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Prediction and Study of Air Thermal Parameters in Unexploited Mine Regions Based on Temperature Prediction Model in Whole Ventilation Network

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Abstract

Mines with heat disaster danger have been increased year by year, in order to provide basic data for mine air-conditioning design, prediction of air thermal parameters in the mine unexploited region becomes particularly important. But at present, prediction of air thermal parameters is realized mainly by empirical formula and forecast method of single-line(main trunk road method), existing many disadvantages such as strong individual subjectivity, bad theoretical property and low forecasting precision. Therefore, a kind of air temperature prediction model in whole ventilation network based on wind enthalpy equation is put forward. By the model, air temperature prediction software in whole ventilation network which can make reasonable forecast of thermal parameters for different high temperature mines is programmed by determining air thermal parameters through wind energy equation and considering the influence of natural wind pressure. Through the prediction of the air thermal parameters of the wind route in the fifth mining area in east wing of Dongtan colliery, it can be seen that air temperature prediction model in whole ventilation network is scientific, reasonable and with strong operating nature, which can meet the requirements of the prediction of air thermal parameters in unexploited region of high temperature mines.

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Keywords: mine; unexploited region; air thermal parameter; air temperature prediction model in whole ventilation network

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The prediction and study about the mine air status parameter originated in the late 1940s, especially in the former Soviet Union scholar A. H. Шербань's fruitful research of the mine roadway thermal calculation, the thermal calculation methods and formulas of the underground ventilation locations were proposed, such as shaft, level and sloping roadway, mining and extraction face, et al[1], which effectively promoted the research and development of the mine thermal conditions and its regulation. However, these formulas are essentially based on empiricalal algorithm, individual subjectivity, and theory is poor. Since the 80s of the 20th century, some mathematical theory methods, such as the calculation method of linear increase, mathematical statistics, the air temperature prediction model based on air enthalpy equation, the virtual laneway method, etc, were progressively applied in the prediction and study of the mine air status parameter, which have made the technology to a qualitative leap in theory[2]. The prediction model of air temperature in full blast network is just based on the prediction mathematical model above to be achieved.

1. Summary of the mine air temperature prediction methods

When roadway initial airflow state parameters are known, we can use formulas and iterative algorithm provided by the second document in the references to predict the end airflow air state parameters. But when the start end is very far away from the predicted point, it is difficult to predict as a calculation section for the actual roadway section shape, size, support type, moisture level is very inconsistent, the ventilation networks determined by develop mining and ventilation design are very complex and there are composite or distributing wind Point and other points in the ventilation circuit. In order to improve prediction accuracy, generally calculate nodes by the definite composite or distributing wind points, the roadway between two nodes as a computing section, or put the similar heat transfer characteristics of roadway as a calculation unit (section). Figure 1 shows the mine ventilation network graph, making point O as the inlet airshaft wellhead, where the air state parameters are known, to predict the air temperatures of Ⅰ working face return airshaft wellhead (node ⑧).

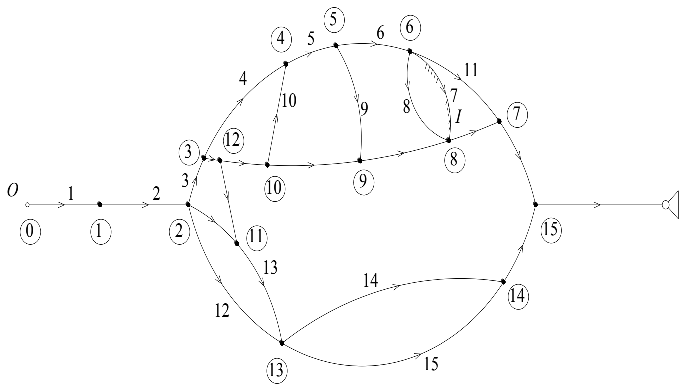

Fig. 1. Mine ventilation network graph

The following two options were introduced to select circuit.

2. Single-line prediction method (main trunk road method)

Starting from the known start node, along with (or against) the direction of airflow, choose a main ventilation circuit leading to the predicted point to collect the various branches on the ventilation circuit (calculated unit or section) end to end, put the end node of a previous branch as the start node of the next branch, and so on until the predicted node. Just like figure 1, select a main trunk circuit from ⓪~⑧ node by the composition of the branch of 1, 2, 3,4,5,6 and 7 to predict.

