Analysis of sources of dust and poisional gases in the atmosphere formed as a result of explosions at quarries of the mining and integrated works

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Abstract. In the process of developing a mineral deposit into the open pit atmosphere, dust and toxic gases are emitted from a number of sources. The intensity of such emissions depends on the properties and condition of the rock, weather conditions, engineering and development technology, the effectiveness of the application of methods for suppressing dust and harmful gases. In this regard, dust and gas contamination in the workplace can vary widely and have a negative impact on humans and the environment. The aim of the work is to analyze the processes of dust formation during blasting operations at the quarry of the mining and integrated works (for example, OAO Mikhailovsky in the city of Zheleznogorsk, Kursk Region). During mass explosions at the quarry of the mining and integrated works, the sources of dust and gas emissions were investigated, and a qualitative and quantitative assessment of their components was given.

1. Introduction

OJSC Mikhailovsky GOK is one of three operating mining enterprises in the Kursk Magnetic Anomaly (KMA) basin. The profile of the plant's operations is the extraction and processing of rich ores (production of sinter ore and blast furnace ore), the extraction and enrichment of unoxidized ferruginous quartzite, and the agglomeration of concentrate and pellets.

Studies in the zones of influence of mining and processing enterprises of KMA, in particular, Mikhailovsky GOK, showed that the open method of development reached the level of development, which began to have a very serious negative impact on the environment, causing landscape changes, contributing to pollution of adjacent territories, air and water basins. In the process of developing a mineral deposit into the open pit atmosphere, dust and toxic gases are emitted from a number of sources. In the process of developing a mineral deposit into the open pit atmosphere, dust and toxic gases are emitted from a number of sources. The intensity of their emissions depends on the properties and condition of the rock, weather conditions, used equipment and applicable technology, the effectiveness of the application of methods for suppressing dust and harmful gases. In this regard, dustiness and gas contamination of air at workplaces can vary within wide limits [1-3].

The presence, composition and nature of moving air currents, which in many cases determine the amount of hazards arising and taken out of the quarry and are the cause of intense dust formation, have
a significant impact on the state of the atmosphere of the quarry as a whole and its individual sections [4, 5].

2. The analysis of emissions into the open pit atmosphere

The analysis of emissions into the open pit atmosphere showed that the most dangerous and harmful to human health are: formaldehyde 16%, hydrogen sulfide 24%, carbon monoxide (II) 23%, sulfur oxide (IV) 19%. The dust generated and flying in the atmosphere of the quarry differs in mineralogical, chemical and dispersed compositions. This is due to the natural and technogenic conditions of the disturbed lands, their location in various climatic zones, and the population of the territories. The mineralogical and chemical composition formed in the dust quarry is close to the mineralogical composition of the rock being developed, especially directly near the source of dust formation. In addition, the chemical composition is influenced by production processes associated with the emission of harmful gases. In this case, adsorption of harmful gases and vapors on the dust surface is observed.

So, the dust generated during a mass explosion contains traces of carbon monoxide, up to 0.475 mg / g of acrolein and up to 0.219 mg / g of nitrogen oxides. The danger is a disease of mountain workers with silicosis, which is associated with inhalation of dust containing free silicon dioxide (SiO2). The content of free silicon dioxide on the ledges of the Mikhailovsky quarry reaches up to 50%.

The amount of damage caused by disturbed lands to the environment is determined by natural and man-made conditions of disturbed lands, their placement in various natural and climatic zones, development of territories. The damage caused to the environment by the processes of the mining and enrichment complex depends on the concentration and harmful nature of the pollutants (Figure 1, a-d).

The dispersed composition of dust depends on a number of natural and technological factors. For example, in roller drilling, the dispersed composition of dust depends on the physico mechanical properties of the drill rock, the type of cone bit, its rotation speed, feed force, the amount of compressed air supplied to the well, the depth of the wells, and the method of combating dust. With distance from the source of dust formation, the dispersed composition of dust in the ejection plume changes due to the precipitation of larger fractions of dust. So, the content of fractions less than 1.4 microns at a distance of 40 m from the blasted block is 63%, and at a distance of 600 m - 80%. The dispersed composition of dust obtained by the counting method; at various distances from the blasting unit at an average wind speed (4 m / s) are shown in table 1.

