https://doi.org/10.33271/nvngu/2024-3/128

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THE ENVIRONMENTAL EFFECTIVENESS OF HUMATE REAGENT IN INTERNAL AND EXTERNAL HYDRO-FILLING OF QUARRIES

Purpose. To develop an environmentally friendly technology for drilling and blasting operations in quarries that will ensure effective degassing and dust suppression during mass explosions by using a natural humate reagent in internal and external hydro-filling.

Methodology. The study used a set of research methods: analytical – to establish the main technical and economic indicators that affect the cost of drilling and blasting operations; technical and economic analysis – to establish the relationship between the cost of operations, air pollution after massive explosions and types of hydro-fillings and concentrations of humate reagent.

Findings. The paper presents the results of pilot tests of the effectiveness of applying the humate reagent in the preliminary humidification of blocks and its use in internal and external hydro-filling, which leads to a significant reduction in dust formation and degassing of mass explosions. During the period of production research from 2017 to 2021, the environmental efficiency of the use of internal and external hydro-filling with the use of humate reagent TU U 20.5-43384697-001:2020 was confirmed at the enterprises of the Metinvest Holding: PJSC Inhulets Mining and Processing Plant, Pivnichnyi Mining and Processing Plant, Tsentralnyi Mining and Processing Plant, as well as ArcelorMittal Kryvyi Rih, JSC Pivdennyi Mining and Processing Plant and Rudomain LLC. When using an aqueous solution of humate reagent with a concentration of 3 % in internal and external hydro-filling, the environmental effect involves on average: dust suppression – 54 %; neutralization of carbon monoxide – 62 %; neutralization of nitrogen oxides – 55 %. The results of industrial tests have confirmed scientific hypotheses regarding the processes of binding dust particles in the dust and gas cloud, as well as the effect of neutralizing explosive gases.

Originality. Dependences of the concentration of humate reagent in internal and external hydro-filling and binding of dust particles during mass explosions with environmental efficiency in terms of dust and gas suppression were established. Industrial research will allow confirming the scientific hypothesis about the neutralization of CO by a humate reagent in mass explosions, which is based on the Langmuir theory.

Practical value. An eco-oriented technology of drilling and blasting operations in quarries has been developed which is based on using humate reagents in internal and external hydro-filling and allows industrial enterprises using massive explosions to reduce dust, carbon and nitrogen oxide emissions.

Keywords: *mass explosions, quarry, hydro-fillings, humate reagent, dust and gas cloud, environmental efficiency*

Introduction. Rocks are blown up in the quarries of mining, processing, and metallurgical enterprises in separate blocks with a single-row or multi-row arrangement of wells using different types of explosives [1]. Mass explosions generate a significant amount of dust and harmful gases, which are carried out from the quarry space in the form of a dust and gas cloud and dispersed over long distances [2]. At the same time, some of the harmful gases remain in the blasted rock mass, which is released into the atmosphere during its excavation [3]. For example, massive explosions in quarries produce from 0.027 to 0.170 kg of dust per 1 m^3 of rock mass [4]. Functioning of mining enterprises results in significant environmental, economic and social consequences [5], which require the urgent development and implementation of environmental protection measures [6].

The operation of mining enterprises is a constant source of negative impact on most environmental components and can lead to their pollution, depletion and degradation [7]. Pollution mainly occurs as a result of the formation of mining by-products in the form of solid, liquid and gaseous substances [8]. By-products become a source of negative impact on the territories adjacent to mining enterprises. At the same time, there is a deterioration in the living conditions of the population in mining regions. The hazard and impact of by-products on biota, including humans, will depend on their chemical composition, and for dust, also on the dispersion and shape of dust particles [9].

Plants can reduce the spread of dust beyond the sanitary protection zones of mining enterprises and act as a biofilter. The effectiveness of air filtration from harmful impurities by individual plants and phytocoenoses is determined by the area of the leaf apparatus and the amount of toxic components accumulated in them. In particular, the ability to effectively capture dust depends on the structure of the plant crown. Since mining operations lead to the formation of difficult conditions for the growth of trees, it is necessary to promptly control the level of greening of the territory of quarries and adjacent areas [10]. That is why, in order to reduce the removal of dust and other pollutants outside of mining enterprises, it is necessary to substantiate technical solutions for securing the dusting surfaces of the quarry.

