PREDICTION OF HEAT RESOURCES BASED ON AIR-FLOW TEMPERATURE FOR DEEP MINING

by

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Original scientific paper
https://doi.org/10.2298/TSCI2502173J

The strata temperature has over 40 °C in the depth over 800 m of metal mine, it seriously affects the efficiency of excavation. In this paper, heat sources in deep space are systematically analyzed, and the heat calculation model are achieved and its release rules evaluated. According to field monitoring, the thermal influencing factors of shaft, horizontal gallery and excavation surface are investigated. Through numerical-analysis, the "assumption-correction" iterative trial algorithm is studied to calculate air-flow temperature, a set of prediction index is established, which can predict air-flow temperature and judge heat level face with temperature threshold. By comparing field monitoring results with the model prediction data, it, the method shows well reliability for evaluated thermal environment in deep resources mining.

Key words: *deep mining, heat resources, heat exchange, prediction model*

Introduction

The temperature in mines increases with mining depth. However, the temperature at the working face of deep strata often exceeds the human body surface temperature, which seriously affects both worker health and underground construction efficiency, becoming one of the significant hazards in deep mining [1-3]. Authors [4-6] analyzed the heat sources in deep strata, obtained the non-linear heat transfer coefficient related to temperature and depth, and deduced both approximate and accurate methods for heat conduction inversion. Authors [7-9] analyzed the dynamic heat transfer process between air-flow and surrounding rock. Bascompta *et al*. [10] proposed a multi-node approach to forecast the underground temperature in a ventilation circuit, incorporating seven interacting variables. At present, several mathematical models have been formed in the field of mine ventilation, including 1-D heat transfer model, 1-D network flow model and 3-D CFD models focusing on ventilation [11-13]. Authors [14, 15] introduced methods such as regression analysis and neural networks into these calculation models to improve their accuracy, though they require large datasets to ensure reliable results. Wei *et al*. [16] developed a deep thermal environment evaluation model based on Analytic Hierarchy Process and fuzzy evaluation method, and identified nine evaluation indicators to determine its degree of thermal damage. In this paper, a complex air-flow temperature

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calculation model is established, and an underground heat prediction system is developed to calculate the air-flow temperature at each point. Through comparing the calculation results with the temperature threshold, the heat degree at the working face can be intuitively obtained.

Heat source air-flow temperature calculation theory

According to the different types of mine roadways, deep well heat sources are divided into inlet shaft heat dissipation, roadway surrounding rock heat dissipation, transport ore heat dissipation, roadway wall oxidation heat dissipation, heat dissipation of electromechanical equipment, local fan heat dissipation, water inrush heat dissipation, personnel heat dissipation. eqs. (1)-(8) shows the types of heat sources, calculation equations and parameter indexes in deep strata.

The inlet shaft heat dissipation is given:

$$Q_{\text{shaft}} = -0.976G\left(273+t_1\right)\left[\left(1+\frac{0.0124h}{101.325+0.012H}\right)^{0.286}-1\right] \tag{1}$$

where G is mass-flow of air-flow, t_1 – the surface inlet air temperature, h – the height of the inlet shaft, and H – the elevation of inlet shaft wellhead.

The roadway surrounding rock heat dissipation is suggested:

$$Q_{\text{gu}} = k_\tau UL\left(t_{\text{gu}} - t\right) \tag{2}$$

where k_τ is the unsteady heat transfer coefficient of surrounding rock and air-flow, U – the perimeter of the roadway, L – the length of roadway, t_{gu} – the average original rock temperature, and t – the average wind temperature at both ends of the roadway

The transport ore heat dissipation calculation is shown:

$$Q_k = G_k c_k \Delta t_k = 0.0024L^{0.8} G_k c_k (t_{\text{guH}} - t_{\text{fm}}) \tag{3}$$

where G_k is the mass-flow of ore, c_k – the specific heat of ore, t_{guH} – the average temperature of the ore in the transport section, and t_{fm} – the wet bulb temperature of air-flow in working face.

The roadway wall oxidation heat dissipation reads:

$$Q_{\text{oq}} = ULq_{\text{oq}} \tag{4}$$

where q_{oq} is the oxidative heat dissipation coefficient of wall surface.

The heat dissipation of electromechanical equipment is given.

$$Q_e = \sum_{i=1}^{n}(1-\eta_i)N_i \tag{5}$$

where η is the efficiency of electronical equipment, N – the power of equipment, and n – the number of devices.

The local fan heat dissipation is given:

$$Q_m = \frac{80GP_F}{\eta_M \eta_F} \tag{6}$$

where P_F is the working pressure of local fan, η_M – the operating efficiency of local fan motor, and η_F – the fan efficiency.

