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SCIENTIFIC APPROACHES TO SOLVING A PROBLEM OF HIGHLY MINERALIZED MINE WATERS

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Abstract. The paper is devoted to the substantiation of an ecologically-oriented approach to solving a problem of highly mineralized mine waters while using appropriate natural effects and phenomena. Environmental safety and energy stability is ensured by involving a complex of renewable energy sources, which includes solar panels and vertical wind turbines. While solving the problems of harmonization of nature management technologies, new scientific approaches are considered; the approaches are based on the phenomena taking place in the natural environment, guaranteeing environmental safety, and meeting the optimal energy and economic parameters. It is shown that the search for new approaches should be aimed at harmonizing mining technologies, which should be focused on a comprehensive combination of physical, chemical, and biological phenomena and effects borrowed from the natural systems. Relying on the analysis of natural effects and phenomena as well as the available methods of mine water demineralization, a new system of a desalination technology using natural phenomena is developed. A scheme of mine water demineralization is developed; all stages of the development of a demineralization complex are considered. Taking into account the principles of ecological and economic feasibility, it is proposed to use renewable energy sources, that meets either partially or completely the electricity needs of the demineralization complex in mines owing to the operation of solar power plants based on solar photovoltaic panels and wind turbines. An energy autonomous complex is organized on the basis of renewable energy sources. It is proved that the demineralization complexes of most Kryvbas and Western Donbass mines can be fully supplied with the electricity from renewable sources. The main provisions of new approaches in solving the problems of negative consequences of mining activities are developed. The main provisions are developed in terms of treatment of highly mineralized mine waters of Kryvbas. The technological objects of the complex are rationally integrated into the natural environment of the territory with the optimal use of natural effects.

Keywords*:* natural phenomena, harmonized technologies, innovative technologies, highly mineralized mine water, demineralization.

Introduction. Most technologies of nature management making up the basis of mining industry are the large-scale ones both in time and space in terms of their negative impact significance and transformation of all the components of natural environment, being currently one of the greatest ecological hazards for current and future generations. That is the basis for our scientific studies and searches for new approaches to the harmonization of modern nature management technologies. In this case, the research objective is to substantiate the environmental-oriented approach to the solution of a problem of highly mineralized mine waters while using corresponding natural effects and phenomena.

Since mineral deposits of Ukraine, being the raw material base for metallurgical enterprises, are being depleted with the course of time while restoration of the environmental component requires time and considerable investments, ecologization of production is timely and urgent for the enterprises of this industry. Consequently, there arises a problem of updating both mining and processing technologies along with the organization of production processes of mining enterprises aimed at rational use of mineral resources, on the one hand, and elimination of environmental impact of mining activities on the environment, on the other hand.

Statement of the problem. For the centuries the humanity obtained metals from rich ores and concentrates. However, current outdated technologies are not capable of solving a problem of complex and rational use of natural resources along with the environmental protection. Moreover, the available technologies do not allow integrated and profitable processing of complex ores and concentrates. It is also obvious that in the near future amenable iron ore will be completely depleted, and a question will arise as for metal extraction from the low-grade ores, dump ores, technogenic deposits, and different wastes. Thus, nowadays there is an urgent issue concerning the development of improved technological schemes of metal obtaining from the ores, concentrates, rocks, and solutions. The available schemes of production and consumption requires their improvement or replacement with the ones, which are in successful and harmonic interaction with the living things, favour biological diversity, and provide decent social life that includes sufficient amount of food, accommodation, health protection, and satisfy means of living for all people.

Ways for solving the problem. Solution of the problems arising at a current stage of economic development involves creative search for new approaches in the thorough analysis of natural phenomena, striving for maximally effective incorporation of the natural management technologies into the natural, material, and energetic flows. The accumulated experience should be aimed at the development of new trends in scientific studies, implementation of certain innovative environmental-friendly technologies, search and implementation of new nontraditional energy sources. To reduce technogenic load on the environment, it is optimal to reduce the mineral mining range, using the already accumulated huge amounts of waste as the resources.

Basing on the technological effectiveness of the ideas based on the natural phenomena and effects, the following question arises immediately: does the society really need such amount of mined resources or can it be just some race of monopoly corporations to get their net profits? The massive transformations and disturbances of the earth’s crust result in the fact that the people living within the areas neighbouring certain mining objects faces such scale of environmental problems that it will be impossible even for several successive generations to overcome them just with the help of traditional methods and approaches.

Relying on that, it becomes obvious that a vector of searching for new approaches should be directed towards harmonization of mining technologies, which should be concentrated on the integration of physical, chemical, and biological phenomena and effects taken from the natural systems.

Ecologization of the natural management technologies characterizes a method of interaction between the technologies and natural environment component; it means operating and reliable selection of a complex of technological measures or environmental protection and reduction of negative technogenic impact on it.