Literature review. The authors of the study [11] conducted comprehensive research on the impact of pollutant emissions into the atmosphere from a surface mining plant on an area of 25.9 hectares with a granite processing plant with a capacity of more than 100 thousand m^3/year. According to the authors, this is a representative mining enterprise that, at this level of production, equipment and technology, emits permissible amounts of NO_2, SO_2, aliphatic and aromatic hydrocarbons, PM10 and PM2.5 dust into the air.

The study [12] established the levels of danger of silicosis and various respiratory diseases for quarry employees and residents of nearby settlements when inhaling crystalline silica contained in granite dust. The impact of inhaled dust nanoparticles on the health and related pulmonary diseases of miners was also studied [13].

To study the levels of dust pollution in the areas adjacent to the Fushun quarries, China, real-time modeling of dust pollution from blasting operations in quarries was carried out using numerical modeling with the Fluent software and field tests using the theories of two-phase gas-solid flow and explosion mechanics [14]. It was found that dust with a particle size of 60–100 μm settled slowly, and dust with a particle size of less than 40 μm settled with difficulty due to strong disturbance by the air flow [14].

Paper [15] investigated the possibilities of using the waste spaces of the open pit for internal dumping and, accordingly, reducing environmental damage from open pit mining and increasing the efficiency of underground operations.

The authors established [16] the regularities of diffusion and distribution of solid particles in the process of dumping in quarries. Using numerical modeling, it was found that the distance of diffusion of solid particles downwind decreases with an increase in their density during the process of dumping. In particular, when the density of FFM was 4,800 kg/m^3.

As a result of comprehensive field studies [17] measuring the background air quality and identifying sources of air pollution from quarries around a cultural heritage site in India, air quality in the area of influence of operating and closed mining enterprises was established.

The paper [18] determined the nature of the dispersion of explosive dust clouds in a deep quarry located in northern China. Based on the results of numerical modeling of different natural wind speeds and directions, as well as the location of the explosion, the patterns of change in the diffusion of explosive dust were determined, which will reduce large-scale and long-term pollution of the surrounding areas.

The authors of [19] found that heavy dust particles have a size from 2.5 to 10 microns, where the upper limit of exposure to PM10 particles can lead to several health hazards, such as respiratory system damage, heart failure, and premature death. The largest amount of dust is generated by many mining operations, such as drilling, loading waste and minerals, blasting in various areas of quarries, and transportation of materials during mining [20].

Let us consider a generalized calculation of pollutant emissions from a massive explosion in a quarry.

To determine the emissions of pollutants during mass explosions, the equivalent maximum one-time emissions are calculated, reduced to a 20-minute time interval.

Calculations of the equivalent maximum single emissions of pollutants for the analysis of air pollution during mass explosions (g/s) are carried out according to the formula

$$M_{mp}^{e}=\frac{39.5\cdot Q_{bl}^{-0.08}\cdot q\cdot V\cdot t}{T}\cdot(1-\mu_1)\cdot(1-\mu_2)\cdot(1-\mu_n),$$

where Q_{bl} is the amount of explosive in the unit to be detonated, kg; q is the specific emission of pollutants, kg/kg of explosives, determined according to the regulatory document "Emission rates (specific emissions) of pollutants during mass and contour blasting in quarries". The values q for the mining conditions of the Kryvyi Rih basin when using trotyl-free explosives for nitrogen oxides are in the range of 0.0002–0.0014 kg/kg of explosives, and for carbon monoxide – 0.001–0.005 kg/kg of explosives; V – volumetric flow rate of dust and air mixture, m^3/s; t – time of block detonation, s; T – the average time interval during which the concentration of pollutants is determined, s (at a 20-minute interval T = 1,200).

The flow rate of the dust and air mixture, m^3/s, is determined by the formula

$$V=0.785\cdot v_0\cdot d_{well}^2\cdot N_{well},$$

where V_0 is the rate of emission of detonation product residues from the well, m/s; d_{well} – the well diameter, m; N_{well} – the number of wells in the block.

The rate of release of detonation product residues from the well, m/s, is determined by the formula

$$v_0=M\cdot v_d\cdot\left[\frac{2\cdot l_{expl}\cdot\gamma_{expl}}{0.33\cdot l_{expl}\cdot\gamma_{expl}+l_3\cdot\gamma_3}\right]^{0.5},$$

where M is a coefficient that takes into account the interaction of detonation products with the well walls, equal to 0.053; v_d is the detonation speed of the explosive, m/s, determined according to Table 1.

