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## INCREASING ECOLOGICAL SAFETY DURING UNDERGROUND MINING OF IRON-ORE DEPOSITS

**Purpose.** To create the technology increasing the level of ecological safety of underground mining of iron ores by means of decreasing the number of harmful substances released into the atmosphere.

**Methodology.** Laboratory and industrial research studies of the condition of the atmospheric air around mine arrangement were conducted by means of a physical-and-chemical method and biological testing. The standard method for calculation of their concentration in the atmosphere was used for determination of features of harmful substance dispersion.

**Findings.** Regularities of ground concentration of total influence of harmful substances changing with taking into account a specific consumption of explosives and distance from an emission source are revealed. The dependence of conditional indicator of damageability of bioindicators changing with increase in distance from a source of emission and specific consumption of explosives is established. The method for calculation of ecological assessment of atmospheric air condition around an emission source is developed.

**Originality.** Dependence of influence of ground concentration of harmful substances on damageability of bioindicators at the cellular and organismal levels is established, which allows estimating an ecological state of atmospheric air on industrial territories.

**Practical value.** Regularities of influence of ground concentration of total impact of harmful substances on a condition of indicator systems are determined that allows estimating the state of the environment and increasing reliability of local environmental monitoring around an iron-ore mine. The technology of drilling-and-blasting operations conducting in which emulsion explosives are used during mining of iron ores by means of the chamber mining methods, which allows decreasing the hazard index of harmful substances influence on the atmosphere, is developed and implemented.

**Keywords:** *explosives, emission source, harmful substances, physical-and-chemical method, concentration of total impact, hazard index*

**Introduction.** Underground extraction of iron ores in the majority is conducted by means of drilling-and-blasting method with application of trotyl-content explosives during application of mine air harms by explosion products, iron-ore dust and further without cleaning is released into the atmosphere, and constitutes danger to the environment in areas of functioning of mining enterprises. Long-term operation of deposits is followed by negative impact on the environment, affecting practically all its elements, and leads to increase in levels of impurity of atmospheric air, water objects, land grounds and also accumulation of a significant amount of industrial wastes in mining regions of Ukraine [1]. Scales of technogenic impact on the biosphere depend on the volume of the main production and are defined by increasing volumes of ore extraction. Such situation leads to changing of natural living conditions of live organisms, including the person, to reduction of biodiversity, increasing in incidence, decreasing in quality and reduction of life duration of the population.

Level of ecological safety of underground extraction of iron ores remains quite low, in connection with insuf-

ficient examination of mechanisms of pollution of mine and atmospheric air by harmful emissions from explosive operations and lack of effective remedies of impact on pollution processes [2]. As a result, pollution of objects of the environment in adjacent territories to iron-ore mines increases. In this regard, establishment of regularities of pollution of atmospheric air from influence of mine sources of emission has the scientific interest that is a basis for development of effective methods of assessment of level of ecological safety and introduction of highly effective nature protection technologies [3] which will allow to increase the level of ecological safety during extraction of iron ores and improve a condition of objects of the environment in industrial regions that is a relevant task [4].

**Analysis of the recent research and publications.** The ore mining industry is one of the most air basin polluting branches on formation level and volumes of emissions of harmful substances into the atmosphere. As a result of activity of mining enterprises, technogenic influence on the air basin is rendered by organized and unorganized emissions of harmful substances that leads to dusting and air pollution in adjacent territories, to growth of incidence and negative impact on live organ-

isms [5]. At the same time, the character and scales of this influence in each case are various and are defined by technological and zonal-and-climatic features of developed deposits [6].

Results of analysis of statistical data of sanitary-and-hygienic indicators of environment state in the Chervonohradsky mining region are represented by the authors of work [7]. Data about number of tests of soil, water and atmospheric air which exceeded standard values have been provided to the uniform system of measurement, namely to conditional indicators of pollution of biological systems, according to the technique that represented in work [8]. The executed research of separate components of environment on sanitary-and-hygienic indicators which considered their average value in Chervonohradsky mining region by means of an integrated conditional indicator of pollution has allowed to establish that the level of environmental pollution in general is determined as "above the average". Category of ecological hazard of the environment of region is "dangerous". On the basis of it, authors have drawn a conclusion that essential environmental pollution in the region demands introduction of the actions that will be directed on improvement of quality of the environment and decreasing in influence of mining industry of the region on a biota and person by means of introduction of low-waste and waste-free technologies for production and beneficiation of mineral deposit. Also, more detailed realization of observation of environment objects not only by means of statistical data, but also with application of bioindication methods. Regularities of biological indicators changing with increasing in distance from emission sources aren't determined in conducted research, and only statistical data and quality standard of the mining region condition are submitted.

