The 6th International Conference on Mining Science & Technology

Study on the heat hazard of deep exploitation in high-temperature mines and its evaluation index

Su Zhao-gui\textsuperscript{a,b,*}, Jiang Zhong-an\textsuperscript{a}, Sun Zhong-qiang\textsuperscript{b}

\textsuperscript{a} Civil & Environment Engineering School, University of Science & Technology Beijing, Beijing 100083, China
\textsuperscript{b} College of Environment Science & Engineering, Hebei University of Science & Technology, Shijiazhuang 050018, China

Abstract

With the increase of mining depth, high-temperature mines have been more and more now; it is about 150 pair mines that have the problem of high-temperature to different extent in China. High-temperature environment directly affects miners' work condition and work efficiency, and is easy to cause insecure behavior and lack of enthusiasm. By investigating thermal source in mine, some surrounding factors that arouse heat hazard are analyzed. The harmfulness to miners in high-temperature environment mostly lies in the destruction of the normal physiological regulation of human body, and the disordering of body's heat balance, such as heat shock, heat cramps and heat exhaustion and so on. The impacts on the safety production in mine include lowering the miner's labor efficiency, easily causing a fire in mine, disordering the mine ventilation system, eroding the equipments and material, resulting in higher accident rates, etc. Finally, by studying evaluation index of heat hazard, the concept of the synthesis-reduced temperature (SRT) and its evaluation criteria are put forward, which is a new method for evaluating the degree of heat hazard in high-temperature mine.

Keywords: deep exploitation; high-temperature mine; heat hazard; hot environment; evaluation index; safety

1. Introduction

With the development of mining industry, the average depth of mines in China is increasing by 10 meters per year. The one-kilometre deep coal mines are becoming more and more. According to the average grads of ground temperature in China, the temperature of wall rock increases 0.35 °C per year\textsuperscript{[1]}. The temperature of one kilometre deep coal mines will be over 35 °C. With the increase of mine depth and the improving of mechanization, the heat harm in high-temperature mines is becoming worse and worse.

The heat hazard of the high temperature mines mainly includes two aspects: one is to harm the body health of miner; another is the impact on the safety production of mine.

There are many indexes that show the hot environment in mine. For example, dry bulb temperature ($t_d$); wet bulb temperature ($t_w$); kata-temperature ($H$); effective temperature ($E.T$); wet bulb globe temperature ($WBGT$); scale cooling power ($SCP$), and so on. But so far, no index is suited to expressing the heat hazard of high-temperature mines.

* Corresponding author. Tel: +86-13831170025; fax: +86-311-88632391.
E-mail address: suzhaogui@163.com.

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doi:10.1016/j.proeps.2009.09.066
So, in order to protect miner, to enhance labour productivity, and to insure production safety, it is very important to research the heat hazard and the evaluation index of high temperature mines.

2. Analysis of the heat sources in the high-temperature mines

There are four heat sources in the high-temperature mines: the calorific radiation of wall rock, the digging machine-electricity equipments, the disposal of coal gangue and mineral, and the air self-compression heat.

The first heat source is the geothermy in natural environment. The deeper the mine is, the higher the rock temperature. The release of geothermy makes the air temperature increase.

The other three heat sources are generated in mining process. The amount of heat release increases with the mine depth, the degree of mechanization, and the number of electrical and mechanical equipments. The oxidation of coal, rock comprising carbon or sulphur, and support materials also generates heat, which makes local temperature rise. The heat of waste rock and coal can be released to the airflow. Owing to great depth of mine, the air temperature will rise under compression.

In addition, there are other heat sources, for example, the hot gushing water, the ground temperature increasing, the lack of wind flow, the compression heat of local fanners and the heat releasing from chemical reaction, etc.

3. Harm to the miner health

The heat of the body comes from the sugar, the fat, the protein and the oxygen that is absorbed by a series of the biological oxidation, and multiplies with the increase of the labor intensity. In order to maintain the body's heat balance, the excess heat of the body is given off outside by the physiological regulation.

The specific heat of the body is 3.48kJ/(kg·ºC). If the weight of a man is 60kg, the heat quantity of the body will be 210 kJ and the body temperature of physics calculation will raise 1 ºC. Table 1 shows the impact of air temperature on body temperature.

| Air wet-bulb temperature (ºC) | The increment of body temperature (rectum temperature ºC) |
|-------------------------------|----------------------------------------------------------|
| ≤29                          | 0.11~0.66                                               |
| 29.5~31.7                    | 0.33~0.77                                               |
| 32.2~34.5                    | 0.66~1.55                                               |
| >34.5                        | 1.44~1.90                                               |

When the air temperature is above 35 ºC, particularly over 38 ºC, the proportion of abnormal body temperature will be significantly increased (Fig. 1); when the body temperature is at 39 ºC ~40 ºC, the blood circulation will be irregular and of the body will sweat a lot; when the body temperature is at 41 ºC ~43 ºC, the heat stroke will happen; if the body temperature is over 43 ºC, people will die.