The resulting potentials that open before us can bring change today, and it must happen today. Despite the fact that we have already begun realizing the importance of balanced processes, still just few people know how to make them economically expedient. This brings up the task of learning how to understand and use all the perfection of the nature, its effectiveness and structural simplicity, how to consider the functionality that is the basis of ecosystem logics – that will be a step towards the desired results that will differ greatly from the ones of the large-scale industrial globalization.

Practical solution of the problem concerning harmonization of mining technologies. Solution of the problem as for negative effects of mining activities is proposed by the scientists of the Academy of Sciences of Ukraine in the concept of new approaches, which feature and key moment are in the principle of a close cycle of mine water backfilling or burial with the corresponding binding agents, with energy supply from the nontraditional solar and wind power sources. The main provisions were developed in terms of handling the highly mineralized mine water of Kryvbas.

General situation with Kryvbas mine water and the methods available for its solution. A problem of mine water of Kryvyi Rih iron ore basin has been formed for rather a long time (more than a century) being now one of the most topical and complex regional ecological problem [1].

Generally, calculated per 1 t of the mined ore, the amount of water pumped from the mine workings across Kryvbas is as follows: for open-cast mining – 0.106 m^3/t; for underground mining – 1.26 m^3/t. The amount of salt of the mineralized water per 1 t of the extracted ore is as follows: for open-cast mining – 0.7 m^3/t; for underground mining – 56.0 m^3/t. Consequently, the main emphasis of the problem of environmental protection against negative impact of highly mineralized ground water should be put on the mine waters [2].

Currently, there are the following most widespread methods of handling highly mineralized mine waters: solution of mine water with fresh water with its further discharging into the surface watercourse; its pumping into deep geological structures; transportation into coastal salt lakes and seas; its treatment with the help of membrane filters; natural evaporation and distillation at the expense of technogenic heating and freezing out. Each of these techniques has its advantages and disadvantages depending on a degree of water mineralization, climatic conditions of the territory, treatment volume, and energy capacity of the technologies and environmental effects of their application.

The technologies meaning water desalination requires also solution of the problems concerning utilization of dry salts, brines or mineralized concentrates. Table 1 represents the volumes of water inflows of highly mineralized mine water and the resulting salt entering the open water courses (Rivers of Inhulets and Saksahan) within the Kryvbas mines. The volumes of entering salts are shown in terms of absolute dry condition and water-saturated state of a solution.

Thus, 15.9 mln m^3 of mine water enter the natural environment annually. This water contains 4.145 mln t of salts in a saturated solution being 0.6 mln t of salts in terms of absolutely dry condition.

Table 1 – Water inflows of highly mineralized mine water and salt entering the open water courses

Mines	Water inflow into a mine		Mineralization, g/l	Volumes of salt entering the natural environment in terms of			
				absolutely dry condition		saturated solution	
	m^3/hour	thousand m^3/year		t/hour	thousand t/year	t/hour	thousand t/year (thousand m^3/ year)
Ternivska	175	1628.3	16.5	2.89	26.87	45.54	423.41
Hvardiiska	117	1186.8	38.0	4.45	45.098	30.45	308.56
Zhovtneva	120	1134.6	58.5	7.0	66.374	31.11	294.99
Batkivshchina	345	4154.6	61.0	21.0	253.431	89.51	1080.2
Frunze	70	613.0	23.0	1.6	14.099	18.09	159.38
Yuvileina	110	964.0	52.0	5.7	50.128	28.50	250.64
Artema	350	3066.0	21.0	7.3	64.386	90.38	797.16
Dzerzhynskoho	365	3197.0	32.0	11.7	102.304	95.06	831.22
Total	1662	15944.3		61.64	622.69	428.64	4145.56

Note: In terms of these conditions, the saturated solution where a substance is solved has reached its maximum concentration and experiences no further solution. In case of saturated salt solutions of Kryvbas mine water, the concentration is 26% by weight.

Physicochemical characteristics of salt solutions (mine water concentrate). Table 2 shows solubility of some inorganic compounds.

According to the data (Table 2), one can see that chlorine salt precipitates from the solution only while interacting with the compounds of argentum, mercury, and thallium. Taking into account expensiveness of some of them and danger of others, *a method of chemical mine water purification* is not acceptable – first of all, from the environmental viewpoint.

Table 2 – Solubility of some inorganic compounds [3]

Ions	Br^+	CH_3CO^-	CN^-	CO_3^{2-}	Cl^-	F^-	I^-	NO_3^-	OH^-	PO_4^{3-}	S^{2-}	SO_4^{2-}
Ag^+	н	м	н	н	н	Р	н	р	-	н	н	м
Al^{3+}	р	+	?	-	р	м	р	р	н	н	+	р
Ba^{2+}	р	р	р	н	р	м	р	р	р	н	р	н
Be^{2+}	р	+	?	+	р	р	р	р	н	н	-	р
Ca^{2+}	р	р	Р	н	р	н	р	р	м	н	м	м
Cd^{2+}	р	р	м	+	р	р	р	р	н	н	н	р
Co^{2+}	р	р	н	+	р	р	р	р	н	н	н	р
Cr^{3+}	р	+	н	-	р	м	н	р	н	н	+	р
Cs^+	р	р	Р	р	р	р	р	р	р	р	р	р