Modern world annual consumption of industrial explosives has exceeded 6 million tons. The main way of rocks breaking is drilling-and-blasting that is confirmed by the data about explosives volumes application during ore deposits mining. The bulk of explosives that applied in ore mining industry is trotyl-content which is a source of increased allocation of gaseous toxic emissions. The group of authors in work [9] has presented results of experimental research on ways of neutralization of gaseous emissions during mass explosions conducting on pits that extracting granites. As a result of the conducted industrial research, it is established that the acceleration of chemical reactions of explosive transformation caused by presence of hydroxide of calcium and sulfate of sodium that reduces the number of toxic emissions. Decreasing in volumes of emissions of carbon oxides and nitrogen is reached by placement of converters in special constructions of tamping devices by means of hashing with explosives, an arrangement of converters on a joint of explosives and tampig that doesn't influence on intensity of rocks breaking, and in some cases even improves it. After course of secondary reactions, the toxic gases (which are contained in explosion products) can be neutralized by salts of alkaline metals, oxides and hydroxides the alkaline-earth metals as they easily connect the formed carbon oxides and nitrogen with formation

of the corresponding nitrates, nitrites and formiates. Besides the influence on atmospheric air, open-pit mining operations negatively influence on soil cover and balance mode of underground waters [10]. The events which protecting the massif from penetration into its surface and thawed snow, snow, mud streams [11] are held at presence of landslides on the territory of pits. The results of influence of explosive operations in pits on environment objects are absent in represented research, just only ways of decreasing the negative impact of mass explosions on atmospheric air.

The results of a research that represented in works [12] are consisted in establishment of regularities of dispersion of a dust cloud after mass explosions on iron-ore pits of Kryvorizskiy basin and level of changing of its ecological hazard. Ecologically effective ways and means of decreasing emissions of dust in the environment are developed on their basis. The calculation method of raising height of a dust cloud with taking into account dispersion of dust particles and other influencing factors is developed. Calculations of a dust cloud dispersion have shown that the far offset of coarsely-dispersed iron ore dust is 0.14–4.4 km, and finely-dispersed is – 40–70 km. Specific emissions of dust at the total area of dispersion of 28770 sq. km reach 1.302 kg/sq. km. Suppression of a dust cloud is executed by method of irrigation [13]. Analytical expression of efficiency estimation of dust capture from diameter of dust particles, drops of water, speed of their movement, amount of irrigated liquid, height of irrigated cloud and also total coefficient of capture of dust particles is established by liquid drops is established. The way of decreasing in height of emission of gas-dust cloud at mass explosions on the basis of parameters optimization of borehole charges is developed. Also, advanced design of of borehole charges tamping which provides application of it as a part of tamping of a rubber stopper with the anchor device is offered. According to the results of research, regularities of stability of plants of bioindicators depending on a specific consumption of explosives at mass explosions aren't established.

**Unsolved aspects of the problem.** The analysis of executed works in the area of technogenic influence of mining enterprises on atmospheric air has allowed to establish that research were conducted for pits that causes necessity of influence assessment on the air basin of mining enterprises that developing ore deposits by the underground method. The lack of scientific substantiation of regularities of general toxic-mutagenic activity of atmospheric air and biological signs of cultures of an agrophytocenosis nearby the industrial platform and territories that adjacent to the iron-ore mine doesn't allow to make assessment of extent of influence on flora, and, therefore, to consider it in technology of underground mining operations conducting. The offered methods of decreasing negative impact on atmospheric air during large-scale blastson pits will allow to consider experience of drilling-and-blasting operations conducting on open mining operations during developing of ecologically directed technology solutions on extraction of ores as an underground method and to re-

duce technogenic influence of mining enterprises on atmospheric air.

**Objectives of the article.** The purpose of work is creation of the technology that increasing the level of ecological safety of underground extraction of iron ores by means of decreasing amount of harmful substances that released into the atmosphere.

The following tasks have been formulated and solved for realization of set purpose:

- to estimate levels of pollution of the environment objects at different distances from emission sources, and to determine regularities of emissions influence of iron ore mines on a condition of atmospheric air on indicators constants;

- to conduct assessment of parameters of ecological hazard of iron-ore mine on emissions into the atmosphere;

- to develop the technology of drilling-and-blasting operations conducting that increasing the level of ecological safety of underground mining of iron ores;

- to define environmental efficiency of technology implementation during underground mining of iron ores.

**Methods.** The formulated tasks were solved by the following methods: laboratory research by a physical-and-chemical method – for studying of regularities of ground concentration distribution of harmful substances; biological testing – for assessment of a atmospheric air condition on the territory that adjacent to the iron-ore mine; methods of mathematical statistics – for processing of research results, identification of regularities and assessment of reliability of experiments results; ecological analysis – for determination of decreasing level of ecological hazard with application of different technologies of drilling-and-blasting operations conducting during ores mining.

**Results.** World reserves of iron ores are equal to more than 150 billion tons, and the richest owners of these raw materials in terms of iron are such countries as Russia, Brazil, Australia, Ukraine, China, India and USA. In Europe and the world our country is allocated with the large rich stocks of iron deposits. In the state balance of minerals of Ukraine, reserves of iron ores are equal to 28491.2 million tons that concentrated in 52 deposits from which for today's time 24 are developed. Ukraine takes the 7<sup>th</sup> place in the world on production of saleable iron ores (4.9 % of world), conceding only to China, Brazil, Australia, India, Russia and USA.

