

Measurement and analysis of virgin-rock temperature in Huanren Metal Mine

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ABSTRACT

With the increase of mining depth, the heat-harm in high temperature deep mines has become increasingly prominent and become a new obstacle for the development of mining in China. Two pitheads from Huanren Metal Mine, a nearly one-thousand-meter-depth mine, were taken as the study objects of this paper. The deep-hole temperature measuring method was adopted to determine the rock temperature. The original rock temperature was analyzed theoretically, and the ventilation cooling depth, the geothermal gradient, and the distribution model of the rock temperature were calculated and verified. The temperature of the deep rock was predicted and some pertinent suggestions to control the thermal hazard were put forward. The results show that the ventilation cooling depth of this mine is 20 m, and the geothermal gradient of the two pitheads is 2.3°C/100 m and 3.6°C/100 m. The model of the airflow temperature agrees well with the measured values. The research in this paper can provide theoretical and technical support for heat-harm prevention and control in Huanren Metal Mine and other similar mines.

KEYWORDS: mental mine; virgin-rock temperature; measurement; geothermal gradient

1. INTRODUCTION

In present day China, about 35 to 40 percent of the mines have entered the deep mining stage and the mining depths of nearly one hundred metal mines are more than 1000 meters. It can be predicted that in the next few decades more and more underground mines will move into deep mining (Dong et al., 2009; Gu and Li, 2003). With the increasing mining depth, the heat-harm has become increasingly prominent, which seriously affects the health of workers, greatly reduces labor productivity, and increases the accident rate. The high temperature in deep mines has become a new obstacle for the development of mining in China. As the most direct and important underground heat source, heat from the wall rock takes about 48% of the total heat transferred into underground air (Donoghue et al., 2000; Hartman et al., 2012). Therefore, the measurement and analysis of the virgin-rock temperature provides very important basic data for temperature-humidity air conditioning.

This study aimed to investigate the virgin-rock temperature and the temperature distribution in the rock and determine the geothermal gradient and the heat flow transferred from the rock to the air flow in Huanren Metal Mine. As a nearly one-thousand-meter-depth mine, two pitheads in Huanren Metal Mine were taken as the study objects. The deep-hole temperature measuring method was adopted to

determine the rock temperature. The original rock temperature was analyzed theoretically. The ventilation cooling depth, the geothermal gradient, and the distribution model of the rock temperature were calculated and verified. The temperature of the deep rock was predicted. The research in this paper can provide theoretical and technical support for heat-harm prevention and control of Huanren Metal Mine and other similar mines.

2. MEASUREMENT

2.1 Measurement instrument

Virgin-rock temperature can be calculated based on the data obtained from borehole temperature (Vost, 1976). In this paper, the temperature was tested in a deep borehole with armored type k thermocouple. The compensating wire for the thermocouple was 25 meter long and sealed and protected by a Teflon tube. The temperature was displayed by a digital thermometer which was designed for type k thermocouple. The measuring range was from -50.0°C to 1300°C, the resolution was 0.1°C, and the precision was 0.1% ±0.4°C.

Fifteen thermocouples were used in the measurement; these thermocouples were all calibrated before the test to ensure the accuracy of the data.

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2.2 Measurement scheme

(1) Measurement of ventilation cooling depth

The temperature of the virgin-rock at the certain depth in a small range is the same when the properties of the rock are homogeneous. In the mine, if the distance between the surrounding rock and the wall of the laneway is longer than the ventilation depth, the temperature of the rock will be a constant, which is the virgin-rock temperature at this level. In the test, three horizontal boreholes in typical rock whose depths were not less than 25 meters were selected as the sampling holes. The thermocouples were put deeply at the bottom of the sampling holes and the openings of the hole were sealed with mud. In the next 24 hours, the temperature in the holes was allowed to stabilize, and then the temperature and the distance between the sample point and the laneway wall were recorded. Next, the thermocouple was pulled out several meters and the test was repeated until the entire thermocouple was pulled out. The ventilation cooling depth is the distance between the sample point and the laneway wall from which the rock temperature does not increase and the highest temperature is exactly the virgin-rock temperature at this level.

(2) Measurement of geothermal gradient

The geothermal gradient is an important indicator to rate the heat-harm in the mine and the essential data to predict the heat-harm and guide the temperature lowering. The geothermal gradient can be calculated with the data obtained by measuring the virgin-rock temperature of different levels. In this paper, the borehole for the rock temperature sampling was ready-made. The measurement was carried out according to the following steps:

(a) Choose seven different levels in which the boreholes meet the test request can be found. The distribution of the levels should be uniform from the top to the bottom as far as possible. The borehole should be horizontal, dry, and without flowing water in it. The depth of the hole should not be less than 25 meters. The bottom of the borehole should keep far away (>25 meters) from the structures which may affect the rock temperature, such as the shaft, goaf, chamber, and so on.

