Thermal control mining system design

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Abstract
We analysed the practical experience and existing theoretical foundation for mines and pits thermal control mining systems design. These systems use perspective views for cryolithic zone mining companies, where the problem of thermal condition specified parameters providing in mine openings is of the most relevance, were evaluated predominantly. We considered ordinary mining systems as well as regenerative and recuperative heating systems, which allow using of return air energy potential. It was drawn the conclusion of practical large-scale implementation of mine air conditioning of thermal control mining systems reasonability.
Key words: MINE OPENING, DESIGN, HEAT TECHNOLOGY, NORTHERN REGIONS, THERMAL CONDITION, ENERGY SAVING, CONTROL, CRYOLITHIC ZONE

The integrated development of mineral deposits includes the secondary use of mine openings for purposes of national economy including the openings, which are not connected with mining production [1,2,3]. However, the number of secondary used openings in the Russian Federation is small, particularly in mines and pits of the North. At the same time, the special underground storages, cold-storage plants, shelters are designed and built. The use of worn mine openings is quite acceptable for them, especially since the mines and pits of the North are located under unique climatic and permafrost conditions, which allow ensuring of openings safety for a long period of time without significant economic costs.

The analysis showed that the main reason of openings secondary use low coefficient is the absence of mining companies interest in preservation of definite volume of openings, which henceforth can be used for purposes not connected with mining production. From our point of view, the successful implementation of deposits integrated development including the mine opening secondary use may be carried out if the worn mine openings of mines and pits higher levels are included into general technological scheme of mineral production. In this case, the openings will be automatically kept in working order, and as mining operations are developed, the part of them may be used for national economy needs. It will also provide some quantity of mine openings optimal utilization as protective constructions in emergency conditions [1].

This suggestion implementation optimum variant is the use of thermal control mining systems in mines and pits; on the one hand, they allow ensuring of energy resources saving for providing of normal climatic conditions on the workplaces and on the other hand, they allow safety ensuring of worn mine openings, which will be included into the general-shaft ventilation system. It should be noted that countrywide energy resources saving is as important as mine openings secondary use. According to International Institute of Energy Conservation (IIEC) data, Russia is inferior by GDP energy intensity to advanced industrial countries of the North by 3-3.6 times, and for example, to Japan by 5 and more times. Energy consumption per unit of industrial product is 2.5-3 times higher in Russia than in the industrialized countries. Calculations of Russian experts show that Even considering the climatic factors and the length of our roads, the unit of Russian industrial products consumes by 1.7 times more energy than, for example, in Canada. Experts note that energy capacity of already energy-consuming Russian economy has been increased by 30% regardless the decline in production volumes, which lasted until quite recently.

The energy conservation problem became one of the high-priority tasks for mines and pits of the North. It is caused by not only high energy cost but also by lack of generating capacities of production. It should be expected the significant increase of costs contribution associated with the microclimate specified parameters establishment to operating costs of mining companies as well as underground facilities, which are not connected with mining production, under discernible trend of cost increase of heat energy, which is already 3-7 times higher on the North East than national average.

Considering the foregoing, we can conclude that the supposed idea of integrated mine openings use by including them in thermal control mining systems is relevant because it allows solving two problems at the same time. Nevertheless, mining systems have not gained widespread in our country. Currently, on the North-East there operates only one coal mine, where thermal control is fulfilled with the help of special heat-retaining openings. There is also average capacity mine in the area of Norilsk, where the heat exchanging chambers for air heating in winter are also used.

The mining systems gained wider use in northern China, where they are used in eight mines with air flow rate up to100 m^3/s and provide a substantial annual savings of energy and fuel. [4]

By Yu.D. Dyadkin classification [5], the control systems, which use the air flow geothermal heat, are referred to “non-energy” systems since their main costs are associated with openings resistance to air-flow overcoming. The air heating up and cooling take place due to natural (rocks and atmosphere gas energy potential) and industrial (return air energy potential) energy sources. By methods of air flow feeding into the mine openings, the considered systems may be divided into three classes: ordinary systems, recuperative systems and regenerative systems [6, 7]. All of these systems may be once-through as well as countercurrent flow ones. These three systems are based on the network of heat-exchanging openings, which may be connected successively, in parallel or by the combined scheme. The distinction consists in that the return air energy potential is additionally used in second and third class systems. At that, in recuperative systems, the heat exchange of return and intake air goes on through the interface surface (in general case, it can be rock massif separating two parallel openings). But in regenerative systems, the rock massif around the single opening serves as intermediate energy storage device, which accumulates energy when return air feeding and gives up energy when intake air feeding heating the air to predetermined values. It is obvious that recuperative systems can operate in regenerative mode [6, 7].