The most significant iron-ore deposits in Ukraine are Kryvorizskiy iron-ore basin, Kremenchuzskiy iron-ore district, Bilozerskiy iron-ore district, Konkskiy district of magnetic anomalies, Prydniprovskiy iron-ore district, Pryazovskiy iron-ore district, Odesko-Bilotserskiy iron-ore district and Kerchenskyyi iron-ore basin. From above mentioned iron-ore basins currently working Kryvorizskiy and Kremenchtskiy iron-ore areas (basin) by open and underground methods and Bilozerskiy iron-ore district by underground method [14]. Ores of Kryvorizskiy basin are mined by 9 pits and 8 mines, Kremenchuzskiy iron-ore district by 2 pits, Bilozerskiy iron-ore district by 2 mines. All pits are pro-

moted on emulsion explosives for the purpose of negative impact decreasing on the environment during explosive operations. It is well known that during detonation of one kilogram of emulsion explosives just 20 liters of gas are thrown out in air that is nearly in 14 times less, than during application of trotyl-content. On underground mining operations in mines of Kryvbas, application of non-trotyl explosives is equal about 3 % that is connected with development of technology of underground mining operations conducting and constructions of charging cars for emulsion explosives application. Therefore, nowadays emulsion explosives are still used on iron-ore mines of Ukraine. Fulfilled air from mines is released through ventilating shafts into the atmosphere without treatment after explosive operations conducting. It is connected with the fact that today there is no effective equipment and treatment facilities for catching and neutralization of gases which are released into the atmosphere in considerable volumes. Depending on an arrangement of mines and their ventilating shafts, the return ventilating air negatively influences on condition of environment objects and health of population that living in the adjacent area.

On the territory of Kryvorizskiy basin from 40 existing mines, only 8 are acting today. The structure of PJSC “Kryvorizskiy Iron-Ore Plant” includes “Rodina”, “Oktyabrskaya”, “Hvardiiska” and “Ternivska” mines, into PJSC “EVRAZ Sukha Balka” – “Yuvileina” and “n.a. Frunze”, in PJSC “ArselorMittal Kryvyi Rih” – “n.a. Artyoma”, and in PJSC “Central Iron-Ore” – “n.a. Ordzhonikidze”. In structure of PJSC “Zaporizskiy Iron-Ore Plant” (PSJC “ZZhRK” which conducts mining of rich iron ores of Pivdenno-Bilozerske deposit (Bilozerskiy iron-ore district, Zaporizhia region) “Ekspluatatsiina” and “Prokhidnycha” mines are included [15]. The analysis of technical indicators of production activity of iron-ore mines of Kryvorizskiy basin and Bilozerskiy iron-ore district has allowed to establish that for extraction of iron-ore by PJSC “ZZhRK” mines about 30000 tons of trotyl content explosives per year that in 5–7 times more than in each iron-ore mine separately using on the average. Therefore, industrial platform and adjoining area of PJSC “ZZhRK” represents the relevant testing ground for research conducting on ecological safety level increasing.

The main pollution sources of air basin in conditions of PJSC “ZZhRK” are following production subdivisions: “Ekspluatatsiina” and “Prokhidnycha” mines, crushing-and-sorting factory (CSF), backfilling, mechanical-repair and motor transportation workshops. Scrubbers and the system of the complete wave movement of the STsVD-20 type are established the heat-cleaning installations (HCI) of wet cleaning like “SIOT” for dust catching after ore breaking on DSF. SMTs-166 and SMTs-199 filters are installed on a backfilling complex for cement dust catching. In mechanical-repair and motor transportation workshops on tool-grinding machines ZIL-900 POU and two precipitating chambers are mounted. After conducting mining operations in mines, the fulfilled current of air is released crude into the atmosphere through 3 ventilating shafts, since today,

treatment facilities for dust catching, and purification of gases from miner air which is thrown out on a surface in large volumes aren't provided by the project.

During 2006–2010 authors took measurements of harmful gases concentration in tests of air by means of a gas analyzer “Palladium-3M” and gas-determinant GH-M. Concentration of carbon oxide and nitrogen oxides for three ventilating shafts of mines was determined. Sampling of analyzed air was realized during inter-shift break after explosive operations conducting at mine.

