UDC 628.5

S. G. GENDLER *(Professor, Doctor of Engineering Sciences, Saint-Petersburg Mining University, Saint Petersburg, Russian Federation)*
S. V. KOVSHOV *(Associate Professor, Candidate of Engineering Sciences, Saint-Petersburg Mining University, Saint Petersburg, Russian Federation)*

ESTIMATION AND REDUCTION OF MINING-INDUCED DAMAGE OF THE ENVIRONMENT AND WORK AREA AIR IN MINING AND PROCESSING OF MINERAL STUFF FOR THE BUILDING INDUSTRY

In building materials extraction, a special feature is that some factors of the same physical nature affect simultaneously the environment and health conditions of mine personnel. Noise and vibrations generated by mining and transport equipment, gases emitted by internal combustion engines and dust produced in almost all productive processes condition both the working environment in mines and the ecological security of adjacent areas, which requires ecological-and-economic appraisal of potential damage as a result of production of basic materials for the building materials industry.

Open pit mining exerts the most aggravating effect on air. The data analysis shows that basic air pollutants are aerosol dust, carbonic oxide and nitrogen dioxide. The main sources of dust are blasting operations and mining and loading equipment, while carbonic oxide and nitrogen dioxide are the products of internal combustion engines of open pit dump trucks.

The working environment certification data show that for all personnel engaged in extraction of building materials, dusting conditions belong to the hazard class 3.1, which calls for carrying out of measures towards dust reduction in the mine work area.

This objective can be reached through introduction of a package of innovative rock breakage technologies such as hydraulic fracturing, hydraulic impact, or hydraulic wedge in combination with the efficient techniques of reduction of dust from such sources as external dumps, dump truck roads, etc.

The laboratory experiments and field research have allowed finding that it is possible to reduce dusting from overburden dumps by coating them with biogenic mixtures of bio humus and sodium carboxymethyl cellulose taken at a ratio of 125:1. For motor road dust reduction, it is expedient to use water solution of Universin agent and sodium carboxymethyl cellulose at a ratio of water — 87.5%, Universin V — 11% and Na-carboxymethyl cellulose — 1.5%.

Key words: *building materials, dust aerosol, dusting, open pit mine, dust-binding substances, bio humus, Universin, sodium carboxymethyl cellulose, dust suppression, working conditions class.*

DOI: dx.doi.org/10.17580/em.2016.01.08

Introduction

Intensification of various-purpose construction has resulted in keeping ahead of extraction of minerals used for production of building materials. For instance, relative to 2003, production of cement material, sand and break stone, which are the basic components in concrete manufacture, has increased by a factor of 4, 1.64 and 1.31, respectively (**Fig. 1**) [1].

More than 2.7 thousand companies in Russia carry out extraction and processing of building materials. Their output is over 1.1 Bm^3. Almost 100% of the output is produced by open pit mining, which results in the long-term withdrawal of immense lands from the national economy. According to the evidence from [1], in 2014 as against 2004, the area taken for the extraction of raw stuff for the building materials industry increased by 23%, which was only second to ferrous metal ore mining (31%).

Aside from seizure of land, cost of which may make, depending on location and proximity to population areas, from between 30 RUB/m^2 and 1800 RUB/m^2 (Moscow Region) to between 24 RUB/m^2 and 342 RUB/m^2 (Leningrad Region), extraction of minerals for the production of building materials by the open pit mining method has aggravating effect on the environment [1, 2]. Depending on location of open pit mines relative to residential zones and other objects that require provision of the preset environmental parameters, this impact may have lethal effect inducing increased illness frequency, reducing reproductive function of people and decreasing species diversity of flora and fauna up to total vanishing of some species.