The length of the explosive charge in the well is determined by the formula

$$l_{expl}=\frac{1.27\cdot Q_{bl}}{\gamma_{expl}\cdot d_{well}^2\cdot N_{well}},$$

where γ_{expl} is the specific gravity of explosives, kg/m^3, determined according to Table 1; l_f – the length of the filling space in the well is determined according to the specification or approximately calculated by the formula

$$l_f=\frac{1.27\cdot f}{\gamma_f\cdot d_{well}^2\cdot N_{well}},$$

where Q_f is the volume of the filling space in the block, kg; γ_f is the specific gravity of the filling space, kg/m^3.

The time of detonation of the unit is determined according to the technical documentation for the mass explosion, and it is recommended to use Table 1 for the estimated calculation.

In the absence of the necessary parameters, it is recommended to use the following formula to calculate the values of the mass of charges

$$t=0.00019\cdot Q_{well}^{1.34}\cdot(n_a-n_b-1),$$

where Q_{well} is the amount of explosives in the well, kg.

The average value Q_{well} is determined by the formula

$$Q_{well}=\frac{Q_{bl}}{N_{well}},$$

where n_a is the number of wells in a row, units; n_b is the number of well rows in the block, units.

Gross emissions of pollutants for the calculation period during rock blasting (tons) are determined by the formula

$$M_p=0.001\cdot q\cdot Q_p\cdot(1-\mu_1)\cdot(1-\mu_2)\cdot(1-\mu_n),$$

where Q_p is the consumption of explosives for the calculation period, kg; q – specific emissions of pollutants during mass explosions.

When placing the quarry ledges and sides on the design contour, contour blasting is performed in the quarry, using trotyl in T-400G detonator blocks and Anemix-P-70/900 cartridge explosive matters as explosives.

Pollutant emissions from contour blasting are calculated the same way as mass explosions. Specific emissions during contour blasting using trotyl in detonators are generalized for all rocks based on the data obtained during studies conducted by the Research Institute of Occupational Safety and Ecology in the Mining and Metallurgical Industry. Specific emissions

Table 1

Explosive and physical and chemical characteristics of explosives

Type of explosives	Specific gravity, kg/m^3	Detonation speed, m/s
Emulsion of explosives Anemix-70, Anemix R-70	1,220	5,150–5,300
Ukrainite PP-2B	1,380–1,530	4,800–5,300
Emonite-N, Emonite-N100	1,400	4,600–5,200
Trotyl detonator grenades T-400G	1,500	6,800–7,000

of gaseous pollutants and suspended solids during contour blasting are shown in Table 2.

Unsolved aspects of the problem. In accordance with the unreported methodology for calculating dust and gas emissions from mass explosions and taking into account industrial research that is constantly being conducted in the quarries of the PJSC Inhulets Mining and Processing Plant, Tsentralnyi Mining and Processing Plant, ArcelorMittal Kryvyi Rih, JSC Pivdennyi, and Rudomain LLC, and monitoring of gas emissions from explosives, the actual dust emissions in the quarries of these enterprises are shown in Tables 3 and 4.

The urgency of the problem of decarbonization in mass explosions in quarries located in Kryvyi Rih was protocoled in the decisions of the Scientific and Technical Ecological Council under the Department of Ecology and Natural Resources of the Dnipro Regional State Administration (clause 1, Protocol No. 2 dated 09.06.2020), the Environmental Planning Council under the Department of Ecology of the Executive Committee of the Kryvyi Rih City Council (clause 4.1 of the Protocol dated 27.10.2017, part II of the Protocol dated 30.06.2018) in the process of implementing the measures of the City Program for solving environmental problems of Kryvyi Rih and improving the environment for 2016–2025, etc.

Thus, the research aims to develop an environmentally friendly technology for drilling and blasting operations in quarries that will ensure effective degassing and dust suppression during mass explosions by using a natural humate reagent in internal and external hydro-fillings.

Summary of the main material and scientific results. During mass explosions, internal and external hydro-filings using water or aqueous solutions of dust and gas suppressants are used to reduce dust and gas emissions. Also, to increase the wetting properties of water, it is recommended to use the addition of surfactants that reduce the surface tension of water and improve its coagulation and dispersion.

The Mining Research Institute has developed additional dust suppression technologies, one of which is preliminary moistening of the surface of the block to be blown up with water or solutions of dust and gas suppressant reagents.

At the same time, the known methods for reducing dust and gas emissions into the air during mass explosions in quarries of mining enterprises still allow for solving the above environmental problem. Thus, Table 5 shows the effectiveness of dust suppression measures during blasting operations according to studies.

