Evaluation of the effectiveness of dust screens and the possibilities of taking into account their influence in software models

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Abstract. The variety of approaches used to reduce dust load from the enterprises of the mineral resource complex is wide. Often the normative methodological base shows a lag behind the development and implementation of new devices and methods of protection. The article considers an example of a granite quarry in the Leningrad region of Russia, on which the construction of dust screens was proposed. The impact of the enterprise’s facilities on the residential area has been assessed. The inverse subsurface nature of the movement of air and the spread of dust from quarry facilities is revealed. Proposed placement of a semi-permeable dust screen along the edge of the quarry provides comprehensive dust protection. An assessment was made of the negative impact of the facility on atmospheric air after installing a dust screen with various options for methodological accounting for the impact of such structures on reducing dust transfer outside the quarry field.

1. Introduction

The enterprise in question is located in the northern part of the Leningrad Region (Russia). The main activity of the enterprise is the extraction of rock during open pit mining of granite mineral deposits (Kuznechnoye-1 quarry) and its subsequent processing to produce granite fractioned gravel and other non-metallic building materials (CSP-2 crushing and screening plant).

The development of the quarry is carried out in a blasting manner. The blasted rock mass is shipped by excavators and vehicles and transported to a crushing and screening plant for processing. Crushed stone production is envisaged according to the technological scheme, which includes three stages of crushing in a closed cycle with preliminary screening, output of career screenings and sorting of the product into inertial screens. Primary crushing of the original rock mass is performed on a jaw crusher, secondary and tertiary - in cone crushers. Interoperational material transfer is carried out by belt conveyors. Finished products are conveyed by stackers by stackers to stacked warehouses. From warehouses, products are shipped to consumers.

The volume of incoming rock mass for processing will be 1250 thousand m³ per year. The maximum annual production capacity of the opencast mine is 100 thousand m³.

During the mining period, during the operation of the equipment at the Kuznechnoye-1 quarry, a certain load on the atmospheric air will be carried out. The main sources of emissions of harmful substances into the atmosphere during the development of the field in question are: excavators, bulldozers, drilling rigs, blasting, loaders, motor vehicles, dump, temporary storage of crushing screenings (wind erosion).
Sources of air pollution at the crushing and screening plant were not considered in this work due to the fact that the problem of their negative impact was widely discussed with the proposal of environmental protection measures in works published earlier [1].

2. Materials and methods
The main research methods used included:
- system-structural analysis of production facilities contributors to the deterioration of the dusty environment;
- methods of mathematical modeling of dust transfer to the factory's facilities.

Table 1. List of pollutants emitted into the atmosphere by sources at the quarry subject to state accounting and regulation

| Code | Name of Substance | The value of the normative criterion, mg/m³ | Hazard Class | Total Emissions g/s | t/year |
|------|-------------------|--------------------------------------------|--------------|---------------------|--------|
| 123  | Iron oxide (in terms of iron) | 0.0400000 | 3 | 0.01499 | 0.04232 |
| 143  | Manganese and its compounds | 0.0100000 | 2 | 0.00141 | 0.00357 |
| 301  | Nitrogen Dioxide | 0.2000000 | 3 | 126.36925 | 10.99296 |
| 304  | Nitric oxide | 0.4000000 | 3 | 21.02245 | 1.78631 |
| 328  | Black carbon | 0.1500000 | 3 | 0.20145 | 0.87346 |
| 330  | Sulfur dioxide | 0.5000000 | 3 | 0.36972 | 2.29260 |
| 333  | Hydrogen sulfide | 0.0080000 | 2 | 0.00005 | 0.00018 |
| 337  | Carbon oxide | 5.0000000 | 4 | 1002.76014 | 17.53215 |
| 342  | Gaseous fluorides | 0.0200000 | 2 | 0.00020 | 0.00076 |
| 344  | Slightly soluble fluorides | 0.2000000 | 2 | 0.00091 | 0.00336 |
| 415  | Mixture of hydrocarbons saturated C₁-C₅ | 50.0000000 | 0 | 4.33088 | 0.02121 |
| 416  | Mixture of hydrocarbons saturated C₆-C₁₀ | 60.0000000 | 4 | 1.60064 | 0.00784 |
| 602  | Benzene | 0.3000000 | 2 | 0.14720 | 0.00072 |
| 616  | Xylene (mixture of isomers) | 0.2000000 | 3 | 0.02796 | 0.20393 |
| 621  | Toluene | 0.6000000 | 3 | 0.13888 | 0.00068 |
| 627  | Ethylbenzene | 0.0200000 | 3 | 0.00384 | 0.00001 |
| 703  | Benzapyrene (3,4-Benzpyrene) | 0.000001 | 1 | 0.00001 | 0.00001 |
| 1325 | Formaldehyde | 0.0500000 | 2 | 0.00377 | 0.04305 |
| 2704 | Petrol | 5.0000000 | 4 | 0.18270 | 0.11762 |
| 2732 | Kerosene | 1.2000000 | 0 | 0.64498 | 3.14022 |
| 2735 | Mineral oil | 0.0500000 | 0 | 0.00027 | 0.00048 |
| 2752 | White Spirit | 1.0000000 | 0 | 0.01438 | 0.29861 |
| 2754 | Saturated hydrocarbons C₁₂-C₁₉ | 1.0000000 | 4 | 0.17215 | 0.08036 |
| 2908 | Inorganic dust 70-20% SiO₂ | 0.1000000 | 3 | 229.93556 | 200.56785 |
| 2930 | Abrasive dust (White corundum, Monocorund) | 0.0100000 | 0 | 0.00142 | 0.00359 |