Despite the variety of the environmental impacts (air, soil, flora and fauna, population of residential zones) due to production of raw stuff for the building materials industry, conditioned both by the mining technology in use and by the mineral processing methods, it seems possible to identify some common characteristics of the aggravating influence. The main sources of mining-induced aero-detrimental effect, including formation and propagation of dust, toxic gases, noise and vibration, as well phreatic decline and local seismicity, are drilling, blasting, mechanical breakage (air-hammers, hydraulic hammers, hydraulic fracturing, hydraulic breakdown) and internal and external dumps; in loose rock haulage,

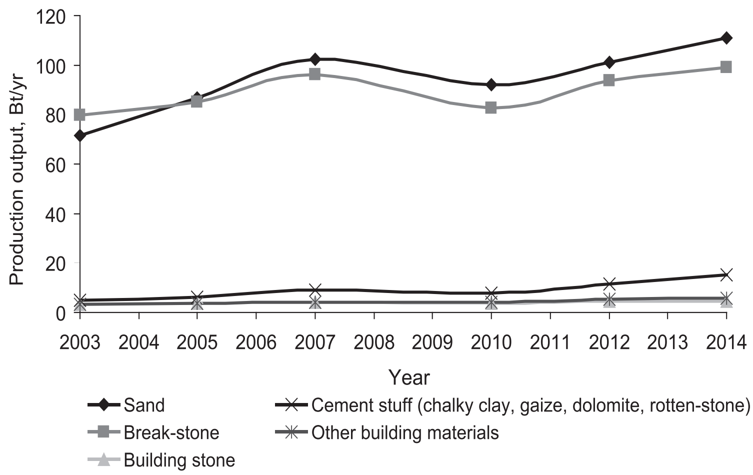

Fig. 1. Dynamics of building materials extraction [1, 3]

aero-detrimental effects are produced in operations of loading (shovels, conveyors), transport (dump trucks), unloading and stockpiling; in processing of extracted raw stuff, the aero-detrimental effect is generated during feeding of process equipment (crushers, mills, screens), operation of the equipment and in re-loading of prepared materials for shipment to a consumer.

A feature of the production of raw stuff for the building materials industry is that noise and vibration generated by mining and transport equipment, as well as gases emitted by operating internal combustion engines and dusting during nearly any productive operation condition both the working environment in mines and the environmental safety of the adjacent areas.

The problems associated with the impact of mining on the environment and mine personnel have been extensively analyzed both by Russian and foreign researchers [3, 4, 5, 6, 7]. However, the cumulative and simultaneous influence of major physical factors on the nature and on mine personnel in the course of mineral stuff production for the building materials industry remains yet to be studied.

In this connection, at each stage of decision-making on mineral tonnage output and on technologies of mining and processing, it should be evaluated and compared which damage may be caused to the mine personnel, environment, and to the local population. It also should be born in mind that building raw materials mining and processing personnel and residents of the areas in the zone of influence of mining and processing plants can twice suffer from the aggravating influence: once as the operating personnel and the other time as the local population.

Estimate of open pit mining effect on the environment and personnel in building materials extraction

Mineral mining is the first stage of building materials production to exert the most various environmental impacts. At this stage, alongside customary negative factors of construction operations such as noise, vibration, air pollutant emission due to equipment operation, there are some features specific to open pit mining. This is, first of all, influence of an open pit mine on the hydrochemical regime of the adjacent area, which results in both phreatic decline and in inflow of toxic chemicals from overburden dump leaching to underground aquifers.

Furthermore, the most efficient open pit mining technology of blasting has considerable seismic effect on objects located in the zone of blasting influence, which results in health problems and in damage of buildings and structures. It is required to debulk explosives in overall blasting circuit and per each stage of delay, to select adequate number of delay stages and intervals between them, etc. All that affects blasting technology performance.

The most aggravating effect is exerted by open pit mining on air [8]. For example, Afanas'evsky open pit mine (Moscow Region) emits 10 pollution agents in air, including 3 solid pollutants and 7 gaseous pollutants. The percentage composition of the air pollution agents emitted by this open pit mine in air is given in **Table 1** [3].

