Thermal control in the ore mines of cryolithic zone

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Abstract
Use of a new type of mining systems of regulation of thermal conditions in ore mines of the North is considered. The peculiarity of ore mines is that the ore body at the same time may underlie in frozen and thawed rock. Mining operations are carried out both on the cryolithic zone horizons, and on the thawed horizons. It is suggested to use during transition of mining operations to the thawed horizons some of mine workings of a cryolithic zone as heat-exchanging. The technique of the choice of optimum amount of air, which is necessary to be supplied through heat-exchanging workings for achievement of the maximum economic effect is developed.
Key words: CONSTRUCTIONAL DESIGN, ORE MINE, CRYOLITHIC ZONE, THERMAL CONDITIONS, VENTILATION

General disadvantage of ordinary mining systems of regulation of thermal mode is that air supply in mine or ore mine should be fulfilled through major openings, where temperature fluctuations are almost identical to temperature fluctuations of fresh air that leads to thaw of rocks surrounding mine workings during the summer period and to freezing in winter [1,2]. These processes have a negative impact on stability of rocks around the exposed mine working, reduce safety level at their operation, cause the necessity of periodic additional fastening of workings [3,4]. Existing mining systems, cannot be definitely used when conducting mining operations on the thawed horizons to what in the next years will proceed the majority of mountain enterprises of the North [5]. In this regard we have developed the new system of regulation of thermal conditions of mines and ore mines of the North providing decrease in costs for air heating and preservation of frozen condition of rock surrounding a load-lifting bore.

The key point of new system is that the amount of air supplied into the ore mine is increased and fed through the downcast mine working, which is specially passed to the depth of thawed rocks. At that, some amount of air is supplied through air shaft, and the rest is fed to the mouth of downcast mine working along the load-lifting bore and heat-exchanging mine workings of the exhausted horizons of ore mine passed in frozen rock. Temperature of rocks around heat-exchanging mine workings has to be higher, or equal to temperature of air heating supplied into the ore mine during winter period. At the same time the additional amount of air fed into ore mine and given out through a load-lifting bore and mine workings of exhausted horizons is defined from the following inequality:

$$\frac{61{,}7\cdot 10^{-3}\cdot Z(S\gamma)^{3}c_{\mathrm{p}}(t_{-«}-t_{.})}{\alpha\cdot U\cdot C_{э}\cdot l}-\sum_{i=1}^{n}G_{i}\geq G\geq-\frac{1}{T_{-\mathrm{p}}}\left(Gt\,\frac{c}{-_{\mathrm{p}}}+\sum_{i=1}^{n}Gt_{i}\right)\text{, kg/s,} \tag{1}$$

where Z – is the cost of heat energy, rub/Gcal;

S,U– are midsections and perimeter of mine workings of exhausted horizons along which there supplied additional amount of air, m^2, m; γ –air relative density: kg/m^3; c_p – air specific heat, kJ /kg· K; l – the total length of mine workings of exhausted horizons along which there given out additional amount of air and coefficient of their aerodynamic resistance, m, kgs /s^{2}m^4; C_e – the cost of electrical energy, rub/kW· h; t_h – temperature of heating of the air fed to the ore mine, °C; t_{sm} – air plenum temperature from a load-lifting bore defined from expression:

$$t_{\mathrm{sm}}=\frac{GT_{-\mathrm{p}}+Gt_{\mathrm{h}}-/-_{\mathrm{p}}+\sum_{i=1}^{n}G_{i}t_{i}}{\sum_{i=1}^{n}G_{i}+G}\text{, °C,} \tag{2}$$

where G – is the additional amount of air fed to the mine or ore mine in a unit of time, kg/s; G_t – amount of transported mineral (rock) along the load-lifting bore in a unit of time, kg/s; t_t – temperature of the transported mineral (rock), °C; G_i – the number of air leaks in a load-lifting bore from the *i th* mine working, kg/s; t_i – temperature of the air fed to a bore as a result of leaks from *i th* mine working, °C; n – total quantity of mine workings interfacing with a load-lifting bore; T_{av} – the average temperature of frozen rocks surrounding mine workings of the exhausted horizons on which air moves, is determined by a formula:

$$T_{av}=\left(\sum_{j=1}^{k}T_{j}\right)\Big/K \tag{3}$$

where T_j – rock temperature on the *j-th* horizon of the mine or ore mine, °C ; K – the number of horizons, where heat-exchanging workings are located.