Total Substances 25 | 1390.94533 | 238.01395 |
including solid 7 | 230.15578 | 201.49417 |
liquid / gaseous 18 | 1160.7895 | 36.51977 |

In the scientific work, the design data of the enterprise were used as initial data. According to the results of the data analysis, a list of the main pollutants emitted into the atmosphere during open pit operation is highlighted (table 1).

The key problem of the enterprise is the emission of inorganic dust with a SiO₂ content of 70-20%. Dissipation calculations were made for all emission sources located at the quarry site, without taking into account background concentrations of pollutants.
This chapter will discuss a method for reducing dust dispersion in a quarry by installing a dust screen. To select a screen location, meteorological characteristics and coefficients that determine the conditions for the dispersion of pollutants in the atmosphere were taken into account. Figure 1 presents examples of dusting sources at the enterprise. Table 2 presents the sources of pollution and their remoteness from the village.

![Figure 1. Sources of air pollution at the production site of the Kuznechnoye-1 quarry](image)

As a calculation tool, the Unified Atmospheric Pollution Calculation Program “Ecolog” (version 4), which implements the provisions of the calculation methodology [Order of the Ministry of Natural Resources of Russia (Ministry of Natural Resources and Ecology of the Russian Federation) dated June 06, 2017 No 273 “On approval of calculation methods for dispersing emissions of harmful (polluting) substances in the atmosphere”], was used. The used modification of the program also implements a building accounting application. The program allows calculating one-time (averaged over a 20-30 minute interval) concentrations of substances in the surface layer based on data on the sources of emissions of substances and terrain conditions under adverse weather conditions. The GIS-Ecolog graphical module built into the program allows you to visualize the calculation results in the form of a
topographic graphic file in the form of isolines of contrast coefficients relative to the maximum permissible concentration taking into account background values.

| Code  | Source of pollution                               | Inorganic dust emission 70-20% SiO$_2$, g/s |
|-------|---------------------------------------------------|--------------------------------------------|
| 6035  | Dropout                                          | 3.27                                       |
| 6005  | Overburden dump                                  | 4.402                                      |
| 6002  | Commando 300 Drilling Rig                        | 1.5752                                     |
| 6004  | ROC L8 Drilling Rig (Atlas Copco)                | 1.4684                                     |
| 6001  | Oversize cutting                                 | 1.628                                      |
| 6007  | Rock mass after the explosion                    | 2.857                                      |
| 6033  | Dropout screening                                | 3.869                                      |
| 6003  | Overburden removal                               | 3.332                                      |
| 6006  | Rock loading in dump trucks                      | 2.946                                      |

Table 2. Sources of pollution at the quarry site

The initial data for the obtained cartographic model were experimental studies conducted by the authors at the object under consideration.

3. Results and Discussion

The contrast coefficient, which is calculated as the ratio of the current concentration of the polluting substance in the atmospheric air to the established standard, is adopted as a parameter for constructing isolines on the map. That is, all values above 1 show how many times the current dust concentration exceeds the established standard.

Figure 4a shows the location of pollution sources at the production facility with the application of contours of contrast coefficients. The enterprise operates in 2 shifts of 12 hours and the mining equipment works continuously, from this we can conclude that all sources of pollution work in the same way simultaneously and continuously. In this regard, in the residential area there may be an excess of normative value up to 4 times for inorganic dust 70-20% SiO$_2$ emissions.

In the course of the analysis of environmental protection measures that could be used at a quarry, water dedusting, the use of foam, reagent irrigation, and the use of dust screens were considered. It is worth noting that the application of the first three methods considered is of a point nature, this significantly reduces the effectiveness of their use for mobile sources of pollution [2,3,4,5,6,7,8]. The use of dust screens is complex and the protection of the air is carried out continuously regardless of the operating conditions of the pollution sources [9].