The technology of ecologically oriented filling, manufacturing, and storing of the effective reagent has been improved since 1993 under the patents held by the Research Institute of

Table 2

Specific emissions of gaseous pollutants and suspended solids during contour blasting

Rock category	Specific emissions, kg/kg of explosives					
	Cold period of the year			Warm period of the year		
	Nitrogen oxides (in terms of nitrogen dioxide) $[NO]_2$	Carbon monoxide	Substances in the form of suspended solids (microparticles and fibers)	Nitrogen oxides (in terms of nitrogen dioxide) $[NO]_2$	Carbon monoxide	Substances in the form of suspended solids (microparticles and fibers)
Cartridge explosive Anemix-P-70/900						
Oxidized quartzite	0.00020	0.0050	0.115	0.00025	0.0060	0.134
Shale	0.00015	0.0030	0.128	0.00023	0.0041	0.149
Magnetite (ferruginous) quartzite	0.00019	0.0050	0.077	0.00026	0.0057	0.098
The use of trotyl blocks of T-400G detonators in contour detonation						
Arbitrary breeds	0.0030	0.063	0.100	0.0037	0.073	0.120

Table 3

Gas generation from explosives

Pos. No.	Ores and rocks	Type of explosives	Specific gas yield $q \cdot 10^{-2}$ (kg/kg of explosives)	
			CO	50 %NO + 50 %NO_2
1	Magnetite horns	Gramonite 79/21	1.24	0.5
2	Magnetite and semi-oxidized hornblende		1.52	0.71
3	Substandard hornblende and shale		1.27	1.43
4	Magnetite horns	Gramonite 50/50	4.15	0.58
5	Substandard and magnetite horns		3.85	0.68
6	Magnetite horns	Granulotol	8.17	0.60
7	Substandard and magnetite horns		3.15	0.66
8	Magnetite horns	Grain pellet 80/20	1.94	0.34
9	Substandard hornblende and shale		1.27 1.18	0.93 1.03
10	Magnetite horns	Grain pellet 50/50	4.16	0.38
11	Substandard corneas		3.85	0.46
12	Magnetite horns	Trotyl	7.56	0.40
13	Substandard corneas		6.52	0.43

Table 4

Dust formation in Kryvyi Rih quarries

Pos. No.	Ores and rocks	Strength according to the M. Protodyakonov scale	Specific dust yield $q \cdot 10^{-2}$ (kg/kg of explosives)
1.	Shale	5–8	4.1–11.0
2.	Shale	10–12	10.0
3.	No-iron horns	6–10	9.4–20.0
4.	Magnetite horns	8–20	6.4–12.4
5.	Silicate-magnesium horns	15–20	16
Average value			11.7

Table 5

Efficiency of dust suppression measures during blasting operations

Pos. No.	Events	Efficiency, μ, %
1	Hydrogel well filling	44
2	External hydro-filling of wells	20
3	Internal hydro-filling of wells	50
4	Application of air-mechanical foam to the block	45
5	Snofilling of wells with the application of snow to the surface of the block	50–70
6	Irrigation of the dust and gas cloud with water aerosol	60–75
7	Water content of the block to be blasted (water saturation of wells):	
	complete	50
	by 75 %	40
	by 50 %	30

Labour Safety and Ecology in the Mining and Metallurgical Industry of the Kyiv National University: No. 20125A dated 30.04.1993 "Downhole charge of granular explosives"; No. 67398A dated 15.06.2004 "Downhole explosive charge with adjustable power" No. 20054A dated 25.12.97, bulletin No. 6 "Compound for suppression of poisonous gases"; No. 21793A dated 30.04.98, bulletin No. 2 "Method of dust and gas suppression at mass explosions"; No. 12846 dated 15.03.2006, bulletin No. 3 "Method of dust and gas suppression at mass explosions in quarries"; No. 12846 dated 15.03.2006, bulletin No. 3 "Method of dust and gas suppression in case of mass explosions in quarries"; No. 105605 dated 25.03.2016, bulletin No. 6 "Method of dust and gas suppression in case of mass explosions in quarries"; No. 118087 dated 25.07.2017, bulletin No. 14 "Composition for suppression of harmful gases"; No. 142503 dated 10.06.2020, bulletin No. 11 "Reagent composition for dust and gas suppression in case of mass explosions in quarries".