It follows from **Table 1** that the basic pollution agents are suspended solids (dust), carbonic oxide and nitrogen dioxide. The main sources of dust are blasting operations and mining-and-loading machines, while carbonic oxide and nitrogen dioxide are the products of internal combustion engines of dump trucks [9, 10]. Inorganic dust with SiO_2 content up to 20% makes 49.8% of all emission of the mentioned open pit mine, whereas dust generation by blasting is 11–15 times higher than dust formation in other technological processes and is almost 8 times higher than dust release from such stationary sources as internal and external overburden dumps.

Table 1. Volume contaminant emission by Afanas'evsky open pit mine [3]

Pollutant	Percentage in total volume, %
Inorganic dust	48.55
Carbonic dioxide CO_2	37.52
Nitrogen dioxide NO_2	9.59
Saturates C1–C5	2.88
Nitrogen oxide NO	1.20
Sulfur dioxide SO_2	0.14
Soot	0.07
Kerosene	0.04
Benzene	0.01
Benzopyrene	0.01

At the same time, it is worthy of mentioning that dust generation by blasting in open pit mine has periodic nature and is mainly connected with formation of a dust and gas cloud after explosion. Aiming to reduce dust release, it is proposed to design decoupled charges with air gaps and to use gas-dynamic locking devices as stemming of boreholes charges, which lower dust release by 40–50% and concurrently eliminate generation of gaseous explosion products [11].

The other dusting sources continuously release dust, and this process depends on meteorological conditions in the region of an open pit mine location. At certain speed and direction of wind relative to residential and office blocks, or other objects coming under the strict observance of the environmental standards, a dust cloud can go 300 m beyond the sanitary protection zone in summer. This conclusion is confirmed by the results of computer-aided modeling of overburden dump dust transport in terms of Afanas'evsky open pit mine [12].

The other aggravating effect of dust in case when it is not released beyond an open pit mine field consists in the mining safety inhibition, which results in higher rate of respiratory diseases. **Table 2** reports the data of the labor conditions certification at Afanas'evsky open pit mine, showing that in terms of dust factor, the labor conditions for all mine workers come under hazard class 3.1.

The highest hazard class of labor conditions at this open pit mine is 3.2 for nearly all personnel [3].

Thus, suspended matter (dust generated during mineral mining) is hazardous for both the personnel of the open pit mine and the population of the adjacent area. Transition from mining with blasting to mining with mechanical breakage of rocks, e.g., using hydraulic hammers, will end in no essential reduction in dust release. The way out is, in our opinion, combination of innovative rock destruction technologies, such as hydraulic fracturing, hydraulic shock and hydraulic wedge, with dust suppression methods.

Table 2. Results of certification of work areas in Afanas'evsky open pit mine [3]

Factor	Class of labor conditions						
	Dozer operator	Drill rig operator	Shovel operator	Shot-firer	Loader operator	Tinker	Dump truck operator
Chemical factor	2	2	2	–	2	3.1	2
Predominantly fibrogenic action aerosols	3.1	3.1	3.1	3.1	3.1	3.2	3.1
Noise	2	3.2	2	2	2	3.1	2
General vibration	2	2	2	2	2	2	2
Local vibration	2	2	2	2	2	2	2
Small-scale climate	2	2	2	2	1	2	2
Light	2	2	2	2	2	2	2
Severity	3.1	2	3.1	2	3.1	2	3.1
Stress level	3.1	2	3.1	2	3.1	2	3.2
Final estimate	3.2	3.2	3.2	3.1	3.2	3.2	3.2

Theoretical and field research into dust formation and dust release reduction methods

All methods of dust release combating may be divided into passive and active control. Passive control suggests construction of permanent structures over dusting surfaces to reduce wind effect [1] or cyclic treatment of dusting surfaces by various agents (water, bitumen, etc.) [14], or screening of dusting surfaces with various chemical mixtures [15]. These approaches enable lowering dust release from stationary sources (overburden dumps, end products stockpiles, waste storage). Active control involves operational dust suppression in the areas of local dust formation, for instance, at internal dumps, at loading, screening or processing stations. The active control involves dust treatment by dispersed water or aqueous solutions of surfactants depending on dust properties and climatic conditions [2]. The intervals of application of these methods equal the duration of specific technological processes. Evaluation of the efficiency of a dust suppression technique requires implementation of experimental research, as a rule [16, 17].