| Distance from the unit to be exploded | Dust dispersion composition (%) at fractions, µm |
|---------------------------------------|-----------------------------------------------|
|                                       | Up to 1,4 | 1,4-4 | 4-15 | 15-50 | More than 50 |
| 40                                    | 63,09     | 25,46  | 9,03 | 1,12  | 1,30         |
| 60                                    | 68,89     | 23,13  | 6,76 | 0,92  | 0,40         |
| 90                                    | 65,74     | 22,69  | 9,89 | 1,66  | 0,02         |
| 120                                   | 72,21     | 21,30  | 6,67 | 1,24  | 0,025        |
| 200                                   | 74,31     | 17,52  | 7,33 | 0,80  | 0,04         |
| 300                                   | 75,11     | 19,50  | 4,80 | 0,57  | 0,02         |
| 600                                   | 79,87     | 15,76  | 3,70 | 0,51  | 0,16         |

Table 1. Dust dispersion composition at different distances from the unit to be exploded.

The air in the quarry can be considered as ordinary atmospheric air, in which in addition to nitrogen (78.08%), oxygen (20.95%), argon (0.93%), carbon dioxide (0.03%), water vapor and fine dust contains toxic gases and vapors such as nitrogen oxides, carbon oxide, hydrogen sulfide, sulfur dioxide and aldehydes. The composition is shown in Figure 2. In some cases, especially when evaluating the gaseous products of an explosion, the notion of “conditional carbon oxide” is used, which is actually the CO generated during the explosion of the explosive and nitrogen dioxide, recalculated as CO (1 NO2 is taken as 6.5 CO). Hydrogen sulfide H2S in the quarry is extracted from the rock. Sources of SO2 in the quarry are fires and explosions in rocks with a high sulfur content.
Sources of aldehydes, in particular formaldehyde $\text{CH}_2\text{O}$, are internal combustion engines and thermal drilling.

**Figure 1.** Photos of OJSC Mikhailovsky GOK Zheleznogorsk, Kursk region. Designations: a - general view of the quarry (4 km from the center of Zheleznogorsk); b - an explosion in the quarry 11/01/2013; c - consequences of an explosion at a quarry in Zheleznogorsk; d - Mikhailovsky GOK hydraulic dump.

**Figure 2.** The percentage of pollutants in the air of the working area of the quarry. Designation: acrolein (8%); formaldehyde (16%); nitrogen oxides (10%); carbon oxide (IV) (24%); hydrogen sulfide (23%); sulfur dioxide (IV) (19%).
In accordance with the “Unified safety rules for open pit mining” (USR), the content of harmful gases in the quarry working area should not exceed the values given in table 2. The main sources of dust and gas in the quarry are drilling and blasting operations (up to 35%), handling operations and dust settled in quarries. In order to explode the rock mass in the MGOK quarry, regular explosives based on TNT and ammonium nitrate are used: granulotol, grammonite. The fragmentation of the rock mass consumes part of the energy released by the explosive. The main destructive factor in the explosion of explosives in the rock are stress waves passing through the medium and causing the movement of rock particles, its destruction and the formation of cracks. It has been established that the main factor affecting the composition and amount of forming harmful impurities is the type, quantity, specific consumption of explosives and rock strength, the height of the ledges and the diameter of the wells.

As a result of the investigations of explosions carried out at the polygon, it was confirmed that with the increase of the rock strength coefficient according to the scale of M. M. Protodyakonov, accordingly, the volume of dust released during the explosion increases. Thus, if at explosive of 1 t of explosives rocks with strength factor $f = 6-8$ (shale) form about 94.5 kg/m$^3$ of dust, at explosion of rocks with $f = 12-14$ (datolytic ore) about 240 kg/m$^3$ of dust particles are released (at size of fraction equal to 1 mm). Physically, this can be explained by increasing the dimensions of the plastic deformation zone in strong rocks, which requires higher explosion energy consumption for their destruction, resulting in an increase in the yield volume of the re-ground fractions.

Table 3 shows data on values of relative aggressiveness of mined rocks, (cond. t/t), where $\alpha_s$ is an indicator of relative aggressiveness of the pollutant (cond. t/t), $\alpha_a$ is an indicator of relative aggressiveness (weighted average) of discarded ingredients (cond. t/t).

Table 4 shows the amount of harmful gases emitted during the explosion of various explosives used at the Mikhailovsky GOK in the Kursk region. Significant emissions of the explosion are toxic gases (mainly carbon monoxide (CO) and nitrogen oxides (NO$_2$)), depend on the grade of explosives and the oxygen balance used explosives.

