabout/more.html.

IMPROVEMENT OF TECHNOLOGICAL PARAMETERS OF THE TECHNOLOGY OF PRODUCTION OF ZEOLITE-SMECTITE TUFFS

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Summary. The essence of the work is to improve the technology of underground mining of zeolite-smectite tuff deposits by hydro-borehole method, taking into account the dominant process factors and operative automatic control and management of hydro-extraction equipment.

This work is caries out a comparative analysis of the properties, characteristics and methods of extraction of volcanic tuffs of various deposits in Ukraine and beyond its borders with zeolite-smectite rocks of the Rivne-Volyn region. The basic directions of use of zeolite-smectite tuffes are singled out. The experience of geotechnical methods of extraction of tuffs , in particular the method of borehole hydro mining, is studied. The parameters of the technology of borehole hydro mining of zeolite-smectite tuff deposits are substantiated. The dependence between the physical and technological parameters of the hydro monitor blasting of the rock mass is established in order to optimize the extraction process. The algorithm of work is developed and simulink-model of the system of automatic control of the hydro monitor blasting based on the control of speed and range of blasting is constructed. This will allow more efficient extraction of zeolite-smectite tuffs for the purpose of their further use in various industries.

Introduction.

In recent decades, the interest in volcanic tuffs has grown considerably in the world, that is associated with the discovery of deposits of zeolite tuffs, which have valuable sorption, cation exchange and other properties. The amount of predicted resources of such zeolite-containing volcanic tuffs in the Rivne-Volyn region are hundreds of millions of tons, that is, they are practically inexhaustible.

The conducted analysis of the deposit of the tuff raw material and the results of geological studies indicate that it is impossible to open the deposit to develop the deposit, as much of it is located under productive private agricultural land, and partly under the forests that belong to the protected area. The impossibility of open development is also due to the excessive flooding of the territory and the increase in the depth of the tuffs in the northern areas up to 200 meters [1].

An alternative way of developing a zeolite-smectite tuff deposit is using geotechnological methods, among which one of the main and most promising is the method of borehole hydro mining. The process of hydraulic fracturing of the array during the development of the deposit is investigated under various conditions and methods of influence, and the dominant parameters that influence the technology of hydrodynamic blasting are revealed. The dependencies of the blasting performance and transport ability of the flow on these parameters are established. Development and research of the mathematical model of the system of automatic control of the process of hydro-monitor blasting of the rock are carried out with the aim of optimizing the operation of the hydro mining equipment in the automatic mode [2-5].

The paper proposes the solution of the actual scientific problem, that consists in the establishment of the regularities of the process of rock blasting and transport in the slurry stream, which are necessary for the substantiation of the parameters of the borehole hydrotechnology for the extraction of zeolite-smectite tuffs and will serve as the basis for theoretical and technical decisions regarding the specifics of the application of the hydro mining equipment.

Characteristics of the deposit of zeolite-smectite tuffs.

Volcanic tuffs are microporous rocks of aluminosilicate composition, formed as a result of the transfer of the tuff material by air flow or interaction with groundwater and undergroundwater, followed by recrystallization under the influence of various natural influences. Such types of tuffs show most valuable properties and contain a large number of useful components [6,7].

Today, there are three main directions of use of zeolite tuffs: environmental protection, industry and agriculture.

In the environmental sphere, zeolite tuffs are used to purify the harmful gas emissions of industrial enterprises from sulfur oxides. Also, tufa purify the muddy waters of industrial water supply, urban and sewage waters from ammonium nitrogen and other types of pollution. The efficiency of the use of natural zeolites in the melioration of soils contaminated with radionuclides and reduction of the impact of pesticides on the environment have been proved.

In industry, natural zeolite tuffs are used:

- for purification and dehumidification of natural gas, air, nitrogen and other gases;
- as a modifying active additives and fillers of rubber, plastics, paper;
- sorption of water and organic acids from lubricant-freon mixtures in the refrigeration industry;
- as additives in the manufacture of ceramics, lightweight concrete, strong and decorative cements;
- for cleaning and lighting juices, wines, ethanol.

Low silica zeolite tuffs (analcime) is a promising raw material for the production of clay, for the production of aluminum, silica, and soda products.

Agriculture is the most massive potential consumer of natural zeolites. Questions of their application in animal husbandry and poultry farming have been studied quite thoroughly and comprehensively. The recommendations for production have been elaborated, and the negative biological effects of the main types of zeolites have not been revealed at the level of the whole organism.

Technological experiments and a number of investigated bioactive, environmental, agrochemical and preservative characteristics of tuffs have shown their suitability for use in various technologies and industries (Table 1) [8-12].

According to deep-seated mapping, volcanic tuffs in the Rivne-Volyn region (рис. 1) are traced along the Mesozoic-Cenozoic sediments along the western wing of the Polissya saddle and the western slope of the Ukrainian crystalline massif in the form of a strip of 1-10 kilometers at depths of 5 to 300 meters.

Tabl. 1

Economic application of basaltic tuffs of Rivne region

Areas of use											
Environmental measures			Agriculture			Building industry			Binding materials	
Reclamation of radioactive contaminated soils	Underground disposal of radioactive waste	NH4 + wastewater treatment	Mineral fertilizer, vegetarian stabilizer	**Storage of seeds**	Additives for feed of cattle and poultry	Manufacturing of bricks, tiles and ceramic tiles	Manufacture of cement and expanded clay	Pigments for paints and colored concrete	Reducing ores	Rolling out fertilizers

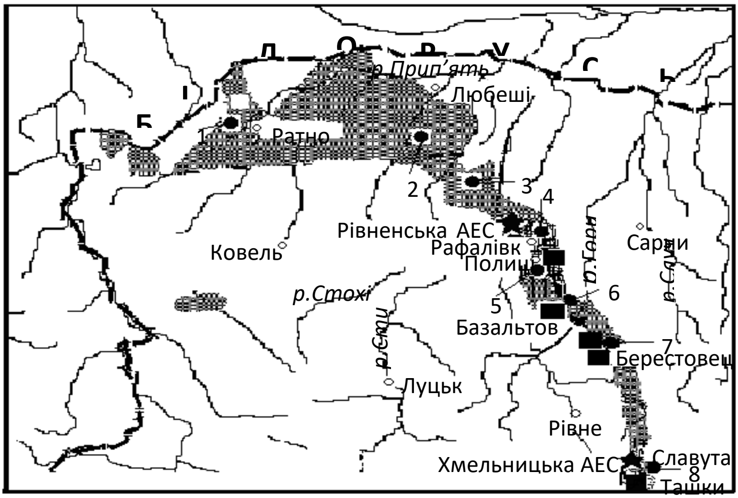

Рис. 1. Typhoid sampling scheme: 1-8 - sampling points; - outputs of tuffs on the Domosozoic-Cenozoic surface; - outputs of tuffs in quarries

On the territory of the Rivne region, tuffs lay in powerful layers forming a thickness from several meters to 140 meters and together with basaltic deposits constitute the so-called trap formation (Volyn volcanic series) of the lower Ediacary. They are stretched in the form of a strip through Volodymyrets, Sarny, Kostopil, Rivne and Goshcha administrative districts. On the open surface of the tuffs appear only in basalt quarries: Polytsi, Berestovets and Basaltove, and outside the region 5 kilometers south-east of Slavuta town of Khmelnytsky region in the career of Tashka [13].

The most detailed tufa of the Rivne region are studied for 2-3 km southwest of the village. Ivanchi, where during the preliminary exploration of basalt raw materials 30 boreholes were drilled. The following horizons of effusive rocks (from the bottom up) are involved in the structure: *1* - lavaclactic breccia, *2* - almond stone basalts, *3* - massive aphanite and plywood basalt, *4* - almond stone facial basalts, weakly weathered, *5* - lavclass breccia, *6* - volcanic tuas of basalt composition. The horizons are overlapped by the lithothrocochromatic, mostly psammites tuffs of basalts.

As quantitative mineralogical analyzes show, in places the tuffs are completely transformed into specific zeolite-smectite rocks. Among them are isolated individual bodies maximally enriched with zeolites (mainly analzim) and smectites of the montmorillonite-saponite series, which contain abnormal amounts of useful petrogenic components and trace elements. Thus, according to the content of petrogenic minerals, volcanic tuffs of the Rivne region are highly altered zeolite-smectite rocks that have undergone significant secondary transformations and hydrothermal mineralization.

The solution of the issue of the development of volcanic tuff deposits by the method of borehole hydrotechnology is impossible without a detailed study of their geological structure and hydrogeological conditions, properties of the massif and rocks that make it, that is, without detailed physical-geological characteristics of the mountain environment. It is necessary to know this also for the scientific substantiation of the processes that accompany the development of the tuff deposits, in order to establish a regime that arises in the deposit during development, based on its natural properties. The decisive role belongs to the correct geological and hydrogeological research to be carried out following the exploration of the deposit and precede the design. Knowledge of physico-geological constants of the mountain environment (reservoir pressure, permeability, porosity, filtration properties of the rock, geometric parameters of the deposit, etc.), composition and properties of the tuffs themselves will provide the opportunity to calculate the parameters of the technology and design of the mining borehole [14, 15].

The general characteristics of the research area were studied according to the data of the design and technical documentation of the DRGP "Pivnichgeologiya". The water-physical and physical-mechanical properties of the tuffs of the Rivne-Volyn region were determined according to the generally accepted methodology. The chemical composition of the tuffs was determined from the data of the spectral analysis.

For direct observation, tuffs are only available on the outskirts of the village Ivanchi, where they form the bottom, as borehole as the base of the southern and eastern sides of the basalt quarry. The tuffs form a continuous horizon, with a visible length of 180 m and an open capacity of 0.3 ... 1.7 m, on the southern side and the bottom of the quarry, which can be traced within the limits of a quarry on an area of about 0,5 km^2, changing the capacity from 0.1 to 7 m, and also fixed around the quarry in boreholes.

The physical-mechanical characteristics of specimens of tuffs taken from a basalt quarry and boreholes drilled in the area of villages Polytsi and Ivanchi, presented in Table. 2.

Tabl. 2

Physical and chemical properties of tuffs in the area of Polytsi and Ivanch

Number of plasticity	Bulk density · 10^3 kg/m^3	Specific surface area, m^2 / kg	Porosity,%	Swelling in water,%	Water absorption by mass,%	Water absorption by volume,%	Strength, MPa
5-7	1-1,2	120	30	36	18	33	5

According to spectral analyses, the average content of trace elements, including environmentally hazardous, in the tuffs from the experimental area corresponds to the clark value calculated for the main rocks of the lithosphere and the maximum permissible concentrations (MPC) in the soils, which is presented in Table. 3.

Tabl. 3

The average content of trace elements in the tuffs of the deposit "Rafalivske" (42 samples), in $1 \cdot 10^{-4}$%

Element	P	Pb	Ba	Mo	Sn	Cu	Zn	Ni	Zr	Co	Cr	V	Mn	Ti
Medium	670	5	350	0,8	5	103	46	34	140	31	47	116	1240	5480
Clarke	1500	6	330	1,5	6	87	105	130	110	48	170	250	1200	8000
MPC	-	30	-	-	-	100	100	100	-	-	100	150	1500	-

Tuffs are characterized by thermal stability, resistance to aggressive media and ionizing radiation, sufficient mechanical strength in a dry state, the absence or presence only of trace amounts of toxic compounds, the absence of contamination of the mineral by microorganisms.

Freshly produced tuffs are borehole cemented, semi-rocks, but with prolonged moisture, they easily decompose with the formation of a loose mass. After grinding these rocks on a chewing mill, the resulting tuff flour according to the granulometric composition corresponds to hardwood sand: contains particles with a size >2 mm - 25%; 1-2 mm - 32%; 0,5-1,0 mm - 9%; 0,25-0,5 mm - 14%; 0,1 - 0,25 mm - 11%; <0,1 mm - 9% of the total mass of air-dry material. After shredding in a ball mill, the tuff material contains about 50% of the physical sand, 33% of the pulverized fraction and 17% of the clay, has a plasticity number of 5-7, and these parameters correspond to a little plastic dusty loamy sand [16].

Analyzing data on the chemical composition of zeolite ores, it can be concluded that the content of chemical elements and compounds of basaltic tuffs of the Rivne-Volyn region is similar to those of other deposits, although the concentrations of the elements themselves are somewhat different. Increased levels of barium, vanadium, copper, zirconium need to be regulated with maximum permissible concentrations. High content of iron, magnesium, lack of calcium, leads to additional research on the use or application of technologies for enriching or impoverishing ores [17].

Investigation of the processes of borehole hydrofoil production of tuffs.

The reason for the use of borehole hydrotechnology is the results of the exploration of deposits and the depth of their occurrence. The task is to refine certain mining-geological indicators on the basis of laboratory studies of physical and mechanical properties of minerals and incinerating rocks.

At present, the theory of hydraulic fracturing is not sufficiently developed, but according to the results of many experimental studies, the mechanism of destruction is due to the simultaneous manifestation of different forces and depends on the properties of rocks and conditions of currents flow[18, 19].

Existing methods for calculating hydrotransport of mineral raw materials are reduced to the definition of critical speed or transport ability of the flow at a given cost and inclination and finding the required inclination at a known cost and transverse section of the channel.

To study the regularities of the motion of the fluid that is pumped onto the surface, appropriate theories and improved designs of lifting aggregates have been developed. Methods of calculating hydraulic elevators are based on the theories of mixing of two streams, the dispersal of a turbulent flooded stream, the spread of a free flooded stream in a liquid. The parameters of the pumping process with the help of an airframe depend on many specific factors, among which the most important are the magnitude of reservoir pressure, the inflow of air to the borehole, the physical properties of the hydromixture, and others.

According to Professor Zinoviy Malanchuk, the method of borehole hydro mining can produce deep deposits of tuffs with complex mining-geological and hydrogeological conditions, and therefore there are a number of features of economic research: the definition of the rational limit of the application of the method and the capacity of the deposit under various geological conditions and the value of the tuffs; research and the choice of the economically expedient diameter of the extraction chamber and the volume of extraction from the camera; economic evaluation of the term of the camera development; studying ways to reduce the cost and increase productivity [20-23].

The development of the tuff deposit by the method of borehole hydrotechnology will allow simultaneously to evaluate the stocks of zeolite-smectite raw materials by improving the geological study of the deposit and carry out additional studies on their composition and properties.

A wide range of researchers have been engaged in the development of technologies for hydro production, but the difference in the conditions of occurrence and composition of minerals determine the expediency of additional and more detailed research directly for deposits of zeolite-smectite tuffs.

Taking into account the methodological and technological difficulties of creating a common model of borehole hydrotechnology, studies have been conducted for individual technological operations.

Blasting of rock and movement of hydrosmixes. The main element of the system - the blasting of minerals includes the reflection of the rock with a jet from the hydro-jet and the supply of pulp to the zone of action of the suction pipe or in the final development. The specificity of the formation of a stream in a borehole hydro-motor is such that the progression of the water flow to the nozzle meets various supports in its path that promote turbulence and cavitation flow, which worsen the quality and parameters of the jet of the hydromonitor. The final formation of the current occurs in the nozzle, the purpose of which is to convert the static pressure of water into the kinetic energy of the stream, also reducing the section of the nozzle at constant water flow speeds up. At the same time, pressure losses in the nozzle, which are proportional to the square of the flow rate, increase. In the final section of the nozzle, the static pressure, taking into account the loss of pressure, passes into the high pressure.

The program of experimental research with the dilution of zeolite-smectite tuffs with a pressure water jet through the nozzles with diameters of 15, 20, 25, 30 and 35 mm and a pressure of 1-3 MPa is to set the productivity, maximum radius of radiance, energy intensity and specific water consumption [24, 25].

For conducting natural studies in the Rafalivske basalt quarry (village Ivanch), abandoned rocks were removed from the experimental site for the exposure of minerals. The speed of the displacement of the hydro-jet nozzle by the sector of the face varied from 0,3 to 2,4 m/s. The blasting of minerals was carried out in layers at a height of the ledge of 20-35 cm, with the displacement of its jet to a marginal distance equal to the value of the radius of blasting. Under the radius of laundering we mean the maximum value of the distance at which the stream moves the largest fractions of the rock. The deflection and transportation of the rock were in essence a single process and were carried out by successive action of the currents in the permanently displaced vibe.

Investigation of the process of blasting of the rock at different diameters of nozzles and for various values of water pressure in the hydro-jet (Table 4) has shown that the blasting of the tuffs by jets of larger diameter leads to an increase in the radii of blasting, and with increasing pressure of the working agent before the nozzle, this increase becomes more significant (Pic. 2).

Tabl. 4

Experimental data of the radius of zeolite-smectite blasting tuffs by a jet of a hydromonitor

Pressure of water in the nozzle	Experiment №		Diameter of nozzle d_0, mm				
			15	20	25	30	35
H_0=1 MPa	1	The value of the radius of blasting R, m	2,2	3,3	4,25	6,0	8,1
	2		2,25	3,2	4,3	6,1	8,1
	3		2,2	3,4	4,5	6,2	8,3
	Medium		2,22	3,30	4,35	6,10	8,17
H_0=1,6 MPa	1		3,5	4,4	5,5	7,4	9,5
	2		3,6	4,55	5,6	7,65	9,7
	3		3,5	4,5	5,6	7,5	9,7
	Medium		3,53	4,48	5,57	7,52	9,63
H_0=2,2 MPa	1		5,1	6,0	7,3	9,1	11,5
	2		5,3	6,15	7,45	9,2	11,6
	3		5,1	6,05	7,4	9,15	10,9
	Medium		5,17	6,07	7,38	9,15	11,33

The destruction of zeolite-smectite volcanic tuffs under the influence of the pulsating action of the stream violated the connection between the individual particles of the rock. As a result of filtration of part of the water in to the pores, they were humidified and wetted, which led to a change in the force of particle adhesion.

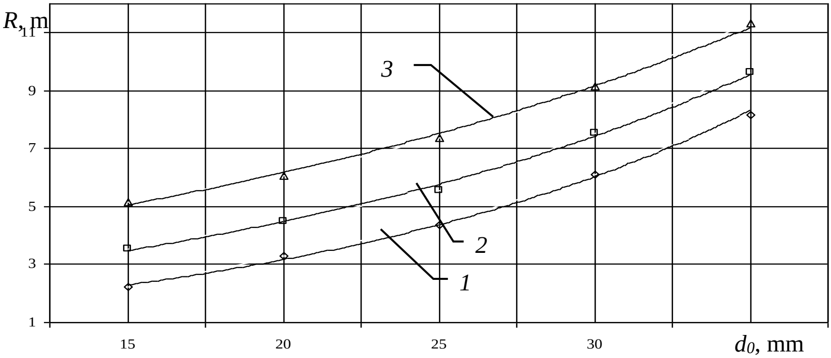

Рис. 2. Dependence of the radius of blasting of zeolite-smectite tuffs on the diameter of the nozzle at different pressures: *1* - H_0=1 MPa, *2* - H_0=1,6 MPa, *3* - H_0=2,2 MPa

In addition, in the not flooded face , the mass of water stream, accumulated in the drain, tore it and, as a result, there appeared stresses in the array, which contributed to the appearance of cracks and the separation of individual pieces of rock.

The averaged productivity of the flushing of the minerals Pr in the limits of the established radii of blasting, and depending on the diameter of the nozzle are shown in Pic. 3.

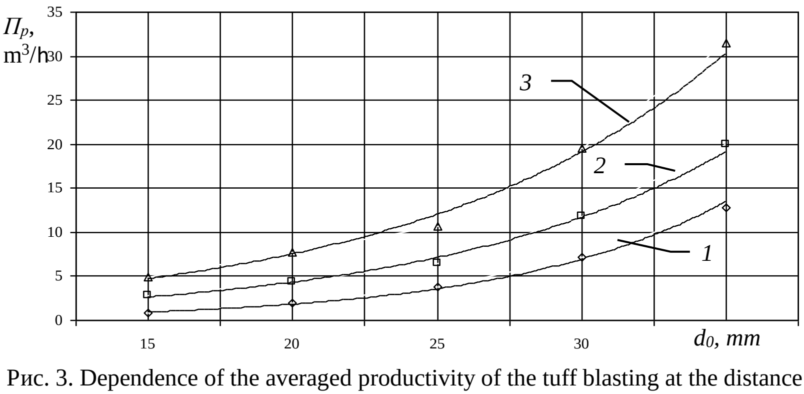

Рис. 3. Dependence of the averaged productivity of the tuff blasting at the distance of the radius of blasting from the diameter of the nozzle at different values of water pressure: *1* - H_0=1 MPa; *2* - H_0=1,6 MPa; *3* - H_0=2,2 MPa

With an increase in the diameter of the nozzle and pressure, the blasting efficiency, as it follows from the graphs, increases.

Investigation of energy consumption for the blasting of minerals is presented in Pic. 4 and 5.

Analyzing the data of experimental studies, it was established that with increasing pressure in front of the nozzle, the energy intensity of blasting increases, and the specific flow of water decreases.

The effectiveness of the blasting of tuffs with identical physical and mechanical properties is influenced by the time of the action of the jets on the whip, which is determined by the rate of movement of the jet over the sector of the face.

The research has established that in case of layer blasting of minerals the increase of the time of the impact of the stream on the array leads to the formation of a kerf and reduces the effectiveness of blasting. Creation of a kerf during rotation of a jet nozzle with an angular velocity ω=1 rpm was observed at a distance of 4...6 m from the nozzle. At the same time, the speed of movement of the stream on the face varied from 0,3 to 0,9 m/s.

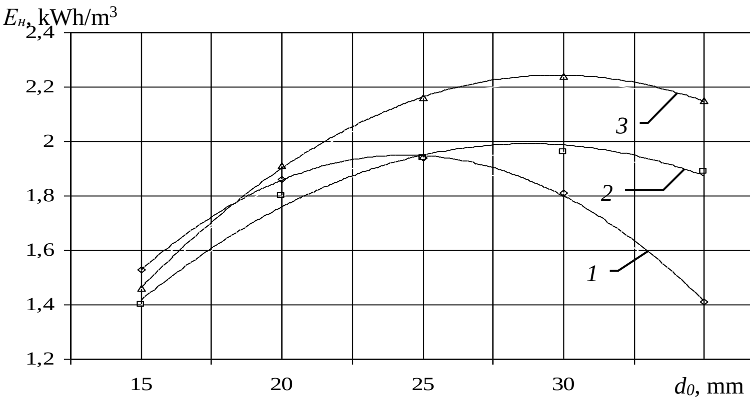

Рис. 4. Dependence of energy intensity of the process of blasting on the diameter of the nozzle of the hydro in various pressures:
1 - H_0=1 MPa; *2* - H_0=1,6 MPa; *3* - H_0=2,2 MPa.

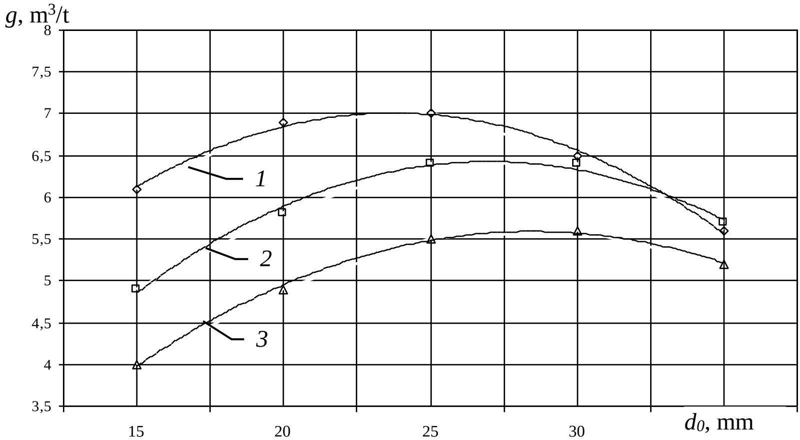

Рис. 5. Dependence of the specific consumption of the working agent under different blasting conditions: *1*-H_0=1 MPa; *2*-H_0=1,6 MPa; *3*-H_0=2,2 MPa

The formation of the kerf was also facilitated by the relatively large value of the meeting point of the stream with the surface. Its value, when displaced by a hole from 0 to 5 m, varied from 25 to 10˚, respectively.

In order to increase the efficiency of extraction of minerals at distances up to 6 m from the jet pump, the angle of inclination of the jet to the surface of the blasting must not exceed 5-7˚.

In the course of an experiment on the blasting of zeolite smectite tuffs, it has been proved that the rational productivity of the destruction of the tuff is achieved at a speed of displacement of the stream in the face 0,7...1,4 m/s, the angle of rotation of the lateral nozzle of the gauge head at 14°, and the layer blasting to height 15-20 cm with the movement of the rock at a distance equal to the half radius of blasting.

Approximation and statistical processing of research data were carried out in Mat Lab and Microsoft Excel software packages. Most of the experimental data was approximated by polynomials of the second order.

The dependence of the radius of blasting on the pressure of the working agent and the diameter of the nozzle for the Rafalovsky quarry of zeolite-smectite tuffs is approximated by the following equation:

$$R(d_0, H_0) = 0{,}9e^{0{,}064 d_0} + 2{,}5 \cdot H_0 - 2{,}5 . \qquad (1)$$

The maximum relative error of the calculation of the radius of erosion of the rock was 9,07%.

The efficiency of the tufts blasting depending on the pressure and diameter of the nozzle of the hydromonitor is approximated by the following dependence:

$$П_p(d_0, H_0) = 0{,}07 H_0 \cdot e^{148 d_0} + 3{,}3 \cdot H_0 - 2{,}8 . \qquad (2)$$

The maximum error in the calculation of blasting efficiency was 12,3%.

When derivation of analytic dependences on experimental data that is a complex function of two variables, that is, for families of curves, the approximation dependence of a certain type as a function of one variable was constructed for each curve. Further, by the values of the coefficients in the equations of these curves, graphic and approximation dependences were constructed, which are functions of the second variable. Replacing the coefficients of the first approximation dependence on the equations of the second variable gives the function of two variables.

The dependence of the energy intensity of the process of blasting the tuffs and the specific consumption of the working agent from the pressure and diameter of the nozzle of the hydro monitors were approximated according to the following equations:

$$\begin{cases} E_и = -a d_0^{\ 2} + b d_0 - c \\ a = 3174 \cdot H_0^{\ 2} - 11158 \cdot H_0 + 12755 \\ b = 134{,}8 \cdot H_0^{\ 2} - 448{,}1 \cdot H_0 + 546{,}1 \\ c = 1{,}09 \cdot H_0^{\ 2} - 3{,}465 \cdot H_0 + 3{,}26 \end{cases}, \qquad (3)$$

$$\begin{cases} q = -a d_0^{\ 2} + b d_0 - c \\ a = -1983 \cdot H_0^{\ 2} + 4203 \cdot H_0 + 9209 \\ b = -174{,}2 \cdot H_0^{\ 2} + 525{,}3 \cdot H_0 + 192{,}3 \\ c = -2{,}71 \cdot H_0^{\ 2} + 10{,}5 \cdot H_0 - 8{,}3 \end{cases} . \qquad (4)$$

The maximum difference between the estimated and the experimental data with this method of approximation is much smaller and, accordingly, was equal to 2,14% for the determination of the energy consumption of erosion and 2,5% for the specific consumption.

Automated process control system.

Technological features of borehole hydrotechnology of mining of minerals and significant energy and resource intensities require the use of modern automation systems to achieve high technical and economic indicators.

The control system for hydro monitor blasting requires the establishment of structural connections between the input and output parameters, the choice of controlled parameters, control effects, the development of the structure of the automation system and the selection of modern technical means of automation. Guiding influences with hydro-monitor blasting are the pressure and flow of water, the speed of movement of the stream along the side of the face and the hydro monitor rotation angle, the telescope hydro monitor sections in the face feeding [26-29].

The complexity and conditions for carrying out the technological process of underground hydrodestry create problems of operational control of technological parameters. The control of the process of hydro-monitor blasting will be carried out on the basis of the control of the distance between the nozzle of the hydro monitor and the rock of the face and the rate of blasting of the rock. The control over resizing camera also provides information on the performance of the blasting process.

The following algorithm of system operation is offered. The signal from the distance sensor enters the controller, which, by changing the distance in time, calculates the blasting rate and gives the control signal according to the proportional-integral-differential law for the frequency converter and thus changes the pressure of the water in the hydro monitor, which causes the change in the rate of blasting. When reaching a certain distance between the wall of the face and the nozzle of the hydro monitor, the controller gives a signal to the next section of the hydro monitor. Using a telescopic hydro monitor allows you to increase the size of the chamber without the use of high-pressure working agent. After pushing the last section of the hydro monitor, the pressure is increased to the maximum possible. To maintain a constant linear velocity of the stream on the wall of the face, a frequency-regulated drive is used to wipe the hydro monitor around the axis. With increasing distance from the nozzle of the hydro in the face of the wall, the linear velocity of the stream along the face of the face will increase, so the controller gives the control signal according to the proportional integral law to the frequency converter and reduces the angular speed of the hydro monitor. After completion of the blasting at a certain depth the controller gives a signal about the need to change the position of the hydro monitor in height [28, 29].

While designing modern complex automation systems for technological processes with the use of complex logic and management laws, it is advisable to simulate these systems at the design stage. The Simulink software package from MatLab MathSoft package is one of the most powerful simulation tools. Simulation Simulink-model of the system of control of hydro monitor blasting in the case of borehole-drilled hydromining of tuffs is shown in рис. 6.

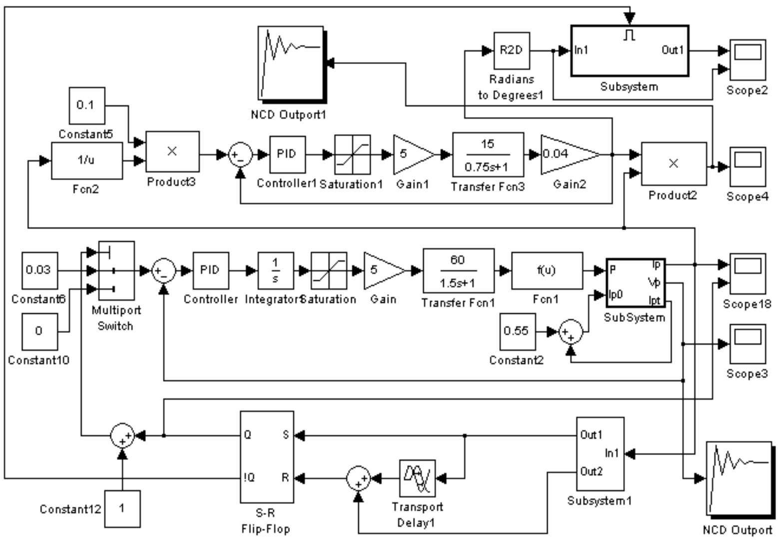

Рис. 6. Structural diagram of the system of control of hydro monitor blasting

The simulation of the control system for hydro-monitor blasting during borehole mining hydro production of minerals will allow to construct and investigate the logic of process control, to select the necessary control laws, and to search for optimal adjustments of the regulators [30, 31].

The simulation model of the control object is shown in рис. 7.

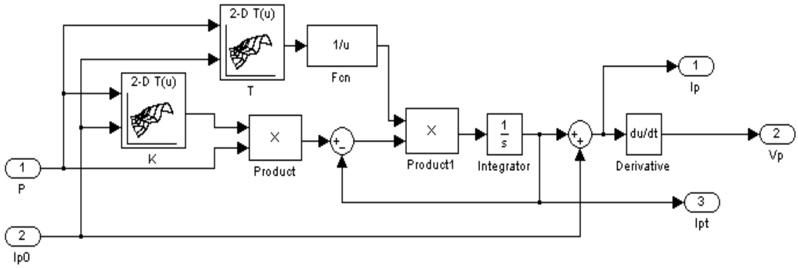

Рис. 7. The simulation object model

The blocks of approximation of the function of two variables *K* and *T* serve to automatically calculate the transfer coefficients of the object and the time constant. Experimental data arrays are introduced into blocks, on the basis of which interpolation and extrapolation by linear or cubic splines are carried out.

The result of the modeling of the control system is the transient characteristics and schedules of the switching of the technological modes of operation, taken at the rate of 0,03 m/s blasting and when setting the speed control with coefficients K_p=30, K_i=4, K_d=25; the task of the regulator of the speed of the stream along the wall of the face 0,1 m/s and the settings K_p=3,3, K_i=5,75. Finding the settings of the controllers was carried out using the parametric optimization blocks NCD Outport and NCD Outport1 from the Simulink library. The transition characteristics of the system along the width of the blasting (рис. 8,*а*) shows the dynamics of the change in the width of the l_P, and the corresponding graph (рис. 8*б*) - the control of the feeding of sections of the telescopic hydro monitor. The length of the signal for pushing the section of the hydro monitor is given in the Transport Delay1 block. In рис. 8,*в* the dynamics of the angular velocity change of the device of rotation of the hydro monitor, and in pic. 8*г* - schedule of change of direction of rotation of the hydro monitor.

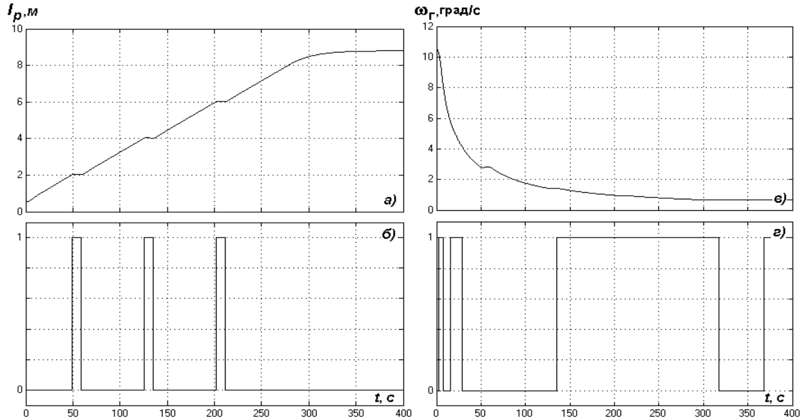

Рис. 8. Transient characteristics of the system: *а* - the range of erosion; *б* - control of the feeding of sections of telescopic hydro-motors; *в* - at the angular velocity of the hydro monitor; *г*) control of the direction of rotation of the hydro monitor

In pic. 9 shows the transition characteristics of the system at the rate of blasting (*а*) and the speed of movement of the stream along the wall of the face (*б*). Transient characteristics show that the system is stable and has the necessary dynamic characteristics and indicators of the quality of transients

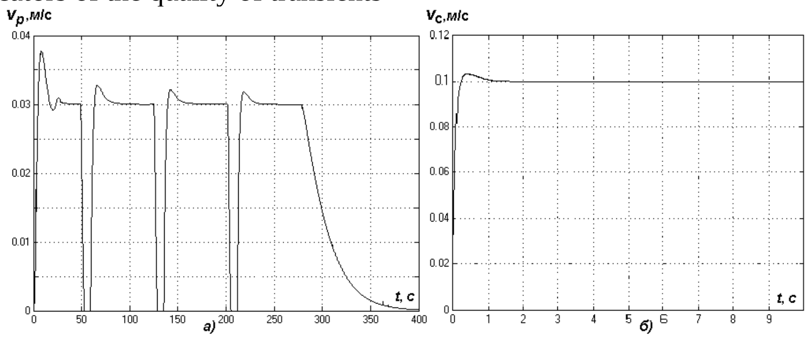

Рис. 9. Transient characteristics of the system: *а* - at the rate of erosion; *б* - at the speed of movement of the stream along the wall of the face

The given simulation model of the control system of the technological process of extraction of zeolite-smectite tuffs is used in the design and calculation of control systems for the process of hydro monitor blasting and is the basis for the construction of flexible control systems that will allow them to be used for extraction of various minerals.

Conclusions.

The conducted researches have established that the most suitable for hydromining are the tuffs of the Rafal node, namely, modification zeolite-smectite varieties with content of more than 50% of smectite components . Porosity of the dispersed tuff material for these varieties of the rock reaches about 30%; swelling in water - 36%, and in the presence of a coagulant - 62%. Water absorption by weight is about 18% and by volume - 33%.

It is proved that with increasing the diameter of the nozzle and water pressure, the radius of the hydro monitor blasting of the tuffs is increased and the productivity increases with exponential laws. The dependence of energy consumption on the size of the nozzle of the hydro monitor and the pressure of the working agent is quadratic: with increasing pressure of the working agent before the nozzle, the energy intensity of erosion increases, and the specific flow of water decreases. In order to prevent the formation of rubbish and increase the efficiency of tuff extraction, at a distance of up to 6 m from the jumper tip, the angle of inclination of the stream to the surface of the erosion must not exceed 5-7˚. At the same time, the flow rate of the stream on the face is limited to 1,4 m/s, and the height of the face when blasting through the nozzles in diameter 25...35 mm should not exceed 20 cm.