The efficient technology of dust release reduction is screening of dusting surfaces of overburden dumps and tailings ponds by bio-substances possessing high adhesive ability.

Developed at the Mining University, the new dust suppression method is based on using a mixture of bio humus, produced after treatment of organic waste by earthworms, and sodium carboxymethyl cellulose (Na–CMC)—one of the main components of dextrin [18]. The mixture added with hayseed is applied on dusting surfaces with the help of agricultural machines. The mixture is held on the surface by spraying or due to natural raining, which activates adhesion properties. Grassing later on will considerably increase strength of the dust suppression layer.

The samples of screening layers of biogenic mixtures with various compositions of components were tested on a laboratory wind test bench. The samples put on trays were subjected to air flow at a velocity of 5 m/s for 5 min. The strongest and most consistent layer was the sample composition of bio humus / Na-CMC = 125:1.

It is worth mentioning that the efficiency of this dust suppression technique greatly depends on the screening layer thickness and air flow velocity, and the decision-making on its wide application requires additional experimental research, including field studies.

One more approach to reducing dust burden on mine work areas and on the environment may be treatment of road surfacing.

In the meantime, it appears that agents currently used for road surfacing treatment are not multicapable to be efficiently applied in various climatic zones. After the relevant analysis, standards were defined for agents used for dust consolidation on road surfacing. Such agents must possess:

— good wetting and adhesive ability;

— consistency of viscous–temperature properties and application conditions: solidification temperature not higher than –5°C (in summer) and –30°C (in winter);

— workability (ready-to-use);

— no corrosive nature relative to rubber and metal;

— non-toxic nature;

— availability and operational economy.

The joint research of the Mining University, Mine Efficiency and Safety Research Institute (NIIOGR, Chelyabinsk) and the University of Mining and Geology St. Ivan Rilski (Sofia, Bulgaria) has shown that these standards are in a varying degree satisfied by such dust-binding agents as Universin-A (low-viscous), Universin-V (high-viscous) and Universin-S (north application) [19].

Dust-binding emulsions based on Universin-A and Universin-V are intended to save consumption and to enhance efficiency of Universin agents. The emulsions possess lower viscosity and oxidizing ability when in soil [20]. They are manufactured by adding an Universin agent with aqueous solution of sodium carboxymethyl cellulose (Na-CMC). Based on the pilot experiments, the following efficient compositions of the emulsion have been selected:

— for summer conditions: water — 89.5%; Universin-A — 10%, Na-CMC — 0.5%.

— for general conditions: water — 87.5%, Universin-V — 11%, Na-CMC — 1.5%.

The technical-economic assessment of road dedusting using various dust-binding agents (DBA) applicable at construction materials quarries is given in **Table 3**.

The application of the emulsions speeds up the process of road surfacing treatment, allows a greater depth of the treatment (up to 7–12 cm) and, owing to Universins, creates

Table 3. Dedusting efficiency of DBA applied in open pit mining

Dust–binding agent	Dedusting period, h	Dedusting cost, RUB/m^2 (valid for 2015)	DBA consumption, l/m^2	Dust suppression efficiency, h·m^2/l
Universin-A	168–240	20–28	0.7–1	187–240
Universin-S	120–168	20–28	0.8–1	210–240
Universin-V	192–504	20–28	0.2–2	252–960
Emulsions with Na-CMC	240–360	10–20	1–1.2	240–360
Oil	24	40	0.1	240
Black oil fuel	600	57	4.0	150
$CaCl_2$	240	60–150	1.5	160
Lignosulphonates	120	80–100	1.0	120
Water	1.5	250–300	1.0	1.3

coating unbreakable by heavy dump trucks and with ability to bind fresh dust for dedusting period up to 15 days.

