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Economic and environmental aspects of using mining equipment and emulsion explosives for ore mining

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Abstract:

The calculation of economic efficiency during the preparatory mine operations using various mining equipment and types of explosives was performed. The general exponential regularity of determining the cost of carrying out 1 m^3 of working depending on the strength of rocks to compression when using different types of explosives and tunneling equipment was established. An environmental assessment of the use of emulsion explosives in an iron ore mine showed a decrease in concentrations of environmentally hazardous substances and a decrease in environmental hazard coefficients, which resulted in a decrease in the pollution of the atmospheric air.

Keywords: iron ore, mining equipment, emulsion explosive, economic efficiency, environmental assessment

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1. Introduction

The state-of-the art stage of the mining industry development in many countries of the world includes the production concentration and improvement of extraction technologies. This is possible due to the use of the latest mining equipment, improvement and development of new methods for calculating the parameters of drilling operations (BPR), which in the system result in an improvement in the indicators of tunneling and mining operations. Known emulsion explosives (EVR) are absolutely safe to transport and store [1-4], environmentally friendly [5, 6] and cost-effective [7-9]. Therefore, nowadays one of the main objectives of mining operations is to increase the efficiency of crushing the rock mass by explosion using EVR and modern mining equipment.

The Association Agreement between Ukraine and the European Union provides for the introduction of European standards and norms in the field of environmental protection, in particular the protection of atmospheric air. In order to reduce the negative impact on the environment, especially on atmospheric air, and according to the Target Regional Program for the transition of mining and processing plants to trotless explosives (VR) in 2011 mining enterprises with an open method of development method used EVR in the amount of 99% of annual needs [10]. As for mining enterprises with an underground development method, until 2008, all iron ore mines of Ukraine used TNT-containing explosives to perform operations related to the extraction of ores. Given the high cost of these VR and their technological and environmental hazards, it is advisable to use similar products that are made directly at the sites of extraction and are safer and more environmentally friendly. On the basis of this, in order to improve environmental safety, since 2009, at the basic enterprise Private Joint Stock Company "Zaporizhzhya Iron ore Plant" (PJSC "ZZRK") the introduction of environmental EVR type "Ukrainit" and trotyl-free VR has begun.

The annual volume of consumption by the mines of PJSC "ZZRK" of trotyl-free VR and EVR of the "Ukrainit" type amounted to 16% of the annual consumption of explosives in 2009, and in 2020 it increased to 78%.

Therefore, the objective of the research is to establish the economic and environmental efficiency of using the EVR and modern mining equipment for underground extraction of ore.

To achieve this objective, the following tasks are solved:

- to determine the economic efficiency of mining while using EVR and different mining equipment;
- to establish regression models of the cost of mining and extraction processes with the use of various explosives and mining equipment;
- to conduct an environmental assessment of the use of emulsion explosives in the underground extraction of ore.

2. Methods

The methodology for establishing the economic and environmental efficiency of using the EVR and various mining equipment in underground ore extraction included the implementation of the following stages:

- a determination of economic efficiency and establishment of patterns of cost of 1 m^3 of horizontal preparatory working and crushing of the rock mass depending on the strength of ore or rock to compression, type of explosives and mining equipment;
- a calculation of surface concentration of environmentally hazardous substances and hazard indices for environmental objects when using TNT-containing VR and EVR in the conditions of mines of PJSC "ZZRK".

To compare the effectiveness of technological schemes of preparation and cutting of the rock mass, treatment operations or individual production processes when using various systems of mining equipment, the cost can be determined separately for each type of operation guided by the methodology fully presented in the papers [11]. The methodology includes the determination of the main costs associated with mining and extracting ore with the use of BPR. Cost calculation is determined by the amount of expenses for the payroll of workers and engineering staff, basic materials, energy,

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depreciation of equipment and the costs of its current repair and maintenance. Specific costs per 1 ton of ore are obtained by separating a specific type of costs for visible extraction by block or by a separate type of preparatory or extracting operations (excavation, extraction and cutting of chamber residues). Therefore, the most universal indicator of the cost of mining and its individual processes was the calculation of costs per 1 m^3 of ore or rock.