continuation of table 2

Ions	Br^{+}	CH_3CO^{-}	CN^{-}	CO_3^{2-}	Cl^{-}	F^{-}	I^{-}	NO_3^{-}	OH^{-}	PO_4^{3-}	S^{2-}	SO_4^{2-}
Cu^{2}+	р	р	н	+	р	р	-	р	н	н	н	р
Fe^{2+}	р	р	н	+	р	м	р	р	н	н	н	р
Fe^{3+}	р	-	-	-	р	н	-	р	н	н	-	р
Hg^{2+}	м	р	р	-	р	+	н	-	-	н	н	+
Hg_2^{2+}	н	м	-	н	н	м	н	+	-	н	-	н
K^{+}	р	р	р	р	р	р	р	р	р	р	р	р
Li^{+}	р	р	р	р	р	н	р	р	р	м	р	р
Mg^{2+}	р	р	р	м	р	н	р	р	н	н	н	р
Mn^{2+}	Р	р	н	+	р	р	р	р	н	н	н	р
NH_4^{+}	р	р	р	р	р	р	р	р	р	-		р
Na^{+}	р	р	р	р	р	р	р	р	р	р	р	р
Ni^{2+}	р	р	н	+	р	р	р	р	н	н	н	Р
Pb^{2+}	м	р	н	+	м	м	м	р	н	н	н	н
Rb^{+}	р	р	р	р	р	р	р	р	р	р	р	р
Sn^{2+}	+	+	-	-	-	м	м	-	н	н	н	р
Sr^{2+}	р	р	р	н	р	р	р	р	м	н	р	н
Tl^{+}	м	р	р	р	м	н	н	р	р	м	н	м
Zn^{2+}	р	р	н	+	р	р	р	р	н	н	н	р

Note: р – well-soluble, м – slightly soluble, н – practically insoluble, + – completely reacts with water or does not deposit from a water solution, - – does not exist, ? – no data on solubility.

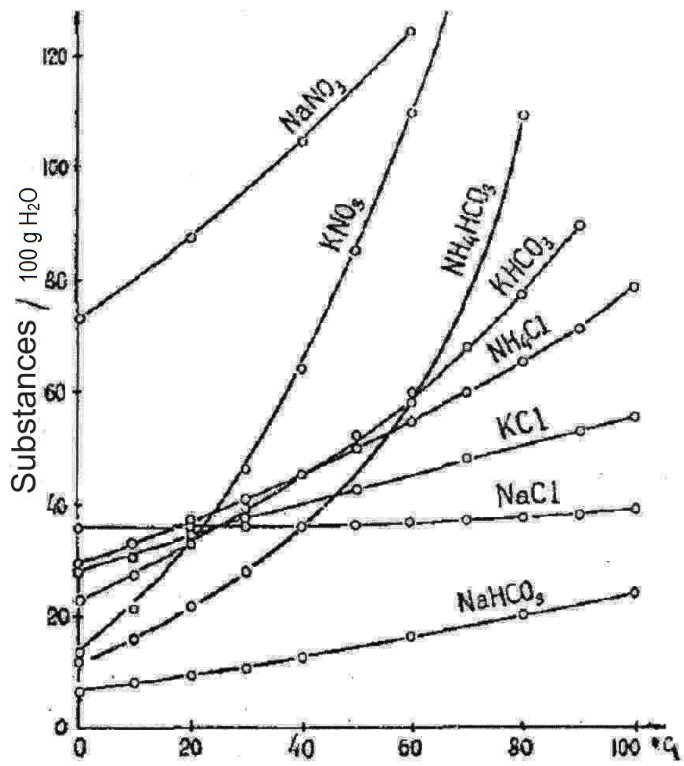

Figure 1 – Effect of temperatures on the substance solubility

Possibility of selective pumping out of mine waters with different mineralization. Ground waters of Kryvbas can be divided conditionally into three categories: pure (mineralization is 0-4 g/l), slightly mineralized (mineralization is 4-36 g/l) and highly mineralized (mineralization is 36-140 g/l).

A boundary mineralization parameter (36 g/l) is taken basing on the possibilities of the available demineralization technologies – *reverse osmosis* and can be reconsidered in terms of more detailed study of the problem.

Dewatering systems of the Kryvbas mines are typical, differing only with the number and location of water reservoirs.

Both structure and set of a drainage system is almost similar at all mines making it possible to organize selective pumping out of slightly and highly mineralized mine waters.

Volumes of slightly and highly mineralized mine waters. Volumes of the selective pumping out from the mines of "Kryvbaszalizrudkom" PJSC are given in Table 3.

Table 3 – Possible selective pumping out of mine waters of "KZRK" PJSC

Mine	Slightly mineralized		Highly mineralized	
	mineralization, mg/l	volume of mine waters, m^3	mineralization, mg/l	volume of mine waters, m^3
Ternivska	14687	1403001	-	-
Hvardiiska	6162	120936	85581	962960
Zhovtneva	24886	315408	76089	813204
Batkivshchyna	26882	365640	62451	3653196

At some mines, mine waters can be divided not into two but into three types (pure, slightly, and highly mineralized); however, that variant requires considerable mine reconstruction and more serious capital investment.