The calculation workload of the prediction circuit selection method is small and simple. However, as it can be seen from Figure 1, its disadvantage is obvious that it often has composite (or distributing) wind point, among the nodes in the main trunk circuit, such as ③, ④, ⑤, ⑥ shown in ⓪~⑧ circuit nodes. Due to the combination or separation of air current which makes the air volume of the predicted branch be accurately determined difficultly, especially to the composite (distributing) wind point in the natural distributing ventilation network, the problem is more prominent[3]. Because the accuracy of air temperature is directly influenced by the accuracy of air volume at this time. When there are composite wind points (such as node ④) in main trunk circuits, by law of main trunk road method, the start point air state parameter of 5 branch associated with the ④ node depends on the end point of 4 branch. But the start point air state parameters of 5 branch are still influenced by 10 branch and the 10 branch is not to be predictable. Therefore, these will affect the prediction accuracy of this method.

3. Prediction model of air temperature in whole ventilation network

There are interactive relationships among the airflow parameters, such as the air volume, air temperature and natural wind pressure in mine ventilation network. In order to overcome the disadvantages of single-line method to improve prediction accuracy of air temperature, the prediction model of air temperature in whole ventilation network has its unique superiority. In this method, first of all, in the guarantee on demand with wind, we can obtain the air volume in branches by calculating wind networks (using node pressure method). Predict air temperature of various branches in the ventilation network based on getting the air volume of the branches in the ventilation network and then obtaining the air density of the various branches, take into account the meshes in the ventilation network, under the influence of gravity potential energy difference, namely, the existence of natural pressure, the air volume in meshes of the branches changes, then turn on the air volume in meshes, air temperature re-iteration, and so on, repeat to achieve the accuracy requirement[4, 5]. This method considers the airflow relationship between the state parameters comprehensively and reasonably, but it requires more basis and the computation is more complex than the first method.

3.1. Basic equations of airflow temperature forecast

According to airflow energy expression, the branch end node basic equation of airflow temperature forecast can be shown:

$$t_2 = t_1 + \frac{\sum Q_h}{MC_p} + \frac{g}{C_p}(Z_1 - Z_2) - \frac{\gamma_r}{C_p}(d_2 - d_1) \qquad (1)$$

There,

M—branch airflow quality flow, $M=\rho_{1.2}Q$, kg/s;

Q—branch volume flow, m^3/s;

$\rho_{1.2}$—average density of the air branch, $\rho_{1.2}=(\rho_1+\rho_2)/2$, kg/m^3;

ρ_1, ρ_2—air density of the branch start and the end node, kg/m^3;

$$\rho_i = \frac{3.484(B_i - 0.3779\varphi_i p_{si})}{273.15 + t_i} \tag{2}$$

B_i—node air pressure, Pa;

$$B_i = \frac{101254}{(1 - \frac{Z_i}{44320})^{5.256}} \tag{3}$$

Z_i—node depth, m;

p_{si}—saturated steam pressure under the node temperature t_i, Pa;

$$p_{si} = 610.6\exp(\frac{17.27}{237.3 + t_i}) \tag{4}$$

d_1, d_2—air humidity ratio of the branch start and end node, kg/kg(d, a);

$$d = 0.622\frac{\varphi\rho_s}{B - \varphi\rho_s} \tag{5}$$

$\sum Q_h$ —sum of the exothermic heat source within the various branches, including the relative heat source such as roadway surrounding rock heat, underground hot water heat, cold and hot pipe heat, heat reduced during coal (rock) transport; absolute heat source such as operation heat, underground oxidation heat, the body heat, et al.

3.2. Determination of air thermal parameters in ventilation network

As a result of the prediction of air temperature in whole ventilation network, the air pressure, temperature and humidity of the branch start nodes in the ventilation network are determined as follows:

A) Start nodes air pressure of the branch in the ventilation network

No matter it is the nodes in series with the branch or the branches related to composite or distributing wind node, the atmospheric pressure of the later branch start point is equal to the atmospheric pressure of the previous end point. For example, figure 1, node①, $B_{1(2)}=B_{2(1)}$; node④, $B_{4(2)}=B_{10(2)}=B_{5(1)}$. (1, 2…for the branch number of the subscript number; (1), (2) represent the branch start point and the end point.)