(b) Insert the thermocouple into the borehole until the depth is not less than the ventilation cooling depth measured previously. Seal the opening with mud.

(c) Record the temperature after 24 hours.

(3) Position of the sample point

According to the test request, the in-site condition was analyzed and the measure point was

decided. Some boreholes in the level of -500 m, -530 m, -560 m, -600 m, -630 m, -660 m, -690 m in the Songlan Pithead and -420 m, -480 m, -540 m, -630 m, -720 m, -760 m, -840 m in the Xiangyang Pithead were selected.

3. DATE ANALYSIS

3.1 Determine the ventilation cooling depth

As the typical rocks in the two pitheads were the same, this measurement was only carried out in the Songlan Pithead. The data from three boreholes were collected at the level of -600 m. Rock temperatures at various distances to the wall in the borehole are shown in Figure 1.

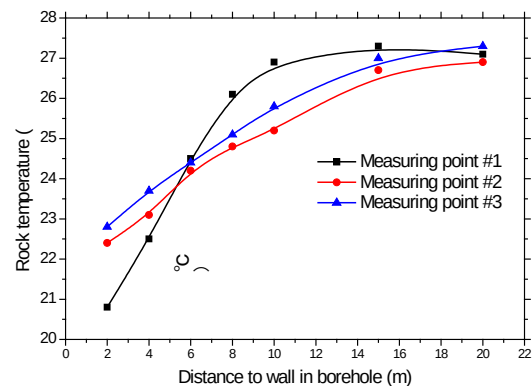


Figure 1: Rock temperature vs. Distance to wall in borehole.

Due to the different velocities and temperature of the air flow around the sample point, there were obvious differences in the initial point and the change process of the rock temperature between the three sample points. The rock temperatures all gradually increased with the distance between the temperature sample point and the wall of the laneway, then stabilized and were not affected by the outside air flow when the distance was more than 15 meters. When the distance reached 20 meters, the rock temperature of the three points became the same and no more change occurred with increased distance, that is to say, the ventilation cooling depth in the mine was 20 meters, and the temperature at this depth was the virgin-rock temperature.

3.2 Calculate the geothermal gradient

After in-site measurement, the virgin-rock temperature at different levels in the Songlan Pithead and Xiangyang Pithead were obtained, as shown in Tables 1 and 2.

Table 1: Virgin-rock temperature at different levels in Songlan Pithead.

Level of sample points	-500m	-530m	-560m	-600m	-630m	-660m	-690m
Relative depth to 1st sample point (m)	0	30	60	100	130	160	190
Equivalent height (1/100m)	0	0.3	0.6	1	1.3	1.6	1.9
Virgin rock temperature (°C)	21.4	22.3	23.7	24.9	26.1	27.3	28.0

Table 2: Virgin-rock temperature at different levels in Xiangyang Pithead.

Level of sample points	-420m	-480m	-540m	-630m	-720m	-760m	-840m
Relative depth to 1st sample point (m)	0	60	120	210	300	340	420
Equivalent height (1/100m)	0	0.6	1.2	2.1	3	3.4	4.2
Virgin rock temperature (°C)	19.3	20.2	21.6	23.5	25.8	26.7	28.7

The geothermal gradient was derived by the fitting method. The levels of the sample points were transferred to equivalent height by Equation 1 while the temperatures remained unchanged. Then the data of height and temperature was fitted with a line, where the geothermal gradient is the slope of the line.

$$h' = \frac{h_{\max} - h}{100} \quad (1)$$

Where $h_{\max}$ is the maximum of all the levels, m; h is the original levels of the sample points, m; h' is the equivalent height, 100 m^{-1} . According to the results of the geothermal gradient fitting shown in Figures 2 and 3, the geothermal gradient of Songlan Pithead was 3.6°C/100 m while that of Xiangyang Pithead was 2.3°C/100 m. Compared with the average geothermal gradient of the earth crust, which is 2.5°C/100 m, the geothermal gradient in the Xiangyang Pithead is normal while that in the Songlan Pithead is larger and should be paid more attention to for the possible heat harm when the mining depth is further increased.

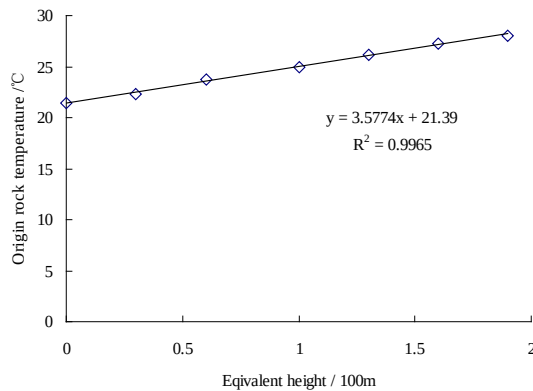


Figure 2: Geothermal gradient fitting of Songlan Pithead.