Further, ground concentration of harmful substances was defined which is necessary for receiving qualitative and quantitative standard of distribution of their total impact on atmospheric air. The executed analysis of ground concentration values of total impact of harmful substances has allowed to establish that with distance increasing up to 1500–2000 m from a emission source, values decreasing by 3–5 times from maximum allowable concentration (MAC). Then there were semi-ranks empirical dependences that defining ground concentration of total influence of harmful substances with taking into account a specific charge of explosives and distance from emission source, a share of units (unit fraction) from maximum allowable concentration:

- for “Pivnichno-Ventylitsiinyi” shaft

$$C_{tot.imp} = 1.39 \cdot q^{1.65} \cdot e^{-0.001 \cdot L}, \quad (1)$$

where  $q$  – an average annual specific discharge of explosives, kg/t;  $L$  – distance to emission source, m;

- for “Pivdenno-Ventylitsiinyi” shaft

$$C_{tot.imp} = 1.07 \cdot q^{1.24} \cdot e^{-0.0009 \cdot L}; \quad (2)$$

- for “Drenazhno-Ventylitsiinyi” shaft

$$C_{tot.imp} = 0.72 \cdot q^{2.34} \cdot e^{-0.0008 \cdot L}. \quad (3)$$

Results of mine air condition research in the context of PJSC “ZZhRK” are fully presented in work [16].

For assessment of toxic-mutagenic activity of atmospheric air, test sites which were located from three ventilating shafts in four parts of the world at distance of 50, 100, 300, 500, 1000 and 2000 m have been defined. These distances are accepted in the way that the most dangerous technogenic sites near emission sources have been explored. Sampling of plants pollen was made within the spring and summer season during 2009–2011. Selection of pollen of each examined species of plants was made in all points of test sites. Assessment of toxicity or potential mutagenicity of atmospheric air was made according to the “Sterility of Plants Pollen” test with application of iodine method of coloring. The essence of a method consists in coloring of cells of fertile and sterile pollen depending on content of starch in them. Calculation of sterile (unviable) and fertile (viable) pollen grains was made with application of the register.

As a result of conducted research it has been established that in 2009 the greatest values of conditional indicators of damageability (CID) of bioindicators in the

range of 0.400–0.550 unit fractions (u.f.) are observed at distance up to 500 m from emission sources. In process of removal from emission sources (from 500 to 2000 m), reduction of CID of bioindicators from 0.400 to 0.250 u.f. is observed, and at distance more than 2000 m, CID decreasing up to 0.200 u.f. In 2010 it has been established that at distance of 600–700 m from emission sources, reduction of CID from 0.600 to 0.400 u.f. is observed. During further removal from emission sources up to 700 to 2000 m, CID decreasing up to 0.300–0.250 u.f. At distance over 2000 m from emission sources CID appries to 0.200 u.f. According to the conducted research in 2011, it is established that near emission sources at distance up to 500–600 m, CID decreases from 0.600 to 0.400 u.f. Then, with distance increasing from 500 to 2000 m, there is a further reduction of CID from 0.400 to 0.250 u.f. Over 2000 m, CID decreasing up to 0.200 u.f. that is connected with reduction of negative impact of pollution sources.

The empirical formula that defining CID with taking into account a specific annual discharge of explosives and distance from emission source is received according to the results of research, u.f.

$$CID = 0.41 \cdot q^{-0.53} \cdot e^{-0.0003 \cdot L}. \quad (4)$$

Further research of toxic-mutagenic activity of atmospheric air have allowed to establish correlation dependence of CID changing from the size of ground concentration of total impact, u.f.

$$CID = 0.53 \cdot C_{tot.imp} + 0.25. \quad (5)$$

The main results of research of toxic-mutagenic activity of atmospheric air around mine sources of emission are presented in work [17].

In July, 2011 selection of sheaves of wheat from the trial platforms of 1 sq.m that located along the prevailing direction of wind at distances 50, 100, 300, 500, 1000 from a source of emission and at distance of 10 000 m (the control platform) for definition of technogenic influence on processes of ontogenesis of winter wheat were executed. For establishment of nature of biological signs changing of winter wheat, research of indicators of ontogenesis of trial sheaves were executed. The analysis of values of linear sizes of wheat has allowed to establish that the harmful substances proceeding from ventilating shafts have significant effect on the linear amount of ontogenesis of winter wheat and promote their increasing at approach to an emission source.

Further research have allowed to receive the empirical equation of dependence of biological productivity on the size of ground concentration of total influence, c/hectare

$$B_{biol} = 82.21 \cdot e^{-0.986 \cdot C_{tot.imp}}. \quad (6)$$

In the absence of emissions that corresponds to the size of ground concentration of total impact equal to 0, biological productivity reaches the maximum value that is equal to 82 c/hectare. During increasing in ground concentration of total impact up to 0.5 c.u from maximum allowable concentration that corresponds to



distance up to 150 m from emission source, it is possible to expect decrease in biological productivity up to 50 c/hectare that corresponds to 40 % of losses. During achievement of ground concentration of total impact to maximum allowable concentration value leads to falling of productivity up to 60 % or in 1.4 times that is equal to about 30 c/hectare. Accounting of the received regularity will allow to give the forecast of biological productivity of winter wheat with changing of ground concentration value of harmful substances total impact.