Pilot tests of the effectiveness of reagents available on the Ukrainian market were conducted by the Research Institute of Labour Safety and Ecology in the Mining and Metallurgical Industry and, according to the research protocols with Inhulets, Pivdennyi, Tsentralnyi, Pivnichnyi Mining and Processing Plants, and ArcelorMittal Kryvyi Rih, the greatest environmental effect on dust and gas suppression in mass explosions was confirmed when using a humate reagent (TU U 20.5-43384697-001:2020). Thus, in 2019, comprehensive scientific research conducted by the Research Institute of Labour Safety and Ecology in the Mining and Metallurgical Industry on reducing the harmful effects of fugitive emissions in mass explosions by pre-moistening the explosive blocks with humate reagent in the quarries of Inhulets Tsentralnyi, Pivnichnyi Mining and Processing Plants was completed. It was confirmed that the humate reagent has an effective oxidizing ability in degassing harmful gases, and also has dust-absorbing properties with a dust suppression efficiency of 30 % and degassing efficiency (carbon monoxide, nitrogen oxides) of about 70 %. In 2020, the state Research Mining Institute and the Research Institute of Labour Safety and Ecology tested a method of replacing water for internal and external hydro-filling with a humate reagent in the quarries of Pivnichnyi Mining and Processing Plant and ArcelorMittal Kryvyi Rih. The efficiency of dust suppression was 50.5 % and degassing (carbon monoxide 63.9%, nitrogen oxides 67.9 %) 65.9 %.

Working hypothesis. Humic acids are part of humus acids, which are almost insoluble in water but soluble in alkalis. Humic acids are high molecular weight acids that also contain nitrogen atoms. They are formed during the decomposition of dead plants with their subsequent humification.

Humic substances are roughly composed of 52–62 % carbon atoms, approximately 31–39 % oxygen, 2.8–5.8 % hydrogen and 1.7–5.1 % nitrogen.

Humic acids have a hypothetical general formula that includes up to 26 carboxyl, 34 phenolic, and hydroxyl groups, as well as up to 6 amino groups.

When dissolved in alkalis, humates are formed with the participation of carboxyl and phenolic groups.

Humic acid + NaOH = Sodium humate + water

The promising use of a carbonic acid reagent for dust suppression in the mining industry is associated with its ability to absorb and accumulate chemical components, sorbing

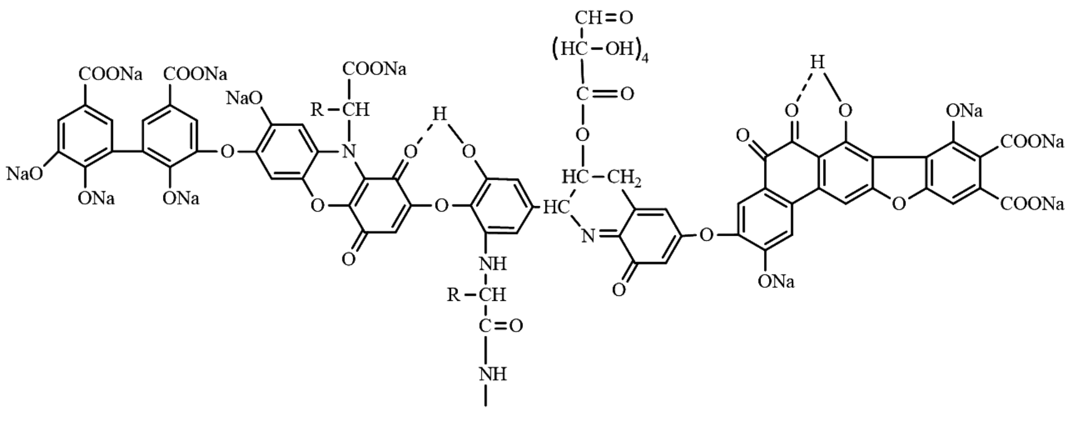

Fig. 1. Hypothetical general formula of humate in general terms

not only dust but also gases (carbon monoxide, nitrogen oxides) generated by mass explosions in the quarries of mining and processing enterprises. Thus, the effective use of the reagent for dust and gas suppression can be explained by its complex interaction with explosion products: physical sorption with CO and dust particles, and chemical sorption when NO_2 interacts with an alkaline solution. Earlier studies showed that alkaline humate solutions can absorb carbon monoxide through chemisorption, which is confirmed by a significant exothermic effect ($\Delta H = -179.0$ kJ/mol). Chemisorption of carbon monoxide is possible due to the polarity of the CO molecule, which leads to its interaction with the polar groups of sodium humates, as well as with oxygen-containing groups that are part of humates – hydroxyl, carbonyl, carboxyl, and phenolic. The interaction has a strong electrostatic nature, and the bonding that occurs can be considered almost covalent. Thus, the fact can be considered confirmed that the process of carbon monoxide adsorption is fully subject to the Langmuir theory, followed by chemisorption, which leads to the neutralization of CO.

