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FEATURES OF FORMING MICROCLIMATIC CONDITIONS IN MINING EXCAVATIONS OF DEEP MINES*





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The article focuses on creation of thermal conditions in underground excavations under the current conditions of deeper level mining and the related difficulties of mine microclimate control. The authors analyze thermophysical processes running in mine air and rock mass, as well their influence on air flow parameters in underground excavations.

Key words: *deep-level mines, underground excavations, thermal conditions, heat transfer, heat liberation sources, microclimate, fill mass, modeling-and-calculus software.*

Mining, at actual stage of development, with the production output to be sustained and enhanced, requires fresh, deeper level reserves to be put on stream. The deeper level mining faces mine ventilation and thermophysics problems. The major issues to be handled are reduction of the increased temperature of rock masses and maintenance of the desired microclimate parameters in accord with the safety regulations PB-03-553-03, Article 115 (air temperature in developing entries, stopes and other operating excavations is not to exceed 26 °C).

It is particularly difficult to control and adjust microclimate conditions in deep-level mines, when natural temperature of rocks reaches +26 °C (generally, such temperature is typical of mining depths below 800–850 m).

Engineering solutions on thermal control arrangements require studying the deep-level mine microclimate mechanism.

The experimental studies carried out in Skalisty, Oktyabrsky and Taimyrsky Mines of Norilsk Nickel MMC, as well as the analysis of the published material on the matter [1–5] show the chief factors of the deep-level mine microclimate mechanism:

- hydrostatic compression of air in vertical and inclined workings;
- mine air-rock mass heat transfer;
- heat liberation from mining-generated sources.

Aimed at the study of effect exerted by each of the listed factors, the algorithms for thermodynamic processes in deep-level mine air and rock mass have been developed, considering particular issues mentioned below:

- hydrostatic heating/cooling of vertical air flow under force of gravity;
- two-layer structure of rock mass, enabling analysis of the air–support–rock mass system;
- influence of thermal expansion of mine air on the air thermodynamic parameters;
- effect of phase changes of mine air moisture (condensation/evaporation).

The mathematical formulation of the problem on the unstable interconnected heat transfer between mine air and rock mass is as follows. The differential equation of rock mass energy balance is:

$$dU_m dt = \lambda_m (\partial T_m \ \partial r) d\sigma, \quad (1)$$

where U_m — internal energy of a rock mass unit, J; T_m — heat flow in rock mass, W/m^2; $d\sigma$ — differential of heat transfer surface area, m^2; λ_m—thermal conduction of rocks.

The differential equation of mine air energy balance is:

$$dU_a \, dt = -a(T - T_a) d\sigma + mRTM\rho(\partial\rho/\partial T) dT dt + (\partial\rho/\partial P) dP dt, \quad (2)$$

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where U_a—internal energy of mine air, J; a — coefficient of heat transfer at the mine air–rock mass interface, W/m^2; T — wall rock temperature, °C; T_a — air temperature, °C; M — molar weight of air, kg/mole; R — absolute gas constant; ρ — air density, kg/m^3.

The differential equations were added with the related initial and boundary conditions. At the external boundary of rock mass, defined by the thermal influence radius, natural temperature of the rock mass (considering geothermal gradient) is assigned.

The developed mathematical models were verified by means of comparing the measured and calculated temperatures of air in air intake and return shafts at deep levels in Skalisty and Oktyabrsky Mines (Fig. 1 and 2).

The calculated relationships backed up by the experimental measurements demonstrate linearity of the air temperature–shaft depth function, due to the rapid formation of a heat-balancing "jacket" and weakening of specific influence of heat transfer on the air temperature.

At the same time, fresh air supply and distribution in underground excavations result in enlargement of the heat transfer surface and reduction of air velocity in developing entries and temporary workings, which enhances effect of the heat–mass–exchange processes on the air temperature in deep-level mines [2, 3, 6].

In addition to the discussed factors of the hydrostatic heat of mine air and the heat–mass–exchange processes, the local microclimate parameters are affected by heat liberation from mining-generated sources—mining machinery engines and fill masses.

The experimental tests of influence exerted by heat of load–haul–dumpers were carried out in transport ramps on undercutting horizons in Mines Nos. 2 and 3 and in Taimyrsky Mine of Norilsk Nickel MMC. The experimental and calculated curves of air heat, engine-generated heat and air flow are shown in Fig. 3.

Apparently, operation of mining machines with gas-engines results in appreciable rise of air temperature and makes worse the uncomfortable working conditions.

A fill mass is to be assumed the heat source like the rock mass. In other words, warming of air by the fill mass is the same process as the rock mass–mine air heat transfer.

In [7] the expression for quantitative estimate of the fill mass cooling time t was derived in the form of:

$$t = bS\lambda_{backfill} C_{backfill}, \quad (3)$$

where b — width of a mined-out void to be filled, m; S — area of inner surface of the mined-out void to be filled, m^2; $\lambda_{backfill}$ — thermal conduction of backfill; $C_{backfill}$ — heat capacity of fill mass, J/(°C·kg).