The water inrush heat dissipation is showed:

$$Q_{\text{w}} = M_{\text{w}} c_{\text{w}} (t_{\text{w}} - t'_{\text{w}}) \tag{7}$$

where M_{w} is the hot water inflow, c_{w} – the specific heat capacity of hot water, t_{w} – the hot water outlet temperature, and t'_{w} – the hot water gushing out of stope face temperature.

The personnel heat dissipation is calculated:

$$Q_{\text{ren}} = q_{\text{ren}} n \tag{8}$$

where q_{ren} is the metabolic heat dissipation of workers during the construction and n – the number of staff.

Since the air-flow temperature calculation system of deep strata belongs to open system, energy exchange in deep strata follows energy conservation law. The geometric model for air-flow temperature prediction in deep strata is established by considering a horizontal roadway, as shown in fig. 1.

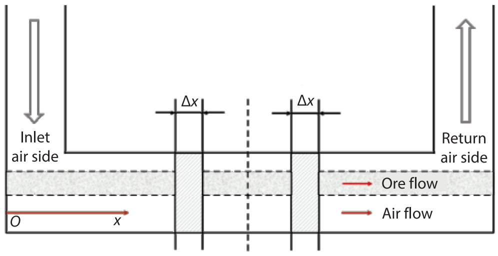

Figure 1. Geometric model of air-flow temperature prediction in deep strata

In an open system where air-flow flows through a roadway, the sum of the energy input and energy variation in the system equals the energy output. The air inlet at the working face is set as the origin of the co-ordinate system, with the air-flow direction being the positive direction of the *X*-axis. There are multiple heat sources in deep strata, the heat balance equation can be uniformly written:

$$\sum Q = G\left(i_2 - i_1\right) \tag{9}$$

where $\sum Q$ is the sum of heat dissipation from various heat sources within a unit distance, G – the ventilation volume, and i_1, i_2 – the enthalpy value of air-flow at the start and end of strata. There is:

$$i = C_P t + \gamma d \tag{10}$$

where i is the enthalpy of wet air, C_P – the heat capacity of dry air, t – the air temperature, γ – the latent heat of vaporization of water steam, and d – the air moisture content.

Air-flow temperature prediction process

The roadways are interconnected to form a network structure in deep strata. Considering the distribution of heat sources and the characteristics of different roadways, the prediction is performed under three different conditions: shaft, horizontal roadway, and excavation surface. The iterative trial algorithm of *assumption-correction* is adopted in the calculation method, the heat dissipation model can quickly calculate, the program flow chart is shown in fig. 2.

Field temperature monitoring and model verification

The geology shows that the surrounding rock temperature is 35.6 °C, with a gradient of 2.65 °C per 100 m. The air-flow temperature at the excavation face exceeds 30 °C. Field temperature monitoring tests were conducted at a depth of –930 m, measuring roadway wall temperature, air-flow temperature, humidity, and water temperature over a period of more than three months. A total of 21 high precision temperature sensors were used. fig. 3, with an accuracy of 0.1 °C.

Table 1 shows the comparison between field measured data and the predicted temperature results. It can be seen that the predictions are in well agreement with the measurements. The maximum error of excavation face is 0.78 °C. The difference for the main roadway is small. Overall, the temperature at the excavation face exceeds the underground working temperature threshold. The prediction error falls within an acceptable range, indicating that the mathematical model reliably reflects the field air-flow temperature in the underground environment.