For automated control of the technological process of extraction of zeolite-smectite tuffs, Simulink-model of the system of control of the hydro monitor blasting based on the control of speed and range of blasting was constructed. The result of the system simulation is the dynamic characteristics of the system in the transition modes and the diagram of switching states of the system. Realization of this system in practice will provide high technical and economic indicators of the process of hydro-monitor erosion.

References

1. **Маланчук З.Р., Стець С.Є., Маланчук Є.З., Жомирук Р.В.**, та ін. Технологія і керування гідровидобутком корисних копалин. Монографія за загальною ред. д.т.н., проф. З.Р. Маланчука. Рівне: НУВГП, 2009. - 480 с.

2. Physico-Mechanical and Chemical Characteristics of Amber / **Z. Malanchuk, V. Moshynskyi, Y. Malanchuk, V. Korniienko**. Non-Traditional Technologies in the Mining Industry. Trans Tech Publications Inc. Solid State Phenomena (Volume 277), 2018, pp. 80-89 doi: https://doi.org/10.4028/www.scientific.net/SSP.277

3. Substantiation into Mass and Heat Balance for Underground Coal Gasification in Faulting Zones / **Lozynskyi V., Saik P., Petlovanyi M., Malanchuk Z., Malanchuk Y.** Inzynieria Mineralna. Journal of the Polish Mineral Engineering Society. 2018. p. 289-300. DOI: 10.29227/IM-2018-02-36

4. **Маланчук Є.З. Жомирук Р.В. Стець С.Є. Швагер Н.Ю. Калиниченко В.А.** Розробка системи автоматичного управління свердловинним гідровидобутком туфів. Науково технічний збірник «Розробка рудних родовищ». – Кривий Ріг: КТУ.-2011 – Вип. № 94.-С. 94-98.

5. Analysis of the existent technologies of amber mining. **Korniyenko V.Ya., Malanchuk E.Z., Soroka V.S., Khrystyuk A.O.** Resources and resource-saving technologies in mineral mining and processing. Multi-authored monograph. – Petroșani, Romania: UNIVERSITAS Publishing, 2018. - 363 p., pp. 209-232.

6. Механіка гірських порід. Лабораторний практикум. Навчальний посібник. **З.Р. Маланчук, В.О. Козяр, А.М. Поліщук**. - Рівне: НУВГП, 2016. С.188

7. Спеціальні технології видобутку корисних копалин. **Маланчук З.Р. Маланчук Є.З. Корнієнко В.Я.** Навчальний посібник – Рівне: НУВГП, 2017, С. 290.

8. Транспортні системи гірничих підприємств. **З.Р. Маланчук В.Я. Корнієнко В.С. Сорока, О.Ю. Васильчук.** Навчальний посібник – Рівне: НУВГП, 2018, С. 190.

9. **Маланчук Є.З. Жомирук Р.В. Стець С.Є.** Оптимізація параметрів автоматизованого комплексу геотехнологічного дослідження родовища. Зб. наук. пр. „Геотехнічна механіка”. – Дніпропетровськ: ІГТМ НАНУ. – 2011 – Вип. № 92.-С.217 – 223.

10. Modeling of the disjunctive geological fault influence on the exploitation boreholes stability during underground coal gasification / **Dychkovskyi R.O., Lozynskyi V.H., Saik P.B., Petlovanyi M.V., Malanchuk Ye.Z., Malanchuk Z.R.** Journal Archives of Civil and Mechanical Engineering. 2018. - 18(4), p. 1183-1197. https://doi.org/10.1016/j.acme.2018.01.012https://authors.elsevier.com/a/1WspB5s1QS-PtW https://www.sciencedirect.com/science/article/pii/S1644966518300128

11. Principles of rock pressure energy usage during underground mining of deposits. / **Khomenko O.Ye., Sudakov A.K., Malanchuk Z.R., Malanchuk Ye.Z.** Scientific Bulletin of National Mining University/ Scientific and technical journal. Dnipro. Ukraine, PP KF «Gerda». №2(158). 2017. – p. 34-43.ISSN 2071-2227 UDC 622.831.24.0010

12. Examining features of the process of heavy metals distribution in technogenic placers at hydraulic mining / **Z. Malanchuk, Ye. Malanchuk, V. Korniyenko, I. Ignatyuk** // Eastern – European Journal of Enterprise Technologies / PC «Technology Center», Kharkiv, Ukraine, - 2017. - № 1(10). - p. 45-51. Режим доступу: http://nbuv.gov.ua/UJRN/Vejpte_2017_1(10)__7.

13. **Маланчук Є.З. Жомирук Р.В. Стець С.Є.** Використання методу Fuzzy Logic для керування процесом свердловинного гідровидобутку туфу**.** Тези міжнародної конференції ”Эффективность реализации научного, ресурсного и пром. потенциала ”, п. Славське, Карпати, 2011., С.165-167.

14. Modeling the process of hydromechanical amber extraction / **Malanchuk Y., Moshynskyi V., Korniienko V., Malanchuk Z**. E3S Web Conf. Volume 60, 2018. p. 1-8 Ukrainian School of Mining Engineeri. https://doi.org/10.1051/e3sconf/20186000005.

15. Research results proving the dependence of the copper concentrate amount recovered from basalt raw material on the electric separator deposit intensity. / **Naduty V, Malanchuk Z., Malanchuk E., Korniienko V.** Eastern – European Journal of Enterprise Technologies / PC «Technology Center», Kharkiv, Ukraine, Volume 5/5(83),– 2016, p. 19-24. ISSN 1729-3774, UDC 622.277 DOI: 10.15587/1729-4061.2016.79524

16. Results of experimental studies of amber extraction by hydromechanical method in Ukraine. / **Malanchuk Z., Korniienko V., Malanchuk E., Khrystiuk A.** Eastern – European Journal of Enterprise Technologies / PC «Technology Center», Kharkiv, Ukraine, Volume 3/10(81),– 2016, p. 24-28. ISSN 1729-3774, UDC 622.232.5:622.2 DOI: 10.15587/1729-4061.2016.72404

17. Modeling of vibro screening at fine classification of metallic basalt / **V. Naduty, Z. Malanchuk, E. Malanchuk, V. Y. Korniyenko** // Theoretical and Practical Solutions of Mineral Resources Mining, 2015. – P. 441–443. doi: 10.1201/b19901-77

18. Revisiting the underground gasification of coal reserves from contiguous seams. / **Saik P.B., Dychkovskyi R.O., Lozynskyi V.H., Malanchuk Z.R., Malanchuk Ye.Z.** New Developments in Mining Engineering 2015: Theoretical and Practical Solutions of Mineral Resources Mining. №6. P. 60-66. ISSN 2071-2227

19. Modeling the formation of high metal concentration zones in man-made deposits. / **Z. Malanchuk, V. Korniienko, Ye. Malanchuk, V. Soroka, O. Vasylchuk.** Mining of Mineral Deposits, 12(2), 2018, p. 76-84. https://doi.org/10.15407/mining12.02.076.

20. **Malanchuk Z., Korniienko V., Malanchuk Y.** Results of research into amber mining by hydromechanical method. Mining Of Mineral Deposits. V.: 11 (1) p. 93-99. DOI: 10.15407/mining11.01.093

21. The results of magnetic separation use in ore processing of metalliferous raw basalt of volyn region. /**Malanchuk Y., Malanchuk Z., Korniienko V., Gromachenko S**. Mining Of Mineral Deposits. V. 10 (3) p. 77-83. DOI: 10.15407/mining10.03.077

22. Regularities of hydromechanical amber extraction from sandy deposits. Ye. **Malanchuk, V. Korniienko, V. Moshynskyi, V. Soroka, A. Khrystyuk, Z.**

Malanchuk. (2019). Mining of Mineral Deposits, 13(1), p. 49-57. http://mining.in.ua/2019vol13_1_6.html

23. Current status and problems of new technologies for coal mining in the western region Ukraine. / **Malanchuk Z., Zaiets V., Vasylchuk O.,Novak A.** Resources and resource-saving technologies in mineral mining and processing. Multi-authored monograph. – Petroșani, Romania: UNIVERSITAS Publishing, 2018. – P. 54-77.

24. Modern geotechnical methods of management of the process of amber extraction. **Malanchuk E.Z. Malanchuk Z.R. Korniyenko V.Ya**. Monograph: "Innovative development of resource-saving technologies of mining of minerals" "St. Ivan Rilsky" Mining and Mining University of Geology (Sofia, Bulgaria), 2018, - 439p., pp. 80-103.

25. Efficiency of using magnetic separation for the processing of metal-containing basalt raw materials. Topical issues of resource-saving technologies in mineral mining and processing. **Malanchuk E.Z. Malanchuk Z.R. Korniyenko V.Ya**. Multi-authored monograph. – Petroșani, Romania: UNIVERSITAS Publishing, 2018. – 270 p., pp.65-89.

26. **Древецький В.В. Стець С.Є.** Спеціальні вимірювання і прилади. Навчальний посібник. – Рівне: НУВГП, 2012. - 288с.

27. **Malanchuk Z., Malanchuk Y., Khrystiuk A.** Mathematical modeling of hydraulic mining from placer deposits of minerals. Mining of mineral deposits. V. 10 (2). p. 18-24. DOI: 10.15407/mining10.02.013

28. **Стець С.Є. Маланчук Є.З. Труш М.П.** Дослідження автоматизованої системи теплового неруйнівного контролю обертової печі. Вісник Інженерної академії наук. Київ 2013, Вип.№3-4.-С.121-126

29. **Стець С.Є. Ганжа О.О**. Моделювання автоматизованого процесу видалення водню з продувних газів синтезу аміаку. Теоретичний і науково-практичний журнал інженерної академії України. - Київ. Вісник ІАУ. – 2012 - Випуск №1. – С. 265-270.

30. **Стець С.Є. Стадник В.С. Стець Н.В.** Система екстремального автоматичного керування процесом дроблення руди з використанням економічного критерію. Зб. наук. пр. Вісник НУВГП. - Рівне: НУВГП.-2016.- Вип.№ 3 .(75).- С. 335-344.

31. **Стець С.Є. Маланчук Є.З. Прокопюк О.М.** Математичне моделювання процесу розкладки мідевмісної гірської породи. Вісник НУВГП. Зб. наук. пр. Випуск 4 (48). Рівне.-2010.- С. 216 – 224.

BOTTLENECKS IN MANAGEMENT OF DEVELOPMENT OF RESOURCE-SAVING TECHNOLOGIES AT MINING AND PROCESSING OF USEFUL RESOURCES

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Abstract.

Mining technologies and processing of useful resources are considered as complex system with the basic principles and adaptive cycle of development. The algorithm of management of bottlenecks in development of the system and its modernization is developed and include definition of the purpose of innovation application, identification of bottleneck, analysis of bottleneck, submission of solutions to the problem of bottleneck, "expansion" of bottleneck, iteration of procedures etc. It is shown that management of the systems of mining and processing technologies under conditions of uncertainty should provide: observation of the states and degrees of possibilities of these states; definition of states that are impossible in accordance with additional information; prediction of states that are not observed, but principally are possible. It is concluded that taking into account the "bottlenecks" in implementing the latest technologies of management of the systems helps to avoid their creation during the development of new systems, as well as in case of modernization of the existing ones.

Introduction. System of mining technologies and processing of useful resources (SMTPUR) is the complex system, which is influenced by both internal (technical, economic, social and environmental) and external (structural limitations, external debt, global environmental problems) factors. Therefore, it is important to consider the system in the context of complex systems that can be developed.

Today, the methods of analysis of complex systems are widely used, mainly on technical, economic and environmental systems [1]. Moreover it comes to systems that are described or based on deterministic functions, or using methods of mathematical statistics. SMTPUR as a complex system includes components of technical, economic, social, and environmental systems, which usually difficult to formalize and are described at level of linguistic terms (concepts) for the most part.

Analysis of the complex system of SMTPUR should adhere to basic principles:

Simplification (to reasonable limits) of processes and structures for their adequate understanding;

Their consideration at dynamics and for perspective;

Taking into account the possibility of ambiguity and unpredictability;

Understanding of system as a hierarchical structure that is able to adaptation and development.

For the formation of adaptive cycle of development (model of system) the three main characteristics should be considered:

Inherent potential of the system, which includes the necessary changes in case of need (***resource***);

Internal control (***connectedness***) of the system, i.e. the degree of connectedness between internal processes and controlled variables (a measure that reflects the degree of flexibility or rigidity of control sensitivity or insensitivity to disturbances);

Adaptability, ***resilience*** of the system (a measure of vulnerability relatively to unexpected or unpredictable stress).

While resource increases at the same time with the growth of connectedness it can be considered that the model is functioning adequately. Upon reaching the "saturation", i.e. after the process will almost without increment of resource system may for a long time to perform its functions as conservative feedback system controlling only resource, rather a sign of its increment. If in a certain point of trajectory it appears that resource increment is negative, i.e. efficiency of system decreases, it becomes a signal of need for local innovation cycle with one subsystem, where efficiency is the lowest. This cycle causes a need to resource consumption for reorganization and adaptation, after which system can reach a higher level in terms of both resources and connectivity. Such local cycles may occur from time to time and the cost of their implementation can be considered as an expense for depreciation. Their realization will lead to more effective and long normal operation of the system.

Consideration of SMTPUR system and its components as fractal structures functioning in the background of "chaos", allows, on the one hand, to understand the processes and relationships, and on the other - to identify limiting the limits within which these processes and relationships may exist.

Management of SMTPUR when implementing methods of technologies intensification are associated with the following difficulties:

- It's considered a lot of parameters that characterize the process;
- There is no analytical relationship between the parameters of the process and reason of decrease the efficiency of the process. Determining this dependence is complicated by the large number of parameters of diversity and their characteristics: it can be quantitative characteristics, quality, binary (is present / is absent), etc.;
- There are no database parameters of SMTPUR with verifiable information on the causes of reduction of the efficiency of technology and database of features of development of mining and processing, which can identify the process.

Effective management of mining and processing enterprise is associated with problems of decision making on the implementation of technologies, which improve the quality. Methodology of decision making on the abovementioned problems can be developed on base of Bayesian approach, logic programming, decision trees, the nearest neighbor methods, and the use of fuzzy logic.

The use of comparative data analysis of "nearest neighbors" provides not only clarifying the features of the process, but also helps to identify the true causes of changes in parameters and their mutual influence. To verify the features of the process it should be considered the raw data on which the annual averaging was done in order to identify the behavior of "nearest neighbors" and the correlation between different parameters of the process.

Information about the current quality of the process is not clear, because only separate control parameters are analyzed. At the same time separate probes analysis needs enough long time to implement, that effects on obtained information reliability. Moreover, there are no enough reliable monitoring data at SMTPUR. All these demonstrate ineffectiveness of determinated methods of analysis.

Methods of fuzzy theory and theory of abilities use instead of determinate functions, which connect between themselves input data, variables, outside factors and parameters with outputs, functions of belonging etc. Theory of fuzzy sets may be used for estimation of effectiveness of development and intensification of SMTPUR and for developing heuristics, which would improve the use of rational method of increase of facilities effectiveness with simultaneous capitals minimizing and maximizing of environment safety.

Thus decision making about implementation of additional procedures of increase of effectiveness of mining and processing of resourses demands expert estimation of belonging functions of separate linguistic variables with taking into account such data as daily and average (monthly, yearly): speed of productivity of process or equipment taking into account the amount of income parameters and their quality; process characteristics etc.

Hierarhy principle of the main parameters allows to take off so named "curse of dimensionality", connected with difficulty of development of system at in- and output with great amount of state parameters. It's connected with people's ability to remember operatively simultaneously up to 10 characteristics. That's why it's desirable to develop hierarchy classification of parameters of state with conclusion tree build, which will determine system of input one-by-one parameters of less size.

Hierarchy principle allows to take into account a lot of parameters of state of system and new states that appear later. At the same time the rules become easier and their amount is decrease by this principle.

According to the principle of three variants estimation of parameters of state the observed parameter is estimated by one of the variants: quantities data, linguistic characteristics or by thermometer principle. Parameter is estimated by possibility of quantities estimation of parameter of state and presence of instrumental facilities of measuring.

To project the intellectual part of management of SMTPUR quality it's necessary to know: range of possible causes of process effectiveness decrease; tree of fuzzy conclusion; base of fuzzy rules *IF* {…},*THEN* {…}; educating choosing.

Decrease of functioning quality of SMTPUR is a result of troubles of processes - bottlenecks. Reasons of decrease of effectiveness of functioning may be classified by certain way. Such classification should be maximally deep for the earliest stages of determination of mistakes of equipment functioning while operating visual information or obtained is not always exact by express-determinations. Necessary reliability of analysis of process effectiveness reduce may be obtained by detailed laboratory measuring and calculations. Determination of class of reasons at the earliest stages of diagnostics allows to deal with certain problem with more detail decreasing time and forces for determination of reason of process quality decrease.

The algorithm of management of bottlenecks in development of SMTPUR includes the next (Fig. 1):

Step 1. ***Clear definition of the purpose*** of innovation application: what important (unique) features will characterize it, what is the cost of a system, who will exploit it and who will benefit from the operation of the system, what is the value of these expected results?
This requires the selection of the parameter for evaluation of the effectiveness of implementation. It may be capacity, performance, special product characteristics (sustainability etc.) or more universal indicator - "effectiveness/cost".

Step 2. ***Identification of bottlenecks*** of system that is proposed, as such, for example, indicators as productivity, are determined by their bottlenecks. Chain may always have a weak link, so all attention should be paid to "strengthening" of the link. To identify bottleneck the following situations may be as signs of it.

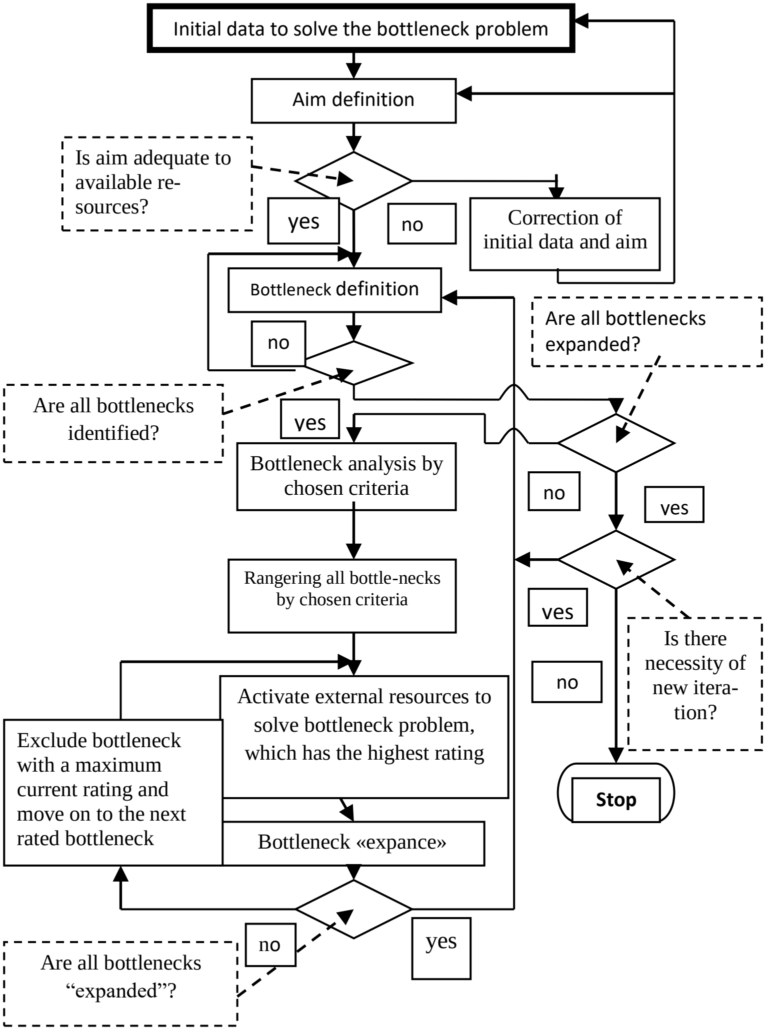

Fig. 1. Algorithm of SMTPUR bottleneck management

Maximum load level, although this is not always a sign of a bottleneck on which the problem could be found (sometimes even system is optimizing on the basis of the maximum load of all resources). Availability of nodes which receive flows of information, materials, finished goods, vehicles and so on.

The presence of downtimes of equipment, subsystems, vehicles, etc. in a locked technological process.

If there are obvious signs of one or more bottlenecks, it indicates that the system designers should look at the system through the eyes of those who use it and should make some adjustments to documentation.

Step 3. ***Analysis of bottleneck***: if productivity or capacity of the system is determined by the capacity of bottleneck, it's necessary; above all, to increase its performance; if it is a downtime of the bottleneck, it's necessary to analise its causes and to remove or minimize them. The next should be realized for that:

Remove any nonessential additional work (operations) which may be translated into other parts of the system.

Eliminate or limit interruptions. Eliminate obstacles.

Insure the bottleneck work in a stable mode.

Ensure the use of quality materials and capital goods.

Ensure prioritization of tasks for the bottleneck that it always services the highest priority tasks.

Provide with sufficient information the developers about the necessary improvement of the system, and the head of the development team must accept, classify and prioritize requests and messages, and fixing of errors needs in case of the next mistakes are activated to provide a good balance between the activities of developers working on the next iteration (improvement of the system on the basis of comments received earlier), and a sense of duty system problems. It should be understood that it is impossible to estrange the developers from such useful information as customer requirements, system performance changes (replacement) of equipment or process units, user reviews.

It is necessary to start from the analysis of bottlenecks because this step of improvement of the system is relatively easy: it does not require much funds or investments and requires only one resource.

Step 4. ***Submission*** of every other solution to the problem of bottleneck. All the resources which are not, by definition, the bottleneck resources, should be considered as a reserve, that in case of necessity can be directed to support bottleneck. Submission can be done as follows:

Movement of less meaningful work of bottleneck on other parts of system.

All parts of the system should work in accordance with the bottleneck mode: no faster or slower to avoid overloading the bottleneck in the future.

Buffer of works at entrance of bottleneck must always be more or less full.

At the exit of botlleneck there should be a buffer to ensure stable operation of the system in case of variations at the output of bottleneck.

All parts of the system must apply for bottleneck entry quality only (certified) signals, goods, raw materials and so on.

Special development team should be completely subordinated to solve problems in the bottleneck that arises: in case of any questions, demands, problems connected with the performance or latency, an urgent need to focus on these issues.

A customer should participate in testing a system to promptly inform developers about their suggestions and comments to improve the system.

A customer's on-site supervisor and a special development team should prepare a new iteration of improvements with the aim to hold always a special team the developers in the "form".

Thus, subordination - is the easy process: it does not require much funds or investments and requires little resources, especially those that directly interact with bottleneck. But there is also one aspect of submission: while the bottleneck resources should be fully used, other resources should have reserve of time to support bottleneck in the case of variations at its output.

Step 5. ***"Expansion" of bottleneck***. This step most managers intuitively make the first: an increasing number of workers, machinery, equipment, and training and control procedures. But this step should be done when most of the "free" improving procedures introduced in the previous steps, is implemented. Then they apply to the following measures:

Increase number and quality of performers working in parallel;

Implementation of different methods of training and more careful control of the personnel and equipment;

Use of improved means and methods of production, more high-speed machinery, more efficient methods and tools for information processing, etc.;

Implementation of more efficient technologies.

"Expansion" of bottleneck in contrast to the first steps requires significant investment. In addition, the implementation of improvements at this stage is dangerous, because most of these "improvements" requires some time to get results and, under certain conditions, on the initial stage of "improvement" may even lead to negative results before it gives the desired "improvement". For example, increasing the number of performer’s speed of work may be reduced while new performers will not take the experience and will be not in the rhythm of coordinated team.

Step 6. ***Return to Step 1***, i.e. the next iteration of all of the above procedures. When we take a step to improve and get a positive result, we start all things from the beginning. The team gathered to solve the bottleneck problem, better and faster repeats the procedure of bottleneck "expansion" and provides more information for system developers. This happens (should happen) while implementing new systems. But in case of optimization of existing systems or upgrading the above steps are valid so as:

The main purpose of optimization whether upgrading and risks associated with their implementation are determined;

Bottlenecks of the current system are identified and analyzed, each of which is characterized by a general contribution to the deterioration of the system, means for its removal, the time needed to implement the removal, effects on other parts of the system, the impact on the future development of the system and so on and priority;

All decisions that are not directly related to the bottleneck are subject to solve the bottleneck problem.

As it is well-known, information cannot be considered without considering any situations of uncertainty. The system of mining technologies and processing of useful resources is a classic model of the system which works in conditions of uncertainty, because its states are determined, as a rule, not in real time, as the external disturbing factor; there is a dense but ambiguous connection between external factors and also with a considerable time lag between events and changes in the system state. Management of such system should provide: observation of the states and degrees of possibilities of these states; definition of states that are impossible in accordance with additional information; prediction of states that are not observed, but principally are possible.

The main tasks of observation of SMTPUR are as follows:

collection of data that directly characterize the state of the system;

comparison of new collected data with relevant data collected at the same points during the previous data acquisition cycle in order to detect the dynamics of the process and factors that could affect the state of the indicators;

analysis of the reliability of the control data (evaluation of the methods used to characterize the data, and the means of data determination - measuring instruments, evaluation algorithms, etc.);

placement of data evaluated from the point of view of reliability, in the data bank indicating the coordinates of the place of receipt of data, dates and all related information;

analysis of data relevant to this system at certain time intervals and taking into account external factors in order to predict state changes;

elaboration of recommendations for measures aimed at stabilizing or improving the state of the system or improving the efficiency of the mining technology and processing operation.

There could be separated the general problems of observation and identification of the states of SMTPUR. Such system is a set of elements of a certain material nature, which are in the relationship. In each of these relations there is a certain variable, the set of its states, and the set of mathematical properties defined on this variable. It is known that if there is a finite sequence of relations that allows a predetermined element of the set $x_1 \in X$, and then such a sequence of relations is an effective identification process.

A system is considered to be observable if it can be determined by a certain multiple experiment, when the inputs of the system that is in an unknown state are fed into the set of inputs and then the corresponding output values are observed. The observation channel forms a measuring system that includes measurement devices and procedures that determine the rules for using devices in different conditions.

Reliability of data about the state of the system. The SMTPUR as a system that is exposed to external influences, some of them are poorly controlled or not defined (since assumptions about the properties of this usually avoid some of the essentially important components, less formal objects are taken into account than is necessary, etc.), and is observed only in a limited number of points, can be regarded as an open system, for which there is a characteristic presence of at least one element of a set for which there is no effective identification process, and a decision regarding the state of the system of whim accept the conditions of uncertainty. Uncertainty arises also in those cases where the conditions of the technological process are evaluated within the area of the process control channel or at the boundary that divide the two specific states. By the way, the controlling zones of the channels do not have clear boundaries, and the results of observation near these fuzzy, blurred boundaries can be characterized only by degrees of membership, and not by clearly defined functions.

In both cases, the uncertainty of the results of the observation leads to unreliability of the assessments of the state of the process. Such a falsehood is characterized by the value inverse to the membership function. That is, the inverse relationship between the degrees of affiliation of an element to a given set from a certain base variable and the rules used or metrics [2-3]

$$d(x_m, x_r) = ((n-1) - \sum_{i=1}^{n} (x_{mi} - x_{ri})^2)1/2,$$

that evaluates the degree of proximity of model estimates (predictions) of signal values (state parameters) x_m, or their distributions to the real values of these signals x_r. Here, as a model estimates, we understand not only the results of the actual modeling (mathematical or physical), but also the data of measurements using the usual (nonstandard) means. Results of measurements using means at the output of which the quality of information is guaranteed are considered as real (true).

This corresponds to situations for which the "usual Euclidian distance" as the criterion of proximity (or discrepancy) is justified:

the observations are mutually independent and may have the same dispersion;

the components of the observation vector are homogeneous in their physical content and they are equally important in terms of their use during identification;

the sign space coincides with the geometric space and the notion of proximity of objects of observation coincides with the notion of geometric proximity in this space.

In practice, it is often more convenient to use a value that is a reverse metrics, a complement of a metrics, with the reliability (TW), and for a quantitative assessment of reliability, which is usually considered in the range [0, 1], to use the relative metrics

$$Dt(x_m, x_r) = \frac{d(x_m, x_r)}{d_{\max}(x_m, x_r)},$$

where $d_{\max}(x_m, x_r) \geq d(x_m, x_r)$ - the metrics value in which the causal relationship between x_m and x_r is not detected or insufficient to make responsible decisions [3].

The size of this metrics depends on the number of states of variables, on the measure by which the restrictions on the variables are set, and on a number of other factors. Considering the following generalized expression for $d_{\max}$

$$d_{\max}(x_m, x_r) = 2\delta\xi_{\max}(x_{mi}, x_{ri}),$$

where $\delta > 1$ - a certain proportionality factor which takes into account the degree of fuzziness of the observation channel data and which depends on its own characteristics of the channel and the degree of clarity of representations about the properties and behavior of the object (process); $\xi_{\max}$ - the maximum permissible value of the relative error of the simulation (forecast) or the permissible error of the integral estimates.

In the cases considered, authenticity is presented as an addition to the unit, i.e.

$$TW = 1 - d_r(x_m, x_r).$$

As a characteristic of reliability, one can also use the functions of modeling estimates for the true value, for example

$$TW = \exp[-(x_r - x_m)\ 2]\ \delta\text{-}2,$$

where δ - the fuzzy of the data, which should not exceed the measurement error by more than 1-2 orders [3-4].

Reliability is not the only characteristic of the quality of information. Information is also characterized by the following properties:

value, which is expressed in the form of increasing the probability of achieving the goal set, after receiving this information;

inactivity, that is, inequality of influence on the final result of the joint use of several information and the consistent use of the same information separately;

non-commutatively, that is, the dependence of influence on the final result of the order, which uses a series of information;

non-consistency, that is, the difference of results in the consistent use of a number of information, irrespective of the results, when part of this series is used sequentially in part, and part - as a result of the joint use;

completeness, that is, the degree of reflection of the real object (process) in the message;

reliability, that is, the degree of conformity of the models used or the data taken and the errors of their determination by the true value.

However, from all the properties listed above, authenticity – is the most important, since it directly affects the value of information and the ability to achieve the goal that is directly related to the effectiveness of the information system.

As reliable can be considered those data that have successfully passed the procedure of critical analysis and generalization of the results of measurements and / or calculations, taking into account known regularities that include the estimation of errors. Reliability can be considered in terms of formally technical (no hidden occasional errors) and socio-psychological or behavioral (lack of distortion due to improper interpretation or reluctance to open the truth). Distinguish also engineering reliability, that is, deterministic confidence in the truth of information, and statistical reliability, that is, reliability, which follows from statistical conclusions.

Errors leading to a reduction in reliability can be classified into three categories:

which do not directly lead to a decrease in the quality of the system's operation, but may, under adverse conditions or combination of such conditions, or in the presence of other similar errors, lower the quality of the functioning of the information system;

which lead to a slight decrease in quality under normal conditions or to a significant one - under adverse conditions;

which lead to a sharp deterioration in quality.

Reliability is the function of the state of any system, to which one or another extent is affected by various factors: random obstacles and noises, environment conditions, aging processes that change the characteristics of the components of the system hardware, the degree of load (overload), the volume of prior knowledge of object or process, etc.

The nature of the errors that are present or periodically occurring in the process of functioning of the information system is different. There are several groups of errors that do not depend on technical parameters of system. The first ones include:

methodological errors that are caused by the imperfection of mathematical models that underline the functioning of the system: the inadequacy of the adopted model for a real object or process in statics or dynamics; lack of a priori information about the nature of the object, or about the processes taking place; fuzzy connections and functional dependencies; attempts to simplify models due to the technical impossibility or complexity of taking into account individual parameters; the impossibility of an objective justification for choosing an optimal model in the presence of a set of quasi-equivalent models;

methodological ones, which are caused by the imperfection of the chosen methods of calculation, that is, the errors of numerical methods, approximation, errors, which are caused by a limited number of iterations, etc.;

output, that is, errors which are caused by inaccuracy of the initial data, statistical fluctuations of processes and interactions, interferences and distortions in the communication channels, errors of the operator, limited redundancy of the information necessary for statistical processing, etc.

The second group has instrumental errors, which, in turn, are divided into component errors, structure, interface and processing. The errors of individual components and system nodes are due to the drift of their characteristics under the influence of external factors and aging processes, the unessential characteristics, the effect of noise and interference, and so on. Structural errors are characterized by the finiteness of the bit representation of real numbers due to the constraints due to the finiteness (for each particular system) of bits of processors, memory, channels, converters and peripheral equipment, which forces to refer to the procedures for representing numbers by a limited number of significant senior discharges and, accordingly, to rounding off or rejecting the rest (junior) digits.

Interface errors are due to the fact that, when docking various technical means with each other, the accuracy of the representation of data is limited by the possibility of means, which has the slightest accuracy, that is, the smallest bit. In addition, they include errors that arise due to time or phase shift, as well as during human interaction with the system (errors when entering data into the system using a keyboard, oral or written sentence, errors during the preparation of intermediate storage media etc).

Processing errors are the most branched class of error, which is characterized by noise and interference, temporary hardware failures and self-abandoned failures, distortion of information during conflict situations, violation of the sequence and (or) loss of particular pieces of data or their duplication, overflow of memory, overloading channels or processors, by cycling programs, etc. A separate group of processing errors consists of integral errors that are associated with the accumulation of errors in individual steps of multi-step processes of information processing, when as a result of a systematic (methodological) error caused by an unrealized data processing algorithm from step to step, information that is not significant is lost at one step, but it is important if it breaks up at a number of processing intervals. In addition, the accumulation of error is possible due to the systematic overflow of registers and other buffer storage devices, as well as (with the use of adaptive data sampling methods) due to the deviation of the true laws of the distribution of random events from those used as working hypotheses and the rejection of data with low (supposed) priority.

The third group includes project errors that are due to syntactic and semantic errors, made during application programming, system programming errors, system developer errors, operator errors due to fuzzy instructions, etc.

Methods for eliminating errors, and thus ways to ensure reliability, depend on the type of error, the requirements put forward to the system, the working conditions and the level of knowledge about processes and phenomena that can cause errors.

All this suggests that for the successful development and application of methods for improving observation and identifying the state of the process, it is necessary to research specific sources of unreliability of the process data, as well as sources of unreliability of the integral estimates of the state of the system.

Sources of unreliability of data on the status of SMTPUR include:

data detectors (indicators in a form that is acceptable for display, communication with channels, storage and documentation);

measuring networks (it is economically inexpedient, and sometimes physically impossible to perform measurements at any point in the system, so large areas remain uncontrolled, and data about their conditions are obtained by interpolation based on data obtained at separate points - nodes of the measuring network, and so the reliability of the data on the state of the process is the function of the density of the measurement network and selected interpolation procedures);

the influence of external factors and time.

Existing methods for increasing the reliability of the results of observation and identification of states use mainly two approaches:

passive, when using a number of design solutions that objectively contribute to increasing the reliability of data, but the evaluation of actual results either is not implemented or is not used to improve the quality of information promptly;

active, when the actual state of the system and the actual results of data processing are evaluated continuously or periodically, and on the basis of these estimates, decisions are made to adjust the data, characteristics of the individual components of the systems, algorithms of their operation, or to decompose the systems in order to improve the quality and efficiency of their work.

Passive methods for improving observation and identification of system conditions are widely used. However, the lack of permanent control and prompt processing of the obtained results and the possibility of providing timely adequate corrective actions do not allow adapting such systems to changing operating conditions (internal and external), which reduces their effectiveness in the presence of strong obstacles, deviation of actual data (statistics) from calculation and degradation as separate components of systems and systems as a whole.

Using of an active approach, a huge role is played by control, all the variety of procedures of which can be reduced to three types: syntactic, semantic, and pragmatic [4-5].

The task of syntactic control can be formulated as follows: collecting and evaluating information in order to decide on the legality (admissibility) of the state and structure of technical and software tools, as well as the format of individual elements of the message in general and in a particular situation in particular. The syntactic control has a formalized and, as a rule, deterministic character, and has the following varieties:

a statement of the fact of exceeding the allowable waiting time;

control of the number of words in the message;

control of the length of the time interval between the words of the message;

control of the form of pulse code;

correctness of discharges of synchronization;

number of digits in the data word;

correctness of the address of the subscriber in one of the words of the message;

parity control;

control of the word (byte) of the state of the technical means.

