UDC 622.271.3.42

# New technical solutions for ventilation in deep quarries

**Sergey G. SHAKHRAI**[1], **Georgii S. KURCHIN**[1]✉, **Alexander G. SOROKIN**[2]
[1] *Siberian Federal University, Krasnoyarsk, Russia*
[2] *Krasnoyarsk Motor Transport College, Krasnoyarsk, Russia*

The paper discusses the issues of ventilating in deep quarries caused by the intensification of blasting operations at great depths, the increased distance of ore truck transportation to the daylight area, constant change in the geometrical parameters of the quarry, its microrelief and direction of mining, and increased isolation of the mined space from the environment. We provide a brief analysis of the current tools for forced airflow in deep quarries, which showed that the use of forced ventilation is often challenging since it leads to high energy consumption, high level of noise exceeding the permissible parameters, and high speeds of forced air flows may blow the dust off the quarry surfaces.

The article presents methods and tools developed at the Siberian Federal University for intensifying the natural airflow in deep quarries by changing the air density at the entrance and exit points of the pit, as well as heating the shady areas using mirrors and solar energy, which do not interfere with mining and blasting operations.

***Key words*:** deep quarry; ventilation; change in the density of the wind flow; humidification of the air; mirror system; solar power

***How to cite this article*:** Shakhrai S.G., Kurchin G.S., Sorokin A.G. New technical solutions for ventilation in deep quarries. Journal of Mining Institute. 2019. Vol. 240, p. 654-659. DOI: 10.31897/PMI.2019.6.654

**Introduction.** One of the peculiarities of mining the deep and ultra-deep open pits is the deterioration of working area environment caused by:

• reduction of the influence of wind and heat forces, ventilating the open pit;

• intensification of blasting operations due to increasing rock mass strength occurring at great depths;

• increased distance of ore truck transportation to the daylight area, which is one of the main sources of air pollution due to gases and dust;

• intensified gas desorption under the influence of pressure relief and rock failures caused by mining operations [16].

Meteorological conditions may disturb the air exchange in the quarry since the temperature difference, less than 1 °C per 100 m of depth, or the temperature inversion distribution that makes it difficult to lift the air masses from lower benches due to their large specific gravity.

The application of traditional methods of forced ventilation – aircraft and helicopter propellers, turbines, heating units – in deep and ultra-deep quarries is often troublesome due to high costs, large size of equipment, obstructions to mining operations, high energy and fuel consumption. The fuel burned in the units and the high speed of airflow blowing the dust off the benches can worsen the condition of the quarry air, and the need to place the ventilation units to a safe distance during blasting operations leads to increased operating costs. The fans require continuous maintenance since the power and performance of the exhaust and draft units directly depend on the inclination angle of the blades [17].

The article proposes new technical solutions for the intensification of natural airflow in the quarries using the heat of the sun rays and pit waters removed by the drainage system, as well as using advanced trenches in the mined rock mass.

**Formulation of the problem.** In the twentieth century, the open pit development method was used globally for mining 95 % of construction materials, about 70 % of ores, and 90 % of brown coal and 20 % of coal. As the development and depletion of shallow mineral reserves advances, the depth of their extraction increases. With deeper horizons, the degree of isolation of the mined space from the environment increases, and the air composition in the quarry worsens. The mining in deep

DOI: 10.31897/PMI.2019.6.654

and ultra-deep quarries with a depth of 500-600 m and more is accompanied by the stimulation of blasting operations due to higher strength of rocks, an increase in the distance of transportation of rock mass to the surface, worse conditions for natural airflow and an increase in the volume of the dead-air areas. As a result, when designing the mining operations, we should pay close attention to social problems – improving working conditions at the workplace [4, 6, 10].