B) Air temperature of the branch start nodes

Determined by energy balance principle:

a) Series branch node

There is no other branches intersect between the pre-and post two branches associated with this node, in Figure 1 node ①, the end point temperature of the previous branch $t_{1(2)}$ is equal to the start point temperature of the later branch $t_{2(1)}$, that is,$t_{1(2)}=t_{2(1)}$.

b) Distributing wind node

Among the branches associated with the distributing nodes, the branch end point temperature of flowing nodes is equal to the start point temperature of all branches out of nodes. Figure 1, node ⑥, $t_{6(2)}=t_{8(1)}=t_{7(1)}=t_{11(1)}$.

c) Composite wind node

It is different from above, the branch start point temperature out of nodes is influenced compositely by the branch end point temperature of flowing nodes. For example, in Figure 1 node ④, two branches from the 4, 10 merge at ④ and then flow to branch 5. According to energy balance principle at this time to determine the start point temperature of branch 5 $t_{5(1)}$, that is

$$t_{5(1)} = \frac{M_4 t_{4(2)} + M_{10} t_{10(2)}}{M_4 + M_{10}} \tag{6}$$

$$t_{i(1)} = \frac{\sum_{i=1}^{n} M_i t_{i(2)}}{\sum_{i=1}^{n} M_i} \tag{7}$$

d) Nodes consisting of several composite wind and distributing wind branches intersections

For example, in Figure 1 Node ⑬, there are two branches 12, 13 flowing into the node, and 14, 15 out of the node. At this point,

$$t_{14(1)} = t_{15(1)} = \frac{M_{12} t_{12(2)} + M_{13} t_{13(2)}}{M_{12} + M_{13}} \tag{8}$$

C) Start point humidity ratio of sub branch

According to quality balance principle (Each node by the above example)

a) Series node

$$d_{1(2)} = d_{2(1)} \tag{9}$$

b) Distributing wind node

$$d_{6(2)} = d_{8(1)} = d_{7(1)} = d_{11(1)} \tag{10}$$

c) Compositing wind node

$$d_{5(1)} = \frac{M_4 d_{4(2)} + M_{10} d_{10(2)}}{M_4 + M_{10}} \tag{11}$$

or

$$d_{i(1)} = \frac{\sum_{i=1}^{n} M_i d_{i(2)}}{\sum_{i=1}^{n} M_i} \tag{12}$$

d) Nodes consisting of several composite wind and distributing wind branches intersections

$$d_{14(1)} = d_{15(1)} = \frac{M_{12} d_{12(2)} + M_{13} d_{13(2)}}{M_{12} + M_{13}} \tag{13}$$

According to the characteristics of mine, when the difference between node and post temperature is not great, the air relative humidity φ can be approximately determined by the method above[6]. In the course of predicting the air temperature in the full wind network, in order to find the end point air state parameters of the roadway, it's essential to use such methods to determine the start point air state parameters first. Forecasting work was achieved by the program from the intake air shaft to the return-air shaft point by point.

3.3. Considering the impact of natural wind pressure

After predicting the air temperature in the roadway, according to (2), calculate the airflow density. Since the difference of point density, there is bound to lead to effects of natural wind pressure in the network. According to density change, calculate natural wind pressure value with wind pressure balance formula, re-calculate the flowing wind networks, obtain the wind volume and wind temperature of the branches, repeatedly iterative calculation and finally get the solution meeting the accuracy requirements[7].

3.4. Program software for predicting air temperature in whole ventilation network

According to the principles and methods of predicting the air temperature, use the language of Visual Basic to compile the software for predicting air temperature in whole ventilation network. The procedures, including the database of thermal parameters and other relevant parameters, the subroutine of calculating the roadway air temperature, the natural wind pressure and the main program of calculating the roadway wind volume and calling subroutine.

4. Applications

To predict the airflow circuit air thermal parameters of the fifth mining area in the east wing of Dongtan coal mine, Yanzhou Mining Group, as an example, to demonstrate the application situation of the prediction model of air temperature in whole ventilation network.

Dongtan coal mine, Yanzhou Mining Group, which possesses a higher degree of mechanization, is a 8 MT/a large modern mine. The mining level is an average of -660m below the ground and the mine heat injury is very serious. With the increase of mining depth, the excavation depth of the five mining area in the East Wing will reach-1000m about , the underground heat injury will be more serious. Therefore, in order to provide the basic data and basis of the underground air-conditioning cooling design, we must have scientific and reasonable prediction of the airflow circuit and air thermal parameters.