It is proposed to coat motor roads with the developed dust-binding mixtures with the help of widely used sprinkling truck PMK-12. The single modification of this sprinkler as compared to regular-duty water-aided dedusting is the addition of a Laval nozzle-based jet with a diameter not less than 40 mm, which will allow avoiding blockage of the jet with the applied mixtures [21].

Conclusion

Extraction and production of raw stuff for the building materials industry exerts considerable damaging effect both on the environment and on mine personnel. The key factors of this impact are dust formation and gases.

Suspended solids (dust) generated during mining constitute the highest danger for mine personnel and for population in the mine location area. Transition from blasting to mechanical breakage of rocks, for example, using hydraulic hammers, will produce no essential reduction in dust release.

The objective of the enhancement of the environmental and mining safety is to be achieved through introduction of innovative rock breakage technologies such as hydraulic fracturing, hydraulic shock and hydraulic wedge in combination with the efficient reduction of dust from other sources.

Reduction of dust release from overburden dumps is achievable by coating dump surfaces with biogenic mixture composed of bio humus and sodium carboxymethyl cellulose at a ratio of 125:1.

Dust generation on open pit mine roads is efficient to suppress using aqueous solution of Universin agent and sodium carboxymethyl cellulose at the following ratio: water — 87.5%, Universin-V — 11%, Na-CMC — 1.5%.

References

1. *Nerudnye poleznye iskopaemye* (Non-metallic mineral resources). Available at: http://statistika.ru. (in Russian)
2. Strizhenok A.V. Ekologicheskaya otsenka severnykh ekosistem, podvergayushchikhsya vozdeystviyu gornoy promyshlennosti (Ecological assessment of northern ecosystems, being under the mining influence). *Zapiski Gornogo instituta. Tom 195 «Poleznye iskopaemye Rossii i ikh osvoenie» = Proceedings of the Mining Institute. Volume 195 «Russian mineral resources and their mastering»*. 2012. pp. 171–173.
3. Bulbashev A.P., Gasparyan N.A., Kovshov S.V., Nikulin A.N., Smirnov Yu.D. Shuvalov Yu.V. *Ratsionalnaya organizatsiya dobychi poleznykh iskopaemykh v karerakh so slozhnymi usloviyami truda gornorabochikh* (Rational organization of mineral extraction in open pit with complex miners' labor conditions). Saint Petersburg : International Academy of Ecology, Human and Nature Safety Sciences, 2009. 464 p.
4. Kurchin G.S., Volkov E.P., Zaytseva E.V., Kirsanov A.K. Problemy ekologii pri dobyche nerudnykh stroitelnykh materialov v Rossii (Ecology problems during the extraction of non-metallic construction materials in Russia). *Sovremennye problemy nauki i obrazovaniya = Modern Problems of Science and Education*. 2013. No. 6. pp. 12–19.
5. Yayli E.A. *Nauchnye i prikladnye aspekty otsenki upravleniya urbanizirovannymi territoriyami na osnove instrumenta riska i novykh pokazateley kachestva okruzhayushchey sredy* (Scientific and applied aspects of assessment of urbanized territories control on the basis of risk instrument and new indicators of environmental quality). Under the editorship of Karlin L. N. Saint Petersburg : Russian State Hydrometeorological University, VVM, 2006. 448 p.
6. Cole C., Fabrick A. Surface mine pit retention. Journal of the Air Pollution Control Association. 1984. Vol. 34. pp. 674–675.
7. P. Wypych, D. Cook, P. Cooper. Controlling dust emissions and explosion hazards in powder handling plants. Chemical Engineering Process. 2005. Vol. 44. pp. 323–326.
8. S. A. Silvester, I. S. Lowndes, D. M. Hargreaves. A computational study of particulate emissions from an open pit quarry under neutral atmospheric conditions. Atmospheric Environment. 2009. Vol. 43. pp. 6515–6524.
9. Aristotelous K. An empirical investigation of how sensitive Carbon dioxide (CO2) emissions per capita is to changes in livestock production. International Journal of Ecology and Development. 2016. Vol. 30 (2). pp. 1–10.
10. Thompson E.O. A Review on Climate Change Effects on Vegetation – Past and Future International Journal of Ecological Science and Environmental Engineering. 2014. No. 1(2). pp. 7–42.
11. Tikhonova O.V. Rezultaty issledovaniy protsessa obrazovaniya pylegazovogo oblaka na karere otkrytogo aktsionernogo obshchestva «Promyshlennaya Gruppa Fosforit» (Results of investigations of powder-gas cloud formation on the open pit of JSC «Industrial Group Fosforit»). *Zapiski Gornogo instituta = Proceedings of the Mining Institute*. 2006. Vol. 167. pp. 113–116.
12. Kuznetsov V.S., Kovshov S.V. Opredelenie parametrov aerotekhnogennogo vliyaniya ploshchadnykh istochnikov na rabochee prostranstvo karerov pri primenenii razlichnykh sposobov pylepodavleniya (Definition of parameters of aerotechnogenic influence of site sources on pit working area using various dust-depressing methods). *Gornyy Informatsionno-Analiticheskiy*