The task of semantic control is the analysis of consistency, logics, consistency of data, that is, meaningful evaluation of control data, which may have the following varieties:

output of data values received, permissible range;

exceeding the permissible deviation from the average value in the redundant data set;

unacceptable discrepancy between data received from functionally reserved devices;

the presence of the record "1" in the control levels of the equipment of the built-in control.

Pragmatic control aims to identify the value, availability, timeliness of data, impact of errors in individual data on performance of the system as a whole, the economic efficiency of data.

The realization of control tasks of SMTPUR (regardless of the type of control) is associated with decision-making processes. These procedures can be classified as follows:

in accordance with the nature of the decision to be made (the only choice from a limited number of alternatives; a unified assessment of the continuous field of possible solutions; the combination of the first two);

according to the nature of the observed quantity;

depending on the length of the observation interval.

By the technique of implementation methods of verification of reliability can be divided into the following groups: accounting, mathematical, introducing redundancy, logical, combined. Accounting methods include the following procedures: an account with the release of a known control result; calculation of checksums; calculation of records; checksum summary; control format; cross-checking; control count of rows and columns of matrices.

Mathematical methods use the following procedures:

mathematical modeling;

substitution in the output equation of the found roots with the subsequent solution and evaluation of the results;

implementation of additional links (including correlation);

detection of trends and displacements in measurements;

verification of limit values;

interpolation of missing data, with the assumption that the data locally represent a polynomial of a certain odd degree;

statistical forecasting;

filtration.

Methods of introducing redundancy use both procedural and informational redundancy. Procedural redundancy implies either multiple consecutive (or simultaneous - with the use of different technical means) solution of the problem with the same source data and, accordingly, the same algorithm with subsequent comparison of results and decision on their reliability, or simultaneous solution of the problem using several different algorithms (equivalent or different in accuracy and time of implementation), as well as a comparison of the results and the assessment of their reliability.

Using of information redundancy involves the following control options:

entering control digits into messages;

plurality of data sources instead of one with the following evaluation;

mediated data and a priori information;

feedback (demand for additional data).

Logical methods include:

meaningful checks (detection of those values that are logically incompatible with a priori knowledge about the plausible boundaries of the change of individual variables);

control over deviations (detecting significant deviations that are characteristics of hardware failures; detecting deviations that reflect the spread of characteristics due to fluctuations in technological factors; the detection of deviations that are a function of time, that is, due to the "aging" of technical means);

control of the given sequence of data;

control of "templates", that is, the justification of the use of members of a particular data array;

time control of task decision;

expert evaluation of the received data.

Combined methods are based on:

selective validation by re-processing the output data to obtain the final result (including alternative algorithms);

control examinations-tests (with verifications, i.e. pre-entered data);

selective assessment of the reliability of the results with the help of special control evaluation programs etc.

Under normal conditions of functioning of SMTPUR and under conditions of mutual influence of man-made and natural factors on the system, there is a number of problems - certain changes, there is a violation of the balance of various factors in the limited territories or and on a global scale. In all of the above cases, control of the state of the system and its dynamics and predicting the probable future problems (as well as their causes) is of utmost importance [4, 6].

Conclusions. Taking into account the "bottlenecks" in implementing the latest technologies of management of system of mining technologies and processing of useful resources helps to avoid their creation during the development of new systems, as well as in case of modernization of the existing ones. Use of fuzzy set theory with reliable limits determination, in which there are appropriate estimations of certain parameters, allows to insure optimal management of SMTPUR.

References

1. **Holling, C.S.** (2001). Understanding the Complexity of Economic, Ecological and Social Systems. Ecosystems. 4.

2. **Baranovskyi, O.M.** (2011). Content monitoring as a new trend in quantative evaluation of changes in social processes: materials science conf. “System Analysis and Information Technology”. Kyiv. Ukraine.

3. **Yeremeev, I.S.** (2008). Decision making under uncertainty during environmental monitoring: materials science conf. “System Analysis and Information Technology”. Kyiv. Ukraine.

4. **Yeremeev, I.S.** (2009). “Modeliuvannia ta prognozuvannia stanu dovkillia” (Modeling and forcasting of an environment). K.: DAJKG. 220.

5. **Belonogov, G.G.** (2004). “Kompiuternaia lingvistika i perspektivnyie informatcionnye technologii” (Komputer lingvistics and perspective informational technologies). M.: Russkii mir. 187.

6. **Eremeev, I.S. and Dychko, A.O. (**2016). “Problema neopredelennosti pri monitoringe okruzhaiushchei sredy” (Uncertainty problems in environmental monitoring procedures). Information Processing Systems. Vol. 6(143). 45-47.

STUDY ON THE ENRICHMENT OF POLYMETALLIC ORES OF THE DEPOSIT HANDIZA

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The work is devoted to the study of the material composition of ore samples and the development of an effective technology for enriching polymetallic ore from the Chinarsay deposit. The results of the study of the material composition of the ore based on spectral, chemical and rational and mineralogical analysis are presented. It has been established that lead, zinc and copper are the industrially valuable components of the ore, the contents of which are given. It is shown that ore minerals are in close intergrowth with nonmetallic - quartz, sericite, chlorite, carbonate, etc. It was noted that the studies were conducted in two directions: collective flotation of all ore minerals with further selection of the bulk concentrate for lead, zinc, copper and pyrite concentrates and direct collective selective flotation to obtain successively lead-copper, zinc and pyrite concentrates.

The following were used as reagents: collectors - butyl xanthate, butyl aeroflot; foaming agents - IM-68, T-92, cresol; environmental regulators - soda ash, liquid glass, zinc sulfate, sodium cyanide; activators - copper sulfate, sodium sulphide; activated carbon, sulfofugol, etc. On the basis of the experiments performed, the optimal flotation mode was chosen. With the selected mode, a relatively high recovery of all components into a collective concentrate of lead, zinc and copper was observed. For the separation of lead-copper concentrate, several variants of schemes and reagent modes were tested. As a result of enrichment, lead, zinc and copper concentrates were selected that meet the requirements of production and are recommended for use in the Almalyk Mining and Metallurgical Combine.

Key words: ore, material composition, research, flotation, analysis, valuable component, selection, concentrate.

Uzbekistan holds the leading place among the CIS countries in explored reserves of gold, copper, lead, uranium and other metals. Under the conditions of independence, the mining and metallurgical industry of the Republic faced a whole complex of complex problems. First of all, this is an increase in the requirements for environmental protection, an increase in the demand for non-ferrous metals, including copper and lead, a shortage of flotation reagents, requirements for the purity of the product produced, the problem of disposal of waste dumps, etc._In this aspect, the task of creating a rational and complex technology for processing technologically complex polymetallic ores is highly relevant. Improving the technology of enrichment of polymetallic ores and methods for the separation of collective concentrates makes it possible to significantly increase the production of copper, lead, rare and noble metals without large costs.

In this aspect, the task of creating a rational and complex technology for processing technologically complex polymetallic ores is highly relevant. Improving the technology of enrichment of polymetallic ores and methods for the separation of collective concentrates makes it possible to significantly increase the production of copper, lead, rare and noble metals without large costs.

Two commercial products, lead and zinc concentrates, are produced at the lead processing plant of the AGMK, which processes the ore from the Handiza deposit. The associated components (copper, silver, bismuth and cadmium) contained in processed ores are concentrated in commercial products and extracted to varying degrees in metallurgical processing. However, the extraction of copper from lead concentrate at a lead plant is associated with a decrease in plant productivity, loss of copper and lead, as well as significant consumption of energy and materials. In recent years, the copper content in the processed ores has significantly increased, which predetermines the production of commercial lead concentrate with a high copper content (from 2.5% to 5%). Increasing the copper content in commercial lead lead reduces its grade and cost when calculated with the consumer. Therefore, there is a need for the development of technology for the extraction of copper from lead concentrate by enrichment methods, and this determines the relevance of the problems posed.The aim of the research is to study the material composition and the development of cost-effective enrichment technology for polymetallic lead-zinc ores. The idea of the work is to use ammonium nitrate as a new effective lead mineral depressor in the separation of lead-copper concentrates by flotation.

Research methods

Samples of lead-zinc ores from the Handiza deposit were selected as the object of study. In the process of research, which was the content of this work, various reagents and laboratory facilities were used. Experiments on the enrichment of lead-zinc ores were carried out in laboratory flotation machines of the brand FM-1M and on pure minerals - FM-2M. Control copper flotation was carried out in FM-1M - with a 3 liter chamber. The cleaning operations (I, II, III, finishing operations of Cu concentrate) were carried out in FM-1M volume of 1 liter. Experiments on pure minerals were carried out in a flotation machine brand FM-2M, with a volume of 100 ml.

Lead gloss when preparing for flotation in the process of dry or wet grinding is quickly covered with a film of lead sulphate. To eliminate this film, the samples were treated for 1 hour with a 15% ammonium acetate solution at W: T = 10: 1, after which the solution was decanted and the operation was repeated with a new portion of ammonium acetate. Then the sample was washed six times (by decantation) with tap water and, finally, distilled water twice, after which we performed experiments with pure minerals.

There may be oxide films on the surface of chalcopyrite grains. To remove the last portion of chalcopyrite of a certain size, before the experiment, they were treated with 4% NaCl solution for 2 hours at W: S=20:1. then the solution was decanted, and the powder was washed first with water, then with tap water and distilled water, with alkalized soda water. For the experiments of flotation of pure minerals, we took samples of 0.5 g. Experiments were carried out in a more liquid pulp.

During the experiment, the foam was collected in a porcelain cup. After settling, the excess water was poured off, and the solid was washed into a small suspended filter with a glass funnel. The filter with the precipitate was dried and weighed. The mass of the frothy product was found by the difference between the mass of the filter and the precipitate and the clean filter. The extraction was calculated by weight of the foam and the original product.

An additional operation was introduced into the flowchart - to remove the copper concentrate and lead lead flotation. Contact with cyanide was carried out in an FM-1M flotation machine with a chamber volume of 3 liters.

The resulting products (main concentrate, control flotation concentrate, tails, and initial sample) were dried on an electric dryer, weighed on an analytical balance, cut, and various analyzes were performed according to a specific procedure.

For the preparation of an aqueous solution of ammonium nitrate, a 1-liter heat-resistant beaker, a thermometer, and a stirrer were used. The dissolution took place within 10-15 minutes at a temperature of 60°C, since at this temperature ammonium nitrate is completely dissolved. The prepared solution - ammonium nitrate can be stored and used in any conditions (the reagent does not decompose).

The most important methodological issue for the development of technology for complex processing of polymetallic ores and concentrates is the study of the material and mineralogical composition of the studied samples, the form of finding valuable components in them, the nature of their relationship with each other.

Study of the material composition of the ore sample

In the process of preparing the ore, average samples were taken to perform spectral, chemical, rational analyzes, as well as samples and average ore samples of 3-0 mm in size for mineralogical studies and particle size analyzes.

The results of the semi-qualitative spectral analysis of the ore sample are shown in Table 1.

Table 1

Results of semi-quantitative spectral analysis of the ore sample

Items	Content, %	Items	Content, %
Silicon	>1	Copper	0,3
Aluminum	>1	Lead	>1
Magnesium	0,3	Silver	0,003
Calcium	0,1	Antimony	0,01

Iron	>1	Zinc	>1
Manganese	0,01	Cadmium	0,01
Nickel	0,001	Gallium	0,001
Titanium	0,03	Beryllium	0,001
Vanadium	0,001	Strontium	0,01
Molybdenum	<0,001	Barium	0,03
Zirconium	0,003		

The results of chemical analysis of the average sample are placed in table 2. The specific gravity of the sample is -2.88 g/cm^3.

Table 2

Results of chemical analysis of an average ore sample

Components	Content, %	Components	Content, %
Silica	71,8	Zinc	2,54
Iron oxide (3+)	3,0	Copper	5,12
Iron oxide (2+)	1,8	Hydrocarbon oxide	0,6
Titanium oxide	0,1	$-H_2O_{hygro.}$	-
Manganese oxide	0,01	Sulfur total	0,8-$H_2O_{гигр}$.
Alumina	5,2	Sulfur oxide(6+)	6,0
Calcium oxide	0,2	Gold, $	-
Magnesium oxide	-	Silver, $	0,0
Potassium oxide	0,15	Zinc	40,0
Sodium oxide	0,08		

The results of the sieve analysis of samples of ore are given in table 3.

Table 3

Granulometric characteristics of the ore sample

Grain class, mm	Output, %	Content, %				Distribution,%			
		Pb	Zn	Cu	Pyrite sulfur	Pb	Zn	Cu	Pyrite sulfur
-3 +2,5	9,9	1,98	4,4	0,49	2,06	7,8	8,8	8,2	9,4
-3+1	54,0	2,72	4,8	0,53	1,84	59,0	52,7	49,2	45,9
-1+0,5	14,2	1,76	5,87	0,53	1,98	10,0	16,8	12,8	12,9
-0,5+0,25	7,4	2,27	4,6	0,61	2,47	6,7	6,9	7,7	8,4
-0,25+0,15	3,8	2,69	4,56	0,61	2,71	4,1	3,5	3,9	4,7
-0,15+0,1	2,8	2,38	5,04	0,73	3,25	2,7	2,9	3,4	4,2
-0,1+0,074	2,3	2,49	5,36	0,82	3,58	2,3	2,5	3,3	3,8
-0,074+0,044	3,0	4,14	6,96	1,47	6,34	5,0	4,2	7,5	8,7
-0,044+0,0	2,0	2,99	4,94	0,9	1,06	2,1	1,1	3,3	1,5
Ore	100	2,49	4,1	0,58	2,17	100	100	100	100

The studied ore sample is characterized by a simple complex of minerals that form them, but they are distinguished by a complex, extremely thin and close mutual germination of minerals among themselves, which, apparently, is a great difficulty in their separation.

Three minerals grow most closely together - galena, chalcopyrite and sphalerite. Ore minerals are in close intergrowth with non-metallic minerals - quartz, sericite, chlorite, carbonate, etc. Ore is not affected by the oxidation processes.

Conclusions on the study of the material composition:

Ore samples should be attributed to the type of disseminated polymetallic ore.

The sample has a copper content of 0.6%; lead -2,54%; zinc-5.12% and silver 40 g/t.

The size of impregnation of useful minerals from emulsion to several mm, their germination is extremely thin and close, especially glenit and sphalerite, sphalerite and chalcopyrite, galena and chalcopyrite are characterized by particularly close intergrowth. Pyrite is somewhat detached.

Ore is difficult to grind, and for the disclosure of intergrowth requires fine grinding, it introduces certain difficulties in the preparation of the material before enrichment.

Ore is a difficult object for enrichment due to the fine impregnation and close coalescence of ore minerals among themselves.

Experimental part

Researches were conducted in 2 directions: collective flotation of all ore minerals with further selection of the collective concentrate for lead, zinc, copper and pyrite concentrates and direct collective selective flotation with obtaining successively lead-copper, zinc and pyrite concentrates. The first way is predetermined by the fact that the disclosure of grains of non-metallic minerals occurs earlier

As reagents were used:

Gatherers - butyl xanthate, butyl aeroflot; foaming agents - IM-68, T-92, cresol; environmental regulators - soda ash, liquid glass, zinc sulfate, sodium cyanide; activators - copper sulfate, sodium sulphide; activated and sulfonated coal and others.

Water-soluble reagents were fed into the pulp in the form of solutions of 1-10% concentration, blowing agents - in the form of droplets, coal (active and sulfonated coal) - in dry form during grinding.

Flotation was carried out in Ginzvetmet flotation machines with a capacity of 3-3.6 liters and Mechanobr with a capacity of 1 l and 0.5 l at T: W=1:1.25-4.Ore grinding before flotation was carried out in a 40ML laboratory ball mill with a ratio of ore: water: balls equal to 1:0.5:6. The enrichment products were analyzed for lead (polarographic and potentiometric method), copper (colorimetric and quantitative methods), sulfide sulfur. In separate experiments pyrite sulfur was determined.

The technological scheme of collective flotation experiments is shown in Fig.1.

Technological scheme of collective ore flotation experiments

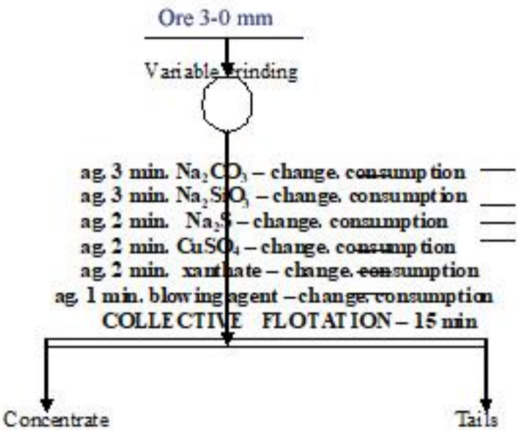

Fig.1

On the basis of the experiments performed, the optimal mode was chosen: grinding, 90 min; size of 89% of the cell - 0.074 mm; Consumption of reagents, g/t: soda -750; sodium sulphide - 190; liquid glass - 200; copper sulphate -240; potassium butyl xanthate -125; blowing agent T-92 60.

With the selected mode, a relatively high extraction of all components into a collective concentrate of lead, zinc and honey is observed: 88.6; 96.0 and 79.6%, respectively, and quite low in content in the tails. In the conditions of the optimal mode, experience was set with cleaning out concentrate to improve the quality of the product. The results of the experiment are given in table.4.

Table 4

The results of the flotation experiment with two cleanup concentrate in the optimal mode

Products	Output, %	Content%			Recovery,%		
		Pb	Zn	Cu	Pb	Zn	Cu
Collective k-t	15,5	18,15	30,12	2,85	85,9	91,2	74,6
Industrial product 1	6,8	0,69	1,14	0,29	1,4	1,5	3,3
Industrial product 2	2,7	3,52	5,98	0,38	2,9	3,2	1,7
Tails	75,0	0,44	0,28	0,16	10,1	4,1	20,4
Ore	100,0	3,28	5,1	0,59	100	100	100

As can be seen from the table. 4, as a result of the two finishing motions, the content of all components in the concentrate increases.

Further studies were conducted in the direction of selection of the collective concentrate. At the same time, lead-copper concentrate, then zinc concentrate was first released.

The following complexes were used as zinc mineral depressors: sodium cyanide, sodium sulfate and zinc vitriol, sodium hydrosulfite, and zinc vitriol. The best depression of zinc minerals is achieved with sodium cyanide and zinc vitriol.

For desorption collector were used: sodium sulphide, activated carbon, sulfonated coal.

The scheme of selective flotation included the preliminary grinding of ore and collective flotation in the optimal mode, two cleanings with subsequent thickening.

The condensed product was subjected to grinding and desorption. Desorption was carried out by mixing the bulk concentrate with sodium sulphide, followed by washing. Table 9 shows the results of the experience of separation of the collective concentrate and the reagent selection mode. The zinc product (tails 2) in the experiment was not scoured.

From table 7 it follows that the selection of bulk concentrate proceeds inefficiently. A part of zinc goes into lead-copper concentrate, which is explained by the close mutual germination of sphalerite with galena and chalcopyrite and activation of sphalerite with copper ions.

Table 5

The results of the experience of selection of collective concentrate (regrinding - 60 minutes; flotation time - 10 minutes a blowing agent - 40 g/t)

Product name	Out put, %	Content, %			Recovery, %			Selection Experience Conditions
		Pb	Zn	Cu	Pb	Zn	Cu	
Concentrate Pb- Cu	10,2	20,3	20,7	4,2	64,5	42,0	77,4	Sodium sulphide - 6 kg/t% solid -50; Washing-2; soda - 1000 g/t; Na_2S - 200.0 g/t $ZnSO_4$- 480 g/t; BKK – 50 g/t;
Promprodukt 1	9,2	0,8	1,62	0,09	2,2	3,0	1,4	
Promprodukt 2	4,5	1,2	1,74	0,2	1,6	1,6	1,6	
Tails 1 (coll.)	69,0	0,16	0,21	0,04	3,3	2,9	5,1	
Tails 2	7,1	13,2	36,1	1,12	28,4	50,5	14,5	
Ore	100	3,3	5,03	0,58	100	100	100	

From table 5 it follows that the selection of bulk concentrate proceeds inefficiently. A part of zinc goes into lead-copper concentrate, which is explained by the close mutual germination of sphalerite with galena and chalcopyrite and activation of sphalerite with copper ions.

It is known that the loading of excess amount of sodium sulphide into the pulp and its subsequent oxidation, the floatability of sulfide minerals in the pulp is restored at different rates [16]. The residual concentration of sulfide - ions, at which the flotation of various minerals, varies. When washing minerals treated with sodium sulfide with various amounts of water, the greatest adsorption of xanthate is observed on the surface of galena. The different behavior of minerals during flotation in the presence of sodium sulphide is also due to its activating effect on the flotation of galena and pyrite, the difference in the amount of adsorbed sulfide ion on the surface of various sulfides, etc.

Depression of sulfides as well as activation is associated with the adsorption of hydrosulfite ions on their surface. Sulfurous sodium was used as a reagent - regulator for the separation of lead - copper and zinc minerals. In order to determine the time required for the "recovery" of the flotation of lead and copper minerals after the oxidation of sodium sulphide (optimal flotation time), fractional removal of the foam was carried out after 2 minutes. The results of the experiments of flotation of ore with various expenses of sodium sulphide are given in table.8.

From tab. 8 it can be seen that the most successful separation of minerals occurs when the consumption of sodium sulphide 2 kg/ton of ore. Naturally, this flow rate is optimal for a flotation time of 10 minutes. When loading in flotation of sodium sulphide in the amount of 1 kg/t, the loss of zinc with the lead-copper product is still significant, and at a flow rate of 3 kg/t in the specified period of time the flotation of lead and copper minerals is still not “reviving”. Later we stopped at the consumption of sodium sulfide in the lead-copper flotation of 2 kg/t, and the flotation time 10 minutes.

For the separation of lead-copper concentrate, several variants of schemes and reagent modes were tested. Common to them was the desire for desorption of xanthate from the surface of lead and copper minerals. For this purpose, the grinding of copper-lead concentrate was carried out in the presence of activated carbon, the collector was desorbed with sodium sulphide, or was grinding without desorbents.

The worst was the third option. Desorption of xanthate is more effective when using desorbents - activated carbon or sodium sulphide. At the same time, to obtain equivalent indicators, it is sufficient to desorb with sodium sulfide without

Flotation of copper minerals goes in an acidic environment (pH about 3). Sulfuric acid is necessary for two reasons:

1. In a highly acidic environment, xanthate is intensively destroyed.

2. Sulfuric acid removes from the solution an excess of sodium sulphide, which did not have time to oxidize or wash off. In order to avoid the formation of hydrogen sulfide, it is necessary to thoroughly carry out the washing operation.

It was established that xanthate from the chalcopyrite surface is not desorbed by sodium sulfite [13]. When exposed to different concentrations of sulfite, a certain amount of collector remains on the surface of galena (5×101-5mg/cm^2).

The floatability of chalcopyrite in the presence of sulfite ions is maximum at pH=3.

Based on the above, as well as numerous experiments to refine the mode of copper flotation of the sample, the optimal consumption of reagents and the conditions of chalcopyrite flotation were chosen. Flotation mode:

- in the desorption of sodium sulfide - 5-6 kg/t Cu-Pb concentrate; - the number of washings - 3; - sulfuric acid - 1-1.5 kg/t, agitation - 5 minutes; - sodium sulfite - 1.2 kg/t, agitation - 10 minutes; - butyl xanthate - 10 g/t, agitation - 2 minutes; - T-92 - 20 g/t; flotation time - 10 min.

The copper content of the concentrate meets the requirements of GOST (grade KM-4). Copper-lead tails contain more lead. Intermediate products are rich in zinc, which determined the decision not to return them to the head of copper-lead separation, but to clean them together with the product, where most of the zinc is extracted (chamber product of lead-copper flotation).

Lead minerals were recovered from the copper flotation tailings. Lead flotation was carried out with one cleaning of the foam product, with the following, selected on the basis of preliminary experiments mode:

soda - 1 kg/t, agitation - 3 min; - sodium cyanide - 10 g/t, agitation - 3 min; - butyl potassium xanthate -15÷+15 g/t, agitation for 2 minutes; - T-92 - 20 g/t, agitation - 1 min.

The time of lead flotation is 12 minutes, the time of the clean-up operation is 10 minutes. The results of the experience of lead flotation in the selected mode are shown in tabl.

In terms of the content of lead and copper, the resulting concentrate is close to the grade KS 5. Because of the increased zinc content in the concentrate, it forces it to be transferred to the grade KS 6.

Thus, technological studies of the disseminated polymetallic ore sample from the Handiza deposit were carried out. The content of useful components in the sample: lead -2,55%, zinc -5.19%, copper-0.56% and pyrite -6.0%.

The ore was enriched by flotation. Laboratory tests were carried out in two directions: *a* - collective flotation of all sulphids with their subsequent separation; *b* - collective selective flotation followed by the preparation of separate concentrates. As a result of enrichment, lead, zinc and copper concentrates were selected that satisfy the production requirements. Considering that the technological tests were carried out on a limited scale, the results of the studies are recommended for semi-industrial conditions.

Table 6

The results of experiments on the separation of Cu-Pb concentrate

№	Product name	Output,%	Content,%			Recovery,%			Separation method
			Pb	Zn	Cu	Pb	Zn	Cu	
1	Rough Cu concentrate	3,6	16,5	9,8	11,25	23,2	6,8	72,5	Pre-ysel-e asset. coal-2 kg / t H_2SO_4 - 1.2 kg / t $Na_2S_2O_4$ - 1kg / t; BKK - 10 g / t
	Cu flotation tails	4,8	30,55	6,17	0,36	57,7	5,7	3,1	
	Pb-Cu concentrate	8,4	27,7	8,34	5,06	90,9	13,5	75,6	
2	Rough Cu concentrate	2,7	25,8	11,52	12,4	27,3	60,	66,3	Desorption Na_2S - 2 kg/t $K_2Cr_2O_7$ - 3 kg/t; BKK - 10 g/t
	Cu flotation tails	5,7	28,4	6,81	0,92	63,9	7,5	9,3	
	Pb-Cu concentrate	8,4	27,7	8,34	5,06	90,9	13,5	75,6	
3	Rough Cu concentrate	3,8	9,74	5,05	10,8	14,5	3,7	73,2	Pre-ysel-e asset. coal-2 kg/t H_2SO_4 - 1.5 kg/t $Na_2S_2O_5$ - 1.5 kg/t; BKK - 10 g/t
	Cu flotation tails	4,6	42,3	11,0	0,29	76,4	9,8	2,4	
	Pb-Cu concentrate	8,4	27,7	8,34	5,06	90,9	13,5	75,6	
4	Rough Cu concentrate	2,2	28,91	5,9	2,8	24,6	2,5	11,0	Regrinding with NaCN -500 g t $ZnSO_4$ - 1 kg/t BKK - 10 g/t
	Cu flotation tails	6,2	31,3	9,22	5,82	66,0	11,0	64,6	
	Pb-Cu concentrate	8,4	27,7	8,34	5,06	90,9	13,5	75,6	
5	Rough Cu concentrate	2,9	14,3	8,75	14,05	16,3	4,9	73,0	Desorption of Na2S - 6 kg/t of the end Na_2SO_3 - 1.2 kg/t;
	Cu flotation tails	5,5	34,55	8,14	0,26	74,6	8,6	2,6	
	Pb-Cu concentrate	8,4	27,7	8,34	5,06	90,9	13,5	75,6	

Table 7

Lead flotation test results from copper flotation tailings

Product name	Output, %	Content, %			Recovery,%		
		Pb	Zn	Cu	Pb	Zn	Cu
Pb concentrate	3,0	50,6	11,22	0,26	59,7	6,5	1,4
Pb concentrateт	0,8	15,65	12,95	0,21	4,9	2,0	0,3
Cu flotation tails	3,8	43,23	11,5	0,25	64,6	8,5	1,7

The study of lead - copper concentrate selection using ammonium nitrate

To confirm the judgment that ammonium nitrate reacts with the surface of galena to form a compound that reduces flotation capacity, the flotation ability of the pure galena mineral was studied. So, as in the collective lead-copper concentrate the main minerals are galena and chalcopyrite, the floatability of chalcopyrite with addition of ammonium nitrate to the flotation pulp was also studied. Analysis of the dependence of the extraction of copper and lead in concentrate on the consumption of ammonium nitrate, pH, contact time show that under certain flotation conditions (pH=7.5-8.5, ammonium nitrate consumption 2.5-3.5 kg/t; contact time 45 min.) possible high copper recovery and low lead extraction. This suggests that ammonium nitrate depresses galena.

The study of the laws of extraction of minerals in concentrates began a long time ago, and it depends on many physicochemical parameters. It was proposed to characterize the flotation rate of the derivative of extraction over time. Considering that the derivative e (flotation rate) of t (time) changes, decreasing at high values of s, it was proposed to estimate the flotation rate of the time derivative of the log function 1n (1/1-e) [10]. Having proposed the kinetics of mineralization of bubbles during flotation, the analogous kinetics of the interaction of molecules and radicals during chemical reactions of the 1st order is obtained in the integral form of the equation.

In the course of testing the equation, the principle of independence of the flotation rate of different factions was confirmed; the magnitude of the experimental constants during flotation of the polydisperse mixture turned out to be close to the calculated average weighted constant values for individual narrow fractions of size.

To test the results of laboratory studies with pure minerals, experiments were conducted with the commercial lead concentrate SOF Handiza, which has an admixture of copper of 2.89% using ammonium nitrate as a galenite depressor.

Preliminary exploratory experiments showed a positive effect of ammonium nitrate as a depressor, however, the reproducibility of the results was unstable. Therefore, we have set up experiments to determine the optimal parameters of flotation separation of lead-copper concentrate.

The experiments performed at the consumption of ammonium nitrate (0-10 kg/t) without prior desorption of the reactants from the surface of the lead-copper concentrate did not yield stable positive results: a significant transition of galena to the froth product was observed. Moreover, with an increase in ammonium nitrate consumption of more than 10 kg/t of concentrate, copper minerals are noticeably depressed. Selection was successful in individual cases and not with fresh concentrate. This is explained by the fact that portions of the minerals are covered with films of flotation agents (xanthate, foaming agent T-80, etc.). These films do not allow the interaction of ammonium nitrate with the surface of the particles.

The process of desorption of the collective concentrate was carried out in the following order:A certain amount of collective concentrate was mixed with sodium sulphurous solution for 15-20 minutes, then the pulp was diluted with tap water to T: W - 1:20, stirred, defended and poured the illuminated portion to a solid content of 50 % The effect of the duration of contacting the pulp with sodium sulphide and the number of washes of the bulk concentrate on the degree of separation of lead-copper concentrates was studied (Table 8). In further experiments, preliminary desorption of the reactants with sodium sulfide was performed.

From the data table. 8 it follows that an increase in the number of washes somewhat improves the separation of copper and lead minerals. However, this separation was not highly efficient. Therefore, in further experiments, one washing was performed with dilution with water to T:W-1:20.Experiments have determined that to remove flotation reagents from the top of the particles, it is necessary to contact the concentrate with sodium sulphide solution for 15 minutes, with the consumption of the last 6-8 kg / ton.

Purified from flotation agents, the collective concentrate was subjected to flotation separation. The dependences of the degree of separation of copper and lead during flotation on the consumption of ammonium nitrate, on the duration of contact with ammonium nitrate, and on the pH of the medium were studied. The results of the experiments (Table 9) on the effect of ammonium nitrate consumption on the degree of separation of copper and lead showed that a fairly complete separation occurs when the consumption of ammonium nitrate is 2.5-3 kg/t, concentrate.

With smaller amounts of ammonium nitrate, it is apparently not enough to cover the film with all the particles of galena with ammonium nitrate, and at high costs of ammonium nitrate, depression of copper minerals begins. The effect of the duration of mixing the collective concentrate with ammonium nitrate after desorption was also studied. Agitation in the experiments lasted from 15 to 60 minutes. The consumption of ammonium nitrate was 2.5 kg/t. The results of the experiments are presented in table.10.

Table 8

The effect of the number of concentrate washes on depression galena (main copper flotation)

Product name	Output, %	Content, %		Recovery, %		The number of washes
		Copper	Lead	Copper	Lead	
Copper float tails	18,1	15,4	21,30	90,7	6,9	1
Copper float tails	81,9	0,35	63,60	9,3	93,1	
Original copper-lead concentrate	100,0	3,07	55,94	100,0	100,0	
Copper concentrate	16,7	16,90	19,4	91,9	5,8	2
Copper Float Tails	83,3	0,30	63,20	8,1	94,2	
Original copper-lead concentrate	100	3,07	55,94	100,0	100,0	3
Copper concentrate	16,1	16,40	19,00	86,0	5,5	
Copper float tails	83,9	0,50	63,00	14,0	94,5	
Original copper-lead concentrate	100,0	3,07	55,94	100,0	100,0	

From tab.8 it follows that in the presence of ammonium nitrate with increasing duration of agitation the lead content in the copper concentrate decreases.

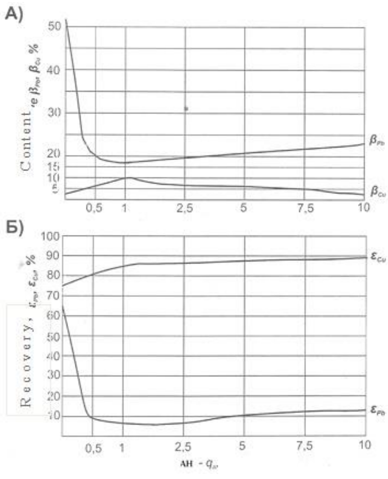

Fig. 3. Dependence of the content of (*A*) and extraction of (*Б*) lead and copper into the coarse concentrate of copper flotation on the consumption of ammonium nitrate (AH)

Table 9

Depending on the degree of extraction of copper and lead during flotation from the consumption of ammonium nitrate

Products name	Content %	Content, %		Recovery, %		Con-suption AH
		Copper	lead	Copper	lead	
Copper concentrate main flotation	56,4	4,6	54,75	77,4	60,20	0
Copper float tailsи	43,6	1,74	46,83	22,6	39,80	
Source Pb-Cu concentrate	100,0	3,35	51,30	100,00	100,00	
Copper concentrate main	23,7	11,4	23,5	80,9	10,86	0,5
Copper float tails	76,3	0,84	59,90	19,1	89,14	
Source Pb-Cu concentrate	100,0	3,35	51,30	100,00	100,00	
Copper concentrate main flotation	22,0	12,6	19,6	82,73	8,40	1,0
Copper float tails	78,0	0,74	60,24	17,27	91,60	
Source Pb-Cu concentrate	100,0	3,35	51,30	100,0	100,00	
Copper concentrate main	21,30	15,30	17,60	84,60	7,30	2,5
Copper float tails	78,70	0,65	60,40	15,40	92,70	
Source Pb-Cu concentrate	100,0	3,35	51,30	100,00	100,00	
Copper Float Tails	78,0	0,74	60,24	17,27	91,60	
Source Pb-Cu concentrate	100,0	3,35	51,30	100,0	100,00	
Copper concentrate main	23,0	12,30	20,40	84,40	9,15	5,0
Copper Float Tails	77,00	0,69	60,50	15,60	90,85	
Source Pb-Cu concentrate	100,0	3,35	57,30	100,00	100,00	
Copper concentrate main	28,90	10,80	33,50	93,00	18,87	10,0
Copper Float Tails	71,10	0,33	58,50	7,00	81,13	
Source Pb-Cu concentrate	100,0	3,35	51,30	100,0	100,00	

Table 10

The effect of the duration of the mixing of the collective concentrate with ammonium sulfate phosphate on galena depression

Product name	Content, %	Recovery,%		Recovery,%		Flotation time
		Copper	Lead	Copper	Lead	
Copper concentrate	25,7	12,9	36,4	82,9	16,5	15
Flotation tails	74,3	0,92	63,7	12,1	83,5	
Source concentrate	100	4,0	56,7	100	100	
Copper concentrate	25,6	12,8	35,4	81,9	16,0	30
Flotation tails	74,4	0,97	64,0	18,1	94,0	
Source concentrate	100	4,0	56,7	100	100	
Copper concentrate	25,3	13,02	32,8	82,4	14,5	45
Flotation tails	74,7	0,95	64,9	17,6	85,5	
Source concentrate	100	4,0	56,7	100	100	
Copper concentrate	25,1	12,85	33,3	79,4	14,5	60
Flotation tails	74,9	1,1	64,6	20,6	65,3	
Source concentrate	100	4,0	56,7	100	100	

When agitating for 15-30 minutes, incomplete galena depression occurs and flotation of chalcopyrite deteriorates. When agitating for 45 minutes, satisfactory results were obtained. Experiments to determine the effect of pH at which lead-copper concentrate was mixed with ammonium nitrate (45 minutes, flow rate 2.5 kg/ton) were carried out with the addition of soda ash solution. The results of the experiments are given in table. 15.