The application of current forced ventilation units in deep and ultra-deep quarries [2, 5, 7, 11, 13] is often challenging since, during their operation, the noise level exceeds the permissible values. High speed of airflow may blow the dust off the benches, which worsens the atmosphere of the working area. Combustion of aviation fuel in engines, as well as coal dust in a turbine (if it is used to ventilate coal mines), carries the risk of formation and increase in the concentration of CO and $SO_2$, acrolein, and formaldehyde in the air. Deterioration of the atmosphere can also be observed when using thermal installations that form convective currents due to the combustion of diesel fuel. A common drawback of forced ventilation is the high fuel consumption and the noise level, the need to remove equipment to a safe distance during blasting operations, which is accompanied by increased operating costs and unplanned shutdown periods. Even a brief list of the shortcomings of current forced ventilation units for deep quarries justifies the continuous search for more effective and safe methods and tools for improving this process in the mining industry.

At the Siberian Federal University, we have developed methods and tools for intensifying the ventilation of deep and ultra-deep quarries by creating the density difference of the air entering and leaving the quarry space, as well as more efficient use of solar energy entering the earth's atmosphere.

The change in air density is provided by passing the wind flow through a water curtain formed by spraying cold or hot water, as it is shown in Figure 1*. In the warm season, the wind flow entering the quarry space passes the water curtain formed by spraying cold water on the leeward side of the quarry; the flow leaves the quarry through a water curtain formed by spraying hot water on the windward side of quarry (Fig.1, *a*).

The broad engineering assessment of this technical solution was performed using the following dependencies. When passing through a water curtain, the moisture content of air $d$ and the mass of vapor in moist air increase following the dependence

$$d = \frac{M_v}{M_d}, \tag{1}$$

where $M_v$ – the mass of water vapor in moist air; $M_d$ – dry mass of moist air.

In this case, the temperature and volume of the gas mixture decrease, and the barometric pressure of the air entering the quarry space increases according to Dalton's law

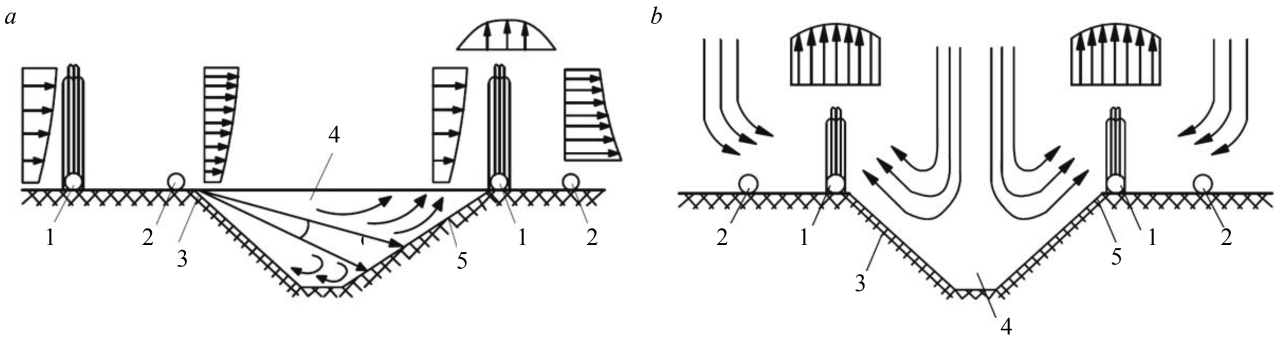


Fig.1. Diagrams of air flows passing through the water curtains in the warm season (*a*), in the cold season and during atmospheric inversions (*b*)
1 – hot water pipeline; 2 – cold water pipeline; 3 – leeward side of the quarry; 4 – quarry space; 5 – windward side of the quarry

* Shakhrai S.G., Godovnikova L.G., Edemskaya K.S. and others. Patent N 2584700. The method of quarry ventilation. Published 22.01.2016. Bull. N 4.

 DOI: 10.31897/PMI.2019.6.654

$$P_b = P_d + P_p, \tag{2}$$

where $P_d$ and $P_p$ – partial pressure of dry air and water vapor, respectively, determined by the Clapeyron equation

$$P_d = \frac{M_d R_d T}{V}, \tag{3}$$

$$P_p = \frac{M_v R_p T}{V}. \tag{4}$$

Besides the higher barometric pressure, as the air humidity increases, its density increases, which follows from the dependence

$$P_w = \frac{P_b(1+d)}{0.2871T(1+1.6078d)}. \tag{5}$$

When passing through the hot water curtain, the air temperature rises. In this case, according to equation (5), there is a decrease in air density.