The calculated times made up to 1 year. When calculating thermal conditions in mines, the natural temperature of rocks (walls) is to be increased by the value of excess temperature due to heat liberation during hardening of binder, found from the formula [7]:

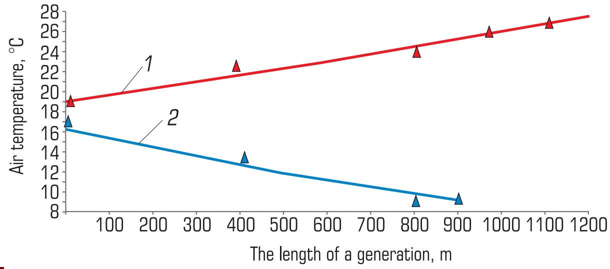

Fig. 1. Air temperature: calculated (solid lines) and measured (symbols) values in shafts VSS-1 (1) and VS-9 (2) in Skalisty Mine

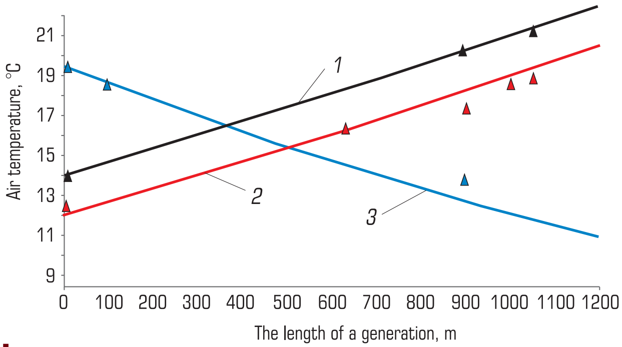

Fig. 2. Air temperature: calculated (solid lines) and measured (symbols) values in shafts KS-1 (1), KS-2 (2) and KS-4 (3) in Oktyabrsky Mine

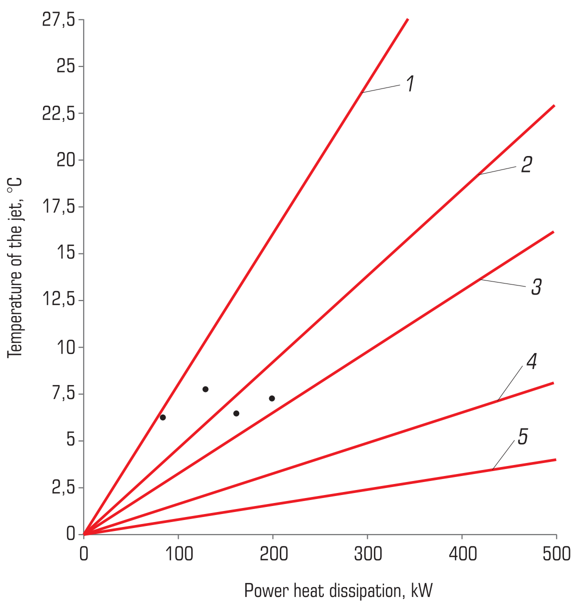

Fig. 3. Calculated curves of air heating and mining machine heat output at different air flow rates, m³/s:
1 — 10; *2* — 17,5; *3* — 25; *4* — 50; *5* — 100
(• — measured values for load-haul-dumper TORO 400D)

$$\Delta T = L\psi 100 C_{backfill}, \quad (4)$$

where L — specific heat of the binder hardening, kg/J; ψ — mass fraction of the binder in the fill mass, %.

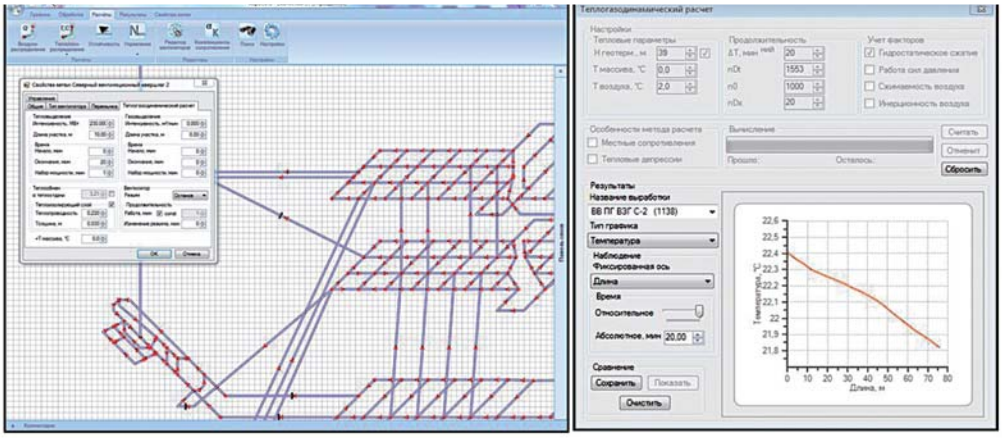

Fig. 4. Windows of AeroSet software to plot topological layout of ventilation networks and calculate heat-and-gas dynamic parameters of ventilation network elements

The developed mathematical models and the obtained research findings were included in the heat-and-gas dynamic calculation module of the AeroSet software featuring friendly graphical interface for plotting symbolic layout of the mine ventilation and heating model, finding parameters of heat sources, or for thermophysical and aerodynamic calculations. Figure 4 shows the heat-and-gas dynamic calculation windows for setting input calculation parameters, general thermophysical characteristics of the model, and for the calculation results.