First of all, according to the development arrangement plan of the five mining areas in the east wing of Dongtan coal mine to map out the appropriate ventilation system graphs and network graphs. Then, based on the ventilation network graph, use the air temperature prediction in whole ventilation network software to predict the airflow circuit air thermal parameters of the five mining areas in the east wing by-node and by branch. There are only predicted results, as shown in Table 1.

It can be shown from the forecast results, the main roadway air temperature of the airflow circuit of the fifth mining areas in the east wing will be over 31℃, relative humidity more than 95.0%; and the air temperature of the fifth mining areas will reach 33.4℃, relative humidity 95.2% at this time. Therefore, we must take practical and effective cooling measures to the underground working environment, making the air thermal parameters meet the permitted range which is provided by "Coal Mine Safety Regulations", to ensure the miners' physical and mental health and the mine's safety.

Table 1. The airflow circuit thermal parameters of the five-mining area in the east wing of Dongtan coal mine

Forecast number	Roadway name	Roadway ventilation and airflow initial thermal parameters				Thermal physical parameters of surrounding rock			Original rock temperature (℃)	Calculation parameters	Thermal parameters of end point		
		Air volume (m^3/s)	Relative humidity (%)	Air temperature (℃)	Atmospheric pressure (hPa)	Specific heat (kJ/kg·K)	Coefficient of thermal conductivity (kW/m·K)	Coefficient of thermal diffusivity (m^2/s)		K_τ (kW/m^2·K)	t_2 (℃)	φ_2 (%)	d (g/kg)
■	Shaft pavement	/	76.2	26.1	1014.1	/	/	/	27.6	/	29.1	80.3	20.2
■	Yard in east wing	116	80.3	29.1	1108.3	0.972	2.728×10^{-3}	1.071×10^{-6}	32.0	0.522×10^{-3}	28.9	90.2	22.1
■	lower Yard of inclining laneway in the fifth mining area	60.0	90.2	28.9	1137.6	0.972	2.913×10^{-3}	1.271×10^{-6}	36.7	0.553×10^{-3}	30.7	93.1	24.0
■	lower Yard of track laneway	52.2	93.1	30.7	1137.3	0.972	2.913×10^{-3}	1.271×10^{-6}	36.3	0.593×10^{-3}	31.0	94.0	24.5
■	upper Yard of track laneway	23.4	94.0	31.0	1125.4	0.972	2.748×10^{-3}	1.260×10^{-6}	35.2	0.637×10^{-3}	32.0	95.0	26.2
■	upper Yard of lifting inclining laneway	23.4	95.0	32.0	1117.9	0.972	2.748×10^{-3}	1.260×10^{-6}	35.3	0.637×10^{-3}	32.4	95.3	26.6
■	Track gateway	19.1	95.3	32.4	1116.6	1.19	3.678×10^{-4}	0.234×10^{-6}	34.0	6.532×10^{-3}	33.0	95.0	27.1
■	Working place	18.6	95.0	33.0	1116.6	1.19	1.704×10^{-3}	0.923×10^{-6}	34.0	6.900×10^{-3}	33.4	95.2	28.0
■	Transportation gateway	17.8	95.2	33.4	1116.6	1.19	3.678×10^{-4}	0.232×10^{-6}	34.0	6.532×10^{-3}	34.0	96.2	29.0

5. Conclusions

With the increasing of mining depth, the ground temperature has increased continuously and the heat disaster has been serious. Therefore, the design of cooling air conditioning is indispensable and the accurate prediction of air thermal parameters in unexploited region of mine is the necessary condition to design the mine air conditioning reasonably. At present, prediction of air thermal parameters in unexploited region of mine is still staying in the stage of empirical formula or single-line prediction method, which exists many weaknesses such as bad theoretical property, low forecasting precision and so on. The air temperature prediction model in whole ventilation network according to the wind enthalpy equation was put forward in this paper. By the model, the air thermal parameters of wind are available and programming calculation is easy to implement. Through the reasonable prediction of the air thermal parameters of the wind route in the fifth mining area in east wing of Dongtan colliery, practice has indicated that the method is reasonable, simple, and convenient for application.

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