The estimated water flow for cooling of 1000 m$^3$ of air, according to [12], is determined by the dependence

$$Q = \rho(x_2 - x_1)\cdot 1000, \tag{6}$$

where ρ – air density; $x_1$ and $x_2$ – absolute humidity values at the entrance and exit from the water curtain. For example, if the absolute humidity of the air passing through the water curtain with a temperature of 25 °C and a density of 1.18 kg/m$^3$ (relative – from 60 to 80 %) changes, the water consumption will be 2.71 l/h per 1000 m$^3$ of cooled air.

Thus, the increase in the cone angle of the free stream α by an average of 3-6° is provided by an increase in barometric pressure and air density at the entrance to the quarry space. The intensification of convective flows is achieved by increasing internal energy and decreasing air density at the exit from the quarry space. To reduce operational and energy costs in the warm season, it is advisable to use ~ 1/4 of the perimeter of the cold water supply pipeline on the leeward side of the quarry, and on the windward ~ 1/4 of the perimeter of the hot water supply pipeline.

In the cold season and during atmospheric inversions with a stable atmosphere, it is necessary to create convective motion in the quarry and ensure the exchange of air masses with the environment [10]. Prevention of cold air entering the quarry and the formation of convective flows is ensured by spraying hot water around the entire perimeter of the upper edge of the bench (Fig.1, *b*).

An additional advantage of water spraying is the wetting and suppression of dust particles from the quarry by air flows on the earth's surface, which is an absolute advantage in relation to using the dust-collecting fans and cyclones for cleaning mine air from solid particles [15]. Cooling by nozzle air-evaporation method, tested at the mines of the Krivoy Rog iron ore basin, made it possible to reduce the temperature of mine air by 3-8 °C at significantly lower costs compared to air cooling by refrigeration units [8, 9].

We should not discard the fact that the deposition of dust along the perimeter of the quarry lowers environmental damage, reducing the formation of wasteland, which following restoration and rehabilitation requires significant financial investments [3, 14].

To intensify convective flows in the quarry during summer period, it is also advisable to use solar energy, which is reflected by a one-piece (Fig.2)* or sectional (Fig.3)** flat mirror mounted on the upper edge of the northern bench of the quarry.

---

* Shakhrai S.G., Kosolapov A.I., Korostovenko V.V. and others. Patent for utility model N 139437. The device for quarry ventilation. Published 20.04.2014. Bull. N 11.

** Shakhrai S.G., Tarasenko A.D., Chuprov M.M. and others. Patent for utility model N 153978. The device for quarry ventilation. Published 10.08.2015. Bull. N 22.

The mirrors are mounted on the frame articulation platform 4. The vertical tilt of the one-piece mirror 2 towards the quarry space 5 and in the opposite direction, as well as the rotation of the reflective element in the horizontal plane, is provided by the pole 1 articulated on the platform 4, sectional mirror 3 and 5 and hinges 1 are mounted on the pole 2 on the platform 4. The vertical tilt of the mirrors and their rotation in the horizontal plane provides heating of the shady benches and pit bottom during daylight hours. The tilt of the mirrors in rainy weather in the direction opposite to the quarry space helps to wash the dust off the reflective element.