The heat-and-gas dynamic calculation module of the AeroSet software allows calculating the conjugate problem on distribution of aerodynamic and thermodynamic parameters of mine air in the mine ventilation network, including local sources of heat transfer, and handling two key tasks of the mine microclimate control:

- calculation of thermal conditions in deep-level mines, considering specific features of the mines; and
- simulation modeling of efficiency of thermal control under mine-technical and thermotechnical arrangements.

The outcomes of the theoretical and experimental research into the microclimate parameters and factors of influence on the thermal conditions in different excavations of deep-level mines in the Norilsk industrial area are generalized in the table.

Deep-level mine openings and key factors of thermal conditions

Factors	Air intake and return shafts	Main airways	Developing entries	Dead ends
Initial air temperature and humidity	+	+	+	+
Moisture exchange	+	+	+	+
Hydrostatic compression	+	–	–	–
Rock mass heat transfer	–	–	+	+
Heat liberation from mining-generated sources	–	–	+	+

Thus, by the key factors of thermal environment generation in deep-level mines, there are four groups of underground openings (their aerodynamic and thermophysical features are within brackets):

- air intake and return shafts (vertical arrangement, low air velocity, small air–rock mass contact area);
- main airways (vertical arrangement, high air velocity, small air–rock mass contact area);
- developing entries on stoping and ventilation–backfilling horizons with end-to-end ventilation (low air velocity due to general air flow separation, large air–rock mass contact area, many mining-generated sources of heat liberation);
- dead-ends (low air velocity, large air–rock mass contact area, mining-generated sources of heat liberation).

These outcomes are supported by the in situ observation on deep-level horizons in mines of Norilsk Nickel MMC (mining depth 1000–1300 m). In particular, the settled distribution of temperatures in shafts is governed by initial heat and humidity parameters of mine air, hydrostatic pressure and moisture exchange—the positive temperature varies linearly from 4–7 to 17–18 °C. In main airways, no high gradient of the temperature is observed in the air flow—within 1–2 °C per each 1000 m. In haulage and ventilation drifts and ramps, the temperature rapidly grows up to 26–28 °C and remains at that level. In dead-ends, owing to heat released from rocks, fill mass and mining machinery, the air temperature can reach 32–34 °C, which urgently requires appropriate temperature reduction measures to be undertaken.

The obtained results are the basis for the development of efficient integrated engineering solutions, including capital and operating costs, toward comfortable and safe working environment in deep-level mine excavations.

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RESEARCH OF SALT ROCKS GAS CONTENT OF III POTASH LAYER IN THE KRASNOSLOBODSKY MINE FIELD

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The article reports the data of experimental studies into gas content of Potash Salt Horizon 3 put on production in Krasnoslobodsky Mine belonging in Mine Group-2 of Belaruskali OJSC. The gas content of Potash Salt Horizon 3 is quantitatively estimated in terms of free and occluded gas, and chemical composition of free gas is analyzed.

Key words: *potash horizon, sylvinite layer, clay–carnallite unit, gas content of rocks, free gas, chemical composition.*

The development strategy of Belaruskali OJSC over the period to 2020 stipulates the ore stock sustaining and accretion with intent to increase the rated output of potash fertilizers up to 12.5 Mt per year. Within the framework of the strategy and toward the sustained capacity of Mine Group-2, Krasnoslobodsky Mine was commissioned in December 2012, at annual design capacity of 6 Mt and the term of life no less than 35 years.

The minefield of Krasnoslobodsky Mine is situated on the northwest of the Starobinsky potash salt deposit (Fig. 1). It adjoins the Mine Group-2 minefield on the east and is bounded by Potash Salt Horizon 3 on the west.

The structure and tectonics of the Krasnoslobodsky minefield area of the Starobinsky deposit feature two northeastern strike faults that split the potash deposit into extended blocks step-plunging west–eastwards.

Potash Salt Horizon 3 (PSH 3) is the main pay horizon of Krasnoslobodsky Mine. The horizon is 16 to 18 m thick in the center of the minefield and to 1 m thick at the edges. The occurrence depth of the horizon varies from 477 to 848 m below surface. PSH 3 consists of three units: the top sylvinite unit is classified non-commercial reserves due to high insoluble residue content; mid clay–carnallite unit is composed of alternating rock salt, clay and carnallite; and bottom sylvinite unit is six sylvinite layers with rock salt bands.