The calculation of the level of environmental hazard was carried out using the technique [12], which takes into account the risk to public health, which is negatively affected by pollutants released when using VR.

3. Results

3.1. Results of calculation of economic efficiency during mining operations

A determination of the cost of mining operations includes the calculation of the amount of all the costs for the implementation of basic and auxiliary processes, accounting for 1 m of the working, but the most universal indicator is the cost of 1 m^3 of the working. The following initial data have a significant impact on the workings developed with the use of BPR:

– mining and geological conditions of the working, namely the cross-sectional area and physical and mechanical properties of rocks;
– BPR parameters, which include the diameter and depth of boreholes and their number, type of BPD;
– mining equipment that is used for drilling boreholes, charging them with explosives and loading the rock mass.

An analysis of mining and geological conditions of iron ore extraction in the mines of Ukraine has shown that mine workings are carried out in rocks and ores of the strength from 30 to 200 MPa. To establish the cost of mining, depending on the change in rock strength, for calculations the strengths of rocks 60, 120 and 180 MPa are taken into consideration. Further analysis of the production activities in mines enabled to establish the most common cross-sectional area of the preparatory working, which is equal to 12 m^2.

When carrying out workings, boreholes of 0.043 m diameter at an average depth of 2.5 m became most widespread. The parameters of the BPR are calculated for the above strength of rocks using the ammunition of the Verkhovna Rada Ammonite No. 6 ZHV and EVR Ukrainit-P-SA, as well as the self-levelling EVR Ukrainit-PP-2, according to the new method of calculating the BPR parameters, taking into account the diameter of the borehole and the diameter of the VR charge itself, the detonation characteristics of the explosive and the strength of the rocks [13-16]. During an analysis of drilling rigs and loading machines used for horizontal workings in the conditions of iron ore mines of Ukraine, it was established that the mines of the Kryvyi Rih basin apply the UBSH drilling rig and the PN-3A loader, and in rare cases the Boomer system with the EST-3.5 loader. In the conditions of mines of PJSC "ZZRK", on the contrary, the systems, which include the Boomer or DD drilling rig with ST and EST or LH cargo and delivery machines are mainly used.

Based on the analysis of the production activities of iron ore mines during horizontal operations, the initial data for calculating the cost of 1 m^3 of mine working will be determined. Initial data for option No. 1: horizontal preparatory workings with an area of 12 m^2, rock strength – 60, 120 and 180 MPa, VR – ammunition Ammonite No. 6 ZHV and EVR Ukrainit-P-SA and liquid EVR Ukrainit-PP-2, borehole diameter – 0.043 m, depth of boreholes – 2.5 m, mining system – drilling rig UBSH-227 with drilling machine B106 or B140, loader PPN-3A, charging machine for liquid EVR Ukrainit-PP-2 – ZEP-10. The initial data for option No. 2 are as follows: horizontal preparatory working with an area of 12 m^2, rock strength – 60, 120 and 180 MPa, VR – ammunition Ammonite No. 6 zhV and EVR Ukrainit-P-SA and liquid EVR Ukrainit-PP-2, borehole diameter – 0.043 m, depth of boreholes – 2.5 m, mining system – drilling rig Boomer S1D with drilling machine COP MD20, truck-delivery machine EST-3.5, charging machine for liquid EVR Ukrainit-PP-2 – ZEP-10. The calculation of the complexity of operations at drilling boreholes in the working development, their charging and blasting, loading of the run-of-mine, as well as a determination of the consumption of energy and materials by variants were carried out according to the formulas presented in the articles [11, 17].