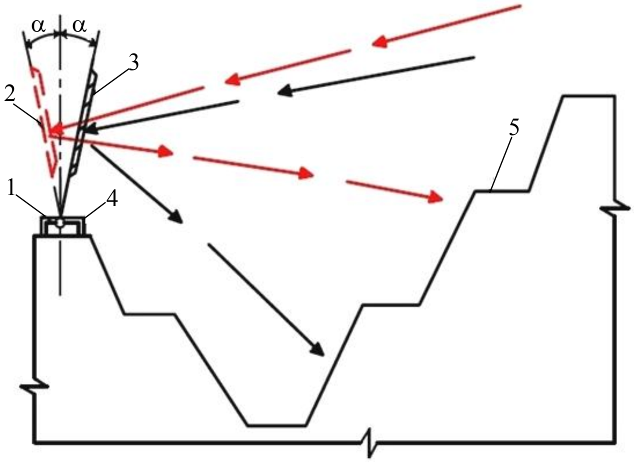

Fig.2. Warming of the quarry with a one-piece mirror
1 – hinge; 2 – pole; 3 – mirror; 4 – platform; 5 – quarry space

The sectional mirror provides a more intensive selective heating of problem areas of the quarry space and eliminates the weakening of convective flows when they contact the cold shady areas.

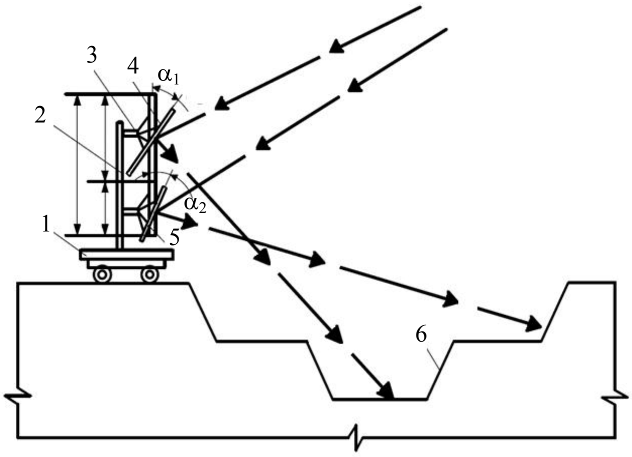

Fig.3. Warming of the quarry with a sectional mirror
1 – platform; 2 – pole for mirrors; 3 – hinge for vertical and horizontal movement; 4 – upper section of the mirror; 5 – lower section of the mirror; 6 – quarry space

Under the influence of sunlight falling on the north side of the quarry at an angle close to 90º, in the daytime, the bench surface can heat up to 50 °C and higher. Solar radiation reflected by flat mirrors with a reflectivity of 80 to 95 % and falling on the south side of the quarry at an angle close to 90°, can heat the bench surface to 30-40 °C or more. Thus, the convective flow speed at the southern side rises, which grows with increasing temperature of the slope [2]

$$U = 0.55k_1\sqrt{g\sin\beta(H-h)\left(\frac{t_s - t_a}{t_a + 0.01\Delta tH}\right)}, \quad (7)$$

where $k_1$ – coefficient taking into account the deceleration of the flow due to the influence of benches; $g$ – gravity acceleration; β – slope angle; $H$ – pit depth; $h$ – depth of the point from the surface at which the airflow speed is determined; $t_s$ and $t_a$ – accordingly, the temperature of the bench surface at the given point located at a depth of $h$, and the air temperature on the surface of the Earth.

The size of the mirrors depends on the depth and square area of the quarry. According to [1], with the deepening of mining operations, its total area grows, and the intensity of solar radiation per the surface unit decreases. For quarries of medium depth, mirrors with an area of 10 to 50 $m^2$ seem to be the most acceptable; for deep pits (up to 100 $m^2$), the area should equal the area covered by the low-temperature electric heating unit placed on the benches [1].

The solar energy reflected by the mirror will ensure the heating of the shady areas without interfering with mining operations (blasting and excavation). Convective flows that occur during heating of the quarry with solar energy, as they move from the bottom to the top, carry away harmful substances and dust from the benches and slopes of the quarry.