Limits of change of additional amount of the air supplied to the mine are defined as follows. The lower limit is caused by the necessity of creation of negative air temperature for a load-lifting bore. It is possible in that case when the amount of heat introduced into a bore with traffic flow Q_t and amount of heat introduced with the air fed to the bore as a result of leaks from workings – Q_i will be compensated by air cold arriving from workings of the exhausted horizons passed in frozen rock – Q. Considering that length of workings is chosen to heat (cool) the air fed up to the temperature of surrounding rock, it is possible to write down the following balance expression:

$Q_i + Q_t \leq Q$, or

$$\sum_{i=1}^{n}G_{i}c_{pi}t_{i}+Gc\,t\leq-Gc_{\mathrm{p}}T_{-\mathrm{av}} \tag{4}$$

If mine working, on which the additional amount of air is fed, is on the same horizon with rock temperature, equal to T, then $T_{av} = T$. If it is located on several ones, then dependence (3) is used. Considering that air specific heat value varies only slightly from the temperature, and in the considered conditions it is approximately a constant value, it is possible to write down the following condition for definition of additional amount of the air fed to the ore mine:

$$G\geq-\left(\sum_{i=1}^{n}G_{i}t_{i}+Gc\,t\,/-_{\mathrm{p}}\right)\Big/T_{\mathrm{av}}. \tag{5}$$

The choice of horizon with one or another temperature is caused, first of all, by the necessity to create the negative temperature of air mix at the output from load-lifting bore. But, to achieve cost cutting for air heating during the winter period, the horizons should be chosen so that temperature of rocks surrounding them was equal or higher than air heating temperatures coming to the ore mine during the winter period. These requirements do not contradict each other as the choice of the horizon with higher temperature of rocks (within negative values) can be compensated by increase in a consumption of air. However, increase rate has an upper limit which is defined on the base of economic reasons. It is reasonable to supply additional amount of air to mine or ore mine only in that case when economic effect due to decrease in costs for heating – $З_1$, will be equal or higher, than costs for air supply on an additio- nal chain of heat-exchanging workings of the exhausted horizons – $З$. Capasity spent at the same time by the main fan will be equal to:

$$N=\frac{\alpha\cdot U\cdot l\cdot\left(G+\sum_{i=1}^{n}G_i\right)^3}{102\cdot\eta\cdot\gamma^3 S^3}\text{, kW,} \qquad (6)$$

where η – total coefficient of efficiency of the fan, which may be conservative accepted as 0.7

Cash expenditure for use of this power of the fan can be found from expression:

$$З=C_e\cdot N\text{, rub/hour} \qquad (7)$$

The amount of heat, which will be saved as a result of air mix supply from a load-lifting bore to the mouth of air supply mine working (during the winter period – through a colorific installation) can be counted according to the following formula:

$$Q_1=\left(\sum_{i=1}^{n}G_i+G\right)c_p\left(t_{sm}-t_h\right)\text{, kJ/s} \qquad (8)$$

Economic effect from air mix supply with a temperature higher than temperature of air heating fed to mine or ore mine, to the mouth of the air supply working through colorific installation will be equal to (taking into account conversion coefficient from kcal in kV· hour, equal 864):

$$З=864\cdot Q_1\cdot Z\cdot 10^{-6}\text{, rub/hour} \qquad (9)$$

The cost of heat energy Z is accepted by us in rub/Gcal as it is standard, and all cost parameters on heat energy in normative documents are given in such units of measure. To fulfill the set goal, $З_l \geq З$ inequality should be fulfilled, or after simple transformations we will obtain the following:

$$G\leq\left[\frac{61{,}7\cdot10^{-3}Z\cdot(S\gamma)^3\cdot c_p\left(t_{\_\text{«}}-t_{\bullet}\right)}{\alpha\cdot U\cdot l\cdot C_{э}}\right]^{0,5}-\sum_{i=1}^{n}G_i\text{, kg/s} \qquad (10)$$

Temperature t_{sm} used in calculations may be set as equal to the melting temperature of ice T_m once in this case the frozen condition of rocks remains and at the same time the maximum effect at heating of the air fed to the ore mine is reached. Generally, temperature t_{sm} is defined from the balance expression:

$$\left(\sum_{i=1}^{n}G_i+G\right)c_p\cdot t_{sm}=\sum_{i=1}^{n}G_i t_i c_{pi}+Gct+GT_{av}c_p, \qquad (11)$$