As an example, the impact of changing the cost of 1 m^3 of horizontal preparatory working according to option No. 1, depending on the strength of the rocks to compression when using the ammunition of Ammonite No. 6 ZHV and EVR Ukrainit-P-SA, as well as the self-levelling EVR Ukrainit-PP-2, is analyzed and presented in Fig. 1.

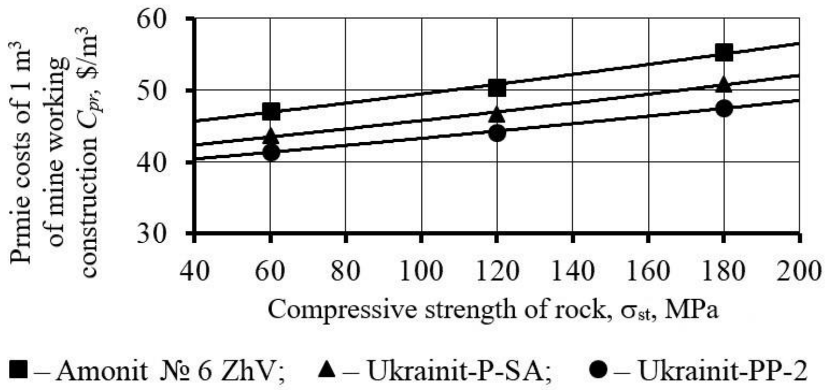

Fig. 1. Graphs of changes in the cost of developing 1 m^3 of horizontal preparatory workings according to option No. 1 depending on the strength of the rocks to compression

As it can be seen from the graph (Fig. 1), when using the cartridge EVR Ukrainit-P-SA, the cost of carrying out 1 m^3 decreases by 11 – 12%, and when using the liquid Ukrainit-PP-2 – by 17 – 19%, with respect to the use of bp-cartridge Ammonite No. 6 ZHV. When using the cartridged EVR Ukrainit-P-SA and liquid Ukrainit-PP-2, it can be seen that there is a decrease in the cost by 7 - 9% compared to the first case.

Further studies of the results enabled to develop the graphs of changes in the cost of 1 m^3 of horizontal preparatory working according to option No. 2, depending on the strength of the rocks to compression when using the Ammonite No. 6 ZHV and EVR Ukrainit-P-SA, as well as the self-levelling EVR Ukrainit-PP-2, which is presented in Fig. 2.

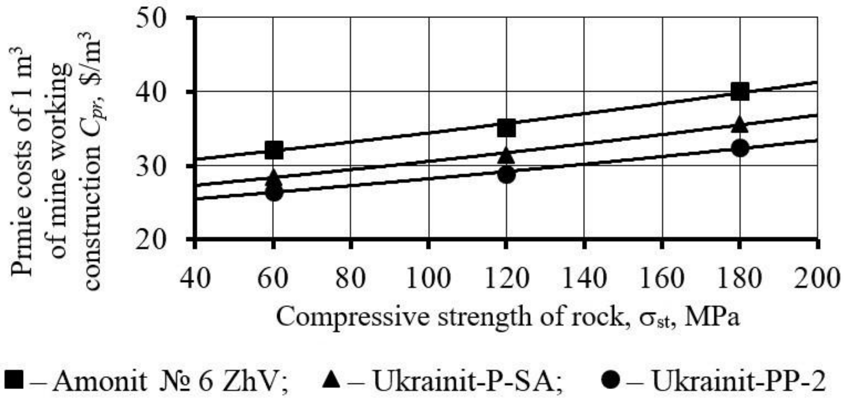

Fig. 2. Graphs of changes in the cost of developing 1 m^3 of horizontal preparatory workings according to option No. 2 depending on the strength of the rocks to compression