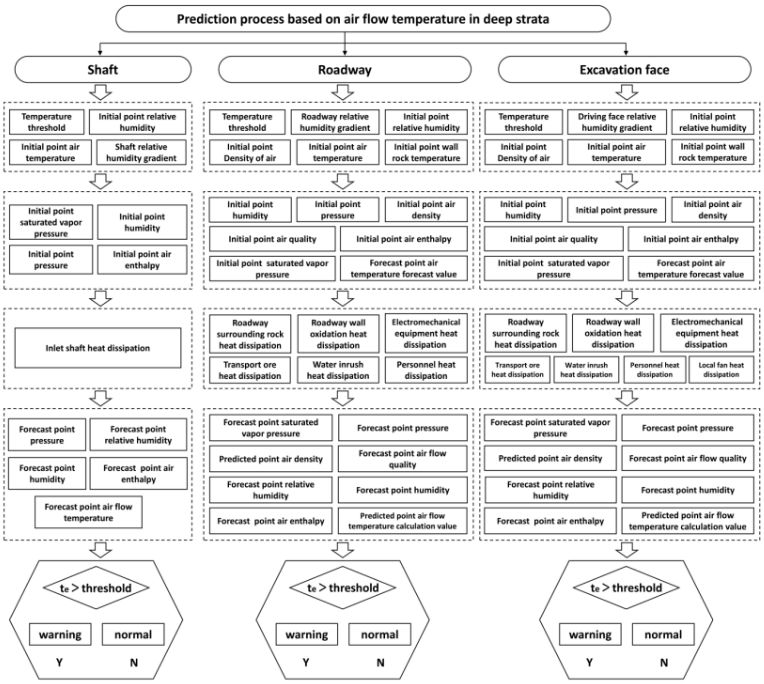

Figure 2. Prediction skeleton based on air-flow temperature in deep strata

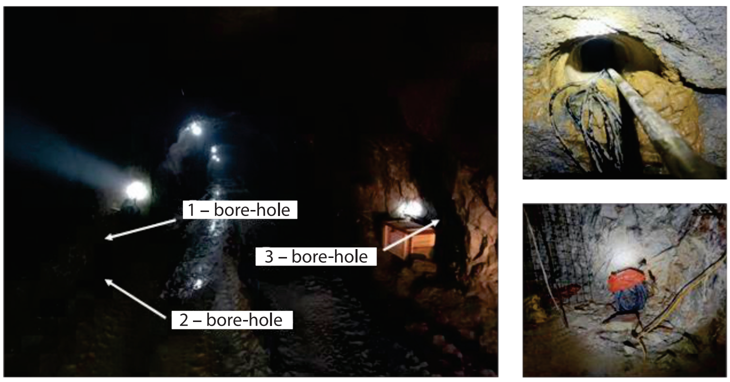

Figure 3. Prediction skeleton based on air-flow temperature in deep strata

Table 1. Types of heat source, calculation equation and parameter index in deep strata

Point number	Point predicted temperature [°C]	Point measured temperature [°C]	Numerical difference [°C]
–930-2#	29.11	28.9	–0.21
–930-3#	29.32	29.1	–0.22
–930-4#	29.89	29.8	–0.09
–930-5#	30.10	30.2	+0.10
–930-6#	37.95	38.6	+0.65
–930-7#	37.42	38.2	+0.78

Conclusion

The high temperature and humidity environment endangers workers' health and disrupts production. This paper summarizes heat release mechanisms, presents calculation formulas, and provides the correlation coefficient range. It analyzes the factors influencing heat release and simplifies unsteady heat conduction and convective processes in deep strata into a basic heat transfer model. A geometric model for predicting air-flow temperature in high temperature strata is proposed, leading to the development of a system for air-flow temperature prediction and high temperature warning. The *hypothesis-correction* algorithm ensures fast convergence of the system's input data.

Acknowledgment

This work was supported by The Deep Earth Probe and Mineral Resources Exploration-National Science and Technology Major Project (Grant No. 2024ZD1004103), the National Key Research and Development Program of China (Grant No. 2023YFC2907403), the National Natural Science Foundation of China (Grant No. 52074021), the Beijing Natural Science Foundation (Grant No. 2242045).

Nomenclature

c_k – specific heat of ore, [kJkg^{-1}°C^{-1}]
C_P – heat capacity of dry air, [Jkg^{-1}°C^{-1}]
d – air moisture content, [%]
G – mass-flow of air-flow, [kgh^{-1}]
G_k – mass-flow of ore, [kgs^{-1}]
H – elevation of inlet shaft wellhead, [m]
h – height of the inlet shaft, [m]
i_1, i_2 – enthalpy value of air-flow at the start and end of strata, [Jkg^{-1}]
k_τ – unsteady heat transfer coefficient of surrounding rock and air-flow, [Jm^{-2}h^{-1}°C^{-1}]
$\sum Q$ – sum of heat dissipation from various heat sources within a unit distance, [Jh^{-1}]
q_{ren} – metabolic heat dissipation of workers during the construction, [Jh^{-1}]
M_{w} – hot water inflow, [kgs^{-1}]
t_{fm} – wet bulb temperature of air-flow in working face, [°C]
t_{gu} – average original rock temperature, [°C]
t_{guH} – average temperature of the ore in the transport section, [°C]
t_{w} – hot water outlet temperature, [°C]
t'_{w} – hot water gushing out of stope face temperature, [°C]
t_1 – surface inlet air temperature, [°C]

Greek symbols

η_F – fan efficiency, [%]
η_M – operating efficiency of local fan motor, [%]

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Paper submitted: July 20, 2024
Paper revised: October 12, 2024
Paper accepted: November 19, 2024