The experiment conducting by definition of technogenesis influence consisted in germination of winter wheat grains. For this purpose on the filter paper which is spread out in a laboratory glassware placed 100 prepared grains. Germination of winter wheat grains was conducted within 72 hours with maintenance of constant ambient temperature equal 25 °C, at the same time every 12 hours defined quantity of the sprouted seeds for the purpose of assessment of their viability. After 3 days, the average length, crude and dry mass of roots of sprouts of the grains which are selected on trial platforms at distance of 50, 100, 300, 500 and 1000 m which then compared to indicators of grains of the control platform (10 000 m) for finding of statistically reliable difference were determined.

The executed analysis of sizes values of biological signs of the sprouted wheat seeds has allowed to establish that the harmful substances proceeding from ventilating shafts have significant effect on the cultures of an agrophytocenosis in the first generation, and promotes increasing in technogenesis at approach to emission source. Research of technogenesis impact on the cultures of grophytocenosis in the first generation of winter wheat have allowed to establish dependences of phytotoxic effect changing from the size of ground concentration of total impact, %:

- on the length of sprouts

$$PhE_{sp} = 0.008 \cdot e^{17.53 \cdot C_{tot.imp}}; \quad (7)$$

- on the length of root system

$$PhE_r = 0.046 \cdot e^{13.96 \cdot C_{tot.imp}}; \quad (8)$$

- on wet weight

$$PhE_{w.w} = 12.16 \cdot e^{2.95 \cdot C_{tot.imp}}; \quad (9)$$

- on dry weight

$$PhE_{d.w} = 7.64 \cdot e^{2.94 \cdot C_{tot.imp}}. \quad (10)$$

The main results of analysis of biological signs changing of winter wheat and technogenesis impact on winter wheat in the first generation are presented in work [18].

The conducted research allow to develop an algorithm of calculation of ecological hazard for time saving and mobility increasing of ecological assessment conducting. The analysis of research results of ecological condition of atmospheric air has allowed to make a method of calculation of parameters both within the industrial platform, and in the territories adjacent to the mine which consists of the following items:

1. Calculation of ground concentration of total impact of harmful substances, u.f. from maximum allowable concentration

$$C_{tot.imp} = 1.06 \cdot q^{1.74} \cdot e^{-0.0009 \cdot L}. \quad (11)$$

2. Definition of CID indicators on a formula (5).

3. Determination of productivity of winter wheat on a formula (6).

Results of long-term research of atmospheric air ecological condition of the industrial platform, and the territories adjacent to plant executed by means of the physical-and-chemical analysis and biological assessment have allowed to make ecological assessment of atmospheric air condition near the emission source. The necessary data on definition of ecological condition of atmospheric air around ventilating shaft of the mine is presented in Table 1.

As you can see from Table 1, in size of ground concentration of total impact, CID and biological productivity of winter wheat, the level of damageability of indicators and atmospheric air condition within the industrial platform and territory that adjacent to a mine source of emission (a ventilating shaft) is defined. For forecasting of technogenesis impact on the cultures of agrophytonesis in the first generation formulas (7–10) are used.

Table 1

Ecological assessment of atmospheric air condition around an emission source

Ground concentration of total impact $C_{tot.imp}$ , unit fraction from maximum allowable concentration	Conditional damageability indicator, CID, unit fraction	Biological productivity, $B_{biol}$ , c/hectares	Level of indicators damageability	Atmospheric air condition
$\leq 0.095$	0.000–0.150	$\geq 74.9$	low	favorable
	0.151–0.300		below the average	alarming
0.096–0.378	0.301–0.450	74.8–56.7	average	conflict
0.379–0.661	0.451–0.600	56.6–42.9	above the average	menacing
0.662–0.944	0.601–0.750	42.8–32.4	high	critical
0.945–1.415	0.751–1.000	$\leq 32.3$	maximum	hazard

The analysis of a research results of atmospheric air near ventilating shafts of PJSC “ZZhRK” was allowed to establish that mine air saturated with harmful substances which are formed as a result of drilling-and-blasting operations conducting in underground conditions exerts negative impact on surrounding flora. As a result of the analysis of executed research, it is established that ground concentration of total impact changes on exponential dependence on emission sources. Further, as a result of biological assessment it is also established that the air proceeding from ventilating shafts has negative effect on development of both the higher plants, and grain crops. With increasing in distance from emission sources influence of mine air on flora decreases. Therefore, the conducted research cause necessity of application of modern environmentally-clean explosives emulsion and development of new technologies of drilling-and-blasting operations conducting both during mine workings drivage, and during stoping operations conducting in underground conditions.