From the graph (Fig. 2) it can be seen that when using the cartridge EVR Ukrainit-P-SA, the cost of carrying out 1 m^3 is reduced by 10 - 12%, and when using the self-levelling EVR Ukrainit-PP-2 – by 17 - 19%, relative to the ammunition of the Verkhovna Rada Ammonite No. 6 ZHV. When using the cartridge EVR Ukrainit-P-SA and liquid Ukrainit-PP-2, there is a decrease in cost by 7 - 9% compared to the first case. This is due to the lower price per 1 kg of liquid EVR Ukrainit-PP-2 in relation to the cartridge EVR Ukrainit-P-SA, with sufficiently approximate detonation characteristics. Further analysis of relationships, which are presented in Fig. 1 and 2 enabled to state that the cost of developing 1 m^3 of the working when using tunnelling equipment, which includes UBSH-227 and PPN-3A, is 25 - 35% higher than when using Boomer S1D and EST-3.5.

After an approximation of the maximum values, according to the graphs shown in Fig. 1 and 2, a general empirical relationship of changing the cost of 1 m^3 of horizontal preparatory working, depending on the strength of the rocks to compression, when using various mining equipment and bp-cartridge Ammonite No. 6 ZHV and EVR Ukrainit-P-SA, as well as self-levelling EVR Ukrainit-PP-2 was obtained.

$$C_{pr} = K_{HO} \cdot K_{VR} \cdot e^{0.0015 \cdot \sigma_{st}} \text{ \$/m}^3 \quad (1)$$

where:

K_{HO} – coefficient taking into account the composition of mining equipment, when using the system, which includes the drilling rig of UBSH type and PPN-3A K_{HO} loader = 1.0, when using the system which includes the Boomer drilling rig and the EST-3.5 K_{HO} truck and delivery machine = 0.7,

K_{VR} – coefficient taking into account the VR type of ammunition - VR Ammonite No. 6 ZHV K_{VR} = 42, for the cartridge EVR Ukrainit-P-SA K_{VR} = 39, for the liquid EVR Ukrainit-PP-2 K_{VR} = 36,

σ_{st} – the strength limit of rocks to compression ≥ 40 MPa.

Thus, the determination of economic efficiency of mining operations with the use of EVR enabled to establish that the cost of carrying out 1 m^3 is dependent not only on the type of VR and mining equipment, but also on the parameters of the BPR.

3.2. Results of economic efficiency calculations in the performance of treatment operations

Ore extraction rates in most cases are completely or almost entirely dependent on treatment operations. If the labour costs of cleaning work are assumed as 100%, then the share of direct extraction of ore accounts for 20% to 80%, which mainly depends on the accepted system of development and physical and mechanical properties of the ore. Analysis of technological schemes of treatment operations [18], shows that the extraction of iron ores in the mines of Ukraine is carried out with the use of fans. Consequently, the economic efficiency of the treatment operations, namely the crushing of rock, can be determined by the volume of the ore layer. As it is known, the cost of extracting a layer of ore includes the calculation of the amount of all the costs for drilling wells and charging them with VR, for 1 ton of ore, but the most general indicator is the cost of 1 m^3 of ore. To obtain the correct results of the cost of extracting 1 m^3 of ore, it is necessary to determine the initial data for calculation. The results of economic efficiency calculation, when extracting a layer of ore using BPR, are influenced by the following initial data:

- mining and geological conditions, namely the parameters of the ore layer, the strength and cuttability of the ore;
- BPR parameters, which include the diameter, total length and number of boreholes in the ore layer, type of VR, LNO and the distance between boreholes;
- mining equipment to be used for drilling and charging boreholes.

An analysis of mining and geological conditions of iron ore extraction in the mines of Ukraine, enabled to establish that the strength of ore ranges from 30 to 200 MPa. Therefore, to assess the nature of the change in the cost of extracted ore, depending on its strength, for calculation the strengths of ore 60, 120 and 180 MPa are taken. Further analysis of the production activities of mines enabled to establish that the extraction of ore is carried out with boreholes of the diameter 0.089 – 0.11 m in layers 15 – 30 m wide and 20 – 35 m high. BPR parameters are calculated according to the zone of intensive grinding and joint action of charges [13] for the above strength of ores using loose VR Gramonite 79/21, trotyl-free VR Ukrainit-ANFO and bulk EVR Ukrainit-PP-2, taking into account the physico-mechanical properties of the rock mass and detonation characteristics of explosives.