There are two types of dust screens: impermeable and permeable [10]. The screen is impenetrable and has an extremely high windage, which significantly limits its height. In open industries, as a rule, permeable screens are used. Such screens significantly reduce wind loads on the screen supports and reduce the vortex formation of air flow during the passage of the screen [11]. The device is made in the form of supports welded from a metal profile, and metal cross-pieces between them, on which a polymer mesh is fixed. The key mechanisms for reducing dusting are reducing the wind flow, the maximum possible drop in the kinetic energy of the incoming wind flow, eliminating the formation of wind flows and a general decrease in turbulence, which ultimately leads to dust deposition in the transmitted stream at some distance from the screen [12]. The height of such structures, as a rule, is 5 m, but in some cases it can reach 8 meters.

Examples of application of dust-proof screens representation are in figure 2.
As noted earlier, the main disadvantage of using such protective structures is the possibility of the passage of polluted air over the screen. When assessing the possibility of using a screen at the object in question during the course of this scientific work, supported by a grant from the President of the Russian Federation MK-130.2020.5, supported, the nature of the spread of pollutants was assessed. It was found that in connection with the formation of anthropogenic excavation, the movement of air masses in the quarry is inverse. As a result of the uneven distribution of temperatures across the layers, the dispersion of pollutants is carried out near the surface, which allows us to talk about the passage of the bulk of the pollutants in the surface zone up to 5 meters. Figure 3 shows the non-scale profile of the temperature

**Figure 2.** Dust screen application examples, a - Murmansk (Russia), a trading port, a terminal for the transshipment of bulk materials b - Rocky Hill Field (Australia) c - Fujian Province (China), an open warehouse of building material
distribution in the Kuznechnoye-1 quarry for average summer air maximums in the area where the facility is located.

**Figure 3.** The non-scale profile of the temperature distribution in the Kuznechnoye-1 quarry for the average maximums of summer air temperatures in the area where the object is located and the direction of movement of the air masses is indicated.

**Figure 4.** The result of calculating the dispersion of inorganic dust 70-20% SiO$_2$: a - initial situation with applied sources of pollution, b - taking into account the dust screen as a building element, c - taking into account the dust screen, as an additional element of the terrain, d - taking into account the nameplate efficiency of the dust screen

A key aspect of designing dust screens is the ability to incorporate structures into programs for dispersing contaminants within the current regulatory framework. According to the methodology [Order June 06, 2017 No 273], any protective structures should be considered as elements of the closure. The dispersion calculation was carried out on the basis of the “Ecolog” 4.0 program with a calculation module taking into account the buildings.
Figure 4b shows the dispersion after calculation according to [Order, June 06, 2017 No 273], taking into account the dust screen as a building element. According to the data obtained, it can be noted that the halos of pollution have changed, but the nature of pollution at the border of the residential area has not changed. Nevertheless, full-scale studies of the influence of such structures, carried out by manufacturers and enterprises of the mineral resource complex, indicate the opposite effect. You can also see that in the territory of the location of sources 6001, 6002, 6004, 6006, 6007 the situation only worsened. In the course of work, the impossibility of the correct use of this methodological tool was established.

It was further proposed to consider the screen as an element of relief. For this, using the normative methodology [Order June 06, 2017 No 273], the relief coefficients of the area were manually calculated taking into account the installed screen. Figure 4c shows the calculation results.

Dust dispersion at the quarry in this calculation near the screen does not decrease, the contrast ratio at the boundary of residential buildings remains in excess. As can be seen, the scattering at the sources is also modified, but does not decrease, as in the previous calculation. Comparing the results obtained, we can conclude that the use of a screen as a terrain (obstacle) did not provide sufficient correlation with the results of well-known field studies of such protective structures.

As one of the possible solutions to the problem, the calculation was also considered with an actual decrease in dust removal volumes according to the passport screen operating efficiency indicated by the manufacturer. The efficiency of the selected dust screens is 70%.

Figure 4d shows the dispersion map after considering the efficiency of the screens. According to the results obtained, it can be concluded that only this calculation option gives the correct dynamics of reducing the spread of dust and can be used as fundamental in the design of screens at such production facilities.

4. Conclusion

Thus, we can say that semi-permeable dust screens are an effective means of combating the spread of suspended solids in quarry conditions with the inverse nature of the movement of polluted air from the extraction space. In enterprises occupying small areas with a high degree of concentration of pollution sources, such a tool will be universal and complex, in contrast to more common methods using water, penalties or a reagent that have a point effect. The work raised the issue of accounting for dust screens with current regulatory methods and software. Comparing all of the above options for calculating the dispersion during installation of the screen as a dustproof structure, we can say that the current methods cannot be used in the calculations for such structures, since their updating is slower than the release of new products in the field of equipment for protecting atmospheric air. In fact, the correct accounting of screens in software models can be made only by amendments based on the passport efficiency of these structures.

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