Extraction of iron ores in the underground way in the majority connected with drilling-and-blasting operations conducting which in many respects define efficiency of deposits development [19]. Considering high cost of industrial trotyl-content explosives (ammonite No. 6 ZhV, grammonite 79/21, grammonite A), their danger at transportation, especially large volumes, and perspectives of development of mining enterprises, application of explosives made directly on places of explosive operations conducting is expedient. It is connected not only with safety of transportation, loading and mining operations conducting, but also with smaller volumes of allocation of detonation products [20]. As such explosives application of emulsion Ukrainit-PM-2B is offered by the authors. So at detonation of 1 kg of such explosives in a cloud 0.056 mol CO or 0.056 mol  $22.4\text{ l/mol} = 1.25\text{ l}$  of carbon oxide are formed. Release of nitrogen oxides thermodynamically is improbable. Besides, existence in products of explosion of oxide of calcium (CaO) provides absorption of oxides of nitrogen which can be formed at violation of a stoichiometric ratio of components or incomplete reaction of components during explosive transformation of charges.

Proceeding from prescription structure and a ratio of components, it is possible to claim that in products of explosion of Ukrainit-PM-2B toxic nitrogen oxides aren't contain. Release of the CO carbon monoxide in quantity up to 1 : 25 l on 1 kg of explosives emulsion is in two times less, than at trotyl-content application. From practice of explosive operations and analysis of scientific and technical data it is known that the qualitative and quantitative composition of harmful gases and solid reaction products of explosive transformation of charge depends both on explosives type, and on detonation conditions (the chemical composition of explosions, physic-and-mechanical properties of rocks, technology of explosive operations). In spite of the fact that settlement prescription structure of trotyl-content explosives is balanced on zero oxygen balance, however during detonation they become sources of large volumes of carbon oxides and nitrogen emission.

During analysis of technology of stoping operations conducting in mining blocks [21], it is possible to draw a conclusion that the technology of ore breaking at the chamber mining method provides application of considerable volumes of trotyl-content explosives. Therefore, for improvement of stoping operations conducting it is offered to improve technological parameters of drilling-and-blasting operations conducting [22], namely to offer new technology with explosives emulsion application during mining of deposits of any thickness. For improvement of stoping operations conducting at the chamber mining method, it was proposed by the authors to improve the existing method of calculation of drilling-and-blasting operations parameters for ore breaking with application of emulsion explosives [23]. The essence of proposed technology of ore breaking is that drilling of fans of wells is conducted in the direction of the underlying sublevel. Then the descending fans of wells is loading my emulsion explosives (Figs. 1, 2).

The results of research of atmospheric air condition given above were conducted during application of trotyl-content explosives on stoping operations. Therefore, scientific interest represents research of atmosphere condition on the industrial platform and adjacent territories of PJSC “ZZhRK” after application of emulsion explosives on underground mining operations.

As a result of the executed research in 2016 by means of the physical-and-chemical analysis and biological assessment of atmospheric air condition, decreasing in concentration of harmful substances which are emitted in atmospheric air during drilling-and-blasting operations after application of emulsion explosives [24] is established. Since 2010 for mine workings drivage on PJSC “ZZhRK” mines, emulsion explosives of Ukrainit-PM-2B in number of about 5 % of the total annual amount [25] is applied. Since the end of 2013,

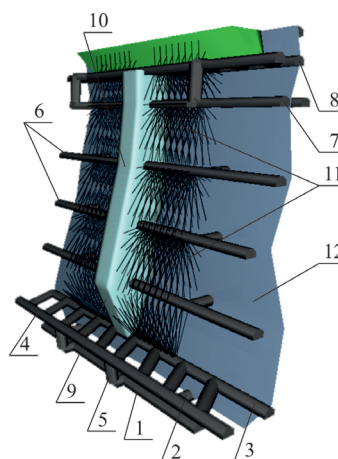


Fig. 1. 3D version of technological scheme of fans of wells arrangement during stoping operations conducting with application of explosives emulsion for ore deposits with thickness of 5–25 m:

1 – haulage roadway; 2 – loading drive; 3 – cutting roadway; 4 – delivery roadway; 5 – raise chute; 6 – subfloor drill roadway; 7 and 8 – ventilating-and-drill roadway; 9 – cutting space; 10 – end stope; 11 – fans of descending wells; 12 – footwall of deposit

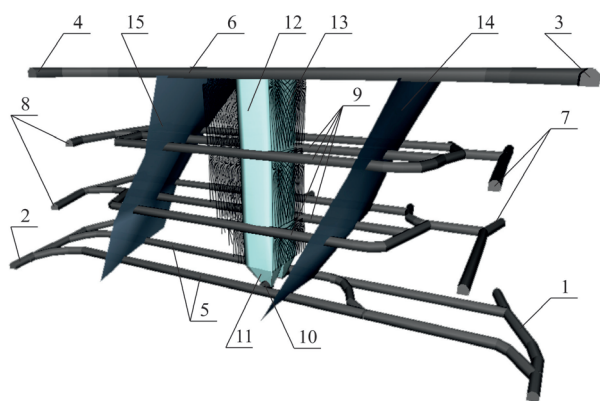


Fig. 2. 3D version of technological scheme of fans of wells arrangement during stoping operations conducting with application of emulsion explosives for ore deposits with thickness of more than 25 m:

1 – haulage roadway of footwall; 2 – haulage roadway of hanging wall; 3 – ventilating drift of a lying side; 4 – a ventilating drift of footwall; 5 – haulage cross-cut; 6 – ventilating-and-drilling roadway; 7 – sub-level roadway of footwall; 8 – sub-level roadway of hanging wall; 9 – drilling cross-cut; 10 – incline under vibration installation; 11 – intake funnel; 12 – end stope; 13 – fans of descending wells; 14 – footwall of deposit; 15 – hanging wall of deposit

on PJSC “ZZhRK” emulsion explosives Ukrainit-PM-2B is applied for stoping operations conducting that is equal about 45 % of all annual volume of the used explosives. Therefore there was a necessity for definition of quantitative assessment of increasing the level of ecological safety after increase in volumes of emulsion explosives application. Determination of ecological hazard level was conducted by means of methodics that considering risk for health of the population which is submitted negative impact of pollutants that are formed with application of explosives. Indicators of hazard during trotyl-content explosives and

emulsion explosives are determined and compared by a methodics. The diagram of dependence of hazard index from distance to a source of emission (Fig. 3) is constructed according to the results of calculation of hazard indicators.

The analysis of received results has shown that during application of trotyl-content explosives, the greatest values of hazard indicators to all analyzed harmful substances is observed. At the same time, in process of removal from emission sources, decreasing of hazard index is happened. Application of emulsion explosives on underground operations in conditions of PJSC “ZZhRK” has led to decreasing of ecological indicators up to 38 %.

On the basis of proposed methodics, calculation is executed and ecological assessment of atmospheric air condition around emission sources at distances of 100, 500, 1000 and 2000 m in the conditions of PJSC “ZZhRK” is conducted in 2017. Results of calculation of atmospheric air condition around sources are presented in Table 2.

From results of calculation, it is visible (Table 2) that during application of 100 % trotyl-content explosives on underground mining operations, the condition of atmospheric air at distance of 100 m from a source of emission has the menacing level, and the level of damageability of indicators is above the average. With increas-

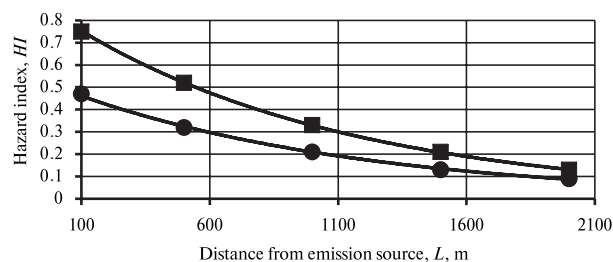


Fig. 3. The nature of hazard index changing from distance to emission source

Table 2

Results of calculation of atmospheric air condition around mine sources of emission

Explosives	$C_{tot.imp}$ , unit fraction from maximum allowable concentration	$CID$ , unit fraction	$B_{biol}$ , c/hectares	Level of indicators damageability	Atmospheric air condition
100 m					
Trotyl-content	0.446	0.486	52.9	above the average	menacing
Emulsion	0.156	0.333	70.5	average	conflict
500 m					
Trotyl-content	0.310	0.414	60.6	average	conflict
Emulsion	0.109	0.308	73.8		
1000 m					
Trotyl-content	0.198	0.355	67.6	average	conflict
Emulsion	0.069	0.287	76.8	below the average	alarming
2000 m					
Trotyl-content	0.081	0.292	75.9	below the average	alarming
Emulsion	0.028	0.265	79.9		



ing of distance up to 2000 m this level moves to the guarding level, and the level of damageability of indicators is below the average. During application of emulsion explosives on underground mining operations in number of 45 % of the general expense of trotyl-content explosives, the atmospheric air condition at distance of 100 m from a source of emission has the conflict level, and the level of damageability of indicators is average. With increasing in distance up to 2000 m, this level moves to the alarming level, and the level of damageability of indicators is below the average. Therefore, application of emulsion explosives on underground mining operations has allowed to reduce influence of harmful substances on atmospheric air and plants up to 35 %, thereby to increase the level of ecological safety in the industrial region.

### Conclusions.

1. Definition of ground concentration of total impact of harmful substances has allowed to establish that their ground concentration is influenced by distance from a source of emission and a specific annual consumption of explosives that has allowed to reveal exponential dependence of ground concentration changing of total impact of harmful substances with distance increasing from each ventilating shaft of the mine. Assessment of the general toxic-mutagenic activity of atmospheric air has allowed to establish correlation dependence of CID changing from the size of ground concentration of total impact.

2. Research of biological signs changing of winter wheat growing on different removal from a mine source of emission have allowed to establish that their linear sizes near a source of emission increasing, and with removal decreasing, and weight indicators, on the contrary, decreasing, and with removal increasing. The exponential dependence of biological productivity changing of a winter wheat on the size of ground concentration of total impact and distance to emission source is established according to the results of research.