These experiments showed that the creation of an alkaline environment (pH 8.9 and above) adversely affects the selection. If at pH from 6.4 to 8.2, the lead content in copper concentrate was 25.7% - 28.9%, then at pH=8.9, this content increased dramatically to 38.1%. This is explained by the fact that the depression of lead minerals is associated with the displacement of xanthate ions from its surface by nitrate ions from its surface.

At low pH, $Pb_3(PO_4)_2$ is formed, which proves the deterioration of the division of lead-copper concentrate. At higher pH=9-10, the equilibrium shifts towards the formation of $Pb_3 (PO_4)_2$. Therefore, we can conclude that at pH=8.5, the hydrophilization of the surface of galenite occurs and the ions HPbO-2, PO_4-3, 4 OH- are formed and due to this, there are impressive results. Therefore, depression should be carried out at a pH of not more than 8.2. Thus, the following conditions for copper-lead selection were determined from laboratory experiments: the pulp of the initial lead-copper concentrate is washed for 15 min with sodium sulphide (consumption 6-8 kg/t) at T: W=1:3. This is followed by dilution with water to T:W=T:20, sludge and discharge of the lighted part to a solid content in the thickened pulp equal to 50%.

Galena is depressed for 45 minutes. while mixing the washed collective concentrate with ammonium nitrate (consumption 2.5 kg/t), then the main flotation and four cleanings of copper concentrate in the open cycle. According to this scheme, a copper concentrate is obtained with a copper content of 18-30% (extraction 50-81%), with a lead content of 2.3-3.4% (extraction 0.2-0.7% o). The results are shown in Table. 11.

When breeding lead-copper concentrate, metal losses in dissimilar concentrates are inevitable. Losses of lead with copper concentrate can be reduced by introducing an additional operation for the removal of copper concentrate.

The operation of the mineralization of copper concentrate, as is known from the practical work of domestic and foreign factories, is carried out by depressing copper minerals with cyanide and by refluxing lead minerals into the frothy product. A de-screwing operation can take place without prior desorption of the reagents from the surface of the minerals, if the honey minerals are represented by chalcopyrite.

Experiments on the de-screwing of copper concentrate with III clean-up were carried out at a flow rate of cyanide from 0.2 to 2 kg/t from the initial lead concentrate. The duration of contact (10 minutes) was chosen experimentally; the flotation time was 5 minutes.

Table 11

Effects of pH on the selection of lead-copper concentrate

Products name	Output, %	Content, %		Recovery, %		PH
		Copper	Lead	Copper	Lead	
Copper concentrate	30	11,62	28,9	95,0	15,6	6 without soda
Flotation tails	70	0,30	67,1	5,0	84,4	
Source concentrate	100	3,70	55,4	100	100	
Copper concentrate	23,1	12,36	25,7	96,0	13,1	7
Flotation tails	76,9	0,2	66,9	4,0	86,9	
Source concentrate	100	3,7	55,4	100	100	
Copper concentrate	30	11,72	28,6	90,0	15,5	8
Flotation tails	70	0,2	66,8	10,0	84,5	

Source concentrate	100	3,7	55,4	100	100	
Copper concentrate	30	11,72	28,6	90,0	15,5	
Flotation tails	70	0,2	66,8	10,0	84,5	8
Source concentrate	100	3,7	55,4	100	100	
Copper concentrate	35,2	10,19	38,1	95,7	23,1	
Flotation tails	64,8	0,25	55,5	4,3	76,9	8
Source concentrate	100	3,7	55,4	100	100	

Table 12

The results of experiments with a four-time cleaning of copper concentrate main flotation

Products	Output, %	Content, %		Recovery, %	
		Copper	Lead	Copper	Lead
Copper concentrate	12,1	26,9	3,4	69,27	0,74
Tails IV cleaning	1,0	20,45	10,5	5,41	0,18
Tails III cleaning	1,7	15,88	21,7	5,73	0,64
Tails II cleaning	2,0	7,6	34	3,23	1,21
Tails V cleaning	3,7	3,25	58,5	2,55	3,86
Source copper concentrate	20,5	19,8	17,1	86,18	6,63

According to the recommended flotation scheme, with cyanide consumption of 1 kg / t of lead-copper concentrate (at best), the extraction of lead into the lead reflux product amounts to 0.60% of the initial product, or 77.6% of the recovery operation. Loss of copper in the doflotation lead concentrate was 5.4% of the initial product, or 7.5% of the operation. The content in lead concentrate is reduced to 1.25%.Since the release of the lead product after de-screwing is insignificant, it can be sent directly to the finished lead concentrate.

To obtain the final version of the technological scheme for separating lead-copper concentrates, we set two similar experiences: desorption of reagents with sodium sulphide for 15 minutes, at pH=8.5; agitation with AH 45 minutes, AH consumption 2.5 kg/t concentrate and four mop-up cleaning with copper concentrate loosening at optimal parameters with open and closed cycles. According to the results of these experiments, we can conclude that the results of experiments in a closed cycle are more real and the copper content in copper concentrate is high.

The results of the experiments in the open cycle of the separation of lead-copper concentrate allow us to conclude that when using lead minerals AH as a depressor (2.5 kg/t of concentrate) and the introduction of a copper concentrate drainage operation (cyanide consumption 1.0-1.5 kg/t) high concentration of copper concentrate is possible. The concentrate contains 23.3% copper; 1.6% of lead, with the recovery of 56.8% of copper and 0.24% of lead.

As can be seen, the results of the experiments turned out to be close and can be considered quite satisfactory in all respects. A copper concentrate was obtained with a copper content of 23.3% and a recovery of -90.45%. With him, 0.2-0.22% of lead was lost. The quality of lead concentrate increased by 5-5,76%. The foamy product of the copper concentrate de-screwing had a yield of 1.4-1.6% and contained 13.7-17.2% of copper, 2.1-7.2% of lead and 2.4% of zinc. This technology has been recommended for industrial testing. Thus, as a result of the research, a new method for the extraction of copper from lead concentrate has been developed.

Based on the research conducted, the following conclusions can be drawn:

1. It has been established that the results of flotation of pure lead and copper minerals mainly depend on the consumption of the reagent, on the size of grinding, on the pH of the medium, the rate of mixing, etc.

2. The process of selection of lead - copper concentrate with the use of ammonium nitrate was studied and the optimal flotation mode was established: washing the initial collective concentrate with sodium sulphide at a rate of 6-8 kg/t for 15-20 minutes, then copper flotation at a rate ammonium nitrate 2.5 kg/t, butyl xanthate 30 g/t, the blowing agent T-80-40 g/t.

3. A new highly efficient technology of selection of collectible lead - copper concentrate was developed using cheap, non-toxic local raw material - ammonium nitrate, as an effective despressor of lead minerals.

4.According to the results of research carried out using ammonium nitrate technology, copper concentrate was obtained with a copper content of 22-28% with extraction of 85.90%. The analysis shows that the use of ammonium nitrate technology is more effective than chrom-peak and sulfite methods.

References

1. **N.Ahmedov** Modern methods of processing ores and concentrates. // Materials of the republican scientific and technical seminar "Problems of processing of mineral raw materials of Uzbekistan". Tashkent: 2015. P.7-10.

2. **Abramov A.A.** Flotation enrichment methods. Textbook. M .: MGGU, 2017. 600 p.

3. **Avdokhin** V.M. Basics of mineral processing. M .: MGGU. 2017. 310 p.

4. **Shishkin A.A., Burokhlin M.S.** and others. Mastering the combined scheme of enrichment of lead-zinc ores. Color Met., 2013, №. 7, P.43-45.

5. **Abramov A.A.** Processing, enrichment and complex use of solid minerals. Volume 2. Mineral processing technology. M.: MGGU, 2004, 510 p.

6. **Abramov A.A.** Technology of enrichment of ores of non-ferrous metals. M: Nedra, 2005, p. 358.

7. **Abramov A.A.** Flotation enrichment methods. M: Nedra, 1998, p. 382.

8. **Alekseev V.B., Gorlovsky S.I., Rybakov V.V.** Enrichment of ores of non-ferrous and rare metals in Asia, Africa and Latin America. M: Nedra, 2004, p. 308.

9. **Abramov A.A., Leonov S.B.** The enrichment of non-ferrous metals. M: Nedra, 2007, p.406.

10. Bakinov K.G. Rational areas of flotation separation, copper and lead minerals. "Non-ferrous metals", № 5, 2002.

11. **Polyakov M.M,** Theory and technology of ore flotation. M.: Nedra, 1990

12. **Beloglazov K.F.** Patterns of the flotation process. M.: MeTallurgizdat, 2004, p. 144.

14. **Bogdanov O.S.** Theory and technology of ore flotation, M.Nedra, 1998.

15. **Konev A.S.** Laboratory tests on the use of zinc hydrosulfite in the separation of lead-copper concentrates. Collection of annotations of scientific research work, part 2. Mekhanobr, 1998.

16. **Klimenko N.G., Klyueva N.D.** et al. Study of the surface properties of sulphide minerals and the composition of the liquid phase during the flotation of polymetallic ores in order to increase the extraction of non-ferrous and noble metals. Report of the Institute of TsNIGRI. M: 2001

17. **Mitrofanov S.I**. Selective flotation. M: Metallurgy, 2007

18. **Mitrofanov S.I., Ratnikov O.A.** Combined methods of processing of oxidized and mixed ores. M: Nedra, **2000**

19. Polkin S.I, Adamov E.V. Enrichment of ores of nonferrous and rare metals. M: Nedra, 1995

20. **Polkin SI, Adamov E.V.** The enrichment of non-ferrous metals. M: Nedra, 1993

21. **Fishman MA, Sobolev D.S**. The practice of enrichment of ores of non-ferrous and rare metals. T. 1-5. M: Metallurgy, 1997

22. **Rubinstein Yu.B. Filippov Yu.A.** Kinetics of flotation. M: Nedra, 2000, p. 375.

24. **Robone F.** Practice of flotation plants. M: Gesgortehizdat, 1999

25. Reference enrichment of ores. TZM: Nedra, 1995, p. 404.

26. Handbook on the enrichment of ores (Processing Plant) finalized and amended. M: Nedra, 1994

27.http://forum.sbridge.ru

28.http://mmin. 1001 ,ru

29.http://www.norcl-ost.net

30.http://stockmail ,ru

NANOMATERIALS IN THE DRILLING FLUIDS FOR OIL AND GAS PRODUCTION: A REVIEW

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Abstract

Nanomaterials are an important product in nanotechnology as it allows directional changes in the properties of substances and the characteristics of the processes in which they are applied. On the other hand, regarding the dependence of the global progress on hydrocarbons, and consequently, the growth in the demand for oil and gas, the increasing nanomaterials application in the oil and gas sector is becoming topical since the nanomaterials improve the processes of exploration, drilling, development of wells, production, and fossil fuels processing.

The oil and gas production relies on drilling and various types of drilling fluids are used to facilitate this process and to improve its efficiency. The most common system is water-based fluids that are relatively inexpensive and environmentally friendly. The analysis on the nanomaterials application in the drilling fluids demonstrates a number of important technological advantages, which they give to the drilling process. Moreover, the nanomaterials are able to minimise the losses of the drilling fluids when the drilling practice.

In the chapter, the features of drilling fluids belonging to the different systems are considered along with the opportunities to create drilling fluids compositions with additives of reagents, namely rocks hardness reducers, a crucial factor for the drilling process intensification.

1. Introduction

Oil and natural gas in the nearest future will remain the dominant energy source worldwide. The demand for these fossil fuels, according to analysts` forecasts, will be steadily high. Despite the rapid growth of alternative energy sources, it is fossil fuels that will be the basis of the fuel and energy balance both globally and locally. The demand for liquid hydrocarbons will most likely increase and, eventually, the demand for oil products, and the opportunities for ensuring their production will increase as well.

However, with the greater exhaustion of mineral resources, their exploration, evaluation, and production are becoming more and more complicated. Additionally, the main problem, which arises due to the exploitation of mineral resources and their mining, is the increase in the volumes and the production rates, in the losses during production, the generation of a large waste amount, the destruction of soil and other environmental impacts. Recently, nanotechnology has been increasingly involved in solving urgent problems in the oil and gas industry.

The far-reaching opportunities being granted by nanotechnology and nanomaterials have significant potential for improving materials and technologies vs. the conventional materials. The nanotechnology application provides enormously for various industries, in particular, for the oil and gas exploration and production. The nanomaterials application might find their echo in the solving issues and challenges those are faced by the oil and gas industry. The promising direction of the nanomaterials utilisation is their addition to the drilling fluids, since they play a pivotal role in the exploration and drilling process, especially in complex structures and extreme environments such as deep wells high temperature-high pressure.

Fossil hydrocarbons, which include oil and natural gas, are an integral part of the scientific and technological development of humankind and are the determining resource of the fuel and energy complex of whatever country. The access to the oil and the natural gas resources, the feasibility of their extraction and subsequently their application are crucial factors in the globalisation process that is taking place currently and will take place in the nearest future. According to BP Energy, the demand for natural gas (1.6% per year) will grow much faster than those for oil or coal, and will be closer to the oil by the end of the forecasting period. Oil demand will increase (0.5% per year) as compared to most other fuels, although the plateau is predicted in the last part from 2030-2040.

According to OPEC (The Organisation of the Petroleum Exporting Countries) estimates, oil will remain the fuel with the largest share, which will be more than 27% by 2040. The use of natural gas will increase throughout the period and by 2040, its share will be just over 25%. It is interesting to note that the use of oil and gas by 2040 will reach over 52% of the world`s energy.

The demand for crude oil will amount to 7.7 mb/d within the period from 2020-2040. For all OPEC liquid fuels, this figure is 10.5 mb/d. In addition, it is expected that the share of OPEC raw materials in global oil supplies will increase from 34% in 2016 to 37% in 2040 (OPEC, 2017).

The long-term demand for oil is expected to increase by 15.7 mb/d, starting from 95.4 mb/d in 2016 and reaching 111.1 mb/d in 2040. The demand in the OECD (Organisation for Economic Co-operation and Development) region is predicted to drop to 8.9 mb/d within the forecast period. Due to the high population growth and the higher potential economic growth, the increase is assumed in the oil demand with the developing countries (DC), approximately 24 mb/d. China will remain the largest consumer of oil during the forecast period, reaching 17.8 mb/d by 2040. India will become the second largest country in terms of the growth in the total demand, increasing its own demand by 5.9 mb/d between 2016 and 2040. However, the global demand for oil will steadily decrease, with the annual average of 1.3 mb/d over 2016-2020 to 0.3 mb/d between 2035 and 2040 (Fig.1).

Table 1 presents the long-term demand for oil per product types. Light products are grouped in three categories (ethane/LPG, naphtha, and gasoline plus ethanol) while middle distillates are grouped into two categories (kerosene, both jet and domestic, and diesel/gasoil plus biodiesel).

To residual products belongs the residual fuel oil (including refined fuel oil); the group “other products” includes bitumen, lubricants, waxes, still gas, coke, sulphur and direct use of crude oil.

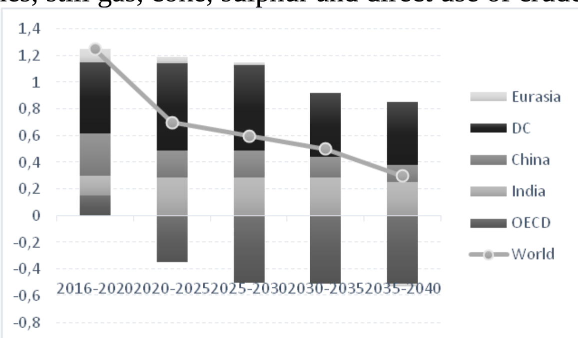

Fig. 1. Average annual change in demand for oil (OPEC, 2017)

Table 1

Long-term demand for oil by product categories (mb/d), 2016-2040 (OPEC, 2017)

Product categories	2016	2020	2025	2030	2035	2040	Growth by 2016–2040
Ethane/LPG	10.7	11.3	12.1	12.6	13.2	13.6	2.9
Naphtha	6.1	6.5	7.0	7.4	8.0	8.4	2.3
Gasoline	25.1	27.0	27.8	28.1	28.3	28.4	3.3
Light products	41.9	44.9	46.8	48.2	49.5	50.4	8.5
Kerosene	7.0	7.5	8.1	8.7	9.3	9.7	2.7
Diesel/gasoil	28.5	30.2	31.0	31.8	32.3	32.6	4.1
Middle distillates	35.5	37.7	39.1	40.5	41.6	42.3	6.8
Residual fuel oil	7.0	6.9	7.0	7.0	6.9	6.9	-0.2
Other products	10.9	11.3	11.5	11.7	11.7	11.6	0.7
Residual products	18.0	18.2	18.5	18.7	18.6	18.4	0.5
World	95.4	100.7	104.3	107.4	109.7	111.1	15.8

During a long term period, the demand for the diesel/gasoil product category is expected to increase by 4.1 mb/d and will reach 32.6 mb/d in 2040.

Fuel residuals are the only fuel category, where the reduction in demand is assumed during the forecast period. Within the period from 2016 to 2040, the demand for products is estimated to the decrease by 0.2 mb/d. However, this behavior will be rather uneven, with the sharp fall in 2020. Then, the slight increase is expected, and after 2030 the demand is expected to decline again.

The price of Brent crude oil from 2016 increased from about 30 dollars per barrel in January 2016 to 65.8 dollars per barrel at the end of February 2019. The rise in prices was particularly significant from September 2017 to September 2018. These higher prices are prompting to invest in the shale oil production, which will be also responsible for an increase of oil production during the years of 2018-2019.

The price of the supplied natural gas also increased significantly during 2017. That increase was particularly strong (by 45%) from July 2017 to January 2018.

2. Drilling and Drilling Fluids

Drilling is one of the most important processes in creating access to both the oil and the gas reservoirs. The choice of proper and efficient performance technique for this operation plays a key role in the optimisation and production of hydrocarbons. In general, the drilling consists of several types:

traditional drilling - conventional wells are drilled vertically from the surface directly to the required area (Fig. 2);

horizontal drilling - technology “bottom driven bits” is capable to sharp turning and drilling horizontally;

slant drilling - at an angle from the perpendicular (usually from 30° to 45°). This approach minimises surface environmental problems;

directional drilling - progressive drilling technique, which allows changing the direction and depth several times in one well (Fig. 3).

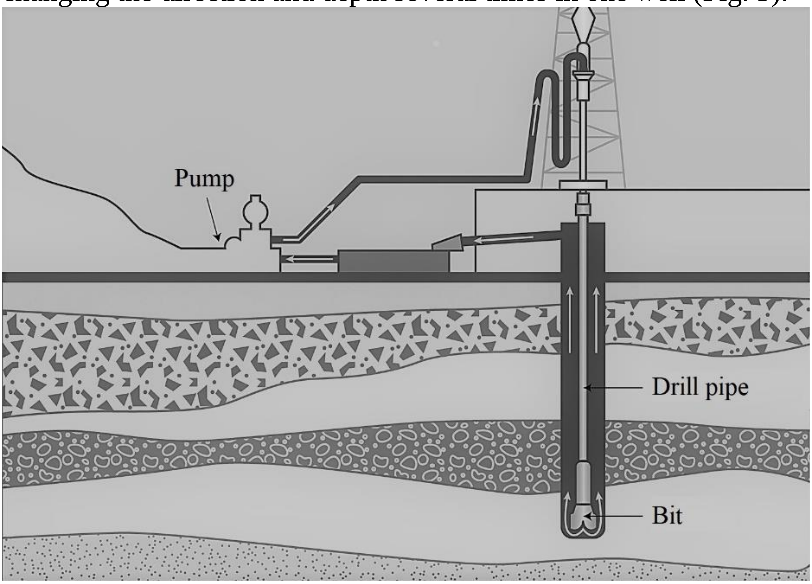

Fig. 2. Traditional drilling

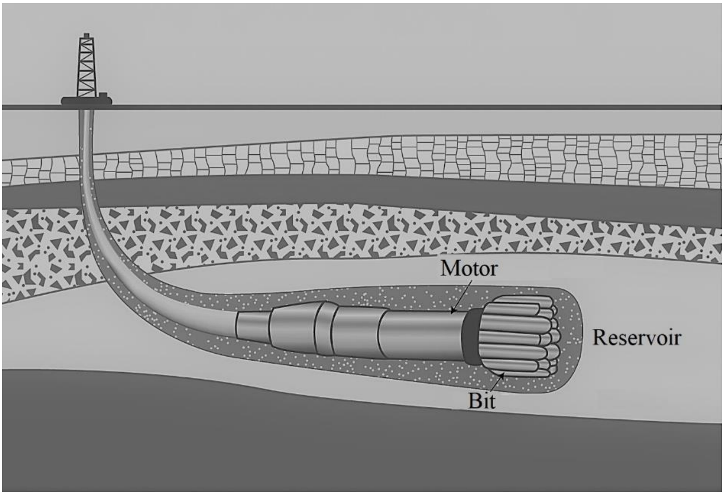

Fig. 3. Directional drilling

Drilling fluids are mixtures of natural and synthetic chemical compounds used to cool and lubricate the drill bit, clean the hole bottom, carry cuttings to the surface, control formation pressures, and improve the function of the drill string and tools in the hole (Fink, 2012).

Drilling fluids possess essential functions during well construction such as transporting cuttings to the surface, minimizing formation damage, preventing well-control issues and wellbore stability, cooling and lubricating the drillstring and providing information about the wellbore.

Various types of drilling fluids are widely used during drilling in various conditions: water-based fluids, oil-based fluids or anhydrous fluids, as well as fluids based on synthetic oils, pneumatic, or gas (Khalil et al., 2017).

2.1 Water-based drilling fluids

Water-based drilling fluids are inexpensive, environmentally friendly and most widely used (Sadeghalvaad and Sabbaghi, 2015). Generally, they include bentonite and phosphate solutions, organic solutions such as lignosulfonate solutions, lignite solutions, and organic colloidal solutions. In total, 80% of the oil and gas wells in the world are drilled via the drilling water-based fluids (Sadeghalvaad and Sabbaghi, 2015). In the study, Maliardi, Sergiacomo and Del Gaudio (2014), presented the results of water-based drilling fluids application. The use of the water-based fluids contributed to high productivity, as well as reduced environmental impacts and improved operational performance of the drilling process. In addition, the rheological properties, in particular, viscosity and friction coefficient have been improved with less environmental effects. The other side of the problem is shown in the study (Ahmed Kamel, 2013): water-based drilling fluids have poor filtration properties and inhibition functions of shale compared to oil-based fluids. With the purpose to improve the performance of water-based fluids and to help them comply with oil-based ones, the water-based fluids are mixed with additives.

Normally, the water-based drilling fluids are modified by inhibitors for clay drilling. There are three ways to study the shale using the drilling fluids based on water (Aftab et al., 2017): firstly, reduce the pressure of the solution penetration, through the interaction of the shale with the drilling fluid; secondly, reduction of the ionic activity of the drilling fluid; and thirdly, the physical blocking the shale wall.

2.2 Inhibitive drilling fluids

Inhibitive drilling fluids are the solutions that prevent clay hydration. This group of inhibitive drilling fluids may include limestone fluids, gypsum fluids and saturated hydrochloric fluids. Water-based fluids without the inhibitors addition increase the problem of shale contamination and promote hydration, which can have an undesirable effect on drilling, and lead to the increase in the cost of the wells under development. The main purpose of water-based fluids with inhibitor addition is to promote the stability of shale. Chloride and sulphate salts are added in water-based fluids for the preparation of inhibitive drilling fluids. These salts can reduce the ionic activity of the drilling fluid compared to shale water, reduce the diffusion of ions and water molecules in the shale (Aftab et al., 2017).

Potassium fluids are the most widely used inhibitive system for water-based fluids applied in drilling water responsive shale. Potassium compounds, for instance, potassium carbonate, potassium hydroxide, potassium acetate and potassium lignite have the potential to improve the inhibitory and rheological characteristics of shales

(Fink, 2012). Potassium chloride is the most common inhibitor in the processes of oil and gas drilling. Potassium ions are attached to the clay surfaces and ensure the stability of the shale under the action of the drilling fluids, and they keep the drill cuttings together, preventing them from being sprayed into smaller particles.

Nevertheless, the potassium chloride has limitations in the application, namely high concentrations of potassium chloride in drilling fluids can destabilize the rheological properties and form two phases separately in the solution (Sehly et al., 2015).

Additionally, the disadvantages include the fact that drilling fluids contaminated with the potassium chloride are very toxic and cannot be isolated in environmentally sensitive sectors (Sehly et al., 2015), therefore, a small amount of potassium chloride in combination with a polymer is used to reduce the environmental and the operational loads.

2.3 Oil-based drilling fluids

The currently used oil-based drilling fluids consist of diesel, mineral oil or low-grade olefins and paraffins. Olefins and paraffins are often called “synthetic”, although some of them are obtained by distilling crude oil, and some are chemically synthesized from “smaller” molecules. The emulsion should be sufficiently stable to add the certain amount of water if the wells occasionally develop flood conditions.

In order to increase the density of the system, barite is used, and specially treated organophilic bentonite is the main thickener in most oil systems. For the better control over the fluid loss under conditions of high pressure - high temperature, organophilic lignite, asphalt-polymeric materials are added. Oil purification is essential to ensure that the particles of the material remain in the suspension. Surfactants can also be used as diluents. Oil systems commonly containing lime to maintain high pH, counteract the adverse effects of hydrogen sulphide (H_2S) and carbon dioxide (CO_2), and increase the stability of the emulsion.

Shale inhibition is one of the main advantages of using the oil system. Most conventional oil-based fluids consist of calcium chloride solution, which provides the best inhibiting properties for most shale.

2.4 Drilling fluids based on the synthetic oils

Synthetic fluids have been developed in the context of an increasing necessity to reduce the impact of offshore drilling operations on the environment along with sustaining the economic efficiency of oil-production plants. If compared against the conventional oil-based drilling fluids, it should be noted that the synthetic fluids can be used to increase the penetration rate; better lubrication in vertical and horizontal wells; solving problems with the stability of wells, for example, caused by reactive shells.

In many offshore areas, the legal regulations prohibit to dump the resulting drill cuttings in the case of using oil-based drilling fluids. The cost of synthetic fluids may be higher than that of oil-based fluids, but, as practice has shown, they have proved to be economically suitable in many offshore sectors. The synthetic-based drilling fluids consisting of alpha olefins and isomerized olefins show a rather low kinematic viscosity. The viscosity characteristics are important in the drilling process in the deep waters. For instance, systems based on esters have shown high kinematic viscosity, which increases at cold temperatures. However, esters (C_8) have a viscosity similar to or less viscous compared to other solutions, in particular, to the systems based on isomerized olefins. Nonetheless, due to the ability to significant biodegradation and low toxicity, esters are generally recognised as the best base fluid in terms of environmental performance.

2.5 Drilling fluids gas/air system

In order to remove the drill cuttings from the well by lifting them to the surface with high velocity, the compressed air or nitrogen are applied. Moreover, drilling with gas or air drilling fluids reduces circulation loss and increases the life of the drill bit as the air cools it and at the same time quickly raises up cutting. The use of compressed air partially solves the problems with wells and their water entering. Using drilling fluid with air can increase drilling velocity (Maranuk et al., 2014).

However, drilling gas fluids do not allow controlling the pressure of formation fluids in drilled holes. Such solutions destabilise the wellbore walls, in this connection, the foam-shaped drilling fluids are formed by combining with the air, and the liquid can stabilise the well, suppressing the pressure to reduce the flow of water.

2.6 Drilling fluids foam system

Drilling fluids of foam systems are gas surrounded by the liquid with the stabilising surfactant. The foam systems are typically used for drilling in circulation loss zones. Moreover, the drilling fluid foam systems are used under conditions where clay drilling is necessary, reducing the problems of erosion in unconsolidated formations. Saintpere et al. (2000) presented the comparative analysis of wellbore foams and conventional wellbore fluids. The research results revealed that the drilling foam had a higher productivity over time necessary to raise up the drill cuttings from the well to the surface. Nevertheless, studies have shown that the behaviour of drilling foam in the process of stable work is more complex compared with the traditional systems of drilling fluids. Therefore, the oil and gas industry pay more attention to the drilling system using fluids, in particular, water based drilling fluids.

2.7 Nanomaterials-based drilling fluids

The fluids containing nanomaterials have promising thermophysical properties in comparison with the conventional fluids, for instance water-based (Rafati et al., 2018; Parizad, Shahbazi and Tanha, 2018). The content of 5% of cuprous oxide nanoparticles (II) can improve the heat conductivity efficiency by 22.4%. Improving the heat conductivity of fluids with nanomaterials has attracted attention to the use of such drilling fluids in the processes of high pressure - high temperature (Nguyen et al., 2012).

Nanomaterials play a multifunctional role in exploration and drilling, especially in difficult and extreme environments such as high temperature deep wells. There are several advantages of using nanomaterials in drilling technology and in the case of adding to drilling fluids (Peng et al., 2018):

stabilisation of the wellbore; nanoparticles can form the compact filtration sediment on the wellbore, which can prevent or reduce the negative effects of water swelling and collapse of the wellbore;

reducing the loss of the filter; by introducing absorbing polymers in the drilling fluids, nanoparticles can seal nano- and micropores in the wellbore, reducing the loss of the drilling fluid;

improvement of the rheology; nanoparticles can increase the apparent viscosity and dynamic shearing force of the drilling system and, as a result, improving the rheological properties;

improvement of the thermal stability; the application of fluids containing nanomaterials can provide higher temperature tolerance, and find effective use in drilling deep wells.

The drilling fluids containing nanomaterials can be applied during and after the drilling process (Amanullah, Al-Arfaj and Al-Abdullatif, 2011). As instance can serve (Li et al., 2016), cellulose nanoparticles, including microfibrillated cellulose and cellulose nanocrystals, increase the filtration and rheological characteristics of water-based fluids. The mentioned study compared the microfibrillated cellulosic system with the nanocrystalline cellulose-based system that demonstrated higher rheological properties, higher temperature and lower fluid density. The results showed that the addition of nanoparticles can improve the rheology and drilling ability, which reduces the loss of drilling fluid due to the effect of “blocking” nanoparticles of micro or nanosized pores in the shale. Nanomaterials with the layered structures, such as bentonite and montmorillonite, can also be used in drilling technology. Montmorillonite as the principle material in drilling fluid systems performs the function of density and viscosity control.

The study of the drilling process with the participation of the nanomaterials is generally focused on the application of nanobjects as components of drilling fluids to achieve the above-mentioned advantages. The effect, which the physical properties of the drilling fluids containing nanomaterials, namely, the addition of nano-silica to the water-based drilling fluid, produces on the shale was investigated by Hoelscher et al. (2012). The results have shown that the nanosized pores in the shale can be physically blocked, which greatly reduces the shale permeability, thereby reducing the pressure difference and increasing the stability. The addition of nano-silica with the particle size of 5-15 nm and the concentration in the range of 20-30% by weight (Ragab and Noah, 2014) allowed reducing approximately 56% of fluid losses, compared with conventional drilling fluids. Moreover, the addition of nano-silica significantly improves the stability of the well walls, reducing the penetration of water by 10-100 times (Sharma et al., 2012). The application of the non-toxic nanoparticles, such as nano-silica, is accompanied by the reduction in drilling and recycling costs, as well as by the environmental benefits.

Li et al. (2012) studied nanomaterials in the drilling fluid to improve the sealing capability in the shale rocks with microcracks. The research was carried out under laboratory conditions with the experiments on the sound wave propagation speed and pressure transmission. The system of drilling fluid with nanomaterials demonstrated strong effects in inhibiting clay swelling and dispersion.

Some other types of nanoscale materials are also used in drilling fluids. For example, two nanoparticle types of metal oxides (CuO and ZnO) were applied along with xanthan gum to improve the rheological, thermal and electrical properties of the water-based drilling fluid (William et al., 2014). The result of the CuO and ZnO nanoparticles addition increased the stability of the fluid to high pressure and high temperature. In another study, multi-walled carbon nanotubes (MWCNTs) were used to improve the thermal and rheological properties of water-based drilling fluids (Sedaghatzadeh, Khodadadi and Birgani, 2012). It was established that the addition of 1 vol.% of carbon nanotubes allowed increasing the thermal conductivity of drilling fluids by 23.2%. Additionally, significant improvement was observed in a number of rheological properties, such as filtration properties and viscosity.

The other way for improving the water-based drilling fluid is the use of nanocomposite material made of TiO_2 and polyacrylamide (Sadeghalvaad and Sabbaghi, 2015). This nanocomposite has a significant influence on improving the viscosity of the fluid, reducing fluid losses and the thickness of the sediment.

The combination of hydrophobic nano-silica and organically modified nanoclay has been used to stabilise emulsion of drilling fluids under deep drilling (Agarwal et al., 2013). The results of the experiments at the temperature of 225 °C has shown that the solution has a good high-temperature stability and is suitable for use under deep drilling conditions. The analyses of the nanoparticles application and nanocomposites in drilling fluids are given in Table 2 and Table 3.

Table 2

Practice of using nanoparticles in the drilling fluids (Aftab et al., 2017)

Drilling fluid type	Nanoparticles	Results
Water-based fluids	CuO та ZnO	Controlled viscosity at high pressure-high temperature
	Nano-silica	Prevented water invasion into shale
	Montmorillonite and palygorskite nanoparticles	Levelled out viscosity, gel strength, fluid loss, spurt loss and density at high pressure-high temperature
Surfactant/polymeric fluids	Nano-silica	Prevented filtrate loss
Water-based fluids	Nano-silica	Minimised clay swelling, filtrate loss at high pressure-high temperature and improved the viscosity
	Nano-silica, MWCNTs	Stabilised drilling fluid rheology
	Nanographite and nanosilica wire	Stabilised viscosity and prevented filtrate loss
	Nano-silica	Reduced loss of circulation and differential pipe sticking
	Nano-silica, MWCNTs	Prevented filtrate loss and maintained shale stabilisation

Table 3

Practice of using nanocomposites in the drilling fluids (Aftab et al., 2017)

Drilling fluid type	Type of nanomaterials	Results
Inhibitive water-based fluids	Polyacrylamide grafted polyglycol-clay nanocomposite	Nanocomposite provided better shale encapsulation than that by polyhydrolytic polyacrylamide.
Water-based fluids	Acrylamide polymer based nano-silica hybrid	Composite stabilised rheological properties and shale inhibition
	TiO_2 - polyacrylamide hybrid	Nanocomposite prevented filtration loss and improved the fluid viscosity
	Organic-inorganic gel hybrid	Composite prevented loss of circulation
	MWCNTs-polymer hybrid	Composite improved the sealing system for formation evaluation under high pressure-high temperature downhole conditions
	ZnO-clay nanocomposite	Composite stabilised the drilling fluid rheology at high pressure-high temperature conditions

1. Surfactants application for rocks weakening

In order to choose the optimal composition of the drilling fluid, it is especially important to know the properties of solid rocks in which drilling is carried out, since in addition to the basic functions, such as creating hydrostatic pressure, cleaning the bottom hole, lifting up the drill cuttings etc., it is necessary to adjust the surface forces that allow the effect of adsorptive lowering for the hardness value (preliminary weakening of the rock).

To solve these problems, the preliminary weakening for the rocks is carried out, which is a process by which the significant changes in their physical and mechanical properties take place with a decrease in the strength indicators. Moreover, the ways of weakening the rocks with rigid connections can be divided into five types, namely mechanical, thermal, chemical, biological and technological. Within each type, the subtypes are distinguished according to the type of energy and considering the method of its approach to the bottom hole (Table 4).

Table 4

Types and subtypes of rocks weakening methods

Type of rocks weakening methods	Subtype
Mechanical	Cutting or drilling gaps. Forcing water into the reservoir under high pressure. Hydro explosion. Loosening the surface of the massive
Thermal	One-sided heating using the flame of a gas burner, hot water, superheated air vapour. The use of alternating temperature effects. Heating throughout the volume with the help of electromagnetic fields. Laser irradiation, radio waves, and ultrasound
Chemical	The use of surfactants as a rock hardness reducer. Dissolving the cement with acids
Biological	–
Technological	Massive saturation with gas

The decrease in the surface energy of the solid exponentially decreases its durability under load, i.e. reduces strength.