Byulleten = Mining Informational-Analytical Bulletin. 2012. No. 10. pp. 132–139.
13. Steedman C. Dust, Manchester University Press. 2002. 146 p.
14. Bartknecht W. Dust explosion: course, prevention, protection. Springer Verlag. 1987. 679 p.
15. Metodicheskie osnovy ekologicheskoy otsenki stroitelnykh materialov (Methodical basis of ecological assessment of construction materials). *Ekologiya. Osnovy restavratsii* (Ecology. Basis of restoration). Available at: http://art-con.ru/node/2709. (in Russian)
16. *Otraslevaya metodika rascheta kolichestva otkhodyashchikh, ulovlennykh i vybrasyvaemykh v atmosferu vrednykh veshchestv predpriyatiyami po dobyche i pererabotke uglya* (Branch method of calculation of the amount of waste, caught and exhausted hazardous substances in atmosphere, carried out by coal extraction and processing enterprises). Perm : VNIIOSugol, 1989. (in Russian)
17. Sharma A., B.M. Marvaha. Alternative building materials analysis for different residential buildings considering embodied energy and material cost. International Journal of Ecology and Development. 2016. Vol. 31 (2). pp. 10–34.
18. Kovshov S.V., Kovshov V.P. Biogenic Fixation of Dusting Surfaces. Life Science Journal. 2014. Vol. 11(9). pp. 401–404.
19. Kupin A. N. *Razrabotka kompleksa sposobov i sredstv snizheniya vybrosov pyli v atmosferu ugolnykh razrezov: avtoreferat dissertatsii na soiskanie uchenoy stepeni doktora tekhnicheskikh nauk* (Development of a complex of methods and means of decreasing of dust emission in coal cut atmosphere: thesis of inauguration of Dissertation … of Doctor of Engineering Sciences). Chelyabinsk : NIIOGR, 1995. 48 p.
20. Ettu L. O, Ibearugbulem O. M, Anya U. C, Awodiji C. T. G., Njoku F. C. Strength of binary blended cement composites containing saw dust ash. International Journal of Engineering and Science (IJES). 2013. Vol. 2(4). pp. 51254–51258.
21. Korshunov G.I., Mazanik E.V., Erzin A.Kh., Kornev A.V. Effektivnost primeneniya poverkhnostno-aktivnykh veshchestv dlya borby s ugolnoy pylyu (Efficiency of application of surface-active substances for the pulverized coal struggle). *Gornyy Informatsionno-Analiticheskiy Byulleten. Otdelnyy vypusk No. 3. Promyshlennaya bezopasnost = Mining Informational-Analytical Bulletin. Special issue No. 3. Industrial safety*. 2014. pp. 55–61.