3. Definition of consequences of technogenic impact in the first generation has allowed to establish that the toxic gases proceeding from ventilating shafts of the mine have significant effect on cultures in the first generation, and promotes increasing of impact extent with approach to it. Results of research have established exponential dependences of phytotoxic effect changing of the size of ground concentration of total impact.

4. On the basis of received results of research, the algorithm of calculation of ecological assessment of atmospheric air condition on the industrial platform of the mine and the territory adjoining to it is developed and the rating scale by means of which parameters of ecological hazard of emissions of the iron-ore mine are defined.

5. The technology of ore breaking during stoping operations conducting at chambers stocks mining with application of emulsion explosives Ukrainit-PM-2B is implemented. The index of ecological hazard from distance to emission source at trotyl-content and emulsion explosives application is defined. It is established that after application of emulsion explosives on underground

mining operations in volume of 45 % from total in the conditions of PJSC "ZZhRK", the index of ecological hazard has decreased up to 38 %.

6. Calculation of atmospheric air condition around mine sources of emission by the offered methodics has allowed to establish that during application of emulsion explosives on underground mining operations, impact of ecologically hazardous substances on atmospheric air and plants has decreased on 35% that has led to increasing of ecological safety level.

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### Підвищення екологічної безпеки при підземній розробці залізрудних родовищ

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**Мета.** Створити технологію, що підвищує рівень екологічної безпеки підземного видобутку залізних руд шляхом зниження кількості шкідливих речовин, які викидаються до атмосфери.

**Методика.** Лабораторні й промислові дослідження стану атмосферного повітря в районі розташування шахти виконувалися за допомогою фізико-хімічного методу й біологічного тестування. Для визначення особливостей розсіювання шкідливих речовин використовувалася нормативна методика розрахунку їх концентрацій в атмосфері.

**Результати.** Виявлені закономірності зміни приземної концентрації сумарного впливу шкідливих речовин з урахуванням питомої витрати вибухових речовин і відстані від джерела викиду. Встановлена залежність зміни умовного показника пошкоджуваності біоіндикаторів зі збільшенням відстані від джерела викиду й питомої витрати вибухових речовин. Розроблена методика розрахунку екологічної оцінки стану атмосферного повітря навколо джерела викиду.

**Наукова новизна.** Встановлення залежності впливу приземних концентрацій шкідливих речовин на пошкоджуваність біоіндикаторів на клітинному та організмовому рівнях дозволяє оцінити екологічний стан атмосферного повітря на промислових територіях.

**Практична значимість.** Встановлені закономірності впливу приземної концентрації сумарного впливу шкідливих речовин на стан індикаторних систем, що дозволяє оцінити стан навколишнього середовища й підвищити достовірність локального екологічного моніторингу в районі роботи залізрудної шахти. Розроблена й впроваджена технологія ведення буропідричних робіт, в якій використовуються емульсійні вибухові речовини при відпрацюванні залізних руд за допомогою камерних систем розробки, що дозволяє знизити індекс небезпеки впливу шкідливих речовин на атмосферу.

**Ключові слова:** вибухові речовини, джерело викиду, шкідливі речовини, фізико-хімічний метод, концентрація сумарного впливу, індекс небезпеки

## Повышение экологической безопасности при подземной разработке железорудных месторождений

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**Цель.** Создать технологию, повышающую уровень экологической безопасности подземной добычи железных руд путем снижения количества вредных веществ, выбрасываемых в атмосферу.

**Методика.** Лабораторные и промышленные исследования состояния атмосферного воздуха в районе расположения шахты выполнялись с помощью физико-химического метода и биологического тестирования. Для определения особенностей рассеивания вредных веществ использовалась нормативная методика расчета их концентраций в атмосфере.

**Результаты.** Выявлены закономерности изменения приземной концентрации суммарного воздействия вредных веществ с учетом удельного расхода взрывчатых веществ и расстояния от источника выброса. Установлена зависимость изменения условного показателя повреждаемости биоиндикаторов с увеличением расстояния от источника выброса и удельного расхода взрывчатых веществ. Разра-

ботана методика расчета экологической оценки состояния атмосферного воздуха вокруг источника выброса.

**Научная новизна.** Установление зависимости влияния приземных концентраций вредных веществ на повреждаемость биоиндикаторов на клеточном и организменном уровнях, что позволяет оценить экологическое состояние атмосферного воздуха на промышленных территориях.

**Практическая значимость.** Установлены закономерности влияния приземной концентрации суммарного воздействия вредных веществ на состояние индикаторных систем, что позволяет оценить состояние окружающей среды и повысить достоверность локального экологического мониторинга в районе работы железорудной шахты. Разработана и внедрена технология ведения буровзрывных работ, в которой используются эмульсионные взрывчатые вещества при отработке железных руд при помощи камерных систем разработки, что позволяет снизить индекс опасности влияния вредных веществ на атмосферу.

**Ключевые слова:** *взрывчатые вещества, источник выброса, вредные вещества, физико-химический метод, концентрация суммарного воздействия, индекс опасности*

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