The intensification of natural airflow in deep pits with the help of a trench is carried out by directing air flows through the ventilation passage created on the leeward side of the pit and made

DOI: 10.31897/PMI.2019.6.654

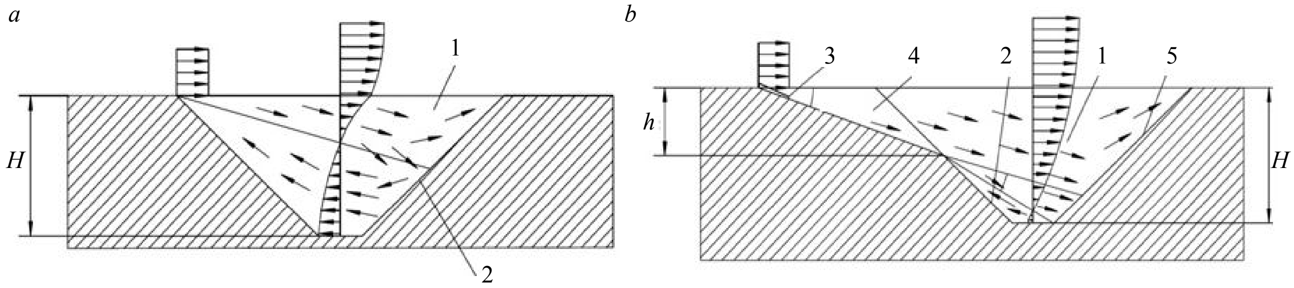


Fig.4. Scheme of natural air flow of the quarry: *a* – without ventilation passages; *b* – with ventilation passages
1 – quarry space; 2 – slope; 3 – windshield (confusor); 4 – ventilation passage; 5 – leeward slope

with an inclination of $\gamma$ = 16-20° to the daylight surface entering the pit space to the depth equal to ~ 0.5 of the total depth of the quarry*. The passage at the level of the daylight surface is equipped with a windshield. The placement of the ventilation passage on the leeward side ensures the intake of air flows and their direction to the recirculation zone of the quarry (Fig.4).

The efficiency of the suggested method of intensification of natural airflow was verified experimentally on the miniature model of the quarry (Fig.5). When designing the model, the authors kept in mind that the angle of slope should exceed the cone angle of the free stream (15° on average), ventilating the quarry. Moreover, the ratio of the size of the quarry at the daylight level in the direction of the wind flow movement to the depth is below six, which makes it difficult to ventilate the quarry [2]. As an indicator, we used smoke coming through the passage or from the upper edge of the bench with the help of an axial flow fan of low power, providing a wind flow speed of 2 to 5 m/s, comparable with the speed of natural wind flows on the daylight surface. During the experiment, it was revealed that the direction of the wind flow along the passage reduces the size of the recirculation area by 15-20 % of the total quarry area against 60-70 % when there is a natural wind flow (from the upper edge of the bench).

**Conclusions.** The proposed technical solutions have several advantages:

• lack of interference with mining and blasting operations;

• spraying cold and hot water intensifies natural airflow in the warm and cold seasons, as well as during atmospheric inversions, reduces the size of the dead-air area by 3-10 %, and provides the possibility of utilizing the quarry drainage water;

• intensification of ventilation with heat supplied to the Earth's surface by the Sun does not require energy carriers produced from non-renewable energy sources;

• it is advisable to intensify natural airflow with the help of wind-guiding passages when the ore body is mined towards the prevailing wind flows; when the mining advances this method will reduce the amount of mined rock mass by the amount equal to the volume of a previously dug ventilation passage;

• this research can be continued and involves creating a complex mathematical model based on the methods of computational fluid dynamics and experimental verification of the obtained results.

Fig.5. Model of the quarry with ventilation passage

* Shakhrai S.G., Sharova N.A. Patent N 2651666. The method of intensification of natural air exchange in deep quarries. Published 23.04.2018. Bull. N 12.

**REFERENCES**

1. Beresnevich P.V., Mikhailov V.A., Filatov S.S. Aerology of quarries. Moscow: Nedra, 1990, p. 280 (in Russian).

2. Bitkolov N.Z., Nikitin V.S. Ventialtion of quarries. Moscow: Gosgortekhizdat, 1963, p. 252 (in Russian).

3. Zairov Sh.Sh., Tursunova I.N. Increasing the efficiency of dust suppression and the efficiency of explosive energy during mass explosions in open pits. *Gornyi vestnik Uzbekistana*. 2015. N 4, p. 31-34 (in Russian).