Table 2. Maximum permissible concentrations for pollutants in the air of the working zone.

| Gas                        | Maximum permissible concentration |
|----------------------------|----------------------------------|
| Acrolein                   | 2 mg/m$^3$                      |
| Formaldehyde               | 5 mg/m$^3$                      |
| Nitrogen oxides (in terms of N$_2$O$_5$) | 5 mg/m$^3$                   |
| Carbon oxide (IV)          | 30 mg/m$^3$                     |
| Hydrogensulfide            | 10 mg/m$^3$                     |
| Oxide of sulfur (IV)       | 10 mg/m$^3$                     |
| Carbon oxide (II)          | - mg/m$^3$                      |

The intensity of dust and gas cloud emission into the open pit atmosphere increases with an increase in the length of the borehole charge, which contributes to the premature opening of the destruction funnel and the free flow of dust and gases. The height of the explosive charge affects the time of the impact of the explosive pulse on the destructive medium. The duration of exposure to explosive detonation products during the explosion of high ledges will increase several times. Depending on the height of the ledge, the angle of the fracture funnel changes, which affects the process of explosion release into the quarry atmosphere. The dust generated at the time of the explosion is carried out from the wellhead and cracks in the rock in the form of a dust and gas cloud and is vertically developed.

This process is called the formation of the primary dust and gas cloud, this is the first stage of its formation. The data of experimental filming of the explosion development process show that after the...
production of a mass explosion, a dust and gas cloud spreads over the entire volume of the quarry and dissipates outside it (Figure 3). When performing research, the works [6-29] were used.

**Table 3.** Values of indicator so relative aggressiveness of extracted rock sat quarries of mining and processing plant.

| Characteristic rocks                                                                 | Value of index (cond. t/t) |
|-------------------------------------------------------------------------------------|-----------------------------|
| Hard weathering rocky, magmatic, metamorphic and sedimentary geochemical inert rocks | αₚ 0,1                      |
| Coherent non-cemented sedimentary geochemical inert rocks                             | αₚ 0,2                      |
| Coherent sedimentary fast-rolling semi-rock geochemical inert rocks                  | αₚ 0,2                      |
| Coherent non-cemented sedimentary rock and enrichment wastes, acidic or containing  | αₚ 0,5                      |
| easily soluble salts                                                                |
| Incoherent non-cemented geochemical inert sedimentary rocks                          | αₚ 0,2                      |
| Cemented sedimentary carbonate rocks                                                | αₚ 0,3                      |
| Incoherent enrichment waste, containing sulphidic, sulphurous, haloid connections   | αₚ 0,3                      |
| Incoherent enrichment waste containing arsenic, mercury and other toxic compounds    | αₚ 1,0                      |

**Table 4.** Amount of harmful gases released during explosion of different explosive.

| Explosive                          | Oxygen balance, % | CO       | CO₂       | N₂       | NO₂     |
|------------------------------------|-------------------|----------|----------|----------|---------|
| Granemit I-30                      | +0,1              | 27,0     | 78       | 215      | 0,21    |
| Granemit I-50                      | +0,3              | 38,8     | 89,2     | 236      | 0,12    |
| Granulated trinitrotoluene         | (-74) - (-76,2)   | 274,6    | 37,6     | 147,8    | -       |
| Grammonite 79/21                   | 0 - (+0,3)        | 48,2     | 65,2     | 229      | 5,6     |

**Figure 3.** Model of dust and gas cloud process of formation in case of mass explosions in the quarry.

Visually fixed dust-gas cloud dispersion time under various weather conditions in the quarry averages from 20 to 40 minutes, its rise height averages 400–600 m (in some cases, up to 800 m), the propagation range reaches 14–17 km. The dust generated at the time of the explosion is carried out
from the wellhead and cracks in the rock in the form of a dust and gas cloud and is vertically developed. This process is accompanied by the formation of a primary dust and gas cloud and represents the first stage of its formation. In the future, the cloud gets its development, moving in the direction of the collapse. At this moment, a secondary cloud forms, completing the second stage of its formation. In this case, the dust and gas cloud, originally formed by the explosion, increases in volume and moves a considerable distance in height and range, polluting the environment and large sections of the earth’s surface adjacent to the quarry.

3. Conclusion
1. The sources of dust and toxic gases formation in the atmosphere of the quarry have been investigated.
2. Qualitative and quantitative assessment of dust and gas emissions components during mass explosions is given.

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