As a result of transferring into deep depths, mineral mining is accompanied by great volumes of highly mineralized mine waters being actually the mining wastes.

These characteristics for the conditions of Kryvbas mines are represented in Table 4.

The data represented in Tables 1-4 are the results of the authors' analysis of the production reports of the indicated iron ore enterprises with underground method of mineral mining.

Generally in terms of Kryvbas, 15.9 mln m^3 of mine waters enter the natural environment annually. These waters contain 4.145 mln t of salts in terms of saturated solution or 0.6 mln t of salts in terms of absolutely dry condition.

Currently, the only generally acceptable method of "solving" the mine water problem both in Kryvbas and Western Donbas is periodical discharge of "excessive" mineralized waters into rivers during the inter-vegetation period. In 2017, to solve a problem of Kryvbas mine water, the Cabinet of Ministers of Ukraine made a decision on the involvement of more than 100 mln m^3 of the Dnieper water into the Inhulets basin to help dilute the excessive mine waters while their discharging and washing the Inhulets bed when the discharging is completed.

Table 4 – Water inflows of highly mineralized mine waters and salt entering the open water courses

Mine	Water inflow into a mine, thousand m^3/year	Mineralization, g/l	Volumes of salt entering the natural environment in terms of	
			absolutely dry condition, thousand t/year	saturated solution, thousand t/year (thousand m^3/year)
Ternivska	1628.3	16.5	26.87	423.41
Hvardiiska	1186.8	38.0	45.098	308.56
Zhovtneva	1134.6	58.5	66.374	294.99
Batkivshchyna	4154.6	61.0	253.431	1080.2
Frunze	613.0	23.0	14.099	159.38
Yuvileina	964.0	52.0	50.128	250.64
Artema	3066.0	21.0	64.386	797.16
Dzerzhynskoho	3197.0	32.0	102.304	831.22
Total	15944.3		622.69	4145.56

Note: In terms of these conditions, the saturated solution where a substance is solved has reached its maximum concentration and experiences no further solution. In case of saturated salt solutions of Kryvbas mine water, the concentration is 26% by weight.

According to the project implemented by the international group in 2017, highly mineralized mine waters are discharged from the reservoir pond of Svistunova ravine along the pipeline with the length of 120 km up to the Dnieper-Bug coastal lake.

Analysis of such variant to solve the mine water problem shows its extreme inacceptability and even hazard for the water ecosystems. A process of mine water dilution and discharging into the river bed do not solve the problem at all; it just mitigates partially its acuteness for Kryvbas, by the problem masking and shifting responsibility to the nature. That does not exclude the problem arising at some other point and complicates the already existing environmental problems of the main water artery of Ukraine – the Dnieper River.

Nontraditional methods and ways of mine water demineralization. At a current stage of nature management, a problem of mine water demineralization should be solved by maximum implementation of the proposed technologies in the natural processes of ecosystems involving natural phenomena and effect and considering features of geological conditions of a specific mine area within its mining allotment with maximum use of local and regional resources – spatial, material, and energetic. Use of spatial resources means involvement of the land disturbed by mining operations to locate technogenic objects for mine water mineralization and burial (at first stages) of the wastes after those activities. The mine water demineralization technologies should be ensured by the regional energy resources involving renewable energy sources.

Scientists of our Institute carried out scientific studies and developed recommendations as for reduction of the influence of highly mineralized Kryvbas mine waters on the water ecosystems. It is proposed to use natural phenomena and effects in the demineralization technologies, which will fit maximally in the natural environment of the territory. The developed system of mine water desalination technologies is completely new, being never implemented before.

As a result of the performed analysis of physical natural phenomena, use of the following processes is the most expedient one: reverse osmosis is accepted for slightly mineralized mine waters; methods of freezing-out, distillation in special devices or in evaporation reservoirs are appropriate for highly mineralized mine waters.

A general scheme of mine water demineralization includes such stages as (Fig. 2):

- preliminary preparation including filtration, cleaning from iron and manganese, and softening of mine waters;
- reverse osmosis based on the use of membranes that pass through clean water and catch concentrates;
- distillation of the reverse osmosis concentrate can be performed by evaporating or freezing out;
- distillation wastes are dried in the closed evaporation reservoir.