4. Zorin A.V. Energy assessment of the intensification of natural air flow in quarries. *Gornyi zhurnal*. 2010. N 11, p. 85-87 (in Russian).

5. Konorev M.M., Nesterenko G.F., Pavlov A.I. Ventilation and dust and gas suppression in quarries. Ekaterinburg: Institut gornogo dela Ural'skogo otdeleniya RAN, 2010, p. 440 (in Russian).

6. Konorev M.M., Nesterenko G.F. Research and prospects for the creation of ventilation and dust and gas removal systems in deep quarries. *Gornyi zhurnal*. 2012. N 1, p. 93-96 (in Russian).

7. Kosarev N.P., Timukhin S.A., Popov Yu.V. Aerodynamics of ventilation processes and units in deep quarries. Ekaterinburg: Izd-vo Ural'skogo gosudarstvennogo gornogo universiteta, 2009, p. 155 (in Russian).

8. Lapshin A.A. Mine air cooling with mine water. *Gornyi zhurnal*. 2014. N 5, p. 104-107 (in Russian).

9. Lapshin A.A. Industrial tests of water-jet cooling of mine air in the conditions of the Rodina mine. Problemy okhrany truda v Ukraine: Sbornik nauchnykh trudov. Kiev: Natsional'nyi NII promyshlennoi bezopasnosti i okhrany truda, 2011. Iss. 20, p. 124-129 (in Russian).

10. Trubetskoi K.N., Krasnyanskii G.L., Khronin V.V., Kovalenko V.S. Quarry design. Moscow: Vysshaya shkola, 2009, p. 694 (in Russian).

11. Morin A.S., Butkin V.D., Kravtsov V.V., Nekhoroshev D.B. Development of methods and means for ventilating deep quarries. Moscow: MAKS Press, 2004, p. 135 (in Russian).

12. Calculation of the cooling system. URL: http://www.humy.ru/munters-fcx5.shtml (date of access 10.12.2018) (in Russian).

13. Ushakov K.Z., Mikhailov V.A. Aerology of quarries. Moscow: Nedra, 1985, p. 272 (in Russian).

14. Skousen J., Zipper C.E. Post-mining policies and practices in the Eastern USA coal region. *International Journal of Coal Science & Technology*. 2014. Vol. 1. Iss. 2, p. 135-151. DOI 10.1007/s40789-014-0021-6

15. Chen S., Wang H., Li Y., Cui H., Zhao J., Zhang X. Theoretical and numerical analysis of coal dust separated by centrifugal force for working and heading faces. *International Journal of Coal Science & Technology*. 2014. Vol. 1. Iss. 3, p. 338-345. DOI: 10.1007/s40789-014-0039-9

16. Wang J., Wu R., Zhang P. Characteristics and applications of gas desorption with excavation disturbances in coal mining. *International Journal of Coal Science & Technology*. 2015. Vol. 2. Iss. 1, p. 30-37. DOI 10.1007/s40789-015-0060-7

17. Zhang S. Experimental study on performance of contra-rotating axial flow fan. *International Journal of Coal Science & Technology*. 2015. Vol. 2. Iss. 3, p. 232-236. DOI 10.1007/s40789-015-0073-2

***Authors*: Sergey G. Shakhrai,** *Doctor of Engineering Sciences*, *Professor*, *shahrai56@mail.ru* (*Siberian Federal University*, *Krasnoyarsk, Russia*), **Georgii S. Kurchin,** *Candidate of Engineering Sciences*, *Associate Professor*, *kurchings@mail.ru* (*Siberian Federal University*, *Krasnoyarsk*, *Russia*), **Alexander G. Sorokin,** *Candidate of Engineering Sciences*, *Director*, *Sorokin.katt@mail.ru* (*Krasnoyarsk Motor Transport College*, *Krasnoyarsk*, *Russia*).

*The paper was received on 11 December*, *2018.*

*The paper was accepted for publication on 10 September*, *2019.*