For air flow parameters thermal calculations in mining systems, it is impossible to use methods being used in heat technology for such systems calculation [9, 10, 11, 12]. The fundamental difference is that in heat technology, recuperative and regenerative systems are usually modeled as lumped parameters systems while mining systems of this class are referred to the distributed parameters systems, which characteristics are variable by the coordinates and time. Hence, maintaining the general modeling ideology accepted in heat technology and considering the mine openings heat exchange features, the programs complex of optimal mining systems parameters selection of these three classes has been developed. It includes numerical methods for thermal conditions predicting, computing experiment optimum planning methods and several variables functions optimum search. For engineering calculations, the regressional dependences were suggested; they allow the use efficiency operative evaluating (without resorting to numerical modeling) of mining systems of various classes in specific conditions [2,7,8,13].

The total costs objective function was minimized for selection of mining systems optimal parameters. This function includes the costs for openings construction and support (reconstruction in the case of secondary use), the costs for ventilation and the costs for conditioning. For minimizing of obtained objective function of various variables, the Hooke-Jeeves Method [14], which does not require the derived functions knowing, was used, which is very convenient in considered case because the air temperature is not determined directly, but it is found out from corresponding differential equation system numerical solutions. For specific operating conditions of ordinary mining system, the calculation results allow determining of such parameters as optimal cross section and openings length, the optimal number of parallel openings and their air flow, annual economic effect from the system use and the feasibility of special heat storage openings construction.

When mine openings transferring to the deep levels and using of reservoir management program with goaf stowing in the mines of the North, the energy potential of the return air is high enough and may be considered as stable secondary energy source. The calculations for deep diamond mine of the North under construction show that the potential return air in average will be $1.0*10^3$kJ/s. Energy input for initial potential development of intake air in average will be 2.5*103kJ/s. It is evident that the use of even half of the secondary source generating capacity will allow reducing of initial energy input for ensuring of the air flow predetermined potential by 20%. The effective means of return air energy use are recuperative and regenerative mining thermal control systems.

The mine openings thermal conditions predicting methods, which are used in mountain thermophysics, do not allow parameters calculating of such systems because they are based on averaging of number of determining parameters, e.g. the heat flow along the length of the opening, which in some cases may cause not only quantitative but also qualitative incorrect results [15]. The following methodological approach was used by us for thermal processes modeling in recuperative and regenerative systems. The general differential equations system describing the heat exchange process in system (stage of model construction), which was solved by numerical technique, was set in dimensionless form. Then by means of fractional factorial experiment, the plan of the model statistical tests is worked out for inherent change level of the main dimensionless complexes and simplexes. The linear model adequacy and regression significance were checked with Fisher analysis and test. For specific cases (marginal and average), the numerical results were compared with the results obtained from regression dependences. The comparative analysis results showed the acceptability of this approach for engineering purposes. The recuperative systems operating in regenerative mode were modeled in the same manner. The systems cost-effectiveness analysis was carried out using the total costs objective function. For specific cases, the effective length, openings cross section, their air flow rate, and also, for regenerative systems, openings aeration cycles duration (control parameter) were determined. It is established that system energy efficiency increases almost threefold when openings aeration cycle time reducing in the regenerative system (the total time of single opening aeration by intake (cold) and return (warm) air is from 216 to 48 hours). For example, the system consisting of two 800-meters-long openings at the return air temperature 150°C increases the outside air temperature by 3-6^0C in winter at a flow rate 100m^3/s with heat-up period duration of 4.5 days and by 10-16^0C with decreasing of the heat-up period up to 1 day. Since the aeration cycle is largely determined by technological possibilities, the air flow fed into the opening through the system can serve as control parameter in those cases where the cycle value is given. As a result of numerical calculations data processing, we obtained the expression for determining of the optimum (in terms of achieving maximum economic effect) flow rate of fresh air, which is reasonably to flow through regenerative system. For example, for deep mines, this value varies from 70 to 120 m^3/s decreasing with aeration cycle time increasing.

The calculations of energy and economic efficiency were conducted for reasonability evaluation of recuperative systems use of various types: "pipe in pipe" and with "separating wall". These calculations showed that the systems total energy efficiency is almost the same [2, 7]. At that, the “warm” circuit energy efficiency characterizing the energy transfer from return to intake air is almost 1.6 times lower in the first type systems than in the second type ones. Moreover, from the economical point of view, the “warm” circuit in opening causes the additional costs, i.e. yields a loss while in systems of the second type, it yields a profit, which is on average 25% more than the loss of the first type systems. This determines the overall systems economic efficiency, which is 1.7 times higher in heat exchangers with "separating wall" than in heat exchanger of "pipe in pipe" type. Thus, from two types of recuperative systems for mine air heating up, the mining systems using the heat exchangers with "separating wall" are more effective and their use for thermal control, in particular of deep diamond mines, is economically feasible.

Conducted researches lead to the following conclusions.

The use of mining control systems allows the integrated use of underground space by maintaining of worn mine openings sufficient amount in working condition for the purposes of both related and unrelated to mining production.
Mining systems are effective means of thermal conditions regulation in the mines and pits of the North and can significantly reduce the energy consumption for mine air conditioning if the correct design of their parameters.

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