An analysis of the use of drilling rigs and charging machines for an extraction of ore in the conditions of iron ore mines of Ukraine, confirmed that the mines of the Kryvyi Rih basin drill boreholes with the use of drilling machines NKR-100 IPA and in rare cases Simba and DL. Charging wells with crumbly VR Gramonite 79/21 or trotyl-free VR Ukrainit-ANFO is carried out with the use of the charging machine MTZ-3, and self-levelling EVR Ukrainit-PP-2 - PZMK-500. PJSC "ZZRK" on the contrary, mainly for drilling wells used drilling machine Simba and DL, and in rare cases, NKR-100 IPA machines which are used for charging wells with crumbly VR Gramonite 79/21 or trotyl-free VR Ukrainit-ANFO, as well as the MTZ-3 charging machine, and the LPG Ukrainit-PP-2 - RTCh-23, and in some cases, the PZKK-500.

Based on the analysis of the production activity of iron ore mines in the field of treatment operations, the initial data for calculating the cost of 1 m^3 of ore will be determined. The calculation of the cost of extracting ore was performed for two options using different drilling and charging equipment using loose VR Gramonite 79/21, Ukrainit-ANFO and self-levelling EVR Ukrainit-PP-2 for the ore of the strength of 60, 120 and 180 MPa. Initial data for variant No. 1: the cross-sectional area is 12 m^2, the dimensions of the ore layer, width – 20 m and height – 25 m; ore strength – 60, 120 and 180 MPa, structural weakening coefficient of the rock mass – K_C = 0.5, borehole diameter – 0.105 m, loose VR – Gramonite 79/21 of 1000 kg/m^3 and detonation rate of 3600 m/s, trotyl-free VR Ukrainit-ANFO of 950 kg/m^3 density and detonation rate of 3800 m/s and liquid EVR Ukrainit-PP-2 of 1000 kg/m^3 density and detonation rate of 4900 m/s, drilling rig – NKR-100 MPA, charging machine – MTZ-3 and PZMK-500. Output data for variant No. 2: cross-sectional area – 12 m^2, dimensions of the ore layer, width – 20 m and height – 25 m; ore strength – 60, 120 and 180 MPa, the coefficient of structural weakening of the rock mass is K_C = 0.5, the diameter of the borehole is 0.102 m, the loose VR is 79/21 of 1000 kg/m^3 density and detonation rate of 3600 m/s, trotyl-free VR Ukrainit-ANFO of 950 kg/m^3 density and detonation rate of 3800 m/s and liquid EVR Ukrainit-PP-2 of 1000 kg/m^3 density and detonation rate of 4900 m/s, self-propelled drilling rig – Simba H1254, charging machine – MTZ-3 and RTCh-23. A calculation of the complexity of work on drilling boreholes, their charging and blasting, as well as a determination of energy and materials' consumption in variants were carried out according to the formulas presented in the work [11].

As an example, the change in the cost of extracting 1 m^3 of ore according to option No. 1, depending on the strength of the compression ore when using loose VR Gramonite 79/21, trotyl-free VR Ukrainit-ANFO and self-levelling EVR Ukrainit-PP-2, is analyzed and presented in Fig. 3.