In addition, the usual chemical interaction between alkaline humate solutions and acidic NO_2 oxide is possible.

First, nitrogen (IV) oxide will be absorbed by the alkaline solution by the reaction

$$NO_2 + NaOH = NaNO_3 + NaNO_2 + H_2O$$

Second, a reaction with humates involving phenolate and carboxyl groups is possible.

The properties of the humate reagent for gas sorption were studied in the laboratory. Using an electric aspirator, a gas containing carbon monoxide and sulfur dioxide was pumped through the test solution at a speed of 0.2 dm^3/min, a gas volume of 2 dm^3, and a pumping time of 10 minutes for one experiment. After passing a portion of the gas through the humate reagent, the residual concentration of carbon monoxide (CO) and other components of the gas mixture was measured, namely: combustible gases and vapors (C_nH_m); nitrogen dioxide; sulfur dioxide; hydrogen sulfide. The difference in gas concentrations before and after passing through the humate reagent was used to determine the amount of gas adsorbed by the reagent.

The results of comparative laboratory studies showed that the humate reagent has the properties of absorbing harmful gases containing carbon monoxide and sulfur dioxide. The minimum efficiency of neutralization of harmful gases with a 2 % aqueous solution of humate reagent for carbon monoxide was 74.6–79.5 %. With a 3 % solution – 79.5–80.6 %, 7 % – 56.6–60.5 %, 10 % – 44.6–55.4 %, 30 % – 36.5–54.5 %.

Results of industrial research. Industrial tests during massive explosions in the open pit of Inhulets Mining and Processing Plant were conducted in June 2021. The goal of the industrial tests was to develop a technologically convenient and economically feasible method of dust and gas suppression by using external and internal hydro-filling, as well as humidifying the filling with a humate reagent.

The explored block No. 146 was located at the –225 m horizon, which was represented by magnetite quartzites.

The volume of blasted rock mass on the block amounted to 25,000 m^3, the amount of Ukrainite was 19,490 kg, and the number of wells was 35. The method of preliminary moistening of the block surface, as well as internal and external hydro-filling, was used as dust and gas suppression measures. Instead of water of technical quality, an aqueous solution of humate reagent with a concentration of 3 % was used, which was prepared from a liquid 30 % concentrate of humate reagent. The total volume of the 3 % aqueous solution was about 30 m^3.

The results of instrumental measurements of pollutant emissions from a massive explosion in the open pit of the PJSC Inhulets Mining and Processing Plant, which was carried out on 25.06.2021 in block No. 146, horizon –255 m, are presented in Tables 6 and 7.

According to the results of the measurements, the specific dust emission was 0.0747 kg/kg/explosive, gas emission for carbon monoxide was 0.00048 kg/kg/explosive, and nitrogen oxide was 0.00014 kg/kg/explosive. When calculating the ef-