For the actual reduction in the surface tension of the solid, the following can be used:

- internal adsorption effect, i.e. adsorption of the surfactants on the internal surfaces of the section of destruction germinal micro cracks;
- the effect of reducing the surface tension of the solid when it is polarised in strong electric fields (the possibility of practical use of this effect requires the research on how it affects the strength properties of rocks).

An important factor in intensifying the process of drilling rocks is the impact of surfactants on them. Surface-active environment affects the nature of the deformation and destruction of solids, mainly near the sharp (dead-end) ends of the developing cracks. In the areas of the solid deformation, the adsorption effect of the medium leads to the change in the effective surface energy per unit surface, which causes the change in the strength properties of the solid.

The greatest adsorption effects occur when new surfaces appear in the process of destruction and have time to be covered with adsorption layers. In this regard, the effectiveness of surfactant action under shock-rotary drilling and in the case of drilling with roller cone bits is higher than that with rotational ones equipped with crowns and cutting bits. The main point is that the influence of the external environment and adsorbing substances on the deformation and destruction of the solid is due to their penetration into microcracks at the significant depth in the pre-fracture zone, which develops within the solid during its deformation.

In the presence of the hardness reducer additives, the pre-fracture zone develops, and the fracturing in it increases, microcracks become deeper and their number per unit volume increases. This causes the greatest (depending on the concentration) facilitation of crystal splitting, with the greatest effect being achieved after a longer time.

The most effective reducers of strength are anion active surfactants in an alkaline medium, which agrees with the data obtained in studying the effect of surfactants on the contact strength of sandstones. Regarding the above mentioned, the creation of compositions of drilling fluids with the addition of reagents, hardness reducers of the rocks is a very urgent task, especially when drilling wells in solid rocks.

The studies reported below have been conducted on the materials grinding in the continuous and the periodic modes, for which grinding chambers of different designs have been used.

The grinding process in the laboratory mill was organised in a way to completely eliminate any dust generation. In each case, when grinding in a periodic mode, the chambers were opened only after they were cooled down to room temperature. Oxidised quartzites were used as the catalyst carrier, and feldspar as the promoter. The chemical composition of the media on which the adsorption properties were studied is presented in Table. 5.

Table 5

Chemical composition of the oxidised quartzite, wt.%

FeO	α-Fe_2O_3	SiO_2	Al_2O_3	CaO	MgO	MnO	P_2O_5	S
3.4	52.7	43.5	0.32	0.18	0.85	0.026	0.047	0.013

The initial state of the rocks was the powder with the fraction of 0.074 mm of about 70%. The experiments both on grinding in the continuous and the periodic modes were followed by the analysis of the particle size distribution of the rocks. The weights of the samples for the continuous mode were approximately 1000 g, and for the periodic mode were 130 g and 65 g. The grinding time was 20 and 40 minutes, respectively. At the stage of selection, the oxidised ore grinding with $MgSO_4$, V_2O_5, ZnO, CuO, rutile and feldspar had been conducted.

The samples were tested according to the following technological scheme: the catalysts in the form of the rings were tested in the flow-circulation plant at the temperature of 110°C, the concentration of sulphurous anhydride reached 1.1% by volume and oxygen was about 17.1% by volume in the initial reaction mixture and at the space velocity of 4000 h^{-1}. Additionally, under laboratory conditions, the rock and the glass were mixed with simultaneous grinding of the latter. That technological operation was carried out in the periodic mode. The grinding time was 10 minutes. As shown by the study of the final product, homogeneous-in-colour powder masses have been obtained in all the cases. In addition to vibro-impact grinding of the glass mass, its self-grinding against the iron powder took place at the same time. Moreover, the process selectively affected only the large fractions of glass (-500 +100) μm.

4. Conclusions

The nanotechnology application possesses a large potential in the oil and gas industry. The nanomaterial application schemes are more and more widely used in the principle processes, namely, in exploration, drilling, production, refining and processing.

Due to their unique properties, nanomaterials open up the new prospects for effective solution of complex tasks for the oil and gas industry.

This chapter discusses the main solutions that nanotechnology can provide in the oil-drilling sector, for instance, increasing productivity of production via nanomaterials application in the drilling fluids.

Nanomaterials play a multifunctional role in drilling and exploration of wells, especially in difficult and extreme environments. The drilling fluids containing nanomaterials acquire a number of important technological advantages, which can significantly increase the stability of the wellbore, reduce the cost of drilling, and improve the thermal and rheological properties of drilling water-based fluids.

In order to increase the efficiency of drilling, preliminary rocks weakening methods are used.

An important factor in intensifying the process of drilling rocks is the impact of surfactants on them, which can directly influence the nature of the deformation and destruction of solids.

Anionic surfactants in the alkaline medium are the most effective rock bottom strengths.

References

1. **Agarwal S., Phuoc T.X., Soong, Y.** et al. (2013). Nanoparticle-stabilized invert emulsion drilling fluids for deep-hole drilling of oil and gas. *The Canadian Journal of Chemical Engineering, 91,* 1641–1649. DOI: 10.1002/cjce.21768.

2. **Aftab A., Ismail A.R., Ibupoto Z.H.** et al. (2017). Nanoparticles based drilling muds a solution to drill elevated temperature wells: A review. *Renewable & Sustainable Energy Reviews, 76,* 1301–1313. DOI: 10.1016/j.rser.2017.03.050.

3. **Ahmed Kamel A.H.** (2013). A novel mud formulation for drilling operations in the permafrost. SPE Western Regional & AAPG Pacific Section Meeting 2013 Joint Technical Conference. Monterey, California, USA: Society of Petroleum Engineers.

4. **Amanullah M., Al-Arfaj M.K. and Al-Abdullatif Z.A**. (2011). Preliminary test results of nano-based drilling fluids for oil and gas field application. SPE/IADC Drilling Conference and Exhibition, Amsterdam, 1-3 March.

5. **Fink J.K.** (2012). *Petroleum engineer`s guide to oil field chemicals and fluids*. Gulf: Professional Publishing, Boston.

6. **Hoelscher K.P., De Stefano G., Riley M**. et al. (2012). Application of nanotechnology in drilling fluids. SPE International Oilfield Nanotechnology Conference and Exhibition, Noordwijk, 12–14 June.

7. **Khalil M., Jan B.M., Tong C.W**. et al. (2017). Advanced nanomaterials in oil and gas industry: Design, application and challenges. *Applied Energy*, *191*, 287–310. DOI: 10.1016/j.apenergy.2017.01.074.

8. **Li G.R., Zhang J.H., Zhao H.Z**. et al. (2012). Nanotechnology to improve sealing ability of drilling fluids for shale with micro-cracks during drilling. SPE International Oilfield Nanotechnology Conference and Exhibition, Noordwijk, 12–14 June.

9. **Li M.C., Wu Q.L., Song K.L.** et al. (2016). Cellulose nanocrystals and polyanionic cellulose as additives in bentonite water-based drilling fluids: rheological modeling and filtration mechanisms. *Industrial & Engineering Chemistry Research*, *55*(1), 133–143. DOI: 10.1021/acs.iecr.5b03510.

10. **Maliardi A., Sergiacomo M. and Del Gaudio L.** (2014). Successful application of innovative technology improves lubricity of high performance water-based mud systems in challenging environments. International Petroleum Technology Conference. Kuala Lumpur, Malaysia: International Petroleum Technology Conference.

11. **Maranuk C., Rodriguez A., Trapasso J.** et al. (2014). Unique system for underbalanced drilling using air in the Marcellus shale. SPE Eastern Regional Meeting: Society of Petroleum Engineers. Charleston, West Virginia, USA, 21–23 October.

12. **Nguyen P.-T., Do B.-P.H., Pham D.-K.** et al. (2012). Evaluation on the EOR potential capacity of the synthesized composite silica-core/ polymer-shell nanoparticles blended with surfactant systems for the HPHT offshore reservoir conditions. SPE International Oilfield Nanotechnology Conference and Exhibition. Noordwijk, The Netherlands: Society of Petroleum Engineers.

13. OPEC (2017). Organization of the Petroleum Exporting Countries. 2017 OPEC World Oil Outlook. Retrieved from http://www.opec.org

14. **Parizad A., Shahbazi K. and Tanha A.A.** (2018). Enhancement of polymeric water-based drilling fluid properties using nanoparticles. *Journal of Petroleum Science and Engineering*, *170*, 813–828. DOI: 10.1016/j.petrol.2018.06.081.

15. **Peng B., Tang J., Luo J**. et al. (2018). Applications of nanotechnology in oil and gas industry: progress and perspective. *The Canadian Journal of Chemical Engineering*, *96*, 91–100. DOI: 10.1002/cjce.23042.

16. **Rafati R., Smith S.R., Haddad A.S**. et al. (2018). Effect of nanoparticles on the modifications of drilling fluids properties: A review of recent advances. *Journal of Petroleum Science and Engineering*, 161, 61-76. DOI: 10.1016/j.petrol.2017.11.067.

17. **Ragab A.M.S. and Noah A.** (2014). Reduction of formation damage and fluid loss using nano-sized silica drilling fluids. *Petroleum Technology Development Journal*, *2*, 75–88.

18. **Sadeghalvaad, M. and Sabbaghi, S.** (2015). The effect of the TiO_2/polyacrylamide nanocomposite on water-based drilling fluid properties. *Powder Technology*, *272*, 113–119. DOI: 10.1016/j.powtec.2014.11.032.

19. **Saintpere, S., Marcillat, Y., Bruni, F.** et al. (2000). Hole cleaning capabilities of drilling foams compared to conventional fluids. SPE Annual Technical Conference and Exhibition: Society of Petroleum Engineers.

20. **Sehly K., Chiew H.-L., Li H.** et al. (2015). Stability and ageing behaviour and the formulation of potassium-based drilling muds. *Applied Clay Science*, *104*, 309–317. DOI: 10.1016/j.clay.2014.12.013.

21. **Sharma M.M., Zhang R., Chenevert M.E**. et al. (2012). A new family of nanoparticles based drilling fluids. In: SPE 160045 presented at the SPE annual technical conference and exhibition, October 8–10, San Antonio, Texas, USA.

22. **William J.K.M., Ponmani S., Samuel R.** et al. (2014). Effect of CuO and ZnO nanofluids in xanthan gum on thermal, electrical and high pressure rheology of water-based drilling fluids. *Journal of Petroleum Science and Engineering*, *117*, 15–27. DOI: 10.1016/j.petrol.2014.03.005.

ON THE PROBLEM OF UNDERGROUND MINE WORKING USE AS A SOURCE OF THERMAL ENERGY

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Abstract

Purpose. The paper is intended to pay attention of scientific community and technical community to the application prospects of underground permanent mine workings (and not only them) as a source of distributed energy required to heat both surficial and underground facilities.

Methodology. Theoretical studies, concerning geothermal processes with the use of analytical mathematical methods, have been carried out. The results of the theoretical studies and experiments have been analyzed and generalized.

Findings. It has been demonstrated that use of underground mine workings as an artificial medium, within which thermal pump manifold (or manifolds) is placed, makes it possible to generate such an amount of thermal energy which can be compared minimally with the energy generated in the process of combustion of the coal extracted from the mine working. In this context, a problem of reuse of mine working, excluded from a production chain but remained to keep their long-lasting stable state, can be solved partially.

Scientific novelty. A new approximate solution of specific problem, concerning heat exchange between a flat-plain manifold and a rock, has been obtained.

Practical relevance. The theoretical results, obtained by the paper authors, make it possible to forecast efficient use of mine workings as thermal energy

sources.

Keywords: underground mine workings, soil thermal pumps, heat and mass transfer, reverse process of rock heating-cooling, thermal energy.

Introduction. A problem to reuse abandoned different-purpose underground facilities is important currently [1,2,3]. Generally, such facilities involve:

- mined-out underground workings;
- different-purpose underground structures, not used for the purpose specified (including abandoned ones).

In the context of reuse, the mine workings, driven within hard rocks, not subjected to caving or flooding, are preferable.

Specification documents do not recommend reusing following mine workings:

1. Those located within areas of potential flooding by means of overflow water including cases when hydraulic structures are restructured suddenly.
2. Those located within following rocks:

- heavily watered;
- soft ones;
- unstable or carstified;
- areas with the intensive landslides;
- prone to spontaneous inflammation;
- prone to the emission of aggressive agents as well as harmful, explosive, and inflammable gases;
- being of increased radioactivity; and
- passing through areas with considerable tectonic faults.

Reuse of underground space relies upon adapting of available mine workings for new purposes. In this context, it is often required to perform extra drifting operations.

At the moment, the mined-out underground mine workings are used for the following [4, 2, 3]:

– warehouses for various materials (i.e. stocks, water reservoirs, oil reservoirs, gas reservoirs, reservoirs for oil products etc.);
- industrial facilities;
- hydroelectric plants (HEPs);
- thermal power plants (TPPs);
- pumped storage plants (PSPs);
- facilities to store, process, utilize harmful (including radioac-

tive) waste; and

- civil defense facilities.

The problem is that according to [5], cross dimensions of underground mine workings, to be used to place different objects within them, should not be less than those represented in Table 1.

In turn, it often results in the necessity to enlarge the available underground premises.

Moreover, if different facilities are located within underground mine workings, it involves the necessity to have:

1. Direct and emergency exits (entrances).
2. Underground transport.
3. Internal engineering structures (including protective structures, and supporting ones).
4. Heating, ventilation and conditioning systems including:
   - water supply;
   - sewage, and water removing; and
   - heat supply, cold supply, and gas supply.
5. Electric devices including:
   - electric supply;
   - electric facilities, and cabling; and
   - electric lighting.
6. Ensuring the fire safety of underground facilities or warehouses.

The abovementioned has helped us conclude that reuse of underground mine workings for economic needs is connected with significant material expenses, and labour intensity; moreover, it is not always possible or expedient.

Table 1

Minimum cross dimensions of underground mine workings if national economic assets are located within them

Premises and facilities		Minimum cross dimensions of the mine workings, m	
		width	height
1	Workshops to manufacture industrial product	4.0-9.0	2.5-6.0
2	Laboratories, auxiliary areas	6.0	3.0
3	Archives, book stacks, and museum vault areas	4.0	2.5-4.5
4	Warehouses, and storage facilities for different products including agricultural ones	5.0-8	2.6-6.0
5	Underground garages, and car parks	4.5-10.5	2.2-3.6

The abovementioned has helped us conclude that reuse of underground mine workings for economic needs is connected with significant material expenses, and labour intensity; moreover, it is not always possible or expedient.

In this connection, relatively innovative technology of heating and conditioning of buildings and structures, based upon the use of so-called thermal pumps, is of considerable interest [6,7,8,9,10,11].

Idea of the technology is as follows: during heating season, low-grade natural heat of earth cover is applied to heat both buildings and structures. While conditioning, excess heat does not dissipate in atmosphere; it is removed into a basement soil. Moreover, thermal energy is accumulated during operation in a reverse mode.

It should also be mentioned that thermal pumps are widely used in industrial but deficient in natural resources countries (for instance, Austria, Sweden, and Japan) which among other things are of high environmental culture [6,8].

The latter confirms indirectly the idea that the use of thermal pumps does not almost involve environmental problems.

Consider in detail the key characteristics of the design of thermal pumps. Thermal engine, represented in Fig. 1, is the basic component of a thermal pump.

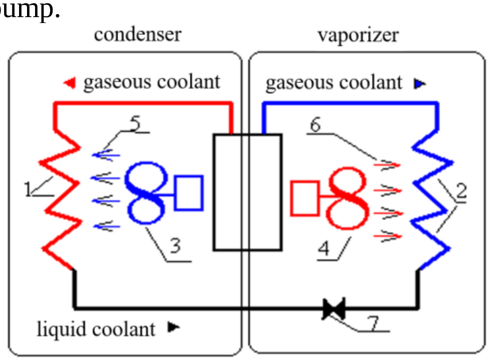

Fig 1. Thermal engine (scheme): *1* - condenser; *2* - vaporizer; *3* - a fan cooling the vaporizer; *4* - a fan operating to heat the condenser up; *5* - a flow of air (liquid) being heated; *6* - a flow of air (liquid) being cooled; *7* - a throttle

Operating principle of the thermal engine is based upon thermal effects of phase transition. Essence of the effect is in the fact that liquid can absorb heat during evaporation and gas can generate heat while being condensed. Thus, thermal engines are used either as a refrigerator or as a heating device (heater).

If thermal engine is used as a refrigerator, energy transformation process is as follows. Condenser is outside of the premises being cooled and vaporizer is inside. In the process of the operation, vaporizing coolant takes heat from the premises. As a rule, hydrochlorofluorocarbons are applied as the coolants.

The gas, which has been formed during phase transition, gets to a compressor converting it into high-pressure steam. Significant amount of heat is released during the compression process. Further, the gas gets into the condenser where it is condensed and liquated. In this context, significant amount of heat is liberated to the environment (for instance, into atmosphere) dissipating in it. Then, coolant pressure drops (as a rule, capillary pipe is applied). After that, the coolant returns to the vaporizer becoming gas again (in this context, heat is absorbed from the environment).

Hence, if thermal engine is used as a refrigerator, the four stages take place: compression; liquification; expansion; and evaporation.

However, thermal engine is just a part of thermal pump which operating principle is as follows: to heat up certain building volume, low-grade heat is taken off from much greater sub-base volume.

Thus, to cool down certain building volume, it is required to raise the temperature of much greater soil amount.

For heat extraction (when thermal pump operates in heating mode) or its extraction (when thermal pump operates in cooling mode), so-called manifolds of thermal pumps are applied. They take much greater area to compare with the heated space area.

Depending upon a type of a medium within which manifold of thermal pump, following types of thermal pumps are available [6, 8]:

“soil-water” (“soil-freezing mixture” more truly);

“water-water” (“water-freezing mixture” sometimes);

“air-water” (“air-freezing mixture” sometimes); and

understructure (or understructures)-water (or freezing mixture).

There is also the practice to locate manifolds of thermal pumps within underground mine workings (Fig. 2).

Table 2 represents experimental data, taken from scientific sources, concerning specific thermal capacity of heat extraction from understructures consisting of different soil types. The data have helped us conclude that:

- values of specific capacity of heat extraction from different soil types are of economic interest as for the use of soil thermal pumps;
- the higher moisture content of soil is, the greater amount of thermal energy may be extracted; and
- Table 2 represents data for limited amount of soil types (for instance, there are no data concerning hard rocks).

Further, it is necessary to decide how much it is possible to use subsoil as thermal energy accumulator for arbitrary type of rock enclosing manifold of a thermal pump. To determine order of the unknown value, it is quite sufficient to consider one-dimensional (in terms of coordinate) problem in such a way as it has been done by [6, 8] authors.

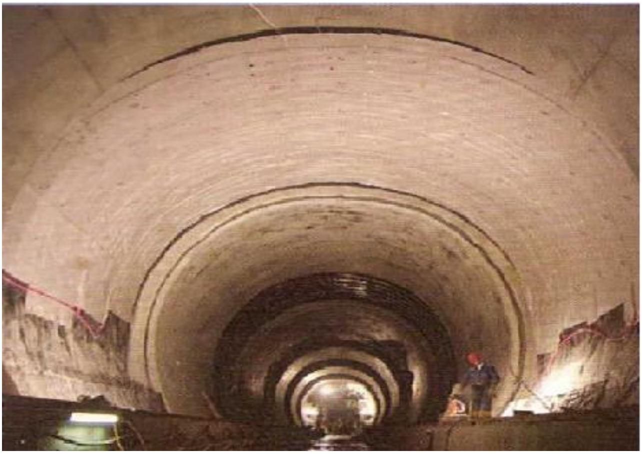

Fig. 2. Mounting of a manifold of thermal pumps within experimental area in Lainzer tunnel (Austria)

Consider temperature field in the central part of flat-plain manifold of thermal pumps, being parallel to day surface, of unstrained dimensions in the plan located within subsoil at *h* depth.

Such an analytical model is in the central part of a flat-plain manifold of a thermal pump.

Table 2

Specific capacitates of soil sampling using different subsoil types

Soil	Specific capacity of heat extraction q W/m^2
Dry sand	10

Soil	Specific capacity of heat extraction *q* W/m^2
Wet sand	15.0-20.0
Dry sandy clay	20.0-25.0
Wet sandy clay	25.0-30.0
Water-saturated sandy clay	35.0-40.0

The research task has been formulated as follows.

Temperatures at an upper boundary T_{v1}(t) (if z=0)(if) and at lower boundary $T_{v2}(t)$ (if $z=H$) of subsoil are known (Fig. 3).

Temperature distribution within the subsoil in terms of $T_0(z)$ depth is known at t-0 time moment.

Density, and thermophysical characteristic of the subsoil are known (i.e. its specific thermal capacity c_p and thermal conductivity coefficient).

Manifold of thermal pump (in winter), and conditioner (in summer) is located at h depth where constant temperature T_w(t) is maintained (Fig. 3).

In this context, optimum thermal contact is available between subsoil parts located over the manifold, and under it [12].

It is required to determine temperature distribution within the subsoil as well as the amount of subsoil thermal energy Q removed during calculation time period t_0 .

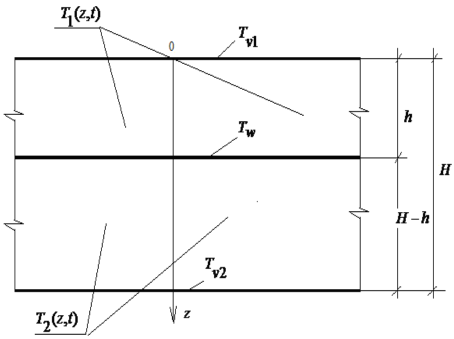

Fig. 3. On the determination of thermal energy of subsoil

From the physical viewpoint, the analytical model, represented in Fig. 3, is within a vertical passing through a centre of unrestricted flat-plain manifold being parallel to the earth's surface.

From the mathematical view, the problem is to solve a system of thermal conductivity equations of the type [12]

$$a \cdot \frac{\partial^2 T_1}{\partial z^2} - \frac{\partial T_1}{\partial t} = 0;$$
$$a \cdot \frac{\partial^2 T_2}{\partial z^2} - \frac{\partial T_2}{\partial t} = 0; \qquad (1)$$
$$a = \frac{\lambda}{\rho c_p}.$$

in terms of fulfillment of both initial and boundary conditions of the type

$$\left.\begin{array}{c} T_1(0,z) = T_0, if\ z \in (0,h); \\ T_2(0,z) = T_0, if\ z \in (h,H); \\ T_1(t,0) = T_{v1}(t); \\ T_1(t,h) - T_2(t,h) - T_w(t) = 0; \\ \frac{\partial}{\partial_z} T_1(t,h) - \frac{\partial}{\partial_z} T_2(t,h) = 0; \\ T_2(t,H) = T_{v2}(t). \end{array}\right\} \qquad (2)$$

and then evaluation of integral of the type

$$Q = \lim_{z \to h} \left\{ \int_0^t \lambda(z) \cdot \frac{\partial T(z,\xi)}{\partial z} \cdot d\xi \right\}. \qquad (3)$$

In this context, $T_1(z,t)$ is subsoil temperature if $z \in (0,h)$; $T_z(z,t)$ is subsoil temperature if $z \in (h,H)$; Q is thermal energy “pumped” into the subsoil during t time and related to a square meter of the manifold; and

$$a = \frac{\lambda}{\rho \cdot c_p}$$

is a coefficient of thermal conductivity [12, and 13].

To determine estimative values, simplify the research task, by setting in (1)

$$
\left.\begin{array}{c}
T_1(0,z) = 0, if\ z \in (0,h); \\
T_2(0,z) = 0, if\ z \in (h,H); \\
T_1(t,0) = 0; \\
T_w(t) = T_w = const; \\
T_1(t,h) - T_2(t,h) - T_w = 0; \\
\frac{\partial}{\partial_z} T_1(t,h) - \frac{\partial}{\partial_z} T_2(t,h) = 0; \\
H = \infty; \\
T_2(t,\infty) = 0.
\end{array}\right\} \qquad (4)
$$

To find solution (1) taking into consideration (4), apply one-sided Laplace transformation in terms of temporary variable. For (1), we have the following

$$
\left.\begin{array}{c}
a \cdot \frac{\partial^2 T_1}{\partial z^2} - \omega \cdot T_1 = 0; \\
a \cdot \frac{\partial^2 T_2}{\partial z^2} - \omega \cdot T_2 = 0.
\end{array}\right\}. \qquad (5)
$$

In this context, initial and boundary conditions (1) in terms of Laplace representation are

$$
\left.\begin{array}{l}
T_1(\omega,0) = 0; \\
T_w(\omega) = \frac{T_w}{\omega}; \\
T_1(\omega,h) - T_2(\omega,h) - \frac{T_w}{\omega} = 0; \\
\frac{\partial}{\partial z} T_1(\omega,h) - \frac{\partial}{\partial z} T_2(\omega,h) = 0; \\
T_2(\omega,\infty) = 0.
\end{array}\right\}. \qquad (6)
$$

In this context, ω is a parameter of Laplace transformation in terms of “t” variable [14].

Taking into consideration both initial and boundary conditions, general solution (5) is

$$\left.\begin{array}{l} T_1(\omega) = \frac{T_w}{2} \cdot \left\{ \begin{array}{l} \exp\left[-\sqrt{\frac{\omega}{a}}(h-z)\right] - \\ -\exp\left[-\sqrt{\frac{\omega}{a}}(h+z)\right] \end{array} \right\}; \\ T_2(\omega) = -\frac{T_w}{2} \cdot \left\{ \begin{array}{l} \exp\left[-\sqrt{\frac{\omega}{a}}(z-h)\right] + \\ +\exp\left[-\sqrt{\frac{\omega}{a}}(h+z)\right] \end{array} \right\}. \end{array} \right\} \quad (7)$$

Then, determine original (7). We have

$$\left.\begin{array}{l} T_1(z,t) = \frac{T_w}{2} \cdot \left\{ \begin{array}{l} erfc\left[-\frac{(h-z)}{2 \cdot \sqrt{a \cdot t}}\right] - \\ -erfc\left[-\frac{(h+z)}{2 \cdot \sqrt{a \cdot t}}\right] \end{array} \right\} if \in (0, h); \\ T_2(z,t) = -\frac{T_w}{2} \cdot \left\{ \begin{array}{l} erfc\left[-\frac{(h-z)}{2 \cdot \sqrt{a \cdot t}}\right] + \\ +erfc\left[-\frac{(h+z)}{2 \cdot \sqrt{a \cdot t}}\right] \end{array} \right\} if z \in (h, \infty). \end{array} \right\} \quad (8)$$

Further, determine a differential of thermal energy Q. Taking into consideration ((3)), we have

$$dQ = \lambda \cdot \left[\frac{\partial T_1(z,t)}{\partial z} + \frac{\partial T_2(z,t)}{\partial z}\right],$$

from which

$$dQ = \frac{\lambda \cdot T_w}{\sqrt{\pi \cdot a \cdot t}} \cdot \left\{\exp\left[-\frac{(h-z)^2}{4 \cdot a \cdot t}\right] + \exp\left[-\frac{(h+z)^2}{4 \cdot a \cdot t}\right]\right\}. \quad (9)$$

Then, set $t=\xi$ in (9) and integrate the expression, obtained in such a way, within $\xi = \in (0.t)$ interval. Thus, we have

$$Q = \frac{2 \cdot \lambda \cdot T_w \cdot h}{a} \cdot \left\{ \begin{array}{c} \frac{\sqrt{a \cdot t}}{\sqrt{\pi} \cdot h} \cdot \left(1 + \exp\left[-\frac{h^2}{a \cdot t}\right]\right) + \\ erf\left(\frac{h}{\sqrt{a \cdot t}}\right) \end{array} \right\}. \quad (10)$$

To make the analysis more convenient, normalize (10) to a dimensionless form. To do that, assume that $= \frac{\sqrt{at}}{h}$, and

$$Q_0 = \frac{2\lambda T_w h}{a}.$$

Taking into consideration the symbols, we obtain

$$\left.\begin{aligned} & Q = Q_0 \cdot Q^*; \\ & Q^* = \left\{ \frac{\xi}{\sqrt{\pi}} \left\langle 1 + \exp\left[-\frac{1}{\xi^2} \right] \right\rangle + erf\left(\frac{1}{\xi} \right) \right\}; \\ & \xi - \frac{\sqrt{at}}{h}; \\ & Q_0 = \frac{2\lambda T_w h}{a}. \end{aligned}\right\} \tag{11}$$

Fig. 4 represents graphic form of nondimensional thermal energy Q^*dependence upon nondimensional time ξ as well as its approximation.

It turned out to be that with the specified degree of accuracy (correlation coefficient is R=0.999), equality (11) may be represented in the form

$$Q^* = 1{,}13\xi. \tag{12}$$

Taking into consideration (12), represent definitely equality (11) as well as final solution of the problem as follows

$$\left.\begin{aligned} & Q = 1{,}13 \cdot Q_0 \cdot \xi; \\ & \xi - \frac{\sqrt{at}}{h}; \\ & Q_0 = \frac{2\lambda T_w h}{a} \\ & a = \frac{\lambda}{\rho \cdot c_p} \end{aligned}\right\}. \tag{13}$$

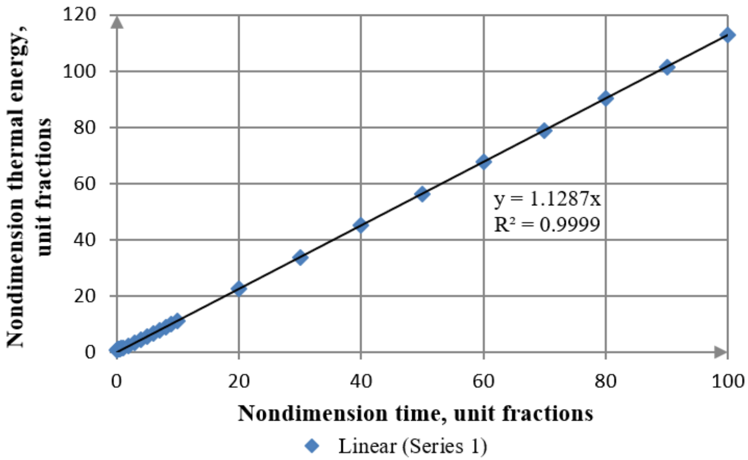

Fig. 4. On the approximation of dependence Q^*
Note. Points symbolize actual values of function Q^*; continuous line symbolizes approximation

While returning to standard (i.e. dimensional) variables, we will obtain following simple formulas to calculate the amount of thermal energy, removed from the subsoil per the calculated time as well as its extraction velocity *dQ/dt*

$$\left.\begin{aligned} Q &\approx 2{,}26 \cdot T_w \cdot \sqrt{\lambda \cdot \rho \cdot c_p \cdot t}; \\ \frac{dQ}{dt} &\approx 1{,}13 \cdot T_w \cdot \sqrt{\frac{\lambda \cdot \rho \cdot c_p}{t}}. \end{aligned}\right\} \qquad (14)$$

Analysis of formulas, represented in (14), has helped conclude:

1. The amount of thermal energy, removed from earth interior, is in direct proportion to the temperature taking place within the area of thermal pump T_w manifold as well as square root of production of conductive heat transfer coefficient per rock density, and its heat capacity.

2. Dependence of the amount of thermal energy, removed from the rock, upon time is described by time increasing function.

3. In this context, the velocity of thermal energy extraction from the subsoil looks like time decreasing function.

4. Under otherwise equal conditions, the amount of the thermal energy, removed from the subsoil, does not depend upon the depth, at which manifold of the thermal pump is placed.

It should be noted that the latter has theoretical value only since in the context of actual conditions, temperature distribution within earth cover depends upon heat inflow from earth interior as well as upon heat exchange at the boundary of a day surface.

Then, analyze the theoretical results obtained by us.

The numerical experiment involves data represented in Table 3.

First, determine specific capacity of heat extraction. To do that, assume $t = 1\ hour$ and $Tw = 1\ ^{0}C$ in lower equation (14).

The calculated values of heat extraction specific capacity are represented in column five of Table 3.

Table 3

Carrying conditions of the numerical experiment, and its results

Material	Density, kg/m³	Heat conductivity, W/m · degrees	Heat conductivity, W · hoir/kg · degrees	Specific capacity of heat extraction, w/m² $q = 1{,}13 T_W \sqrt{\lambda \rho c_p}$
Dry sand	1500	0.33	0.00022	12
Wet sand	1650	1.13	0.00058	37
Clay	1600--2900	0.7-0.9	0.00021	17-20
Granite	2600--3000	3.5	0.00024	53-57

Comparison of the values with those experimental ones represented in column two of Table 3 (Table 2) made it possible to make a conclusion concerning their satisfactory fit. That confirms rather high accuracy of the theoretical forecast performed by us.

Further, evaluate economic efficiency to use available underground mine workings for production with the application of soil thermal pumps.

Consider a meter of a mine working length where dimensions of square cross sections are 3×3 meters. The mine working is full of coal.

Taking into consideration the fact that specific coal weight is 1.2-1.5 t/m^3, weight of the coal, mined within the section, is

$$P_{coal} = 3 \cdot 3 \cdot 1 \cdot (1.2 \div 1.5) = 10.8 - 13.5\ tons =$$

$$= 10800 - 13500 \quad kg$$

Taking into account the fact that the thermal value of a kg of coal, specified in the context of the research, varies from q_{coal}= 2,22 Wh/kg (lignite) to q_{coal}= 7,50 Wh/kg 7.5 (anthracite), following amount of thermal energy is released while burning the coal which was mined

$$\left. \begin{aligned} Q_{coal} = P_{coal} \cdot q_{coal} = (10800 \div 13500) \cdot (2,22 \div 7.5) \\ = (23975 \div 101250)\ W \cdot h \end{aligned} \right\} \quad (15)$$

Then, determine the amount of thermal energy which may be released from the mine working with the use of thermal pump. Assume that manifolds of thermal pumps are arranged throughout internal surface of the mine working as it is demonstrated in Fig. 2.

Assume in addition that during 180 days thermal pump operates in heating mode and 180 days it operates in conditioning mode.

First, determine surface area of the mine working. We get

$$F_{mine\ working} = 4 \cdot (3.0m \cdot 1.0m) = 12\ square\ meters$$

Then, using upper equality (14), and data, represented in Table 3, determine specific thermal energy extracted from subsoil during six months.

We obtain

$$q_{m.н.} \approx 2.26 \cdot 1^{o}C \cdot \sqrt{\lambda \cdot \rho \cdot c_p \cdot (24\ hor) \cdot (180\ day)} =$$

$$= 148.5 \cdot \sqrt{\lambda \cdot \rho \cdot c_p}.$$

Since 180 days thermal pump operates in heating mode and 180 days it operates in conditioning mode, we get

$$q_{m.н.} = 2 \cdot 148.5 \cdot \sqrt{\lambda \cdot \rho \cdot c_p} = (3100 \div 14913) \frac{W \cdot h}{square\ meters}$$

To determine thermal energy, obtained from the analytical section of the mine working, multiply its area by previously calculated value of specific thermal energy. Thus, we have:

$$Q_{т.н.} = F_{mine\ working} \cdot q =$$
$$= (3100 \div 14913) \frac{W \cdot h}{squaremeters} \cdot 12\, squaremet$$
$$= (37023 \div 101250)\ W \cdot h \tag{16}$$

Comparison of (15) and (16) has helped conclude that the use of the mined-out working to place manifold of thermal energy within it will make it possible to obtain annual amount of thermal energy generated while burning coal, mined in the working.

In general, the research data have helped make following conclusions:

1. A problem of the abandoned underground mine workings takes place since in addition to above all else, they are environmentally hazardous.

2. Generally, traditional methods to reuse underground mine workings to be utilized are labour-intensive, materials-intensive, and expensive.

Moreover, the mine workings, subjected to their reuse, should satisfy tough conditions of strength, stability, ecology, minimum dimensions, and geometry.

3. There is efficient innovative technology to heat up building, and structures, and to heat water with the use of so-called thermal pumps. The technology makes it possible to save nonrenewable energy sources (i.e. gas, oil, coal etc.). The technology is based upon the use of low-grade environmental warmth for heating needs, and water heating-up.