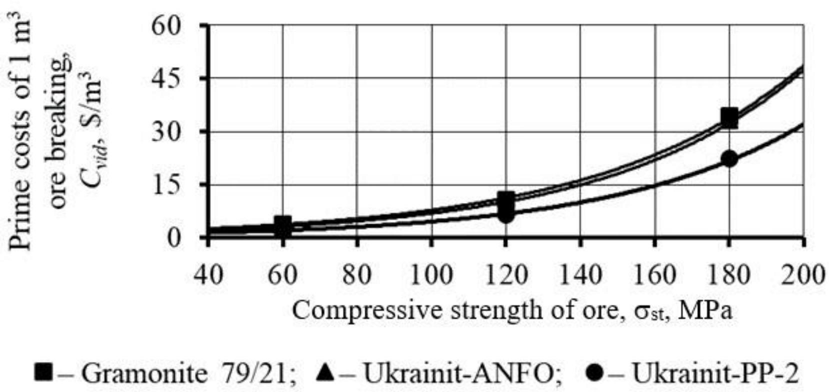

Fig. 3. Graphs of change in the cost of extracting of 1 m^3 of ore according to option No. 1, depending on the ore strength to compression

As it can be seen from the graph (Fig. 3), when using the self-levelling EVR Ukrainit-PP-2 and when using the NKR-100 IPA drilling machine and the PZMK-500 charging machine, the cost of extracting 1 m^3 of ore of the strength 60 – 180 MPa decreases by 48%, in relation to the use of loose VR Gramonite 79/21, drilling machine NKR-100 MPA and charging machine MTZ-3. Comparison with trotyl-free VR Ukrainit-ANFO, drilling rig NKR-100 MPA and charging machine MTZ-3 shows that when using the liquid EVR Ukrainit-PP-2 and when using the NKR-100 IPA drilling rig and the PZMK-500 charging machine, the cost of extracting 1 m^3 of ore of the strength 60 – 180 MPa decreases by 32%.

Having carried out the approximation of the maximum values according to the relationships given in Fig. 3, the general empirical formula of changing the value of the extraction cost of 1 m^3 of ore, depending on the strength of the ore to compression when using the drilling rig NKR-100 MPA and charging machines MTZ-3 and PZMK-500 was obtained:

$$C_{vid} = K_{VR} \cdot e^{0.019 \cdot \sigma_{st}} \ \$/\text{m}^3 \qquad (2)$$

where:

K_{VR} – coefficient taking into account the type of VR, when using loose VR Gramonite 79/21 K_{VR} = 1.16, for trotyl-free VR Ukrainit-ANFO K_{VR} = 1.02, and for liquid EVR Ukrainit-PP-2 K_{VR} = 0.73.

Further studies of the results allowed to build graphs of changes in the cost of extraction of 1 m^3 of ore according to option No. 2, depending on the strength to compression when using loose VR Gramonite 79/21, trotyl-free VR Ukrainit-ANFO and bulk EVR Ukrainit-PP-2, which is presented in Fig. 4.

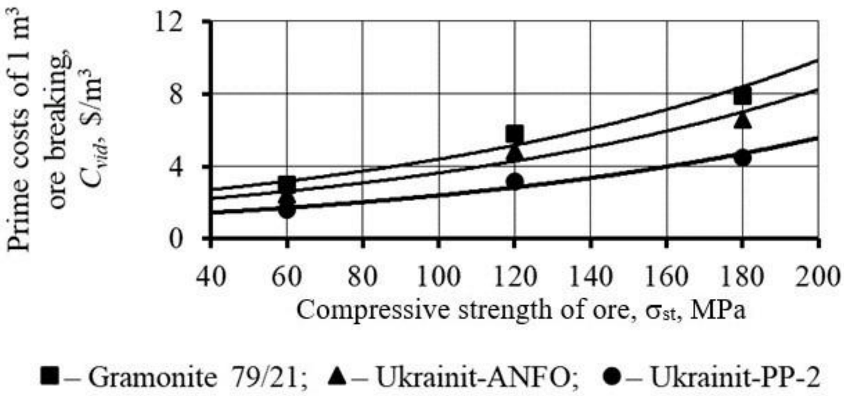

Fig. 4. Graphs of change in the cost of extracting 1 m^3 of ore according to option No. 2, depending on the ore strength to compression