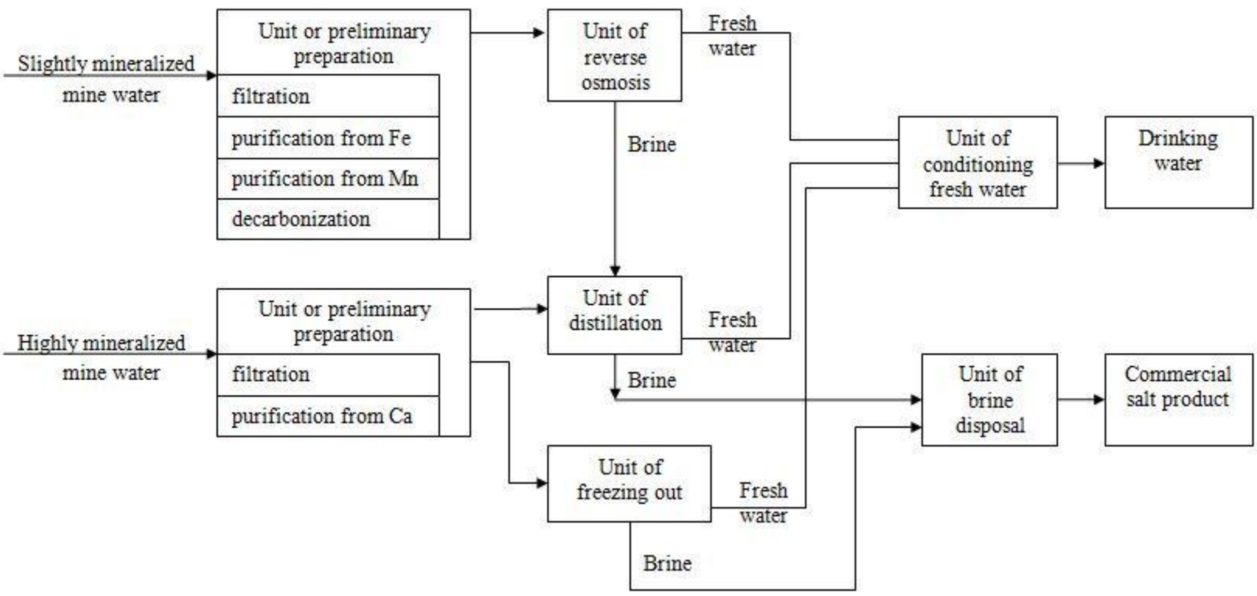

Figure 2 – Scheme of mine water demineralization

The following was taken into consideration while calculating the balance of material and energy resources:

- 100% of slightly mineralized mine waters are processed by the reverse osmosis technology with the generation of 75% of fresh water and 25% of concentrate;

- 50% of highly mineralized waters are treated by freezing out and 50% – by distillation. In this context, concentrate is obtained in the amount of 10% from the distillate amount and 20% from the amount of freezing out;

- the concentrate obtained after reverse osmosis, distillation, and freezing out is cleaned in an evaporation reservoir. This method demonstrated its efficiency from the earliest times. The tchoumaks used it effectively delivering salt throughout Ukraine. This technology helped solving the mine water problem at Zaporizhzhia Mining and Concentration Plant. This method can be combined with the formation of a technogenic rock-salt deposit that can be a precious present for our future generations. Salt after mine water demineralization can be placed on the mining allotment areas [5].

The selection of water desalination method in addition to natural and climatic factors as well as production and economic conditions depends on the type of stable energy source. Therefore, two options for energy supply of the demineralization complex are considered: 1) from the traditional power grid; 2) from the renewable energy sources.

Taking into account the principles of environmental and economic feasibility, we propose to use renewable energy sources that can partially or completely meet the electricity needs of the demineralization complex in mines through the operation of solar power plants based on photovoltaic panels and wind turbines.

For the production conditions of demineralization, it is proposed to use vertical wind power plants with a capacity of 500 kW, each of which will receive 786 thousand kWh of electricity per year; in case of their location on high dumps, this figure can reach 1257 thousand kWh. Three wind turbines, which energy potential is 3771 thousand kWh, can be placed at the area of 1 hectare.

Analysis of the averaged data on the average monthly energy of solar radiation with taking into account climatic conditions (cloud frequency and intensity) for fixed panels facing south showed that at the area of 1 hectare it is possible to located 1334 panels that can generate 973 thousand kWh of electricity per year.

At the Kryvbas mining and processing plants, the area of worked-out land that is not used in agriculture is 587 hectares. Their use for the needs of renewable energy will allow obtaining more than 570 mln kWh of electricity.

Thus, it is determined that the demineralization complexes of most Kryvbas mines can be fully supplied with electricity from the renewable sources.

Development of the mine water demineralization complex is preceded by the creation of an industrial research site, where the main provisions of the proposed Concept should be verified. Taking into account the complexity and multifactorial nature of the demineralization problem, it is recommended to create an industrial research site in stages.

The first stage of the industrial research site development involves specifying the effectiveness of membrane technology of mine water treatment of different mineralization and performing construction and installation operations to create an evaporation basin for the demineralization wastes of reverse osmosis.

The second stage includes developing the additional installation and research of highly mineralized water treatment processes using various methods of thermal evaporation (sun, alternative sources, traditional energy).

The third stage will be devoted to the study of mine water treatment technology by freezing out.