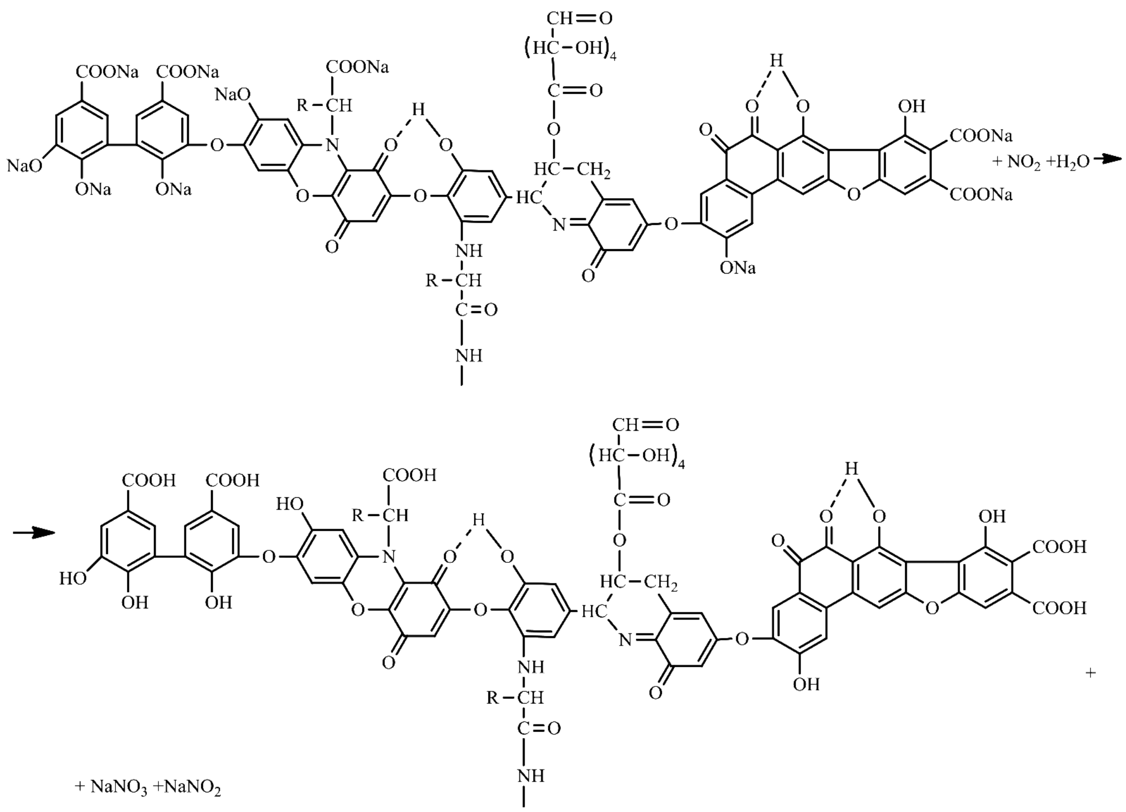

Fig. 2. Possible reaction between humates and NO_2

Table 6

The results of calculations of gas emissions after a massive explosion in the quarry of PJSC Inhulets Mining and Processing Plant

Date of selection	Gas type	Concentration mg/m^3	Arithmetic mean concentration, mg/m^3	Volume of dust and gas cloud, m^3	Specific emissions, kg/kg of explosives	Total specific emissions, kg/kg of explosives
As of 25.06.2021 horizon –225 m, block No. 146	Calculation of gases in a dust and gas cloud					0.00048
	CO	7.0	6.5	816,655	0.00027	
	CO	6,0				
	Calculation of gases in rock mass					
	CO	567	550	–	0.00021	
	CO	533				
	Calculation of gases in a dust and gas cloud					0.00014
	NO_2	3.0	2.5	816,655	0.000105	
	NO_2	2.0				
	Calculation of gases in rock mass					
	NO_2	107.0	102	–	0.000039	
	NO_2	97.0				

Table 7

Results of calculations of dust emissions after the explosion in the quarry of the PJSC Inhulets Mining and Processing Plant

Date, horizon, block	Data for calculating the dust concentration on the detonated block				Arithmetic mean concentration, mg/m^3	Specific consumption of ES, kg/m^3	Mass of the ES, kg	and gas cloud volume, m^3	Specific dust-division	
	Air consumption according to the rotameter, l/min	Air volume, l	Emphasis on the filter, mg	Concentration, mg/m^3					kg/m^3 of rocks, which are undermined	kg/kg of explosive substance
25.06.21, Horizon –225 m bl. No. 146	5.0	$\frac{3.33}{3.07^{1)}}$	5.45	1,773.98	1,782.12	0.78	19,490	816,655	0.0585	0.0747
	5.0	$\frac{3.33}{3.07^{1)}}$	5.50	1,790.25						

1) – reduced air volume (temperature 273 K, pressure 101.3 kPa)

fectiveness of dust and gas suppression measures, we got the following data of the massive explosion on 28.05.2021, block No. 117, horizon –120 m. The specific indicators were: 0.159 kg/kg/explosive, gas emissions made: carbon monoxide 0.00124 kg/kg/explosive, nitrogen oxide 0.00031 kg/kg/explosive.

Thus, the efficiency of using an aqueous solution of humate reagent with a concentration of 3 % in the external and internal hydro-filling was: dust suppression – 53 %; neutralization of carbon monoxide – 61.3 %; neutralization of nitrogen oxides – 54.8 %.