Where we may find:

$$t_{sm}=\frac{GT_{av}+Gt\,c\,/\,-_{p}+\sum_{i=1}^{n}G_i t_i}{\sum_{i=1}^{n}G_i+G}\text{, °C,} \qquad (12)$$

Let us note once again that it is reasonable to set t_{sm} on the basis of a condition of preservation of frozen state of rocks around load-lifting bore as it is the main requirement. However, at the same time, the value of this temperature can be calculated according to the formula (12) which is convenient for using to evaluate the correctness of the choice of the horizons on which heat-exchanging workings are located, i.e. the correctness of the choice of t_{sm} parameter. If calculation according to the formula (12) shows lower value, than value of temperature of the air fed to the ore mine, then it is necessary to choose lower horizons with higher temperature of rocks (within negative values of temperature). The most general algorithm of calculation when t_{sm} is not set under the condition $t_{sm} = T_m$ is the following.

1. Let us determine by the formula (5) the lower limit of change of parameter G, under the condition $T_{av} \geq t_h$.

2. Let us determine the value of t_{sm} parameter with the help of the formula (12).

3. Let us check the condition $t_{sm} > t_h$ and, if the condition is satisfied, we determine upper limit of change of parameters G according to the formula (10). And, if the condition is not satisfied, we choose heat-exchanging workings with more high temperature of surrounding rocks, and repeat all procedure of calculation.

There possible also another variant, when the amount of heat introduced into bore due to air leaks from the thawed horizons is such that it will be impossible, even at the lowest T_{av}, to provide the air temperature at the exit of the bore below, or equal to the value T_m. In this case it is necessary to reduce total quantity of leaks, by sealing of ventilating constructions on the thawed horizons. It should be mentioned that this case may be referred rather to theoretical ones. The analysis of amount of air leaks on interfaces of mine workings of the working horizons with load-lifting bores, provided on mines and ore mines of the North, shows that they are several times lower than the ones, which could lead to the considered limit case. The main differences of suggested mining system of regulation of thermal mode consist in the following.

1. Ventilation working is carried out not to the working horizons of ore mine, but to a depth of thawed rocks.

2. Supply of air return is carried out separately: through load-lifting and ventilating bores.

3. Working of the exhausted horizons, through which the part of ventilating stream is fed in a load-lifting bore, is chosen on the base of condition $T_{av} > t_h$.

4. Additional amount of air moves to the ore mine (additional in relation to the basic, which is calculated by the known rules – on gas, dust, etc.).

5. The air proceeding from load-lifting bore and workings of the exhausted horizons moves to the mouth of ventilation working wherefrom it moves to ore mine again.

To define the most cost-efficient additional amount of air fed to ore mine, let us write down the following expression, representing a difference of costs for heating and air supply to ore mine:

$$З_0 = N \cdot C_e - 864 \cdot Q \cdot Z \cdot 10^{-6}, \text{ rub/hour} \quad (13)$$

Investigating this function on a maximum, i.e. having solved the equation:

$$\partial З_0 \Big/ \partial\left(G + \sum_{i=1}^{n} G_i\right) = 0. \quad (14)$$

Taking into account the expressions (6) and (8) we will obtain:

$$G_{opt} = -\sum_{i=1}^{n} G_i + \left[\frac{61{,}7 \cdot 10^{-3} \cdot c_p \left(t_{\_«} - t_{.}\right) Z (S\gamma)^3}{3{,}0\alpha \cdot U \cdot l \cdot C_э}\right]^{0{,}5}, \text{ kg/s.} \quad (15)$$

Comparing formulas (15) and (10), one may see that the optimum additional amount of air is connected with an upper admissible limit by the ratio:

The developed technique of the choice of optimum amount of the air fed to heat-exchanging mine workings supplements previous researches on the choice of optimum modes of airing of mine workings used in mining systems of regulation of the thermal mode of mines and ore mines [5,6,7,8,9,10]. The technique allows to define efficiency of use of mining systems of regulation of thermal mode in the ore mine when conducting mining operations on the thawed horizons. Fulfilled evaluation calculations for the suggested technique have shown that this system of regulation of the thermal mode in ore mines of the North is both energetically and cost-efficient.

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