4. Following thermal sources are used currently to heat buildings and structures, and water heating-up:

- subsoils and mine workings within them;
- water reservoirs (i.e. rivers, lakes, seas, oceans etc.); and
- air.

5. Water-saturated and nonwater-saturated subsoils as well as underground mine workings are the most promising sources to be used in a reverse mode (they are applied to cool down premises in summer, and to heat them up in winter).

6. Accurate solution and approximate solution of the problem, concerning heat exchange of a manifold of thermal pump, placed at certain depth, with infinite subsoil have been obtained. The following has been determined:

- the thermal energy, extracted from earth interior, is proportional directly to the temperature within the location of a manifold of thermal pump as well as square root of production of conductive heat transfer coefficient per rock density, and its heat capacity;

- velocity of the thermal energy extraction from the subsoil in the context of constant rock temperature within the area of its extraction decreases with the course of time; and

- satisfactory correspondence between experimental values and analytical values of specific capacities as for the heat extraction from a subsoil takes place.

7. Under otherwise equal conditions, the amount of the thermal energy, extracted from the mined-out working by means of thermal pump, can be comparable with the energy generated during combustion of coal which was extracted from the mine working.

8. While laying manifolds of thermal pumps within the abandoned underground mine workings, much milder demands are placed on the latter to compare with the mine workings where production activities are performed and warehouses are located.

Moreover, the amount of the thermal energy, obtained from the flooded underground mine workings, excesses significantly the amount of energy, obtained from the unwatered mine working.

What is more, the demands, placed on the strength and stability of the mine workings, where serviced, a fortiori unserviced manifolds of thermal pumps, are less rigid to compare with the mine workings where staff operate and material valuables are placed.

References

1. **V.N. Ermakov** Razvitie protsessov podtopleniia zemnoi poverhnosti pod vliianiem zakrytiia shaht/ **V.N. Ermakov, A.P. Semionov, O.A. Ulitski** [i dr.] //Ugol Ukrainy. – 2001. –№6.

2. Povtornoie ispolzovanie podzemnykh sooruzhenii i otrabotannyh vyrabotok-

[Elektronny resurs]. – Rezhim dostupa: http://remontikas.ru/interesno/Povtornoe_ispolzovanie_podzemnyh_sooruzheniy_i_otrabotannyh_gornyh_vyrabotok.

3. **Salnik Vitali** Atomnye elektrostantsii uidut pod zemliu [Elektronny resurs]: Bigness.ru (31.03.2012).

4. **Betke F.** Elertrichestvo iz-pod zemli/ **Philipp Betke** // Ekonomika i biznes.– 2010.- S.44-46 (12.03.2010).

5. SNiP 2.01.55-85 Obiekty narodnogo hoziaistva v podzemnyh vyrabotkah.

6. **Morklianik B.V.** Zakonomirnosti deformuvannia geomehanichnoi systemy “fundament-gruntovy masyv” v zoni dii kolektora teplovogo nasosa. Avtoreferat dysertatsii na zdobuttia naukovogo stupenia doktora tehnichnyh nauk. Dnipopetrovsk, 2015 - 32 s.

7. **Shapoval V.G.** O tselesoobraznosti ispolzovaniia gruntovyh osnovanii v kachestve nakopitelei tepla / V**.G. Shapoval, B.V. Morklianyk, A.V. Shapoval** // Zbirnyk naukovyh prats, seria: Galuzeve mashynobuduvannia, budivnytstvo. - Poltava, 2008. -Vyp. 22. -S. 138-142.

8. **Shapoval, V.G.** Osnovania i fundamenty teplovyh nasosov: monografia / **V.G. Shapoval, B.V. Morklianik**. – Lvov: SPOLOM, 2009. - 64 s.

9. Geotermicheskie teplovye nasosy dlia otopleniia i prigotovleniia goriachei rashodnoi vody. Tetrad proektanta.– Kiev. Junkers-2009-103 s.

10. **Brandl H.** Energy foundation and other thermo - active ground structures. Geotechnique 56. – 2006. - №2. - pp. 81-122.

11. **Brandi H.** Energy piles and diaphragm walls for heat transfer form and into the ground. Procssding of the 3-h international Geotechnical Seminar on Deep Foundations on Bored and Auger Piles. Ghent. Technical University, Vienna, Austria-1998-pp. 38-60.

12. **Kartashov E.M.** Analiticheskie metody v teorii teploprovodnosti tverdyh tel. – M.: Vysshia shkola, 1985. - 480 s.

13. Posobie k SNiP 2.01.55-85 Teplofizicheskie raschioty obiektov narodnogo hozaistva, razmeshchaiemyh v gornyh vyrabotkah.

14. **Korn G. i Korn T.** Spravochnik po matematike. - M.: Nauka, 1974. - 840 s.

MINE SURVEYING SUPPORT OF CONTROLLING LOSSES OF BALANCE INDUSTRIAL RESERVES

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Summary

The considered methods of the surveyor providing of works are on determination of volumes of crop and setting of norms of quality indexes of balance industrial supplies of bowels of the earth, in that examine the losses of balance-industrial supplies and impoverishments of content of quality indexes of minerals as the determined (non-random) sizes. The conducted review of methods and technical upshots will allow to bring down losses of balance industrial supplies and impoverishments) of content of quality indexes of minerals at a booty, ware housing and necessity of variegation of content of quality indexes of minerals in the stream of iron-ore mass.

The offered methodology of setting of norms of the balance-industrial supplies prepared to the booty is approved on the careers of Kryvyi Rih, and the methodology of setting of norms of preparedness of the balance-industrial supplies prepared to the booty, worked out for operating ore-mining enterprises modernized and adjusted to the use on the stage of planning. By an experience way the set values to the coefficient of reserve of extractive units, time domain between loosening of array of ferrous quartzite's in an extractive coalface accordingly in months and in changes and at presence of in the career of the motor-car and railway transporting of iron-ore mass from coalfaces for different time domains the got dependences for the calculations of norms ready to the booty of balance-industrial supplies.

Executed calculations of supplies taking into account the balanced manner on maintenance quality indexes minerals of supplies, show that the losses of balance-industrial supplies and impoverishments of content of quality indexes of minerals far more than they are certain on the accepted methodologies and that is why careful attitude toward the well balanced on maintenance quality indexes minerals of supplies in iron-ore mass, their timely maintenance and bringing in exploitation are major measures in relation to the guard of bowels of the earth and environment.

Offered methodology of control of the use of found-balance and maintenance of balanced on maintenance quality indexes minerals of supplies, that is attracted in exploitation, calculations conduct that after formulas, that take into account the volume of useful components attract that with breeds and balance on maintenance the quality indexes of minerals of supplies, so losses of balance-industrial supplies of that or other part of found-balance supplies of deposit. If not to conduct the separate account of all sources of entering iron-ore mass of useful components, then throw away opportunity objective comparison of job performances for the improvement of

the use of bowels of the earth of areas of arrays of hard minerals that are in different mining-and-geological terms.

It is well-proven that for the correct choice of normative the level of losses of balance-industrial supplies and impoverishment of content of quality indexes of minerals in iron-ore mass in every concrete case of the use of criterion of estimation of economic efficiency, that full enough takes into account the difference of variants of development for operating and capital charges. The criteria of economic evaluation at setting of norms of losses of balance-industrial supplies are differential mountain rent and income.

Introduction. Estimate rationality of process of mastering of mineral resources the indexes of plenitude of exception of them from the bowels of the earth and to the further processing. Planning of development of mountain works in the process of exploitation of balance-industrial supplies of deposit, bed, ore body or areas of array of hard minerals 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. The complete losses of minerals consist on the average of losses: in the process of booty - 10-30 primary processing (enriching) to 20–40 metallurgical redistribution - 10-15. That is why a task of the complex mastering of bowels of the earth is *actual*.

Researchers are based on materials of work of ore mining enterprises of Krivbass that are in the central part of the Ukrainian shield that is the basic geostructural element of south-west of the east Europe platform.

The aim of the work is the development and introduction of methodology of determination of losses of balance-industrial supplies and impoverishment of content of quality indexes of minerals taking.

For the achievement of the aim, such tasks are untied:

- the analysis of present methods of determination of losses of balance-industrial supplies and impoverishment of content of quality indexes of minerals;

- the improvement of existent methodologies of determination of losses of balance-industrial supplies and impoverishment of content of quality indexes of minerals taking into account the complex mastering of bowels of the earth;

- the establishment of norms of losses of balance-industrial supplies and impoverishment of content of quality indexes useful minerals;

- it is establishment of norms of the balance-industrial supplies prepared to the booty.

The idea of work is analysis and determination of methods of calculation of optimal losses for development of economy of ore-mining enterprises and indexes of plenitude of the use of resources of bowels of the earth at present labor and material resources.

The research object is balance-industrial supplies of bowels of the earth.

The subject of research is losses of balance-industrial supplies and impoverishments of content of quality indexes of useful minerals.

An determination of losses of balance-industrial supplies and impoverishment of content of quality indexes useful minerals. Basic indexes of the use of supplies of bowels of the earth are losses of balance-industrial supplies and impoverishments of content of quality indexes of minerals in an array and in the stream of iron-ore mass [1]. In quality of indexes to them reciprocals - coefficient of exception of minerals from the bowels of the earth and coefficient of changeability of content of quality indexes of minerals are accepted at the booty of balance-industrial supplies.

Methodology recommends also [2] the coefficient of obstruction of content of quality indexes of minerals. The first four indexes of the use of balance supplies are accepted officially by all ore-mining enterprises in accordance with [2] on determination, setting of norms and account, to the economic evaluation of losses of balance-industrial supplies of hard minerals.

For correct determination of losses of balance-industrial supplies and impoverishment of content of quality indexes of minerals in iron-ore mass, the same as indexes of exception from the bowels of the earth and changeability of content of quality indexes of minerals of iron-ore mass, value has a choice of method of the surveyor providing of works, that most full answers that is why or to other type of minerals. The indexes of losses of balance-industrial supplies and impoverishment of content of quality indexes of minerals are needed for the decision of economic tasks in iron-ore mass must take into account not only content of quality indexes of minerals, lose that impoverishing breeds, but also where and on what stage of the survey or providing of project mountain works lose these minerals and impoverish.

Only classification of losses of balance-industrial supplies of hard minerals [3-6], built because of division on the technological processes of booty and places, where losses of balance-industrial supplies are. This classification is given for all methods of development and all hard minerals. Taking her for basis, will consider the types of the surveyor providing of works on determination of losses of balance-industrial supplies and impoverishment of content of quality indexes of minerals in relation to the terms of development of iron-ore deposits.

Subdivide the losses of balance-industrial supplies into the losses of balance-industrial supplies in guard that does not withdraw even after liquidation of ore-mining enterprise and if barrier temporal in some period of time envisage their partial or complete exception, then minerals in that does not attribute to the losses of balance-industrial supplies, but set off to the balance supplies the operating losses of balance-industrial supplies (quantitative and quality), that is related directly to the booty of balance-industrial supplies, as they largely differ in technological reasons and places of their formation.

In relation to that or another way of development or to the certain mining and geological conditions, a number of varieties of losses of balance-industrial supplies will be it is or diminished, or megascopic. Depending on the type of losses of balance-industrial supplies and impoverishment to content of quality indexes of minerals in an array and in the stream of iron-ore mass choose the corresponding methods of the surveyor providing of works on their determination, and the detailed selection of types of losses of balance-industrial supplies and impoverishment of content of quality indexes of minerals in an array and in the stream of iron-ore mass allows in every separate case to choose more exact methods of the surveyor providing of their determination.

Determination of volume of losses of balance-industrial supplies and impoverishment of content of quality indexes of minerals in iron-ore mass.

Characterize the losses of balance-industrial supplies an amount and quality of part of minerals that abandon in the bowels of the earth, in comparing to liquidate balance-industrial supplies. Foremost at a choice and comparison of methods and systems of development, determination of production capacity of mine (career), height of floor (to the ledge), estimation of balance-industrial supplies and establishment of standard on minerals, comparison of opening methods, determination of rational parameters of the systems of development and surveyor providing of technology of mountain works.

The coefficient of exception of balance-industrial supplies from the bowels of the earth characterizes an amount and quality of the obtained part of balance supplies. If balance-industrial supplies are lost on content of quality indexes of minerals does not differ from the balance-industrial supplies of block determine their volume directly in the process of the surveyor providing of realization of mountain works in a coalface, for example at the semilongwall of development of loss of balance-industrial supplies determine in parts units by a direct method.

At the surveyor providing of mountain works at the systems of development with bringing down of array of hard minerals of loss of balance-industrial supplies determine an indirect method.

Impoverishment of content of quality indexes useful minerals in iron-ore mass (changeability of content of quality indexes of minerals) characterize a decline in the process of booty of balance-industrial supplies of content in them quality indexes of useful components and increase of part of the finished mixing breeds in comparing to the same indexes in the balance supplies of array of hard minerals. In separate case at the surveyor providing of mountain works of development of iron-ore deposits of hard minerals, impoverishment of content of quality indexes of minerals in iron-ore mass determine attitude of mass of the finished mixing breeds toward the obtained iron-ore mass. Characterize the coefficient of changeability of content of quality indexes of the obtained balance-industrial supplies content of quality indexes in him useful components or harmful admixtures, parts of the finished mixing breeds, by humidity, grade and other factors on that the degree of fitness of minerals depends for the further processing or use in a national economy. Impoverishments of content of quality indexes of minerals in iron-ore mass determine in parts of units a direct method. Both types the brought formulas [6] over allow to estimate the use of balance-industrial supplies in two cases, when lose balance-industrial supplies with balance content of quality indexes of useful components, and at impoverishing on maintenance the quality indexes of obtained minerals breeds there are not useful components or there are useful components.

In two another cases, when lose balance-industrial supplies that on content of quality indexes differ from middle balance on maintenance the quality indexes of minerals and at impoverishing on maintenance the quality indexes of obtained minerals breeds there are not useful components or there are useful components. For more clear surveyor providing of works on control of the use of found-balance and maintenance of balanced on maintenance quality indexes minerals of supplies, that will be in the near time attract in exploitation, calculations conduct after formulas, that take into account both mass of useful components attract that with breeds and balanced on maintenance the quality indexes of minerals of supplies and losses of balance-industrial supplies of that or other part of the found out supplies.

In third case, when lose the balance-industrial supplies of minerals, content of quality indexes of that differs from balance supplies on maintenance the quality indexes of minerals, but at impoverishing on maintenance quality indexes minerals breeds there are not useful components, determine the indexes of the use of balanced on maintenance quality indexes minerals of supplies [6].

In most general, fourth case, when content of quality indexes of minerals in balance-industrial supplies, lose that, differs from middle content of quality indexes of minerals in the balance-industrial supplies of array of hard minerals and impoverishing on maintenance the quality indexes of minerals of breed contain useful components, formulas for determination of indexes of the use of balance-industrial supplies of bowels of the earth [6].

Formulas are however above-mentioned suitable only for one component minerals without the account of possibilities of the complex use of passing components of minerals. Today all less than one component minerals become and less than. In ferrous quartzite's except a basic component there is much copper, vanadium, zinc, lead and other useful components, part from them in composition wastes use as building material. On some deposits, beds, ore bodies or areas of array of ferrous quartzite's content of quality indexes of titan, vanadium, cobalt, copper, zinc, sulphur, nickel, phosphorus, germanium and non-metallic minerals sometimes higher, what in the basic deposits of minerals of the coloured metals. The applied formulas are for determination of indexes «visible» losses of balance-industrial supplies and impoverishment of content of quality indexes of minerals in iron-ore mass concordantly [5; 7; 8] both adulterations in iron-ore mass of useful components of containing breeds and their additions or reductions take into account in her due to abandonment in the losses of balance-industrial supplies of impoverished or enriched on maintenance the quality indexes of minerals of part. However the end-point allows exactly to take into account and divide the sources of bringing in iron-ore mass on maintenance the quality indexes of useful components and source of losses of balance-industrial supplies and on maintenance quality indexes minerals of supplies, as a result visibility of prosperity is created sometimes even in case of impermissible severe losses of balance-industrial supplies. At content of valuable component in breeds that apply, (often it arrives at 0,3–0,5 middle content of quality indexes of minerals) such visibility of prosperity is possible even at 30 % losses of balance-industrial supplies.

If not to conduct the separate account of all sources of entering iron-ore mass from the balance-industrial supplies of useful components, then lose another possibility of objective comparison of work for the improvement of the use of bowels of the earth of areas of arrays of hard minerals that are in the different mining (at presence of in the breeds of useful components and without them, at possibility of abandonment in the losses of balance-industrial supplies of poor on maintenance quality indexes minerals and without them) and geological conditions. In an order to take into account this important circumstance, some other factors (even partly), for example multicomponent of minerals and possibility of determination of losses of balance-industrial supplies at the surveyor providing of booty and complexity of the use of mineral raw material, it is expedient to replace an index – content of quality indexes of useful components (metals) by next indexes:

- minerals, that withdraw the value of content of quality indexes in the balance supplies of $ц_б$;
- in supplies, that lose $ц_п$;
- at impoverishing on maintenance quality indexes minerals breeds of $ц_р$;

- by a value on maintenance quality indexes in digging, that withdraw $ц_д$.

Then for four losses of balance-industrial supplies and impoverishment considered earlier cases on maintenance the quality indexes of minerals of breed determine after next formulas

а - when $ц_б$=$ц_п$ і $ц_р$=0

$$П = 1 - (Д_ц / Бц_б)\,; \tag{1}$$

$$Р = 1 - (ц_д / ц_б)\,. \tag{2}$$

б - when $ц_б$=$ц_п$ і $ц_р \neq 0$

$$П = 1 - \frac{Д(ц_Д - ц_р)}{Б(ц_Б - ц_р)}\,; \tag{3}$$

$$Р = 1 - \frac{ц_Б - ц_Д}{ц_Б - ц_р}\,. \tag{4}$$

в - when $ц_б \neq ц_п$ і $ц_р$=0

$$П = 1 - \frac{Дц_Д}{Бц_Д}\,; \tag{5}$$

$$Р = \frac{Б(ц_Б - ц_п) - Д(ц_Д - ц_п)}{Б(ц_П - ц_Р)} \tag{6}$$

г - when $ц_б \neq ц_п$ і $ц_р \neq 0$

$$П = \frac{Б(ц_Б - ц_п) - Д(ц_Д - ц_р)}{Д(ц_П - ц_р)}\,; \tag{7}$$

$$Р = \frac{Б(ц_Б - ц_п) - Д(ц_Д - ц_р)}{Д(ц_п - ц_р)} \tag{8}$$

With these formulas study not only entering sources balance-industrial supplies of useful components but also entering sources iron-ore mass of harmful components.

Indexes of the use of bowels of the earth are with taking into account of sibilance on maintenance quality indexes minerals of supplies. Experience of development of iron-ore deposits testifies that in many cases she is carried out in a few stages. On the measure of working off the richest deposits, beds, ore bodies or areas of array of hard minerals in exploitation attract more poor on maintenance quality indexes minerals. In a number of cases with high efficiency already work off deposits, beds, ore bodies or areas of arrays of balance-industrial supplies that yet recently distinguished as sibilance. Maintenance and account presently of sibilance on maintenance quality indexes minerals of supplies matter Therefore, especially for creation of raw mineral-material base of country on the nearest years.

On many deposits of hard minerals exploitation of poor and sibilance on maintenance quality indexes minerals of supplies is already conducted. In the Kryvyi Rih pool develop ferrous quartzite's in that on maintenance quality indexes iron presents 32-37 % id est 0,76-0,82 % and 0,61-0,73 % medium on maintenance the quality indexes of minerals in the balance-industrial supplies of rich on maintenance quality indexes minerals. Mark at the same time, that a guard and rational use of balanced on maintenance quality indexes minerals of supplies on enterprises carries out levels not on a due. Yes, from data [8-13], at development of rich on maintenance quality indexes minerals of supplies of Kryvyi Rih counterfeited and, thus, up to a point 2,6 milliards of т of ferrous quartzite's are lost for future development. On some ore mining enterprises the surveyor providing of mountain works is at development of balance-industrial supplies on mine enterprises carry out levels not on a due. To such attitude toward the balanced on maintenance quality indexes minerals of supplies the methods of their determination and account applied at this time promote in a great deal. In accordance with them the volumes of losses of balance-industrial supplies, impoverishment on maintenance the quality indexes of minerals and indexes of exception of balance-industrial supplies provide for to determine without an account on maintenance the quality indexes of minerals, lose that and volumes presently balanced on maintenance quality indexes minerals of supplies, that bring over to the booty. On the deposits of hard minerals where clear differentiations are between ore bodies and containing breeds that apply and does not contain the quality indexes of useful components, and also on deposits work off that the systems with a book-mark et al, fully sufficiently methods of the surveyor providing of works on an account, that provide for [5;14], however in most cases they do not allow to provide the complex and rational use balance-industrial and balanced on maintenance quality indexes minerals of supplies.

Zabalance on maintenance the quality indexes of minerals supplies enormous money is expended in secret service of that, unfortunately, while economically not estimated and, thus does not have a value. In the total in mining districts a giant loss the consequences of that it is while difficult to estimate is inflicted a future raw mineral-material base. Quite obviously, that the problem of the complex mastering of bowels of the earth cannot be decided on the basis of estimation and account of the use only of balance-industrial on maintenance quality indexes minerals of supplies, id est supplies of today, without a corresponding estimation and account presently of zabalance on maintenance quality indexes minerals of supplies, or supplies of future periods the especially nearest. Not to take into account them - so to conduct disorderly predatory exploitation of bowels of the earth, but especially their part – balanced on maintenance quality indexes minerals of supplies, that can as it is visible on the example of Kryvyi Rih considerably exceed balance supplies.

Accordingly [3] from the surveyor providing of works on the account of losses of balance-industrial supplies and impoverishment on maintenance the quality indexes of hard minerals, the «actual» losses of balance-industrial supplies and impoverishments determined only on maintenance the quality indexes of minerals, losses of balance-industrial supplies and impoverishments are on maintenance the quality indexes of minerals of balance supplies. The lack of these methods consists in that they do not take into account useful components in finished mixing to iron-ore mass of breeds, losses of balance-industrial supplies balanced after impoverishment on maintenance the quality indexes of minerals and corresponding to them indexes of exception from the bowels of the earth of balance-industrial supplies and changeability of content of quality indexes of minerals in the obtained balance-industrial supplies concordantly [3]. Use of indexes and formulas in [2;6] and branch instructions [2;4] take into account a multicomponent on maintenance the quality indexes of minerals of balance-industrial supplies on the basis of determination of their value, and also total content of useful components in the obtained balance-industrial supplies regardless of or there were they in balance-industrial supplies or introduced with impoverishing on maintenance the quality indexes of minerals breeds or balanced on maintenance the quality indexes of minerals supplies. At the same time, unlike the actual losses of balance-industrial supplies and impoverishment on maintenance the quality indexes of minerals, such indexes, as a coefficient of exception of balance-industrial supplies from the bowels of the earth, the coefficient of changeability on maintenance the quality indexes of minerals and «visible» losses of balance-industrial supplies and impoverishments on maintenance the quality indexes of minerals (concordantly [5]) quite not take into account neither a possible rejection on maintenance the quality indexes of minerals, lose that from middle on maintenance the quality indexes of minerals of balance-industrial supplies, nor part and impoverishing on maintenance quality indexes minerals of breeds (of content in them useful or harmful components.

None of formulas [6] and branch instructions [2;4] for determination of volumes of losses of balance-industrial supplies, impoverishment on maintenance the quality indexes of minerals, coefficients of exception of balance-industrial supplies from the bowels of the earth and changeability of content of quality indexes of minerals does not take into account the possible bringing in exploitation with the impoverishing breeds of balanced on maintenance quality indexes minerals of supplies or them possible earning additionally, that eliminates normal exploitation of these balanced on maintenance quality indexes minerals of supplies in the future.

On ore-mining enterprises planning content of quality indexes of useful components in iron-ore mass is provided due to earning additionally presently substandard balanced on maintenance quality indexes minerals of supplies, that eliminates their normal exploitation in the future. Earning additionally of supplies of poor on maintenance quality indexes minerals is inflict a loss not only to the bowels of the earth, but potentially and to the environment, because instead of present it will be to master the new deposits of hard minerals and accordingly to distort the ecological balance in new districts. Therefore for more complete and complex use of bowels of the earth and improvement of conservancy it is necessary to take into account all subtleties of the use of balance-industrial and balanced on maintenance quality indexes minerals of supplies in close connection with conservancy.

That more exactly and clearly to control the use self of balance-industrial supplies, but not balance-industrial supplies together with balanced on maintenance the quality indexes of minerals of supplies and by the enriched useful components by breeds and simultaneously to provide an account and maintenance of balanced on maintenance quality indexes minerals of supplies, that can be in the near time also attracted in exploitation, it is necessary to use formulas [15–20], what is taken into account by receivables in iron-ore mass of useful components separately from balance-industrial supplies, containing breeds and balanced on maintenance quality indexes minerals of supplies, and also what quality indexes and how many useful components abandon in the lost iron-ore mass, but not in general in the bowels of the earth.

Taking into account of amount and quality of attracted in the booty of balanced on maintenance quality indexes minerals of supplies, and also amount and content of quality indexes of attached here and broken, restored to a state, useless for further development in the future, balanced on maintenance quality indexes minerals of supplies. Balance of content of quality indexes of metals at the surveyor providing of works at development of balance-industrial supplies with the partial bringing in exploitation of him balanced on maintenance quality indexes minerals of supplies and adulteration it is hard to iron-ore mass of certain part of impoverishing on maintenance quality indexes minerals of breeds looks like

$$Дa=Бc+q_1Бc_3-ПБc+Bb \qquad (9)$$

where $Д,Б,В$ is mass accordingly the liquidated balance-industrial supplies obtained, and finished mixing to loosen to iron-ore mass of impoverishing on maintenance quality indexes minerals of breeds, т; and, c, c_3 and b is content of quality indexes of metal or other useful component accordingly in the obtained iron-ore mass from the array of balance-industrial supplies, content of quality indexes of minerals in balance-industrial supplies, at balanced on maintenance quality indexes minerals supplies and impoverishing on maintenance quality indexes minerals breeds, q_1 is a fate of attracted in exploitation of balanced on maintenance quality indexes minerals of supplies (in relation to balance-industrial), part of units.

If mass of the lost balance-industrial supplies equals П×Б, then mass of finished mixing to loosen to iron-ore mass of impoverishing on maintenance quality indexes minerals of breeds can be certain after expression

$$В=Д+ПБ-Б-q_1Б \tag{10}$$

Putting of this expression in a formula (9), determine the losses of balance-industrial supplies (in parts of units) after a formula

$$П=1+\frac{q_1(c_3-b)}{c-b}-\frac{Д(a-b)}{Д(c-b)} \tag{11}$$

and impoverishment of content of quality indexes of minerals in iron-ore mass after a formula

$$P=\frac{Д(c-a)}{Д(c-b)}-\frac{Бq_1(c-c_3)}{Д(c-b)} \tag{12}$$

If balanced on maintenance the quality indexes of minerals supplies does not attract in exploitation, and only earn additionally and violate, id est when $q_1=0$, then formulas (11) and (12) look like

$$П=1-\frac{Д(a-b)}{Б(c-b)}; \tag{13}$$

$$P=\frac{c-a}{c-b}. \tag{14}$$

Calculations in obedience to these the formulas show, if to examine the supplies o minerals taking into account the balanced on maintenance quality indexes minerals of supplies, then volumes of losses of balance-industrial supplies and impoverishment of content of quality indexes of minerals in iron-ore mass in reality far more than they are certain on the accepted methodologies.

Therefore careful attitude toward the balanced on maintenance quality indexes minerals of supplies, their timely maintenance and bringing in exploitation are major measures in relation to the guard of bowels of the earth and accordingly all environments. Like a previous conclusion balances of mass and values to the case of the surveyor providing of works on the account of the partial bringing in exploitation and earning additionally of balanced on maintenance quality indexes minerals of supplies in relation to the terms of multicomponent minerals can be presented by the next system

$$\begin{cases} Дц_д = Бц_б + q_1 Бц_з - ПБц_б + Вц_р \\ В = Д + ПБ - Б(1 + q_1) \end{cases} \qquad (15)$$

where $ц_Д$ and $ц_б$ is a value of digging from the array of balance-industrial supplies and minerals in the array of balance-industrial supplies; $ц_з$ and $ц_р$ is a value of mineral sat the balanced on maintenance quality indexes minerals of supplies and impoverishing on maintenance quality indexes minerals of breeds.

Uniting the system of equalizations relatively $П$, obsessed

$$П = 1 + \frac{q_1(ц_з - ц_р)}{ц_Д - ц_р} - \frac{Д(ц_Д - ц_р)}{Б(ц_б - ц_р)}; \qquad (16)$$

$$P = \frac{В}{Д} = \frac{ц_б - ц_Д}{ц_б - ц_р} - \frac{Бq_1(ц_б - ц_р)}{Д(ц_б - ц_р)} \qquad (17)$$

Expressions of indexes of losses of balance-industrial supplies and impoverishment of content of quality indexes of minerals in iron-ore mass (11) and (12) characterize only the state of the use of sibilance on maintenance quality indexes minerals of supplies basic to the component. They are the useless for description uses that sometimes attract in exploitation or the counterfeited balanced on maintenance quality indexes minerals of supplies that also beds together with other minerals, breeds of opening and driving of making, feigns etc. For the decision of task of the complex use and mastering of deposit, bed, ore body or areas of array of hard minerals, creation had rejected and unrejected technologies of booty of balance-industrial supplies and processing of content of quality indexes of minerals in iron-ore mass it is necessary to create the corresponding methods of the surveyor providing of works on determination of losses of balance-industrial supplies and processing of content of quality indexes of minerals in iron-ore mass.

Determination of volumes of losses of balance-industrial supplies and impoverishment is on maintenance the quality indexes of minerals taking. At development of complex deposit, bed, ore body or areas of array of hard minerals withdraw one useful fossil, and other often loses for further development. The value of passing minerals sometimes considerably exceeds the value of basic useful fossils and, naturally, loss from the losses of balance-industrial supplies large enough. However, at determination of volume of losses of balance-industrial supplies and loss from them this variety of losses of balance-industrial supplies, similarly as volumes of losses of balance-industrial supplies balanced on maintenance the quality indexes of minerals supplies that operate in present tense methods quite not take into account. In quality of losses of balance-industrial supplies will consider privation of possibility of the useful use of mine-out space. So, for example, at the systems with bringing down and with a complete book-mark this possibility is practically eliminated, at the systems with cleansing open-space and with his partial book-mark there is large possibility of the use of greater volumes of mine-out space.

At the surveyor providing of works on the account of potential value of passing minerals that bed together with a basic useful component, mine-out space of breeds and wastes of mountain and ore mining and processing production balance of values on a deposit, bed, ore body or areas of array of hard minerals is presented like previous. At terms, when lose all passing minerals and does not use other possibilities (mine-out space, opening breeds, wastes of booty of balance-industrial supplies and enriching of content of quality indexes of minerals, is in iron-ore mass), losses of balance-industrial supplies in two simplest cases, when $ц_п=ц_б$ and $ц_р=0$, and also $ц_п=ц_б$ and $ц_р\neq 0$, determine by formulas

$$П = 1 - \frac{Д_1 ц_{Д1}}{Бц_{б1} + \sum_{i=1}^{n} r_i Б_i ц_{бi}} \tag{18}$$

$$П = 1 - \frac{Д_1 (ц_{Д1} - ц_{Др1})}{Б\left(ц_{бi} + \sum_{i=1}^{n} r_i Б_i ц_{бi} + ц_{бр1} \right)} \tag{19}$$

where $Д_1, Б$ is mass of digging from the array of balance-industrial supplies and balance-industrial supplies in the bowels of the earth of basic useful fossil, т; $ц_{д1}$ and $ц_{б1}$ is a value of content of quality indexes of minerals in iron-ore mass of obtained useful fossils from the array of balance-industrial supplies and balance supplies of basic useful fossil, hrn./of т; ri is a coefficient that shows, in the how many times greater or less balance-industrial supplies of i-a of useful fossil from the array of balance supplies of basic useful fossil; Бі is balance-industrial supplies of i-a of useful fossil, т; $ц_{бi}$ is a value of content of quality indexes of minerals in iron-ore mass of i-a of useful fossil obtain that from the array of balance-industrial supplies to the hrn./of т; $ц_б p_1$ is a value of impoverishing on maintenance quality indexes minerals of breeds, obtain that, on basic useful fossil, hrn./of т.

Like there can be the decided tasks on determination of losses of balance-industrial supplies and impoverishment to content of quality indexes of minerals in iron-ore mass for another cases, id est when $ц_п \neq ц_б$ and $ц_р=0$, and also when $ц_п \neq ц_б$ and $ц_р \neq 0$ [6].

In connection with the tendency of increase of the productivity of obtaining units on the booty of balance-industrial supplies and opening breeds the size of the productive productivity of quarry on rocky mountain mass in a prospect must increase. In addition, in connection with the improvement of technique and technology of explosive works increase the number of blocks, that simultaneously use during a mass explosion that conduces to the increase the sizes of the productive productivity of quarry on rocky mountain mass, and thus, to the increase of range of changeability of the productive productivity of quarry in that the size of time domain does not depend on the productive productivity.

Thus, basic indexes of the use of supplies of bowels of the earth are losses of balance-industrial supplies and impoverishments of content of quality indexes of minerals in iron-ore mass and in relation to that or another way of development or to the certain mining and geological conditions, a number of varieties of losses of balance-industrial supplies can be it is or diminished, or megascopic.

1. Depending on the type of losses of balance-industrial supplies and impoverishment of content of quality indexes of minerals in iron-ore mass choose corresponding to them methods of the surveyor providing of works on their determination. The detailed selection of types of losses of balance-industrial supplies and impoverishment of content of quality indexes of minerals in iron-ore mass allows in every separate case to choose the exact methods of their determination.

2. On the basis of the conducted analysis of present methods of determination of volumes of losses of balance-industrial supplies it is analyzed to content of quality indexes of minerals in relation to the terms of development of iron-ore deposits and it is set that the complex mastering of bowels of the earth, requires application of corresponding methods of determination and estimation of losses of balance-industrial supplies of minerals that take into account to the feature of complexity and plenitude of the use of all supplies balance and all minerals.

3. In connection with the tendency of increase of the productivity of obtaining units on the booty of balance-industrial supplies and opening breeds the size of the productive productivity of quarry on rocky mountain mass in a prospect must increase. In addition, in connection with the improvement of technique and technology of explosive works increase the number of blocks, that simultaneously use during a mass explosion that conduces to the increase the sizes of the productive productivity of quarry on rocky mountain mass, and thus, to the increase of range of changeability of the productive productivity of quarry in that the size of time domain does not depend on the productive productivity.

4. Methodology of control of the use of found-balance and maintenance of balanced on maintenance quality indexes minerals of supplies, that is attracted in exploitation, calculations it is necessary to conduct after formulas, that take into account both mass of useful components attract that with breeds and balanced on maintenance the quality indexes of minerals of supplies and losses of balance-industrial supplies of that or other part of found-balance supplies and if not to conduct the separate account of all sources of entering iron-ore mass from the balance-industrial supplies of useful components, then throw away opportunity objective comparison of work for the improvement of the use of bowels of the earth of areas of array of hard mineral, that be in different mining-and-geological conditions.

5. On the ore-mining enterprises, working off balance-industrial supplies execute with the groundless bringing in exploitation of part of balanced on maintenance quality indexes minerals of supplies, as a result violate their arrays and throw away opportunity the effective use in the future of basic part, or application of the system of

development and the methods of redemption of mine-out space do not allow to return on old areas for the exception of balanced on maintenance quality indexes minerals of supplies.

6. Implementation calculations show, if to examine the supplies of minerals taking into account the balanced on maintenance quality indexes minerals of supplies, then the losses of balance-industrial supplies and impoverishments of content of quality indexes of minerals far more than they are certain on the accepted methodologies in reality.

7. Certainly, that for the correct choice of optimal level of losses of balance-industrial supplies and impoverishment of content of quality indexes of minerals in every concrete case uses the criterion of estimation of economical efficiency that takes into account the difference of variants of development on running and capital expenses.

References

1. Collection of guidance on the protection of mineral resources. (1973). Collection of guidance on the protection of mineral resources. Moscow, Moscow: Nedra.

2. Uniform rules for the protection of mineral resources in the development of solid mineral deposits. (1987). Uniform rules for the protection of mineral resources in the development of solid mineral deposits. Moscow, Moscow: Nedra.