As a result of research at the stage of industrial research site, the effectiveness of the following technological processes will be evaluated:

- preparation of mine waters for their demineralization on membrane plants, which should include purification from petroleum products, phenols, iron, manganese, carbonates etc.;
- modes of treatment of slightly mineralized mine waters of different mineralization (from 5 mg/l to 45 mg/l) on the reverse osmosis units;
- specification of the intensity, energy consumption, productivity, material capacity of the above technological operations;
- obtaining electricity from the operation of solar power plants and its conversion into energy for transmission to the grid;
- economic substantiation of the expediency of mine water demineralization.

The results of the research will help proceed to the development of a standard working project of the demineralization complex and to extend the proposed Concept of mine water treatment to the mines of Kryvbas, Western Donbas, and other mining enterprises of Ukraine.

It should be noted that the main provisions of the demineralization complex were adopted by the Ternivska mine of “Kryvbaszalizrudkom” PJSC and are included in the action plan of the Ministry of Ecology and Natural Resources of Ukraine to reduce gradually the mine water discharging in the Inhulets.

Main provisions of new approaches in solving the problems of negative consequences of mining activities.

The problems of negative effects of mining are proposed to be solved in the concept of new approaches, which features and key point are in the principle of a closed cycle of mine water backfilling or burial with the appropriate binding agents, with the energy from nontraditional sources of solar and wind energy. The main provisions are developed in terms of treatment of highly mineralized mine waters of Kryvbas.

1. The problem of mine waters of the Kryvyi Rih iron ore basin has been formed for more than 130 years. It is one of the most pressing and complex regional environmental issues. Since the 1960s, a number of attempts have been made to solve it; however, the problem has not only not been solved but, with the deepening of mining operations, has even intensified due to increased volumes of pumped groundwater with its increasing mineralization.

In general, the amount of water pumped from mine workings per 1 ton of the extracted ore in Kryvbas is as follows: for opencast mining – 0.106 m^3/t; for underground mining – 1.26 m^3/t. The amount of salts of mineralized waters per 1 ton of the extracted ore is as follows: for opencast mining – 0.7 kg/t; for underground mining – 56.0 kg/t. Thus, the main focus of the problem of environmental protection from the negative impact of highly mineralized groundwater should be placed on mine water. Currently, the problem of mine water has become so relevant that its postponement becomes unacceptable.

2. Water inflows of highly mineralized mine waters of Kryvbas are about 16 million m^3 per year. Thus, 600 thousand tons of salts in terms of absolutely dry condition enter the natural environment (hydrosphere) with these waters.

Certain options for mine water demineralization were considered in the 1960s and 1980s; though, they did not find their wide application since they required significant electricity costs. However, over the past 50 years, significant progress has been made in improving the demineralization technology. Thus, a return to this idea has become logical and necessary.

3. Based on the experience of field operations and research performed at INMPE of the NAS of Ukraine, it was concluded that environmental problems associated with discharges of lightly mineralized mine waters into open water courses should be solved by producers involved in these discharges, i.e. the problem should be solved within each of the mines separately by maximizing the integration of the proposed technologies into natural environmental processes, with taking into account the peculiarities of geological conditions and development of a particular mine within its land (mining) allotment with maximum use of local and regional resources – spatial, material and energetic.

4. The use of mine water as a component of the backfilling mixture in the transition of mines to the technology with backfilling of the mined-out space could involve only 20-25% of the current water inflow into the mine. Therefore, the existing methods of reducing the volume of mine waters by demineralization, which reduce the amount of salt waste by 5 – 20 times or more, were considered. In this case, implementation of the idea of salt waste burial within the land allotments of mining enterprises becomes feasible.

5. Another method to reduce the amount of highly mineralized water is to remove clean and slightly mineralized water from their volumes. Previous analysis of mine waters of different levels showed that their mineralization ranges from 4.1 g/dm^3 to 138 g/dm^3. Therefore, there was a need to determine the possibility of selective pumping of mine water, in connection with which the data of the horizontal inflow of groundwaters and their mineralization were analyzed. Relying on the analysis, the groundwater of the mines at some plant can be divided into slightly mineralized (mineralization is 4-36 g/l) and highly mineralized (mineralization is 36-140 g/l). The limiting parameter of mineralization (36 g/l) is accepted, proceeding from the possibilities of a technology of weakly mineralized water treatment – reverse osmosis.

Dewatering systems of the Kryvbas mines are mainly typical, differing only with the number and location of water reservoirs. Therefore, all of them can be easily converted to work in a new (selective) mode.

6. Wide range of mine water mineralization stipulates the use of different desalination methods, which depend on the concrete conditions; they will have their similarities and differences in terms of each specific mine.

Each method has its own rational scope, which depends on multiple factors and especially on the cost and quality of mineralized water, conditions of its collection and transportation. According to the preliminary estimates, the best prospects are for reverse osmosis and distillation method – multistage evaporation in the vertical-tube and horizontal-tube film devices. Freezing out method is also rather promising.