As it can be seen from the graph (Fig. 4), when using the self-levelling EVR Ukrainit-PP-2 and when using the Simba drilling rig and the RTCh-23 charging machine, the cost of extracting 1 m^3 of ore of the strength from 60 to 180 MPa decreases by 46%, in relation to the use of loose VR Gramonite 79/21, Simba drilling rig and charging machine MTZ-3. Comparison with trotyl-free VR Ukrainit-ANFO, drilling rig NKR-100 IPA and charging machine MTZ-3 shows, that when using the self-levelling EVR Ukrainit-PP-2 and when using the Simba drilling rig and the RTCh-23 charging machine, the cost of extracting 1 m^3 of ore of the strength 60 – 180 MPa decreases by 32%. The strength of ore to compression, type of mining equipment and parameters of BPR have a significant impact on extraction costs.

After an approximation of the maximum values given in Fig. 4, a general empirical relationship of changes in the cost of extracting 1 m^3 of ore, depending on the ore strength to compression when using Simba drilling rigs and MTZ-3 and RTCh-23 charging machines is obtained:

$$C_{vid} = K_{VR} \cdot e^{0.008 \cdot \sigma_{st}} \ \$/\text{m}^3 \qquad (3)$$

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where:

K_{VR} – coefficient taking into account the type of VR, when using loose VR Gramonite 79/21 K_{VR} = 2.0, for trotyl-free VR Ukrainit-ANFO K_{VR} = 1.6, and for liquid EVR Ukrainit-PP-2 K_{VR} = 1.1.

Thus, the determination of economic efficiency in extracting ore, using EVR, enables to state that the cost of extracting 1 m^3 of ore is influenced not only by the type of VR and mining equipment, but also by the parameters of the BPR.

3.3. Ecological assessment of using emulsion explosives in the underground extraction of ore

The current realities enforce the environmental safety of mining activities. Quite often the authors highlight the need of finding a complex solution to this problem [19]. During the years 2006 – 2010, measurements of the concentration of harmful gases in air samples around the ventilation shafts of mines of PJSC "ZZRK" were carried out and the distribution of surface concentrations was calculated. From 2009 to 2011, the toxic-mutagenic activity of atmospheric air around ejection sources, using the test "sterility of plant pollen", was investigated to determine the effect on the processes of ontogeny of winter wheat in 2011 and studies of linear values of the size and weight indicators of wheat near the ventilation shafts, as well as the analysis of the values of biological signs of germinated wheat grains [20] were carried out.

Due to the analysis of the research results, it was found that mine air entering the atmosphere from the ventilation shafts negatively affects the development of both plants and grain crops which is caused by substances released into the atmospheric air in the result of conducting BPR using EVR [21, 22]. Based on the proposed methodology in 2017 – 2018 some calculations were made and an environmental assessment of the state of atmospheric air around the mine ventilation shafts was carried out [12, 23]. This made it possible to reduce the technogenic impact on atmospheric air, reducing the environmental hazard index to 35%.

Therefore, there is a scientific and practical interest in establishing the technogenic impact and the index of environmental hazards on atmospheric air with an increase in the volume of annual consumption of EVR and trotyl-free VR to 78% of the total annual expenditure on explosives. Such questions are also in other thermochemical transformations of raw materials [24, 25]. For environmental assessment of the EVR use by the mines of PJSC "ZZRK" in the extraction of iron ore, the change in the concentration of harmful gases when using 100% TNT-containing VR in 2008, and when using 22% of TNT-containing VR and 78% of the EVR type "Ukrainit" in 2020 was analyzed which allowed to establish an environmental assessment of EVR "Ukrainit" use in the conditions of mines of PJSC "ZZRK".