3. **Sidorenko V.D., Fedorenko P.I., Sholokh N.V., Peremetchik A.**V. (2010). New directions in mine surveying. Krivoy Rog, Krivoy Rog: KTU Publishing Center.

4. Sectoral instructions for the determination, accounting and rationing of ore losses in the development of iron ore, manganese and chromite deposits at the enterprises of Minchermet USSR. (1975).

5. Sectoral instructions for the determination, accounting and rationing of ore losses in the development of iron ore, manganese and chromite deposits at the enterprises of Minchermet USSR. Belgorod, Belgorod: VIOGEM.

6. **Sholokh M. V.** (2017). Methodology for the standardization losses of ready-to-extract solid minerals. // For participation in the 2nd International Scientific and

Technical Internet Conference «Innovative Development of Mining Industry». Kryvyi Rih, Kryvyi Rih.

7. **Sholokh M. V., Sholokh S. M., Sergieieva M. P.** (2018). An analysis of surveyor control of losses of balance-industrial supplies is at mastering of bowels of the Earth. // Innovative development of resource-saving technologies for mining. Multi-authored monograph. Sofia, Sofia: Publishing House «St. Ivan Rilski».

8. **Sholokh M. V.** (2018). Determination and research of norms of the ferrous quartzites prepared to booty. // Development of scientific foundations of resource-saving technologies of mineral mining and processing. Multi-authored monograph. – Sofia, Sofia: Publishing House «St. Ivan Rilski».

9. **Sholokh M. V.** (2018). An analysis of surveyor control of losses of balance-industrial supplies is at mastering. // International Scientific and Technical Internet Conference «Innovative Development of Resource-Saving Technologies of Mineral Mining and Processing». Book of Abstracts. Petroşani, Romania, Petroşani, Romania: UNIVERSITAS Publishing.

10. **Sholokh M. V.** (2018). Optimization of correlation of losses of balance-industrial supplies and obstruction of content of quality indexes of minerals is in the stream of iron-ore mass. // International Scientific and Technical Internet Conference «Innovative Development of Resource-Saving Technologies of Mineral Mining and Processing». Book of Abstracts. Petroşani, Romania, Petroşani, Romania: UNIVERSITAS Publishing.

11. **Sholokh M. V.** (2018). Planning of development of mountain works in the process of exploitation of balance-industrial supplies. // International Scientific and Technical Internet Conference «Innovative Development of Resource-Saving Technologies of Mineral Mining and Processing». Book of Abstracts. Petroşani, Romania, Petroşani, Romania: UNIVERSITAS Publishing.

12. **Sholokh M. V., Sergieieva M. P.** (2018). Taking into account of amount and quality of attracted in the booty of balanced on maintenance quality indexes minerals of supplies. // International Scientific and Technical Internet Conference «Innovative Development of Resource-Saving Technologies of Mineral Mining and Processing». Book of Abstracts. Petroşani, Romania, Petroşani, Romania: UNIVERSITAS Publishing.

13. **Sholokh M. V.** (2017). Economic estimation of losses of balance-industrial stocks and dissipation of content of qualitative indexes of minerals in iron-ore mass. Kryvyi Rih, Kryvyi Rih: Sat scientific works "Herald of the KNU".

14. **Sholokh M. V.** (2016). Methodology for determining and standardizing the content of qualitative indices of minerals in industrial balance stocks. Kryvyi Rih, Kryvyi Rih: Publishing Center of KNE KNVN.

15. **Sholokh M. V.** (2017). Modeling processes of forming the quality of ore and minerals in the ore raw material of the ore stream. Kryvyi Rih, Kryvyi Rih: Scientific and Technical University. Collection "Mining Bulletin" of the State University "KNU".

16. **Sholokh M. V.** (2017). Normalization of balance-industrial stocks of ferruginous quartzite by degree of readiness for extraction in an open way. Kryvyi Rih, Kryvyi Rih: Scientific and Technical University. Collection "Mining Bulletin" of the State University "KNU".

17. **Sholokh M. V.** (2017). Standardization of ready-to-use balance-industrial stocks of ferruginous quartzites with open method. Kryvyi Rih, Kryvyi Rih: Sat scientific works "Quality of Mineral Raw Materials", FAP Chernyakhovsky D. A.

18. **Sholokh M. V.** (2018). The effect of losses of balance-industrial stocks and impoverishment of the content of quality indicators of minerals on the process of averaging. Kryvyi Rih, Kryvyi Rih: Scientific and Technical Collection "Mining Bulletin".

19. **Sholokh M. V.** (2018). Surveying providing prediction and management of qualitative indicators in the development of iron ore deposits. Dnipro, Dnipro: Forum of miners-2018.

20. **Sholokh M. V., Sergieieva M. P.** (2018). Modeling of characteristics of volumetric-qualitative parameters of flows of iron-ore masses of quarries and mines. Kryvyi Rih, Kryvyi Rih: Scientific and Technical University. Collection "Mining Bulletin" of the State University "KNU".

21. **Sholokh M. V.** (2018). Normalization of balance-industrial stocks of ferruginous quartzite by degree of readiness for extraction. Premier Publishing r o Vienna, Premier Publishing. r o Vienna: The Second International Scientific Congress of European Scientists. - Proceedings of the II International Scientific Forum of Scientists «East-West» (May 10-11, 2018).

ANALYSIS OF WAYS REDUCING DRILLING WASTE IN OIL AND GAS PRODUCTION INFLUENCING ON NATURAL ENVIRONMENT

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The influence of drilling waste, while setting in the well, during oil production and exploitation of oil and gas wells is considered. When evaluating the ecological hazard of the well drilling process, the properties of drilling mud, drilling sludge and drilling wastewater are analyzed. It is outlined that the chemical composition of drilling waste depends on the properties of the drilling mud and the mineral composition of the drilling sludge. The mineralogical composition of the drilling sludge is determined by the lithologic composition of rocks that are drilled through; it may change depending on the well depth. The factors of influence on the natural environment during drilling and exploitation of the deposit are defined. The modern technologies of oil drilling sludge decomposition into components are analyzed. The analysis of modern drilling waste recycling method results can be used to increase the ecological safety of oil-producing areas. The results of drilling waste composition research can be used for further recycling and rational usage.

1. Analysis of the ecological state of oil and gas production regions

1.1 General characteristics of oil and gas production in Ukraine

The oil and gas industry in Ukraine has a negative impact on the hydro-, atmospheric, lito- and biosphere [1]. Drilling wells and producing hydrocarbons are environmentally hazardous processes

[2]. Oil and natural gas reserves in Ukraine are concentrated in the following geographic and geological regions: the Donets'k-Dnipro basin, the Precarpathian basin, the Black Sea-Crimean region [3].

The most progressive mineral-energy resource is hydrocarbon raw materials (oil, gas and condensate). Nowadays, Ukraine has 323 hydrocarbon deposits.

Most of them, i.e. 191 deposits, are situated in the Eastern region, 96 ones are in the West, and 36 ones are in the South. The average annual output is 4 million tons of condensed oil and 18 billion m^3 of gas, which is equal to 10 and 20 % respectively, considering the amount of these raw materials consumed by the country per year [4].

The depth of oil and gas wells that are drilled in Ukraine is on average from 2500 meters to 6000 meters. Technologically, the drilling process includes three main stages:

- mechanical destruction of rocks in the well;
- removal of rocks out by means of a drilling mud (DM), which is prepared outside before being fed by pumps into the well under pressure;
- mounting well walls by casing pipes (technical or operational columns).

The process of drilling is accompanied by occurance of drilling waste (DW): drilling sludge (DS), worked out drilling mud (WDM), drilling wastewater (DWW) [5].

Characteristics of the drilling sludge, which occurs during the oil and gas well drilling, testifies about impurities in it (Table 1).

Table 1

Comparative characteristics of the drilling sludge, coming out at oil production enterprises

Indicators of research/batch, type of waste	DS1	DS2
Oil products, g/kg	0,3	0,4
Humidity, %	53	47
Dry residue, g/kg	63,8	56,6
pH	7,2-7,6	10,8-11,0
Cl, g/kg	18,1	7,7
Ca^+, Mg^+, g-equal/l	0,025	0,07

As the well is deepened onto the following face (the location of the mechanical device (the drill) that destroys the rock), drilled rock, coming out along with a circulating drilling mud (flushing liquid), is formed [1]. Outside, drilling waste passes the cleaning system and then it is delivered into the sludge barns, where it is sorted out into drilling sludge (DS), worked out drilling mud (WDM) and drilling wastewater (DWW).

Well drilling is carried out mainly in sedimentary deposits, where clay rocks are dominant. Drilled clayey particles, risen outside, are mixed with the drilling mud filtrate and swell.

The mineralogical composition of the drilling mud is determined by the lithologic composition of rocks that are drilled. It may change according to well deepening. The chemical composition of the drilling sludge depends on its mineral composition and the properties of the drilling mud [6].

1.2 Pollution of the oil and gas production regions in Ukraine

If oil or its products fall into reservoirs, they intoxicate hydrobionts and reduce the concentration of dissolved oxygen. For instance, with insufficient oxygen content various defects in fish embryo structure may occur. When the oxygen level in water decreases, the fish embryos can not fill in their swimming bladders with air, swim up and start eating, and as a result die. Increasing the content of biogenic elements leads to the eutrophication of the reservoir, the transparency of water drops sharply, sunlight almost does not penetrate into water and there is no process of photosynthesis [7].

The problem of possible contamination of drinking water occurs in places bordering drinking water intakes. This problem is urgent while drilling deep oil and gas wells, which cause changes in ionic and organic composition of water. Conditionally three stages of man-made metamorphism of groundwater can be distinguished:

- On the first stage of deep well drilling, there is a slight contamination of groundwater with sulfate ion, organic matter and chlorine ions.
- On the second stage, namely after the opening a deep of the oil and gas well productive horizon in ground waters, the content of magnesium ions increases approximately twice, chlorine and sulfate ions increase almost 1.5 times, oil products increase approximately 4 times, and phenols increase 1.3 times.
- On the third stage, after the completion of deep well drilling, processes of landscape self-cleaning come to pass. Over the next two

years, as the research shows, the number of certain contaminants decreased by about 2 times [8].

2 Impact of drilling itself and drilling waste on the natural environment

The main types of oil and gas well drilling process waste are as following:

- DS (drilling sludge), water suspention, the solid part of which contains drilled rock products of the face and well walls, a drilling rig and casing pipes abrasion products, clay minerals (when flushed with an argillaceous solution) [9];
- DWW (drilling wastewater), water formed while flushing the drilling rig, drilling equipment and tools, after cleaning the vibration grid and cooling pumps; it contains residues of worked out drilling mud, chemical reagents and oil. DWW is a multicomponent system; the main components of DWW contamination are suspended organic matter and oil products. In appearance, drilling wastewater is a brown or dark brown mixture, which is practically opaque with a slight odor of oil products [10];
- WDM (worked out drilling mud) is a solution that has been excluded from the drilling process for further recycling or disposal [11].

The analysis of drilling waste amount showed that when drilling one gas-condensate well to the depth of 3000 m, about 355 m^3 of drilling sludge, 371 m^3 of worked out drilling mud, 728 m^3 of drilling wastewater are formed on average [12].

According to the way of occurance, wastewater formed during the exploration and setting in of oil and gas deposits can be divided into: ballast; drilling; used for cooling; oil and hydrogen mixture; layer; production and rain; household; fecal [13].

DWW is an aggregate-resistant colloid-dispersed system stabilized by chemicals used for drilling mud processing. As for its composition, it contains various mineral and organic matter represented by clay, weighting agents (barite, hematite), oil products, chemicals of various nature, soluble salts, including residues of drilling mud and other compounds [14].

Drilling wastewater is highly versatile and can accumulate contaminants. Therefore, it should be considered as a real environmental threat to the hydro and lithosphere.

Drilling sludge includes 60-80% of rocks; it is mostly silvered mixture of clay, sandstone, argillites, limestone, siltstones, sand. In addition, the composition of the drilling sludge includes organic matter (8% of CMC, starch, lime, etc.), water soluble salts (up to 6%), weighing agents, clay. Therefore, unauthorized dumping of drilling sludge into the environment without special measures to dispose it is inadmissible.

In general, chemical composition of drilling mud is following: 50-60% of SiO_2; 10-18% of Al_2O_3; 3-4% of CaO. The rest is organic matter. The humidity of the drilling mud is 40-45%, the density is 1450-1600 kg/m^3.

The granulometric composition of drilling mud is determined by the type of a drill, its diameter; mechanical properties of the rock; drilling mode; the properties of the drilling mud and effectiveness of its cleaning.

The fractions of sand and clay, the content of which in drilling mud reaches up to 30%, are characterized by the following particle sizes: r=0,05-1,0 mm (35-45%), r<0,05 mm (35-50%).

The composition and properties of oil and gas well drilling waste depends on the mineralogical composition of the drilled rock and the worked out drilling mud. For instance, the approximate mineralogical composition of the drilled rock in the Donets'k-Dnipro basin area on the territory of Kharkiv region includes, in percentage: sand - 11%; limestone - 14%; argilite - 18%; aleurolite - 13%; clay - 19%; sandstone - 25%.

The composition of worked out drilling mud is determined by the specific type of drilling mud used for well drilling (on water or carbohydrate basis, clayey or polymer ones).

For preventing drilling waste penetration into the drilling site and the migration of toxic substances to natural objects, an engineering system for its organized collection, storage and disposal is provided; it is a construction of sludge barns. All drilling waste is dumped into sludge barns, or sludge collectors, in case it is impossible to recycle, dispose, or remove some waste to special polygons immediately. Unfortunately, it can have negative impact on the environment and the health of people living nearby the oil and gas producing regions [15].

Sludge barns are one of the main sources of the environment pollution. When constructing sludge barns, trees, shrubs are cut down, ground cover is destroyed, land exploitation is carried out.

It was researched [16], that there are some changes in the acidity and mineralization of groundwater near the sludge collectors. In addition, nearby the sludge barns, an increase in the concentration of chlorides, heavy metals and oil products in soil and groundwater can be observed.

Sources of the environment pollution are conditionally divided into temporary and permanent. Sludge barns, in which liquid waste is leaked and filtrated, are referred to permanent sources of pollution. Sludge barns used for collecting oil and gas well drilling waste, are constructed with a calculated volume of waste up to 500-800 m^3 per well. The joint storage of all drilling waste does not allow it to be recycled simultaniously, and because of the drawbacks in barn constructions and the specific needs for soil condition, there is no reliable protection of the environment.

Before exploiting the barn, its walls and bottom are insulated with a film coating of waterproof materials: materials based on bitumen, polyethylene film, roofing materials such as ruberoid, etc. The laying of this material must be carried out following strict requirements of construction rules and regulations. The absence of waterproofing coating in the barn causes soil, reservoir and groundwater pollution [17]. When using saline drilling mud, the MAC increase of Cl^- and Na^+ in samples of barns and water sedimentation tanks can occur, which leads to salinization of soils and a significant increase in the total mineralization of groundwater.

When drilling oil and gas wells, a significant man-made load on atmosphere, hydro, and lithosphere objects appears to be and as a result it impacts on the amount of generated drilling waste, in which gas condensate is more than 1 000 m^3 per one well, including 170-355 m^3 of DS, 230-371 m^3 of worked out drilling mud (WDM), 600-728 m^3 of drilling wastewater (DWW).

The main reasons for the deterioration of the environment while exploiting the oil and gas deposits are the following:

– frequent cases of open emission of oil, gas and formation water while opening the productive formation of wells;

- constant pollution of reservoirs and deep formation water with liquid hydrocarbons, highly mineralized water and harmful salts;

- highly polluted atmosphere while exploiting gas deposits and gas storage facilities.

2.1 Impact of drilling waste on the lithosphere

In case worked out drilling mud (WDM), drilling wastewater or drilled rock containing toxic salt components, as well as oil and oil products, fall into the soil, all properties of soil can deteriorate sharply and as a result the yield of certain crops grown in these areas decreases.

The composition of drilling wastewater varies depending on the chemicals included in the drilling mud and drilled rock (Table 2).

Table 2

Characteristics of drilling mud

Indicator	Unit of measurement	Amount
pH	–	7-10
Density	g/cm^3	1,0-1,2
Mechanical impurities	mg/l	180-13000
Oil products	mg/l	10-5300
Dry residue	mg/l	2880-12030
COD	mg O_2/l	100-9300
BOD	mg O_2/l	7-520
Total mineralization	mg/l	1300-22600

The impact of drilling wastewater on the soil and flora mainly comes down to the pollution with oil products and chemicals used to prepare the drilling mud. After contaminating soil with oil products, the air mode and water properties of the soil are violated. At the same time there are changes in microorganisms living in the soil: the number of macroorganisms and bacteria that assimilate nitrogen compounds is reduced. There is a suppression of redox enzymatic processes that, as a result, reduces biological activity and fertility of soils. As a rule, drilling waste has an alkaline reaction, followed by the occurance of easily dissolved humates that are easily washed away from the surface of soils, causing reduction of the total humus content [12].

In the areas polluted with drilling sludge, containing oil products, vegetation dies almost completely.

Drilling wastewater, the main polluting element of which is worked out drilling mud, penetrating into the soil, destroys the soil structure, changes the soil mode and nutrition of plants, as well as its physical and chemical properties. If the concentration of these dangerous pollutants is insignificant, the soil can self-purify and recover. With the increase in pollutant content, more than the maximum acceptible concentration, it threatens all living organisms.

Soil contaminated with hazardous waste drilling is a source of danger for humans, since oil products that are part of drilling waste due to migration ability through food chains occurs in agricultural products, leading to the risk of carcinogenesis.

2.2 Impact of drilling waste on the atmosphere

When drilling oil and gas wells, there is a large amount of pollutants of different toxicity falling into the environment.

Changes in the WBD composition are caused by the technology of drilling and technological parameters (temperature, pressure) of the process, opening the horizon with various chemical fluids (gas, oil and underground water), different mineralogical composition of drilled rock.

When storing drilling sludge, worked out drilling mud and drilling wastewater, and further processing or recycling of drilling waste in sludge barns, evaporation of light fractions of oil products (hydrocarbons) from the mirror of the barn occurs, that negatively affects the atmosphere, especially during snow melting [18].

The amount of light hydrocarbons, that evaporate from the sludge barns and pollute the atmosphere, can range from 0.5 to 2.5 tons per year.

2.3 Impact of drilling waste on the hydrosphere

Non-normative (non-project) arrangement of a sludge barn (absence of earthworks, drainage trenches, violation or lack of waterproofing in the barn) is the main reason for negative impact of drilling waste on underground water and reservoirs. In addition, negative impact is also possible if the drilling mud or drilling wastewater located outside the sludge barn, join atmospheric fallout, as well as during the flooding of the rig territory in the period of intense snow melting.

Atmospheric fallout and snow melting cause the transition of drilling waste dissolved salts to aqueous solutions with the migration of these substances into the aquifers.

In case of improper control over the barn filling and untimely cleansing, flows of the liquid waste phase through the upper boundary of the barn are quite possible.

Also, the penetration of oil, drilling wastewater and worked out drilling mud into underground freshwater horizons is possible in case breaches in the conductor of the operating column occur or due to flow through the low-quality cement stone behind the column.

Contamination of underground water and reservoirs with oil products and chemicals causes suppression of normal organic life, changes in the composition of biocenoses, fish burial and spawning loss.

Under the influence of drilling waste on the water environment, the intensity of photosynthesis and the degree of survival among phytoplankton is reduced.

Components of drilling waste can become hazardous to the environment. It is determined as balance violation in inanimate and living systems of the environment (increased concentration of chemicals, negative effects in the system condition, etc.), reducing the level of safety for living organisms and humans in the environment.

Therefore, the placement and further recycling of drilling waste in sludge barns or at the drilling site can cause significant damage to the environment. Thus, recycling of solid (drilling sludge) and liquid (drilling wastewater and worked out drilling mud) drilling waste that have negative impact on the environment is an important task to be solved [19].

3 Analysis of methods for drilling waste cleaning and recycling

Drilling waste recycling can include recycling, extraction, deactivation and burial of drilling waste.

Types of impact on drilling waste are conditionally divided into physical, chemical, biological and combined. On temporary ground, waste recycling takes place during drilling, right after drilling, several years after drilling and during transportation.

The final materials of waste recycling include construction, meliorative and reclamation final products.

In order to increase the ecological safety of the environment during drilling, at least 3 storage barns for collecting and storing waste with an average total volume of 2500 m^3 and, in addition, an emergency barn for the products of setting in and testing a well with a volume of 200 m^3 (per one well) are constructed. The depth of the barns is 2.5–3 m. The first barn is used to collect worked out drilling mud and drilling sludge; the second one is for collecting and storing drilling wastewater; the third is to collect purified (clarified) water [20].

There is an open and closed system of handling drilling waste.

The open system is unacceptable, while using it, there is an enormous negative impact of pollutants on the environment. The closed system is more efficient to handle the drilling waste:

The closed system of handling drilling waste makes it possible to:

- minimize the amount of drilling waste;
- recycle and process drilling waste;
- carry out the disposal of only safe materials related to the environment.

Solid waste recycling, i.e. drilling mud, is the implementation of technological operations associated with changing the chemical, physical or biological properties of waste. It is done in order to further environmentally safe storage and disposal.

The main methods of drilling sludge recycling are:

- thermal (burning, drying);
- solidification
- physico-chemical methods of drilling waste recycling
- chemical (extraction, solidification using organic and inorganic reagents);

– physical (gravitaty sediment, separation in a centrifuge, separation by filtration, freezing)

– biochemical or biological (biotermal, microbiological decomposition and contaminated soil reclamation).

Types of influence on liquid waste are conditianally divided into: mechanical, physical, chemical, biological, combined [21, 22].

Mechanical methods of purification allow to catch only large fractions of polluting WWD on vibrating screens, which is only the first stage of purification with the further refinement by other more effective methods.

Coagulants are used to accelerate the sedimentation of suspended particles of disperse systems, as well as to intensify the sedimentation of these particles, flocculants.

As a coagulant, aluminum sulfate $Al_2 (SO_4)_3$ is used, and it is efficient to use polyacrylamide (PAA) as a flocculant. Coagulants lead to disruption of disperse system stability and aggregation of fine fractions into flakes. The main function of polyacrylamide is to help increase the size of the flakes when coagulated [23].

Coagulation plays an important role in water purification processes for the removal of suspended colloid particles, which may add unpleasant taste, color and feculence to drilling wastewater.

Coagulation is the particles adhesion process of the colloid system to their collisions in the process of thermal (Brownian) motion, mixing or direct movement in the external force field. Primary particles in such clusters are connected by the forces of intermolecular interaction directly or through the layer of the surrounding (dispersive) medium. Coagulation is accompanied by progressive aggregation of particles (increasing in size and mass of aggregates) and by decreasing their number in the volume of the dispersion medium, the liquid.

Influenced by coagulants, extremely small dispersed particles are combined in large masses, which later can be removed when separating the solid and liquid phases.

Flocculation is a kind of coagulation, in which small particles, suspended in liquid, form fluffy clusters, i.e. floccultes. Flocculation in liquid disperse systems occurs under the influence of specially added substances - flocculants.

In accordance with the Stokes law, frozen and colloid particles are settled down for a rather long time; therefore the intensification of the deposition process is a necessary measure to reduce the time of purification of drilling wastewater.

Water treatment by coagulation is carried out by adding mineral salts with hydrolyzed cations, anodic dissolution of metals, or just by changing pH of the medium, if treated water (drilling wastewater) already contains in sufficient amounts cations, able to form hydrolyzable poorly soluble compounds.

The most common flocculants are polyacrylamide (PAA); copolymers of acrylamide, acrylonitrile and acrylates; sodium salts of polyacrylic and polymethacrylic acids, etc.

Colloid particles, that are part of the drilling wastewater, are conditionally divided into three types: mineral, organic and biological. Mineral colloids include sedimentary rocks, colloid clays, hydroxides and metal salts. Organic ones include humic and sulfinic acids, which are formed by decomposition of plant and animal mains, as well as dyes, surface active substances, etc. Biological colloids are microorganisms, they can be both pathogens and non-pathogens.

A number of interactions between negatively charged colloid particles and positively charged ones takes place during coagulation.

The colloid suspension is destabilized under the influence of two mechanisms, these are the neutralization of charge and direct chemical binding.

Neutralization of the charge occurs when a positively charged coagulant neutralizes the negative charge situated around the colloid particle. When the charge around each particle is neutralized, they gradually approach, reducing their effective radius. Finally, they become unstable and can collide with each other. When colliding, particles join each other, forming large masses and flakes.

In practice, while purifying drilling wastewater, aluminum salts, iron salts or their mixtures in various proportions are usually used as coagulants. Sometimes, magnesium, zinc and titanium salts can also be used.

The most common coagulants used nowadays include aluminum sulfate, aluminum hydroxychloride, aluminum hydroxychloride sulfate, sulfa-iron-containing reagent, etc.

The effectiveness of coagulants is affected by a large number of factors. The water coagulation technology should take into account the composition and properties of wastewater contaminants, the dose and composition of the coagulant, the temperature and pH of the water, the conditions for the introduction and mixing of the reactants. The decisive factor for maximizing the efficiency of using coagulants in cleaning drilling wastewater is the creation of conditions for their hydrolysis in the right direction by changing the concentration of coagulant in the disperse system, the pH value and the ionic composition of the dispersion medium. The optimal pH values, when using aluminum sulfate as coagulant, is achieved in the range of pH values of the medium from 5 to 7,5, and sodium aluminate from 9.3 to 9.8; when using iron chloride in the range of values from 3,5 to from 6, 5 or 8 to 11; when using iron sulfate from 9 to 10,5.

The common disadvantage of all known coagulants is the inability to regenerate and return the product. Also, the disadvantages of the method include the fact that during the change in the chemical composition of the WWD, process of the particles sedimentation can become unregulated [24].

3.1 Thermal method of drilling sludge processing

This method is quite common, it is usually implemented in open barns; furnaces of various designs (rotary drum kilns, bubbling fireboxes, etc.). The method also includes drying in dryers of different designs; pyrolysis; thermal desorption; electric fire processing; thermolysis; heat treatment.

When burning drilling sludge in a rotary drum kiln, the solid phase is mixed with the loam (30-60% of weight and 40-70% of weight, respectively) and granulated. The liquid phase is used repeatedly to prepare the drilling mud. The disadvantage of this method is high cost.

Pyrolysis is the process of decompositing organic compounds under the influence of high temperatures with absence or lack of oxygen with the formation of harmful by-products like pyrogas and pyrolysis resin, solid phase and heat of waste gases for futher recycling.

Thermal desorption of drilling sludge is the thermal heating of waste with subsequent condensation and capture of the hydrocarbon phase. This method costs a lot because of high energy consumption and low economic efficiency.

Electric fire burning of drilling sludge is characterized by setting almost ideal conditions for environmentally friendly burning of any toxic waste.

In heat treatment of drilling sludge, it is completely disposed at a temperature of 800-850 C due to the chemical conversion of compounds.

The drilling sludge can be practically recycled forming final products: curbtone, cinder blocks, paving slabs, coupling mixture and granular filler for concrete [16].

The high-temperature treatment of the drilling sludge passes two stages:

- preparatory;
- high-speed burning at a temperature of 950 - 1200 °C.

The disadvantage of high-temperature burning is that it needs special equipment and expensive energy resources [17].

In the process of thermolysis drilling sludge forms the following substance:

- water (40% of weight);
- solid carbon residue (21% of weight);
- hydrocarbon distillate (30% of weight);
- hydrocarbon gas (9% of weight) [18].

The thermal method of drilling sludge processing is all-purpose, drilling sludge does not require preliminary preparation (cleaning from garbage, stones, oil products), and the volume of the processed product is ten times less than the initial volume of drilling sludge. But when burning, a large number of dangerous and harmful gases are released in the atmosphere. In order to prevent this negative effect, it is obligatory to conduct emission clearance. This requires additional material, financial and energy resources. The economic efficiency of thermal methods is reduced by the need of drying drilling sludge with high humidity [20].

3.2 Solidification of drilling sludge

Solidification involves processes that encapsulate the contaminated material with the formation of solid material, and limit the migration of the pollutant by reducing the surface area that is alkalined and / or by applying a low permeability material on the contaminated material. Solidification is carried out by means of mechanical processes, which mix material and one or more reagents. Solidification keeps the contaminated material in granules or monolithic matrix.

Solidification technology allows obtaining a durable material on the basis of neutralized waste. The process of neutralizing the sludge is carried out by mixing with sorbent and cement in certain proportions. After that, the organic substances present in the sludge are bound by the introduced sorbents. Cations of heavy metals contained in the sludge are converted into heavy insoluble hydroxides. Solidification of neutralized waste, as a result of hydration processes introduced into the cement system, leads to even stronger binding of neutralized toxic compounds and prevents their further dissolution in case of various environmental factors influence [21]. This product can be used in construction industry.

Advantages of solidification method in drilling sludge processing are:

- it improves the structural property of the soil, waste and sludge (e.g., strength) to facilitate land reusage;
- it can be used for cleaning on or outside the area;
- processing endpoint can be achieved within a relatively short period;
- it can be used in dry or wet conditions, reducing problems of water removal and waste control;
- simple, available equipment and materials are used;
- it does not require transportation of waste from the facility;
- economically effective;
- inert filler, obtained as a result of solid phase drilling waste processing, is used for the reclamation of soil set for temporary sludge collectors;
- no fee for waste placement in case of such treatment with drilling waste.

3.3 Biochemical (biological) methods of drilling waste recycling

Biological substances (bacteria, cultures of fungi, plants) are used. This method is based on the ability of microorganisms to process hydrocarbons. In this case, biochemical reactions occur, accompanied by spliting, mineralization and partial gumification of the contaminated soil layer.

Disadvantages of the biochemical (biological) method are the following:

- long process, requiring large funds for the purchase of biological products;
- the use is limited by the selective action of bacteria;

- bacteria, as a rule, are highly sensitive to the composition of the drilling mud and changes in environmental factors (temperature, humidity, pH, etc.), which prevents the desired result.

A well-known method for processing drilling mud additionally involves purifying it with a corsotry of non-pathogenic oil-oxidactive elements: *Rhodococcus erythropolis*, *Bacillus subtilis*, *Fusarium sp.*, taken in the ratio 1:1:1.

Biological method is optimal in combination with other methods of DW recycling. The degree of DW purification is increased up to 91% after the previous extraction of oil products from sludge by the xylene and treatment with selected consortium of necessary microorganisms.

The success of biological oil purification depends on the ability to establish and maintain conditions facilitating the increase of oil biodegradation level in the contaminated area.

Recycling of the bottom layer of sludge barns can be carried out by the method of biodestruction in field conditions.

Furthermore, the composting of oil waste is carried out together with the overpopulated block of cattle (15 kg/m^3), razor (straw – 45 kg/m^3) and addition of calcium salts ($CaCO_3$ – 5 kg/m^3).

Soil, contaminated with hydrocarbons, causes large damage to the natural environment, as the accumulation of pollutants in animals and plant tissues can cause death or mutation.

Thus, the biological methods of DW processing are used mainly at one of the stages of complex DW handling, which contain oil products. Since the content of oil products in the DS is relatively small, this method is not justified from the technical, ecological and economic plan [3, 20].

3.4 Physical methods for drilling waste recycling

This method is based on changing the physical properties of DW under the influence of various power factors.

Physical methods of DW processing are divided into [25]: gravity sediment, separation in centrifuge, separation by filtering, freezing.

The most commonly used apparatus for separation and further waste processing are centrifuges, filters, hydrocyclones and separators.

Sludge filters, or settlers, are used for dewatering such drilling waste as oil sludge. The advantage of gravity sediment is unnecessity of large capital for operating costs, and the disadvantages include the long-term process of settling and the low effectiveness of oil residues and other impurities separation. The separation of drilling mud in the centrifuge occurs in the decanter. The principle of its action is based on the actions of centrifugal forces. In a decanter, oil sludge in a mixture of heated fresh oil is fed into three-phase decanters, where the separation into three phases occurs: hydrocarbon, water and mechanical impurities. The isolated hydrocarbons are ginen for recycling, water is given for purification, mechanical impurities that are enriched in hydrocarbons and containing water, are recycled as new waste, the amount of which is much less than the amount of the primary sludge, but still significant. The advantages of this kind of DS recycling include the ability to reduce the amount of waste, as well as reuse of water that is separated from oil products. The disadvantages include special equipment, such as hydrocyclones, separators, and centrifuges.

The method of filtering through the press only separates water portion of the waste from heavy impurities; this process is characterized by a rather low throughput. In case of such filtration, the problems of the filtered material recycling and the separation of water remain unresolved. This method does not solve the problem of the complete recycling of oil waste [26].

The influence of freezing and thawing on the dewatering of the sludge emulsion, its structure, number and respiratory activity of the sludge microflora, toxicological characteristics of the sludge liquid phase are determined. It has been found that freezing and thawing causes sludge structure destabilization, followed by quick dewatering centrifugation. For a 20-minute centrifugation it separates from the sludge up to 28% of water, whereas after freezing and thawing it accounts more than 39%. Thus, freezing and thawing destabilize the sludge structure and facilitate increasing the efficiency of its dewatering under the modeling conditions of centrifugation. This method is more suitable for mixtures consisting of synthetic organic substances.

Vibrating screens are used to clean DW from sludge (liquid phase from solid). Using the method of V.N. Ponomarev and Yu.N. Shtonda separation into phase components of the emulsion layer is carried out by the method of water-organic system demulsification on the basis of different intensification effect of mass transfer processes under phase inversion conditions.

3.5 Chemical methods of waste recycling

The chemical method of DW recycling on the basis of reagent encapsulation is an effective technology for recycling waste. When it is used, the physical and mechanical transformations of DW into neutral for the environment material are carried out. Each particle of this material is covered with a hydrophobic shell of calcium carbonate, which is formed by slaking lime with water and carbon dioxide:

$$CaO+H_2O=Ca(OH)_2,\ \Delta H=-65{,}26\ kJ/mole$$

$$Ca(OH)_2+CO_2 = CaCO_3+H_2O$$

When slaking lime, there is an exothermic reaction (the allocation of thermal energy), the evaporation of excess moisture and the death of microorganisms is carried out. Granules, after maturation for 24 hours, have high strength, and the rate of of hazardous substances release in the environment is reduced to hundreds of times.

The ratio of DW and quicklime is, according to experiments, from 1:0,8 to 1:1,2.

Also, for the implementation of the DW reagent processing method, a neutralizing composition (NC) is used as a mixture of calcium oxide, sorbent and a modifier.

The method of DW inertia is binding of toxic substances to sorbents, thus obtaining solidification material on the account of mixing activator. The mixture for solidification is used in the following proportion: 40-80% of cement; 20-60% of natural silica gel; 20% of non-liquid glass. The result of solidification is the material for leveling the terrain, the construction of insulating screens and the construction of roads [27].

Composite building material, containing DW with density 1.38-1.8 kg/dm^3, cement 4-12 wt. (astringent); dehumidifier and mineral filler, can also be obtained.

Conclusion:

The least costly means that have been used previously, such as recycling of drilling waste by discharging wastewater to the relief, pumping wastewater, crushed pulp of DW and DS into the reservoir, dumping the DS without any treatment in the barns, are unacceptable and do not follow modern requirements to the environment protection.

It is expedient to use drilling sludge as additives for production of building materials, considering the composition of the sludge and raw materials.

Drilling wastewater has to be cleaned with coagulants and flocculants.

It is also efficient to add worked out drilling mud as filler for production of polyethylene, also using polypropylene waste compositions.

The development and improvement of methods for drilling sludge, drilling wastewater and worked out drilling mud processing are important for further research direction.

References

1. **Chernova A. O., Shestopalov O. V**. (2016). Otsinka vplivu burovogo shlamu na navkolishne prirodne seredovische. Harkov: X Mizhnarodna naukovo-praktichna studentska konferentsiya magistrantiv, 66-67

2. **Holliger C., Gaspard S., Glod G.** (1997). Contaminated environments in the subsurface and bioremediation: organic contaminants. FEMS Microbiology Reviews, 20, 3-4, 517-523.

3. **Ableyeva I., Plyatsuk L., Budyonyy O**. (2014). Study of composition and structure of drill cuttings to justify the method choisen for their further recycling. Visnyk Kremenchutskoho natsionalnoho universytetu imeni Mykhaila Ostrohradskoho, 2, 172-178

4. Natsionalna dopovid pro stan navkolyshnoho pryrodnoho seredovyshcha v Ukraini u 2014 rotsi. (2016). - Kyiv: Ministerstvo ekolohii ta pryrodnykh resursiv Ukrainy, FOP Hrin D.S. https://menr.gov.ua/files/docs/У%202014%20році.pdf

5. **Ryazantsev N. F., Karnauhov M. L, Belov A. E.** (1982). Ispyitanie skvazhin v protsesse bureniya [Tekst] Moscow: Nedra.