Slightly mineralized mine waters allow using reverse osmosis while highly mineralized – methods of distillation or freezing out. A general scheme of mine water demineralization includes the following stages:

- preliminary preparation involving filtration, purification from iron and manganese and softening of mine waters;
- reverse osmosis, based on the use of membranes which pass through pure water and retain concentrates;
- distillation of the reverse osmosis concentrate can be carried out by evaporation;
- demineralization waste can be disposed using any of the options represented in the paper.

7. Demineralization technologies need to solve a problem of utilization of salt wastes formed during the operation – dry salts or highly mineralized concentrates (saturated solutions). Due to demineralization, the volumes of salt-containing waste are reduced respectively – when brought to a dry condition, their volume decreases by 30-60 times, when brought to a condition of a salt-saturated solution – by 5.0-15.0 times.

Thus, depending on the option, 300 thousand m^3 of dry salts or 3.4 mln m^3 of demineralization concentrates (saturated solutions) will need to be disposed of each year. Taking into account the components of the backfilling mixture, which will be produced on the basis of demineralization concentrate, this volume will be 6.8 mln m^3 per year.

8. Analysis of the available land areas disturbed by mining operations and unsuitable for traditional use showed their significant number and variety. In terms of Kryvbas, there are 15.6 thousand hectares of land disturbed by mining operations; within that huge area, one can find several hectares for a landfill. It is clear that such an environmentally hazardous facility must be properly equipped. The paper emphasizes the need for three levels of environmental protection for the landfill equipment:

- protection of landfills from the influence of external hydrogeological factors (underground aquifers and water-bearing rocks);
- protection of rock masses from the influence of salt solutions;
- storage of salt waste in the form of a waterproof material.

It should be borne in mind that the mine water demineralization and salt waste burial should be included into a series of technological operations (along with treatment, drainage etc.) of a single technological process of underground iron ore mining within the land and mining allotment. Therefore, the mine water management problem should be solved individually for each mine, with taking into account its technological and hydrogeological features.

Analysis of the condition of the disturbed land areas of Kryvbas has helped defining the following: 33.2 mln m^3 of backfilling mixture can be buried within the lands disturbed by mining, which will be enough for 4.9 years of the underground mine operation in Kryvbas. It will be possible to store a salt-containing mixture for 10 years within the existing open pits of InGOK or PivnNGOK using the technology of internal dumping with the formation of a “pioneer open pit”. When storing all salt waste on the surface in hydraulically insulated structures for 10 years, it is necessary to use an area of 253 hectares. In Kryvbas, where 15.6 thousand hectares of land have been disturbed, this list could be extended; although this issue requires a detailed and in-depth environmental rationale.

9. The consolidated economic assessment of the options for the treatment of Kryvbas mine waters makes it possible to identify the area of competitive options, which includes the following schemes:

a) selective separation of water inflows + demineralization according to the appropriate scheme with bringing salt waste to dry codnition + storage of dry salt waste in the appropriately equipped warehouses;

b) selective separation of water inflows + demineralization to obtain a concentrate + treatment of the concentrate in order to convert it into an insoluble state + burial in the form of a backfilling mixture;

c) selective separation of water inflows + demineralization to obtain concentrate + natural evaporation of concentrate in the specially equipped evaporation basins.

Thus, the consolidated technical and economic assessment of the three options for the mine water treatment allowed determining the following rating sequence:

- option of demineralization to the condition of dry salt waste and its burial –10.0 mln c.u.;

- option of demineralization to the state of concentrate and its storage in the evaporation basin –15.9 mln c.u.;

- option of demineralization to the state of concentrate and its burial in the backfilling mixture –19.9 mln c.u.

10. The following was taken into account when calculating electricity needs:

- 100% of slightly mineralized mine waters are processed by the reverse osmosis technology, in this context 75% of fresh water and 25% of concentrate are formed;

- 100% of highly mineralized waters are purified by distillation. This forms a concentrate in the amount of 25% of the distillation volume;

- in case of economic feasibility, the concentrate obtained after reverse osmosis and distillation can be converted into a dry condition by the method of thermal distillation.

The selection of water desalination method in addition to natural and climatic factors as well as production and economic conditions also depend on the availability of a stable energy source. Therefore, the paper considers two options for energy supply of the demineralization complex – from a grid and from the renewable energy sources.

Renewable energy sources make it possible to meet partially or completely the electricity needs of the demineralization complex at the mines by means of solar power plants based on photovoltaic panels and wind power plants.

11. Within the area with moderate wind speed (from 3 m/s to 13 m/s), wind turbines with vertical axis of turbine rotation are more efficient. In the meteorological situation of Kryvyi Rih, a traditional (horizontal) wind turbine with a capacity of 100 kW will be able to generate 29.4 kWh of electricity, while a wind turbine of similar capacity with a vertical turbine can generate 212.4 kWh of electricity. Thus, in the conditions of Kryvyi Rih, vertical wind power plants can produce 7 times more electricity than the traditional (horizontal) ones. It is also determined that 973 thousand kWh can be generated from an area of 1 hectar, being 973 thousand kW·year of electricity per year. *Therefore, demineralization complexes of a significant number of mines can be fully supplied with the electricity from renewable sources* [6].