3.3 Distribution model of the virgin-rock temperature

The virgin-rock temperature at certain depths can be calculated by Equation 2.

$$t_n = t_a + \frac{(H - H_a) \times G}{100} \quad (2)$$

Where t_n is the virgin temperature of the rock which is H meters below the earth surface, °C; t_a is the rock temperature of the zone of constant temperature, °C; H is the depth of the rock from the earth surface, m; H_a is the depth of the zone of constant temperature, m; G is the geothermal gradient, °C/100 m.

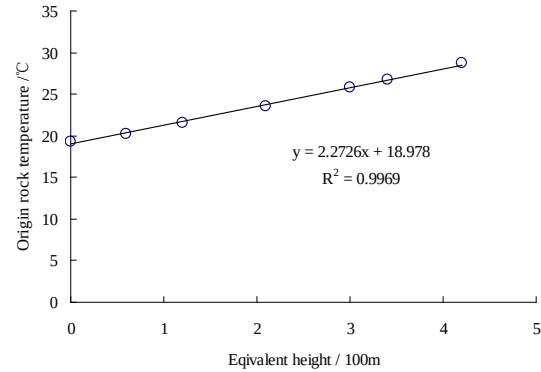


Figure 3: Geothermal gradient fitting of Xiangyang Pithead.

According to the information from the mining company, the depth of the zone of constant temperature in Huanren Mine is 30 meter, t_a is 4.4°C for the Songlan Pithead and 9.9°C for the Xiangyang Pithead. The distribution models of the virgin-rock temperature for the Songlan Pithead and Xiangyang Pithead are Equations 3 and 4, respectively.

$$t_{n,s} = 4.4 + \frac{(H - 30) \times 3.6}{100} \quad (3)$$

$$t_{n,x} = 9.9 + \frac{(H - 30) \times 2.3}{100} \quad (4)$$

Based on these two equations, the temperature of the deep rock can be predicted. Take Songlan Pithead as example, the virgin-rock temperature will increase to 30°C when the mining depth reaches -741 m. If the mining depth reaches -936 m, the virgin-rock

temperature will be 37°C which will be a severe problem.

3.4 Air flow temperature

Based on the assumption that the inlet air temperature in the laneway is constant and the heat transfer in the rock is stable, according to the heat exchange between air and rock, the air temperature can be calculated by Equation 5 (Ventilation Research Laboratory, 1976).

$$t_l = \frac{(S-1)t_n + t_0}{S} \quad (5)$$

Where t_0 is the inlet air temperature in the laneway, °C; t_l is the temperature of the air which is L meters far away from the inlet, °C; S is calculated as:

$$S = 10^{\frac{L \cdot K \cdot P}{2600Q}} \quad (6)$$

Where L is the distance from the inlet, m; P is the circumference of the laneway, m; Q is the air quantity, $\text{m}^3 \text{s}^{-1}$, K is calculated as:

$$K = \frac{8.7\lambda}{1.33 + \frac{\lambda}{v^{0.8}}} \quad (7)$$

Where λ is the heat transfer coefficient, $\text{W/m}^2 \text{°C}^{-1}$; v is the average velocity of the air flow, m/s.

In order to verify the applicability of the model, the data from -600 m level in the Songlan Pithead were put into the model, the value of the parameters were listed in the Table 3.

Table 3: value of the parameters from Songlan Pithead

Parameters	$t_0 / \text{°C}$	$v / \text{m/s}$	$t_n / \text{°C}$	P / m	L / m	$\lambda / \text{W/m}^2 \text{°C}$
Value	12.8	1	26.9	10	95	2.975

Based on the model, the temperature at the sample point is 20.6°C while the measured temperature is 20.3°C, the error is 1.48%. The model agreed well with the measured data and can be used to predict and control the heat-harm in the mine.

4. CONCLUSION

In this paper, Songlan Pithead and Xiangyang Pithead, two of pitheads of Huanren Metal Mine, were studied. The virgin-rock temperature was measured, the obtained data was analyzed theoretically, the ventilation cooling depth, the geothermal gradient and the distribution model of the rock temperature were calculated and verified, and the temperature of the deep rock was predicted. The results showed that the ventilation cooling depth in the Huanren Metal Mine is 20 meters. The geothermal gradient in Songlan Pithead is 3.6°C/100 m while that in Xiangyang is 2.3°C/100 m. The Songlan Pithead should be paid more attention to due to the possible heat harm when the mining depth is further increased. The model to calculate the airflow temperature is in agreement with the measured data, which showed its good applicability in this mine. This model can give strong support to predict and control the heat harm in the mine. The heat harm in the Huanren Metal Mine has already appeared preliminarily and is not serious at this time, but it should be closely monitored. With the increasing mining depth, the heat harm will become more and more severe. At the early stage, it can be improved by optimizing the ventilation network. After that,

more effective cooling measures should be taken into consideration.

5. ACKNOWLEDGEMENT

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