6. Sait Kompanii «NK «Hazinvestproekt» Retrieved from http://gazinvestproject.com/ua/reagents.html

7. **Sytnyk Yu., Shevchenko P., Zabytivsky, Yu.** (2007). Ekoloho-toksykolohichna kharakterystyka chornoho velykoho ozera Shatskoho natsionalnoho pryrodnoho parku. Visnyk Lvivskoho universytetu, 13-26.

8. **Karabyn V., Kolodii V., Yarontovskyi O., Kozak Yu., Karabyn O**. (2007) Shchodo dynamiky zabrudnennia gruntovykh vod Peredkarpattia u zoni tekhnohenezu rodovyshch nafty. Pratsi Naukovoho tovarystva im. Shevchenka. Lviv. T. XIX: Heolohichnyi zbirnyk, 43, 182-190.

9. **Mironov N.A., Usmanov I.R.** (2013) Ispolzovanie burovogo shlama pri stroitelstve dorog. Elektronnyiy zhurnal Cloud of Science URL: https://cyberleninka.ru/article/n/ispolzovanie-burovogo-shlama-pri-stroitelstve-dorog.

10. **Pukish A. V., Semchuk Ya. M**. (2007). Doslidzhennia khimichnoho skladu ta fizyko-khimichnykh vlastyvostei burovykh stichnykh vod. Rozvidka ta rozrobka naftovykh i hazovykh rodovyshch, 1 (22), 141-144.

11. **Budonyi O.P., Matiushenko I.Iu**. (2011) Rekultyvatsiia shlamovykh ambariv pry burinni naftovykh i hazovykh sverdlovyn. Kremenchutskyi natsionalnyi universytet imeni Mykhaila Ostrohradskoho Naukovyi zhurnal «Ekolohichna bezpeka», 67–69.

12. **Rykusova N.** (2017). Impact of drilling operations and waste of drilling of oil and gas wells upon natural environment. Bulletin of NTU “KhPI”. Series: Mechanical-technological systems and complexes, 20, 98-102. Available at: http://mtsc.khpi.edu.ua/article/view/109628

13. OST 51-01-03-84 «Ohrana prirodyi. Gidrosfera. Ochistka stochnyih vod v morskoy neftegazodobyiche. Osnovnyie trebovaniya k kachestvu ochistki» [Elektronniy resurs] - Retrieved from: https://ohranatruda.ru/ot_biblio/norma/245002/

14. **Bulatov A. I., Makarenko P. P.,. Shemetov V. Yu** (1997) Ohrana okruzhayuschey sredyi v neftegazovoy promyishlennosti. Moscow: Nedra.

15. **Skipin L. N., Galyamov A. A., Gaevaya E. V., Zaharova E. V.** (2014) Tehnogennoe vozdeystvie shlamovyih ambarov na okruzhayuschuyu sredu poluostrova Yamal. Vestnik KrasGAU, 146-150.

16. **Kozitskaya Yu.N., Moskvina I.L.** i dr. (2004). Izmenenie fiziko-himicheskogo sostava pochv i gruntovyih vod vblizi shlamovyih ambarov. Mat.

Vserossiyskoy konf. «Ekologicheskie problemyi promyishlennyih regionov». Ekaterenburg, 187-189.

17. **Pukish A.V., Semchuk Ya.M.** (2006) Ratsionalne vodokorystuvannia pry sporudzhenni naftohazovykh sverdlovyn. Rozvidka ta rozrobka naftovykh i hazovykh rodovyshch: vseukr. nauk.-tekhn. zhurn. - Ivano-Frankivsk : Fakel. 1(18), 22-26.

18. **Dryhulych P. H.** (2006) Tekhnolohichni rishennia pidvyshchennia ekolohichnoi bezpeky obiektiv rozmishchennia vidkhodiv burinnia. Naukovyi visnyk Natsionalnoho Tekhnichnoho Universytetu Nafty i Hazu. Ivano-Frankivsk : IFNTUNH ,2, 149-154.

19. **Shestopalov O. V.** et. al.; (2015) Okhorona navkolyshnoho seredovyshcha vid zabrudnennia naftoproduktamy. Kharkiv: NTU "KhPI", 116.

20. **Rykusova N.** (2018) Suchasni metody pererobky ta utylizatsiyi vidkhodiv burinnia naftohazovykh sverdlovyn. Ekolohichni nauky, 2, 1 (20), 130–135. URL: http://ecoj.dea.kiev.ua/archives/2018/1/part_2/29.pdf

21. **Pichugin, E. A.** (2012). Otsenka ob'emov othodov bureniya v Zapadnoy Sibiri i podhodyi k ih utilizatsii. Molodoy uchenyiy, 8, 58-61. https://moluch.ru/archive/43/5175/

22. **Ishbaev T.G.** (2012). Various pathways to ulilize oil drilling waste", Ecological problems of oil production. Collection of reports of scientific and technical conference, Ufa, Oil and Gas Business, 11–13.

23. **Shestopalov O., Rykusova N., Hetta O.** ta inshi. (2019). Revealing patterns in the aggregation and deposition kinetics of the solid phase in drilling wastewater. Skhidno-yevropeiskyi zhurnal peredovykh tekhnolohii. Kharkiv. 1/10 (97), 50-58.

24. **Rykusova N.I., Hetta O.S., Shestopalov O.V.** (2018). Ochyshchennia stichnykh vod promyslovykh pidpryiemstv za dopomohoiu metodu koahuliatsii ta flokuliatsii [Tekst]. International Multidisciplinary Conference Science and technology of the present time: priority development directions of Ukraine and Poland (19-20 October 2018) Volume 6. - Wolomin, Republic of Poland, 2018. – p. 120-123

25. **Bashirov V.V.** (1992) Tehnika i tehnologiya poetapnogo udaleniya i pererabotki ambarnyih shlamov. Moscow: Nauka.

26. **Liubyn V.S., Iskovych-Lototsky, R.D.** (2013). Analiz metodiv ta obladnannia dlia filtruvannia ta ochystky volohykh dyspersnykh materialiv. Vinnytsia. Vseukrainskyi naukovo-tekhnichnyi zhurnal «Vibratsii v tekhnitsi ta tekhnolohiiakh», 2 (70), 185189.

27. Ponomarenko D. V., Perevalov S. N. (2012) Othodyi ili syire: novoe videnie staroy problemyi. Neftegaz, 9, 35-39.

THE INFLUENCE OF PERIODIC PULSE ACTION ON THE EFFICIENCY OF VIBRATING SCREENING WITH DEHYDRATION

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Abstract.

The *subject of research* is the process of screening with dehydration. *Methodology*: Synthesis of the results of theoretical and experimental studies using computer simulation methods.

Purpose. Evaluation of the impact of a periodic pulse effect on the efficiency of vibrating screening with dehydration. *Originality and practical value.* Impulse action compared to harmonic intensifies the passage of water through the cells of the sieve up to 40%.

The use of new methods of vibro-impact screening allows efficiently separating and dehydrating the material containing small size classes, which, at 18-20 % moisture, is not classified using traditional methods.

The use of these conditions made it possible to reduce the moisture content of the oversize product to 7-10%, and to increase the class + 0÷-0.1 mm to 70-80%. The results of dehydration are comparable to the humidity indicators, which are obtained by dehydration of materials on centrifuges.

To determine the rational parameters, mathematical models have been created for pulsing with impulse effect, kinetics of dehydration and screening with dehydration.

Mathematically described the process of sifting fine particles and removing the liquid in the capillary-docking bridges between the particles. This is achieved by simulating the transition of a fluid along the layer height using a discrete Markov process with discrete states.

On the basis of which calculation methods have been developed and implemented.

Introduction

The development of technology and technology for the extraction of mineral raw materials at the present stage has led to the fact that the raw materials supplied for enrichment contain about a third of sludge particles.

The task of improving the quality of commercial products while increasing the volume of enrichment is inextricably linked with the processing and dehydration of small and thin classes, the number of which is constantly growing. Similar problems also arise when additional wetting of technogenic raw materials (ore, coal sludge, screenings, etc.), consisting mainly of particles less than 1-5 mm in size (fine-grained raw materials), occurs.

Transportability and cost of such products depend on their humidity, high values of which reduce the efficiency of using these materials, therefore, the improvement of technologies associated with fine particles and sludge is an important task.

At the same time, special attention is paid to resource-saving technologies, which allow to reduce the cost of commercial products and increase their competitiveness in the market [1-5].

The efficiency of water removal depends on the particle size distribution, the nature of the location of the particles and their physico mechanical properties. The water holding capacity of materials depends on the specific surface of the particles and on the energy spent on interaction with water.

The greatest difficulties are caused by dehydration of fine and small particles, since products formed from them, retain significant amounts of water due to the highly developed surface of the particles, actively interacting with water, and acting capillary and electrostatic forces. The porosity and permeability of these media is usually low.

With a decrease in the particle size in the products, the binding energy of the liquid with the solid surface increases, i.e. resistance to water flow in the pore space. The more this energy, the harder it is to separate the liquid.

Therefore, it is most difficult to remove water bound by capillary forces (surface tension) [6-11].

The cheapest and most widely used is mechanical dehydration. Improving the efficiency of moisture removal from thin precipitations by mechanical methods allows you to save energy consumed during the thermal fine-tuning of products to commercial moisture.

For these purposes, a wide variety of equipment is used with different principles of operation: vibrating screens, centrifuges and filters.

Screens are simpler and cheaper than centrifuges and filters, and even in those cases when centrifuges and filters are used, vibrating screens are installed in front of them. In addition, screens, unlike centrifuges and filters, can simultaneously perform two operations: separation by size and dehydration [1-11].

The results of recent studies indicate a fundamental possibility in the processing of wet man-made raw materials to obtain commercial products by fine classification (the cut-off size of separation is 0.05-0.2 mm) and the maximum possible dehydration of the resulting product. At the same time, thin classification according to the specified size with high efficiency for narrow strips of the separated classes of dry bulk materials is a problem.

For these purposes, the Ukrainian industry does not produce serial equipment. Currently under development in this direction and individual tests. Classifying pulp with a solids content according to these classes is even more difficult, since its solution is complicated by the additional viscosity of the liquid and clay inclusions dissolved in it. To overcome these forces on the working surface, accelerations are needed, which significantly exceed their level at the existing serial vibrating screens.

Hence, close attention to the improvement of vibrating screens, which will ensure an increase in the efficiency of processing technologies, the quality of raw materials, energy and resource saving, and a reduction in the harmful effect on the environment [1-11].

Vibrating screening is widely used for sizing and dehydration of mineral raw materials in various industries. However, as practice has shown, traditional methods can effectively roar only materials with particle sizes greater than 1 mm, and reduce the moisture content of the finished product to 18-22%, depending on the size.

Classification of materials with a particle size of 0.5-1 mm by traditional methods does not give good results, and with a particle size of less than 0.2 mm, in some cases it is not classified at all because of their adhesion to the screening surface.

Of particular difficulty is the processing of wide size classes, when it is necessary to separate thin classes (as a rule, off-spec product) and to dehydrate the finished (maximum) product as much as possible [12]. It should be said that the oversize product, located on the screening surface, also reduces the effectiveness of the effect on the particles and the liquid in its cells.

Therefore, the tasks aimed at finding solutions to improve the separation and dehydration, of course, are relevant.

Analysis of technical solutions for dehydration of enrichment products on vibrating screens and areas of their use showed [13] that in order to further increase efficiency, it is necessary to intensify the sifting surface mode (at the stage of raw material flight) and loosening the raw material by imparting additional accelerations to it without adding power.

This will lead to the destruction of the water film in the cell of the screening surface due to surface tension and viscosity of the liquid and the capillary butt bridges between the particles, which will facilitate the free passage of thin solid particles through the screening surface with the liquid and ensure high efficiency of the classification of fine materials and dehydration. For overcoming of forces of surface-tension impulsive influence is perspective due to a vibroblow directly to the sieve or through an intermediate element [12-13].

At the Institute of Geotechnical Mechanics. N.S. Polyakova NAS of Ukraine (IHTM NAS of Ukraine) over a long period of research carried out to improve the efficiency of separation by size and dehydration with a thin and extremely thin screening. Previously carried out studies [12] found that for effective separation and dehydration of mineral raw materials requires a pulse effect on the screening surface and the processed raw materials.

The purpose of this work is to evaluate the effect of a periodic pulse effect on the efficiency of vibrating screening with dehydration.

Material and research results.

The separation by size and dehydration of the mineral raw material on the vibrating screen occurs as a result of the passage of particles and liquid through its layer and holes in the screening surface.

The passage of fluid through the openings of the screening surface is one of the components of the process of dehydration of mineral raw materials on a vibrating screen, so it is necessary to study the effect of excitation modes on the passage of fluid through the cells of various sieves under harmonic and pulsed effects.

Experiments were performed on various screening surfaces. For this, steel and polyamide nets with square holes of 0.63, 0.1 and 0.05 mm were used. The studies were performed by an experimental method and are aimed at establishing the influence of the amplitude and frequency of vibration excitation on the passage of fluid.

The experiments were performed on a screen model (Fig. 1), consisting of box 1, under which beam 2 was installed with an elastic element 3 and drummers 4 (main) and 5 (optional).

On the elastic gaskets 6, steel rods 7 are mounted on which the grid 8 was located.

When the base 9 is harmonically excited, the drummer is affected by a variable inertia force, which leads to periodic discontinuities of the contact of the drummer 4 with the rods 7. As a result, shock impulses are transmitted through the rods 7 the grid 8 and the processed raw material 10.

Mode with "double blows" was carried out using an additional drummer 5 with the stiffness of the elastic element different from the stiffness of the elastic element of the drummer 4. Above the grid 8 on

At a distance of l, activator 11 was mounted.

Disintegrating elements 12 were located on the activator 11.

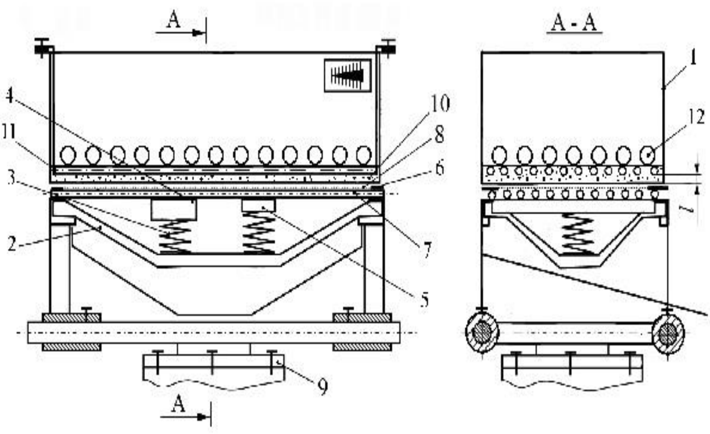

Figure 1 - The model of the roar with percussion and activator: *1* - box; *2* - beam; *3* - elastic element; *4* - the main drummer; *5* - additional drummer; *6* - elastic gasket; *7* - rods; *8* – grid; *9* - base; *10* - layer of raw materials; *11* - activator; *12* - disintegrating elements (DE)

Experimental studies have established that the pulse effect compared with the harmonic intensifies the passage of water up to 40% [10,11,14,15].

These results are one of the components in the mechanism of dehydration of mineral raw materials.

The next stage on the screen model (Fig. 1) was the study of the passage of particles and liquid through a layer of mineral raw materials. To do this, on the model of the screen, modes were found and studied that ensure the efficiency of extraction of the undersize product with the maximum decrease in humidity. In the processing of raw materials of a narrow range of size, the regimes with "single blows" were applied, and for a wide range - "double" (a new method of vibro-impact screening) [14-21]. With "double blows", for the period of excitation, in addition to the main one, an additional impulse is applied. Due to the main oversize product, it is thrown up and during its flight an additional impulse is applied to the screening surface, which amplifies its oscillations. As a result, the capillary bridges break and the capillary meniscuses become unstable in the cell of the screening surface, separation and cleaning of the screening surface from adhered raw materials is improved, which intensifies the process of separation and dehydration.

On the model of a screen with a screening surface in the form of a metal grid with a 0.1 mm cell, the main and additional drummers were installed, the natural frequency of which was within 20-35 Hz. The preliminary tension of the additional drummer was set so that it would work after the impulse was applied by the main drummer with a delay of 0.2 stages of the flight of the thundering material.

Under laboratory conditions, studies were carried out to determine the efficiency of screening and dehydration of quartz particles of a narrow size class +0÷-0.2 mm, the results of which are shown in Fig. 2. The humidity content of the initial product was 25-30%.

Experiments were carried out with a disturbance amplitude of 2 mm and a frequency of 35 Hz.

As a result of experiments, the moisture content of the oversize product decreased to 8-10%, while the separation efficiency of the class +0÷-0.1 mm was 85-90%.

a *b*

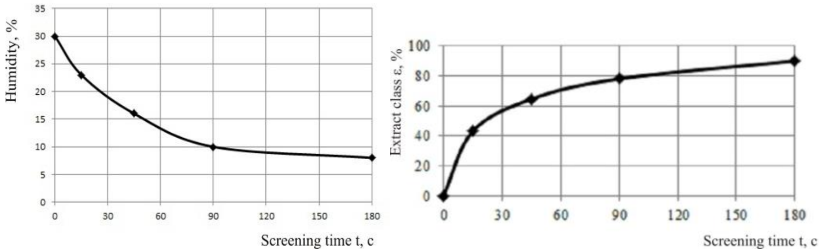

Figure 2 - Dependence of the moisture content *W* of the upper part of the product and the extraction of *ε* class of -0.2 mm in the undersize product from the time *t* of dehydration and frequency f and amplitude A of vibration excitation during dewatering of a material of size +0÷-0.2 mm with the help of "single blows" and DE

As is known from practice, the most difficult is the process of processing materials formed from wide classes of size, which are not generally classified or dehydrated by traditional methods.

To solve this problem, a method of screening and dewatering hard-to-class materials was developed [13,19]. When the class is smaller than the capillary constant, this process is prevented by surface tension forces, which are overcome due to the dynamic effect by giving normal and shear pulses to the material and the screening surface. The pulses carry disintegrating elements (hereinafter DE) spherical or ellipsoidal shape, having different sizes. When creating perturbations, DE hits the material, squeezing water out of it. Due to the application of the material and the screening surface in local areas of normal impulses, the oscillations of the screening surface and the material on it are amplified, intensifying the process of classification and dehydration. Since the disturbing force is directed at an angle to the screening surface, the DE falls on it also at an angle, giving the material a shear impulse, which contributes to its more intensive loosening and destruction of the capillary bridges between the particles. DE of ellipsoidal shape with vibration disturbances receive rotational movements from one side to the other, increasing the shear impulses upon impact. Since the thickness of the layer of material varies along the length of the working surface, it is necessary to act on it in different ways, so the pulses also change along the length of the screening surface. All this leads to more intensive loosening of the processed raw material and the passage of water through it, resulting in increased efficiency of material separation, cleaning of the screening surface from particles stuck in the holes and adhered material, which intensifies the process of classification and dehydration.

Thus, the mode of oscillations is not intensified not the entire mass of the duct, but only the rattling material and sifting surface without additional power supply.

However, in the case of the classification of slurries, the presence of such an impact leads to more intensive removal of liquid from the material and destruction of the water film in the cell of the sieving surface, due to surface tension and viscosity of the liquid. This facilitates the free passage of thin solid particles through the screening surface along with the liquid and provides high efficiency in the classification of fine materials and dewatering.

Under laboratory conditions, a screen model equipped with amplitude and frequency regulators, with a screening surface in the form of a metal grid with a 0.1 mm cell, on which DE was located in the form of balls with a diameter of 10 to 25 mm, experiments were carried out to determine the efficiency of classification and dehydration quartz size +0÷-10 mm with a high content of clay particles. The moisture content of the original product was 30%. The influence of the frequency and amplitude of oscillations on the screening of the material and dehydration of the oversize product was studied.

For research, granite screenings were used - waste from the mining and processing of granite with a particle size of +0÷-10 mm with a high content of clay particles, the composition of which is shown in Figure 3 and coal slimes (Figure 4). The moisture content of the original product is 30%.

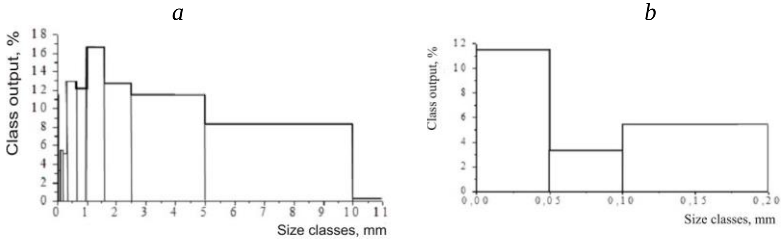

Figure 3 - Granular composition of granite sifting:
a - size range from 0 to +10 mm; *b* - size range from 0 to 0.2 mm

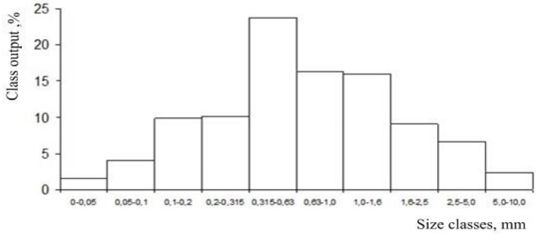

Figure 4 - Granular composition of coal slimes

Initially, experiments were carried out with a perturbation amplitude of 1 mm and a perturbation frequency of 20 Hz. With these parameters, the DEs oscillate, but operate in the non-impact mode. As a result of experiments, the moisture content of the oversize product decreased only to 20-25%, while the separation efficiency of class +0÷-0.1 mm was 35-40%.

Further, the perturbation amplitude was increased to 4 mm at a perturbation frequency of 20 Hz. Under these conditions, the regimes of periodic separation of DE from the screening surface and the impact of the material being processed on it and the material being processed were implemented.

As a result of experiments, the moisture content of the oversize product decreased to 11-12%, while the separation efficiency of class +0÷-0.1 mm increased to 60-70%.

For additional process intensification, a new method of vibro-impact screening has been proposed [7], which consists in the following. Above the screening surface at a distance less than the height of material tossing is attached an activator of a lattice structure (Fig. 1).

The activator is excited by harmonic oscillations, which are converted by the shock elements into periodic shock pulses.

The material is fed to the lattice activator, where under the action of forced vibrations of the activator, the material is loosened to move freely through the holes of the activator onto the screening surface.

Due to the interaction of percussion elements with the screening surface, its vibrations are amplified, as a result of which the super-high material is thrown.

During the period from the moment of separation of the material from the screening surface to the fall, it is informed by additional pulses due to the activator oscillations. To enhance the effect, the activator is additionally excited by disintegrating elements, with the help of which they act on the material and liquid to be separated in local areas with normal and shear pulses.

As a result, capillary bridges break and the capillary meniscus in the cell of the screening surface loses stability, material separation by particle size is intensified and the screening surface is cleared from particles stuck in the cells and adhered material, which intensifies the process of classification and dehydration.

Under these conditions, regimes were found and studied that ensure a further increase in screening efficiency when classifying and dewatering quartz with a size of +0÷-10 mm with a high content of clay particles (the moisture content of the initial product was 30%).

Figures 5*a* and 5*b* show the dependences of the moisture content *W* of the oversize product and the extraction of *ε* -0.1 mm class in the undersize product from the time t of dewatering when screening granite sifting.

Figures 6a and 6b show the dependences of the moisture content W of the oversize product and the extraction of ε - 0.1 mm grade in the undersize product on the time t of dewatering when screening coal slurry.

a *b*

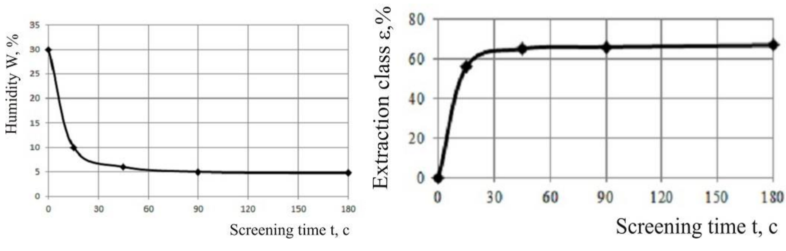

Figure 5 - Dependence of humidity *W* of the super-sieve product and extraction of ε class -0.1 mm in the undersize product from the time *t* of dehydration at the screening of granite sifting

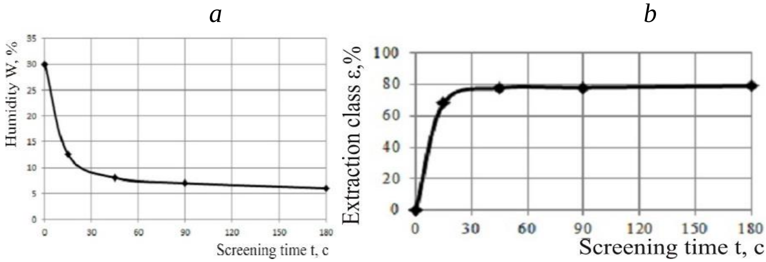

Figure 6 - Dependencies of humidity *W* of the super-sieve product and extraction of *ε* -0.1 mm class into the undersize product from the time t of dehydration at the screening of coal sludge

From plots 5-6, it can be seen that as a result of experiments (disturbance amplitude 2 mm at a disturbance frequency of 35 Hz), extraction of class +0÷-0.1 mm increased to 70-80%, while the humidity of the oversize product was reduced to 7-10%.

The results obtained are of practical interest for processing enterprises. However, to select rational parameters of the process of liquid removal, located in the capillary connecting bridges between the particles, and separating the thin and hyperfine classes, it is necessary to be able to calculate them. The empirical determination of rational parameters at screening through the nonlinearity of the process and the influence of a large number of factors requires significant material costs.

In such a situation, it is reasonable to increase the efficiency of classification and dehydration on the basis of studying the physics of the process.

In connection with this, in the IGTM NAS of Ukraine, mathematical models of a pulse with an impulse effect, dehydration kinetics and screening with dehydration [22-23] were developed, on which, using numerical experiments [24], the features of these processes were studied for materials of narrow and wide size spectra for various modes of vibro-impact screening.

The mathematical model of the screen with shock excitation of the screening surface is designed to determine the structural and dynamic parameters that provide the vibro-impact mode of the screen.

Based on the calculation, the masses of the screen box, the screening surface and the drummers, the vertical displacement, rigidity, amplitude of force, frequency, time, speed after and before the impact, the number of impacts are determined. It allows you to analyze the impact of any of the defining parameters of the screen, as well as the work of existing screens in order to identify ways to modernize them.

A mathematical model of dehydration through a layer of mineral raw materials describes the kinetics of this process. It mathematically describes the process of removing the fluid located in the capillary docking bridges between the particles.

This is achieved by simulating the transition of a fluid over the height of a layer by a discrete Markov process with discrete states.

Geometrically and geometrically described the conditions under which the fluid moves between particles. Based on the calculation, the probabilities of liquid transitions from one elementary layer to another, from disintegrating elements to elementary layers, from elementary layers to disintegrating elements are determined; passing the liquid through the holes of the screening surface.

A mathematical model of screening with dehydration describes the kinetics of this process. It mathematically describes the process of sifting particles of a given size and removal of fluid located in the capillary connecting bridges between the particles. This is achieved by simulating the transition of particles and fluid along the layer height by a discrete Markov process with discrete states.

Based on the calculation, the probabilities of transitions of particles and liquid from one elementary layer to another, from disintegrating elements into elementary layers, from elementary layers to disintegrating elements are determined; the passage of particles and fluid through the holes of the screening surface.

The study of the kinetics of dehydration and screening with dehydration with vibro-impact screening on a mathematical model using numerical experiments was performed for materials of narrow and wide size spectra with different modes of vibro-impact screening.

The research results (Figure 7,8) allowed to establish that the experimental and calculated data differ by no more than 15 %, i.e. formulas of the mathematical model with a confidence probability of 0.95 adequately describe the experimental results.

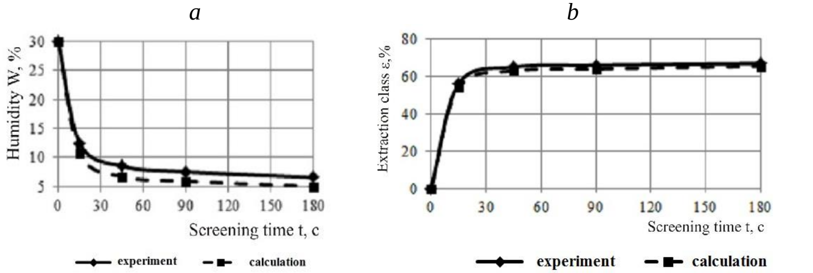

Figure 7 - Experimental and calculated dependencies of the moisture content *W* of the oversize product and extraction of *ε* class of -0.1 mm in the undersize product from the time t of dehydration at the screening of granite sifting

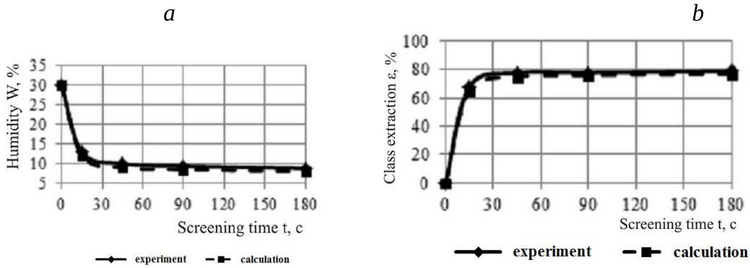

Figure 8 - Experimental and calculated dependencies of the moisture content *W* of the oversize product and extraction of *ε* class of -0.1 mm in the undersize product from the time t of dehydration at the screening of coal sludge

Conclusions.

Based on the above, we can draw the following conclusions.

To increase the efficiency of screening with dehydration, a pulse action is used - a vibro-impact, which can be communicated both directly by the screening surface (sieve) and through an intermediate element made in the form of a larger screen or a lattice structure.

Experimental studies have established that the pulse effect compared with the harmonic intensifies the passage of water through the cells of the sieve up to 40%.

The use of new vibrating screening methods with a periodic impulse effect makes it possible to effectively separate and dehydrate the material containing small size classes, which, at 18-20% moisture, are not classified using traditional methods.

The use of these conditions allowed to reduce the moisture content of the oversize product to 7-10%, and the extraction class +0÷-

0.1 mm to increase to 70-80%. The results of dehydration are comparable to the moisture indicators, which are obtained by dehydration of materials in centrifuges.

To determine the rational parameters of the screening process with a periodic impulse effect, mathematical models of the impulse screen, dehydration kinetics and screening with dehydration were created, on the basis of which calculation methods were developed and implemented.

For the successful application of screens with impulse effects, it is necessary to solve the problem of synthesis for a particular raw material of the optimal vibration spectrum, ensuring maximum efficiency of classification and dewatering with minimum energy consumption and maximum durability.

In operating conditions of screens with significant changes in the time of granulation and productivity of the original product, it is also important to provide self-adjusting excitation mode.

Currently, IGTM NAS of Ukraine is working to create a vibrating screen, which will implement the following characteristics: expansion of the impact spectrum on the processed material, screen life, operational management capabilities, increased stability, automatic control and simplicity of design.

References

1. **Vaisberg L., Kartavy A., Korovnikov A.** (2005). *Screening surfaces of screens. Construction, materials, experience.* SPb .: VSEGEI.

2. **Poturaev V., Franchuk V., Nadutyi V.** (2002). *Vibration technology and technology in energy-intensive industries.* Dnepropetrovsk, Ukraine: National Mining Academy of Ukraine.

3. **Borokhovich D., Krush I., Obodan Y.** (2007). *Experience in the use of the Kroosh technology for sifting nonmetallic bulk materials.* Ukraine: Vibration in the technique and technology. The entire Ukrainian scientific and technical magazine.

4. **Naduty V., Kalinichenko V.** (2004). Vibrating screening of the rock mass of high humidity. Dnepropetrovsk, Ukraine: National Mining University of Ukraine.

5. **Naduty V., Lapshin, E.** (2005). *Probabilistic processes of vibration classification of mineral raw materials.* Kiev: Naukova Dumka.

6. **Laplace P**. (1966). *Theory of capillary attractions.* New York: Academic press. Tenth Book of Celestial.

7. **Finn R.** (1989). *Equilibrium capillary surfaces. Mathematical Theory*. Moscow: World.

8. **Beilin M.** (1969). *Theoretical bases of coal dehydration processes.* Moscow: Nedra.

9. **Meinel A.** (1999). *Zu den Grundlagen der Klassierung sieschwieriger Materialien*. Aufbereitungs–Technik.

10. **Naduty V., Lapshin E., Shevchenko A., Burov A.** (2011). Improving the efficiency of moisture removal in the fine screening of the rock mass due to the pulse effect. Dnepropetrovsk, Ukraine: National City University: Scientific Herald. Scientific and technical journal.

11. **Lapshin E., Shevchenko A., Prokopishin L., Burov, A.** (2011). Experimental studies of the vibration effect on the passage of fluid through the screening surface. Dnepropetrovsk, Ukraine: Metallurgical and mining industry. Scientific, technical and production journal.

12. **Lapshin E., Shevchenko A.** (2012). Ways to intensify the dehydration of mineral raw materials on vibrating screens. Dnepropetrovsk, Ukraine: National Mining University. Enrichment of minerals. Scientific and technical collection.

13. **Lapshin E., Shevchenko A.** (2012). Analysis of the state of the development of vibration screening with the dehydration of mineral raw materials. Dnepropetrovsk, Ukraine: Interdepartmental collection of scientific papers. Geotechnical mechanics.

14. **Naduty V., Lapshin E., Shevchenko A.** (2011). Determination of the conditions for the passage of fluid through the screening surface of a vibrating screen. Dnepropetrovsk, Ukraine: National Mining University. Enrichment of minerals. Scientific and technical collection.

15. **Naduty V., Lapshin E., Shevchenko A.** (2011). Mathematical modeling of the passage of fluid through the screening surface during vibrating screening. Ukraine: Vibration in the technique and technology. The entire Ukrainian scientific and technical magazine.

16. **Lapshin E., Shevchenko A.** (2012). Determination of specific energy required for the dehydration of mineral raw materials during vibrating screening. Dne-

propetrovsk, Ukraine: Enrichment of minerals. Scientific and Technical Collection of the National Mining University.

17. **Lapshin E., Shevchenko A.** (2012). The energy intensity of the process of dehydration of mineral raw materials during vibrating screening. Dnepropetrovsk, Ukraine: Metallurgical and mining industry. Scientific, technical and production journal.

18. **Shevchenko A.** (2012). Influence of specific load, design and regime parameters on the intensity of dehydration of mineral raw materials during vibrating screening. Dnepropetrovsk, Ukraine: Interdepartmental collection of scientific papers. Geotechnical mechanics.

19. **Shevchenko A.** (2012). Ways to improve the efficiency of screening and dehydration of mineral raw materials on the vibrating screens of screening. Dnepropetrovsk, Ukraine: Interdepartmental collection of scientific papers. Geotechnical mechanics.

20. **Naduty V., Lapshin E., Shevchenko A.** (2012). The study of the kinetics of dehydration during vibrating screening. Dnepropetrovsk, Ukraine: Enrichment of minerals. Scientific and Technical Collection of the National Mining University.

21. **Chetverik M., Bubnova O., Babii K., Shevchenko O., Moldabaev S.** (2018) Review of geomechanical problems of accumulation and reduction of mining industry wasters, and ways of their solution. Dnepropetrovsk, Ukraine: Mining of Mineral Deposit.

22. **Lapshin E., Shevchenko A.** (2011). Mathematical modeling of the kinetics of dehydration during vibratory screening. Ukraine: Vibration in the technique and technology. The entire Ukrainian scientific and technical magazine.

23. **Lapshin E., Shevchenko A.** (2012). Mathematical modeling of the kinetics of screening and dehydration of mineral raw materials. Dnepropetrovsk, Ukraine: Enrichment of minerals. Scientific and Technical Collection of the National Mining University.

24. **Shevchenko A.** (2018). Numerical experiments on the study of the dehydration of mineral raw materials with vibro-impact screening. Kremenchug, Ukraine: Bulletin of the Kremenchug Mykhaylo Ostrogradsky National University. Modern technologies in mechanical engineering, transport and mining.

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