12. Before developing a complex of mine water demineralization, it is necessary to check the main provisions of the above Concept at the industrial research site. Taking into consideration the complexity and multifactorial nature of the demineralization problem, it is recommended to create an industrial research site in stages.

The first stage of the industrial research site development involves specifying the effectiveness of membrane technology of mine water treatment of different mineralization and study of the composition of a backfilling mixture of salt-containing demineralization wastes.

The second stage includes developing the additional installations and research of highly mineralized water treatment processes using various methods of thermal evaporation with further analysis of a composition of water-resistant mixture of demineralization wastes.

As a result of studies at the industrial research site, the effectiveness of the following technological processes will be assessed:

- preparation of mine waters for their demineralization on membrane installations, which should include purification from oil products, phenols, iron, manganese, carbonates etc.;
- determination of the optimal modes of treatment of slightly mineralized mine waters of different mineralization (from 5 g/l to 35 g/l) on the reverse osmosis installations;
- specification of the optimal modes of desalination of highly mineralized mine waters in terms of distillation plants;
- specification of the intensity, energy consumption, productivity, and material capacity of the above technological operations;
- assessment of the reliability of electricity supply through the operation of *wind power plants* and its conversion for possible transmission into the state grid;
- evaluation of the reliability of electricity supply through the operation of *solar power plants* and its conversion for further transmission into the grid;

- assessment of the environmental safety of demineralization waste storage at the appropriately equipped landfills;
- economic substantiation of the demineralization expediency.

13. Results of the studies in terms of the industrial research site will allow developing a standard working project of the demineralization and disposal complex to extend the proposed Concept of mine water treatment to the mines of Kryvbas, Western Donbas, and other mining enterprises of Ukraine.

In addition, it should be noted that successful testing of a new mine desalination technology opens up great prospects for increasing the capacity of alternative energy generation (wind and sun) at mining enterprises in connection with the use of land disturbed by mining activities (dumps, sludge dumps, open pits), which record the increased potential for use of the sun and wind, and their allotment is already paid by the enterprise taxes.

Conclusions. Solving the problems of harmonizing of the environmental technologies and eliminating the negative consequences of mining activities is proposed in terms of new approaches. Based on the analysis of the effects and phenomena of nature as well as available methods of mine water demineralization, a new system of desalination technology was developed. In terms of this system, according to the laws of nature and basing on the renewable energy sources, an autonomous complex is organized, which includes: preliminary treatment of mine water distillation, drying of demineralization waste in a closed evaporation basin, vertical wind power plants, and a solar power plant based on photovoltaic panels. The technological objects of the complex are integrated rationally into the natural environment of the territory and make optimal use of the existing natural effects.

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НАУКОВІ ПІДХОДИ ЩОДО ВИРІШЕННЯ ПРОБЛЕМИ ВИСОКОМІНЕРАЛІЗОВАНИХ ШАХТНИХ ВОД

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Анотація. Робота присвячена обґрунтуванню еколого-орієнтованого підходу щодо вирішення проблеми високомінералізованих шахтних вод при використанні відповідних природних ефектів та явищ. Екологічна безпека та енергетична стабільність забезпечується за рахунок застосування комплексу відновлювальних джерел енергій, який включає сонячні фотопанелі та вертикальні вітроенергетичні установки. Розглянуто нові наукові підходи при вирішенні проблем гармонізації технологій природокористування, які базуються на явищах, що мають місце в природному середовищі, гарантують екобезпеку та відповідають оптимальним енергетичним і економічним параметрам. Показано, що пошук нових підходів має бути направлений на гармонізацію гірничодобувних технологій, які варто зосередити на комплексному поєднанні фізичних, хімічних і біологічних явищ та ефектів, запозичених у природних систем. На основі аналізу ефектів та явищ природи, існуючих методів демінералізації шахтних вод розроблено нову систему технології знесолення з використанням явищ природи. Розроблена схема демінералізації шахтних вод і розглянуті всі етапи створення комплексу демінералізації. Враховуючи принципи еколого-економічної доцільності, запропоновано використання відновлюваних джерел енергії, які дозволяють частково або повністю задовольнити потреби в електроенергії комплексу демінералізації на шахтах за рахунок функціонування сонячних електростанцій на основі сонячних фотоелектричних панелей та вітроенергетичних установок. На базі відновлювальних джерел енергії організовано енергетично автономний комплекс. Доведено, що демінералізаційні комплекси більшості шахт Кривбасу та Західного Донбасу можуть бути повністю забезпечені електроенергією за рахунок відновлюваних джерел. Розроблені основні положення нових підходів у вирішенні проблем щодо негативних наслідків гірничодобувної діяльності. Основні положення розроблено на прикладі поводження з високомінералізованими шахтними водами Кривбасу. Технологічні об'єкти комплексу максимально раціонально вписані в природне середовище території з оптимальним використанням природних ефектів.

Ключові слова: природні явища, гармонізовані технології, новітні технології, високо мінералізовані шахтні води, демінералізація.

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