An analysis of the values of surface concentrations of environmentally hazardous substances allowed to establish that the maximum concentration of environmentally hazardous substances of carbon monoxide and oxide as well as of nitrogen dioxide was found in 2008, when during the year 100% of TNT-containing VR was used in underground mining operations. When in 2020 78% of EVR type "Ukrainit" and 22% of TNT-containing VR were used the value of maximum concentrations of environmentally hazardous substances in comparison with 2008 decreased, for carbon monoxide by 5.0 – 5.5 times, and oxide and nitrogen dioxide by 1.2 – 1.3 times. This indicates that when EVR type "Ukrainit" is used, it causes a decrease in concentrations of environmentally hazardous substances and reduces the burden on atmospheric air.

A determination of the environmental hazard level was carried out using the methodology presented in the papers [12, 26]. The results of calculating the change in the hazard index in relation to the distance to source of emission were established when using 100% of TNT-containing VR in 2008. The highest values of coefficients and hazard indices for all environmentally hazardous substances were observed: carbon oxide - 5.3 times, and nitrogen oxide and nitrogen dioxide - 1.25 times compared to the use of 100% TNT-containing VR in 2008. There is also a decrease in the hazard index of 1.5 times on average when using the EVR "Ukrainit", compared with the use of TNT-containing VR, which is a decrease in the environmental hazard index to 36%. This indicates that the use of EVR type "Ukrainit" in the underground extraction of ores leads to a decrease in the concentrations of environmentally hazardous substances of carbon monoxide and oxide as well as nitrogen dioxide, formed after underground operations which reduces the burden on atmospheric air.

4. Conclusions

1. The calculation results of economic efficiency of mining operations with the use of EVR showed that the cost of developing 1 m^3 of working is affected not only by the type of VR and mining equipment, but also by the parameters of the BPR. Analysis of the cost values of carrying out 1 m^3 when using domestic and foreign mining equipment, also showed that when using the cartridge EVR Ukrainit-P-SA, the cost of developing 1 m^3 decreases to 11% on average and when using self-levelling EVR Ukrainit-PP-2 – up to 18%, in relation to the cartridge VR Ammonite No. 6 ZHV depending on the strength of the rocks when using domestic and foreign tunneling equipment using VR-cartridge Ammonite No. 6 ZHV and EVR Ukrainit-P-SA, as well as liquid EVR Ukrainit-PP-2.

2. A determination of economic efficiency in the implementation of treatment operations with the use of EVR enabled to conclude that the cost of extracting 1 m^3 of ore is affected not only by the type of VR and mining equipment, but also by the parameters of the BPR. Comparison of the cost of extracting ore when using various drilling rigs and charging machines, made it possible to establish that when using self-levelling EVR Ukrainit-PP-2 the cost of extracting 1 m^3 of ore decreases to 48% on average in relation to the loose VR Gramonite 79/21, and in relation to trotyl-free VR Ukrainit-ANFO – up to 32%. Exponential formulas of the cost determination in the case of extracting 1 m^3 of ore were obtained when using various drilling rigs, charging machines and loose VR Gramonite 79/21, trototyl-free VR Ukrainit-ANFO and self-levelling EVR Ukrainit-PP-2.

3. An environmental assessment of the EVR use of in the ore extraction in the conditions of the PJSC "ZZRK" mines over the period of 12 years showed that in 2020 78% of EVR type "Ukrainit" and 22% of TNT-containing resulted in 5.3-fold reduction of environmental hazards as regards carbon monoxide, and 1.25 times of nitrogen oxide and nitrogen dioxide compared to the use of 100% TNT-containing VR in 2008. This led to a decrease in the hazard index by of 1.5 times (up to 36%) on average when using EVR "Ukrainit", compared with the use of TNT-containing VR. The use of EVR type "Ukrainit" in underground ore extraction leads to a decrease in concentrations of environmentally hazardous substances of carbon monoxide and nitrogen oxide and dioxide, generated during underground operations and enables to reduce the pollution of atmospheric air.

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