Conclusions. A significant environmental effect in terms of dust and gas suppression during mass explosions in comparison with known reagents, surfactants, or hydrogels is achieved by forming an external hydro-filling of well explosive charges using polyethylene sleeves with a diameter of 0.3–1 m, which are pre-filled with a humate reagent. Unlike a hydrogel, which contains a mixture of aqueous solutions of ammonium nitrate and sodium liquid glass, the process of adsorption of carbon monoxide by a humate reagent is fully subject to the Langmuir theory, followed by chemisorption, which leads to the neutralization of CO. At the same time, the effects of elevated temperatures of explosive gases on the processes of thermal decomposition of nitrate and sodium compounds of hydrogels, and, accordingly, the environmental safety of using hydrogels as fillers of external and internal waterstops in mass explosions have not been studied.

Laboratory studies of the environmental effect of the humate reagent have been confirmed as a result of comprehensive industrial tests, which proves the fact of its effective use for dust and gas suppression due to its complex interaction with explosion products: physical sorption in relation to CO and dust particles, chemical sorption when NO_2 interacts with an alkaline solution.

According to the results of industrial research, it is proposed to place the external well filling in polyethylene sleeves along rows of wells. The length of the sleeves can be determined by the geometric parameters of the charged block surface and the contour of the wells. In order to reduce dust emission during mass explosions by more than 50.5 %, reduce the impact of air shock waves and improve the quality of rock crushing along the entire height of the ledge, it is advisable to form the well filling of the inactive part of explosive well charges, compacted to 2,450 kg/m^3, with 30 % humate reagent and crushed rock with the 5–20 mm fraction.

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Екологічна ефективність гуматового реагенту у внутрішніх і зовнішніх гідрозабійках кар’єрів

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Мета. Розробка екологоорієнтованої технології буро-вибухових робіт у кар’єрах, що дозволить забезпечити ефективну дегазацію й пилопригнічення при масових вибухах шляхом застосування природнього гуматового реагенту у внутрішніх і зовнішніх гідрозабійках.

Методика. У роботі використано комплекс методів досліджень: аналітичний – для встановлення основних техніко-економічних показників, що впливають на собівартість буро-вибухових робіт; техніко-економічний аналіз – для встановлення взаємозв’язків собівартості робіт, забруднення атмосфери після масових вибухів із видами гідрозабійок і концентрацій гуматового реагенту.

Результати. Наведені результати дослідно-промислових випробувань ефективності застосування гуматового реагенту при попередньому зволоженні блоків і при його використанні у внутрішніх і зовнішніх гідрозабійках, що призводить до суттєвого зниження пилоутворення й дегазації масових вибухів. У період виробничих досліджень із 2017 по 2021 рр. в умовах підприємств холдингу Метінвест ПАТ «ІнГЗК», «ПівнГЗК», «ЦГЗК», а також «АрселорМіттал Кривий Ріг», АТ «ПівдГЗК» і ТОВ «Рудомайн» підтверджена екологічна ефективність застосування внутрішньої й зовнішньої гідрозабійок з використанням гуматового реагенту ТУ У 20.5-43384697-001:2020. При застосуванні водного розчину гуматового реагенту концентрацією 3 % у внутрішній і зовнішній гідрозабійках екологічний ефект у середньому складає: пилоподавлення – 54 %; нейтралізація оксиду вуглецю – 62 %; нейтралізація оксидів азоту – 55 %. За результатами промислових випробувань підтверджені наукові гіпотези щодо процесів зв’язування частинок пилу у пилогазовій хмарі, а також ефекту нейтралізації вибухових газів.

Наукова новизна. Встановлені взаємозалежності концентрації гуматового реагенту у внутрішніх і зовнішніх гідрозабійках і зв'язування частинок пилу при масових вибухах з екологічною ефективністю за показниками пило- та газопригнічення. Промислові дослідження дозволити підтвердити наукову гіпотезу про нейтралізацію CO гуматовим реагентом при масових вибухах, що ґрунтується на теорії Ленгмюра.

Практична значимість. Розроблена екологоорієнтована технологія буровибухових робіт у кар’єрах, що базується на використанні гуматового реагенту у внутрішніх і зовнішніх гідрозабійках та дозволяє промисловим підприємствам, які використовують масові вибухи, знизити викиди пилу, оксидів вуглецю та оксидів азоту.

Ключові слова: *масові вибухи, кар’єр, забійки, гуматовий реагент, пилогазова хмара, екологічна ефективність*

The manuscript was submitted 04.03.24.