In the hot environment of mine, the conditions around the body are deteriorated; the heat balance of body temperature may be destroyed due to the dysfunction of body temperature regulation which results in the heat accumulation.

The serious harm in the high-temperature mine would lead to the following heat damage:

1) The heat stroke

The symptoms of heat stroke include the sudden rise of body temperature (up to 40 ºC), the stop of sweating and heat releasing, dry skin. The patient may be shocked or become wildly irritable. The heat attack is the most serious heat damage, and 20% to 80% of the heat attacks are fatal which must be dealt with promptly. We should quickly withdraw the patients from hot environment and provide warm water.

2) The heat cramp

The heat cramp mainly is caused by the loss of too much salt. The patient feels tired and dizzy, aches in some muscle, and even gets stomach convulsion.
3) The heat exhaustion
This is a kind of chronic disease; the seriousness of its harm is next to above 2 kinds. The symptoms include feeling tired, headache, dizziness and rational fuzzy, and sometimes little sweating.

![Graph showing the relation of the number of abnormal body temperature and the air temperature]

Fig. 1. The relation of the number of abnormal body temperature and the air temperature

4. Impact on the safe production in mine

4.1. Lowering the miner's labor efficiency

![Graph showing the relationship between the wet-bulb temperature and the labour efficiency]

Fig. 2. The relationship between the wet-bulb temperature and the labour efficiency [2]

The influence of production safety in hot environment mainly has “tangibility” and “intangibility”.

The so-called “tangibility” means that the bad hot environment directly harms the body health of miners, in particular, the workers in the locale of production. The emergence of various diseases lowers the attendance and affects the entire production efficiency.

The impact of “intangibility” is that the long-term working in the high-temperature environment disorders the person's central nervous system, which can cause the miners spirit trance, fatigue, weakness at every pore, no focusing attention, easy slumber and slow coordination, etc. Those situations become the main reasons that cause the lower production efficiency of the miners. There are significant impacts on the labour efficiency in hot environment; Figure 1 is the relationship between the wet-bulb temperature and the labour efficiency in hot environment [2].

When the wet-bulb temperature is higher than 30, the labour production efficiency obviously drops; for the same wet-bulb temperature, the labour productivity also evidently decreases with the decline of wind speed.
4.2. Causing fire danger in mine

There are two main factors causing fire in the high-temperature mine. First, the electrical equipments can easily cause the fire. Because the electrical equipments are difficult to release heat, the temperature of the electrical equipments quickly rises, which can burn the equipments and cause a fire. Especially, the connection point of the wire or the cable is easy to fire. Second, the hot environment causes the spontaneous combustion of the coal or the coal dust, and even the fire accident. The main reason is that the new coal owns the excessive heat energy being difficult to give off in hot environment.

4.3. Disordering the mine ventilation system

The hot wind pressure that comes from the subterranean heat disorders the mine ventilation system, which may cause the wind flow stagnation or the circulation wind. For example, from June to August in 2001, owing to the function of the subterranean heat, the enterable wind quantity of the east wing was reduced and the mine ventilation system the circulation wind appeared when the main ventilators stop running in Chengjiao Mine. The airflow of the circulation wind in east rail roadway is heading face → the east No.2 contact lane → the winch chamber in east wing top platform → the local fanner → the heading face.\[4\]

4.4. Eroding the equipments and materials

The hot environment in mine usually comes from the groundwater gushing, which makes the airflow temperature rise up and the humidity increase. The equipments and materials can be easily eroded under such conditions.

4.5. Reducing the running time of the machine-electricity equipments

The service life of mechanical equipments in hot environment, especially, the internal combustion engines and the electrical equipments becomes short because of the deterioration of working conditions. The high-temperature environment destroys the insulation of the borehole cable or the motors. Blasting equipments degenerate easily at the high temperature, which is disadvantageous to the safe production.

4.6. Resulting in higher accident rates

Table 2. The relation between the accident rate and the temperature in mine\[5\]

| Air temperature of labor location (ºC) | 27 | 29 | 31 | 32 |
|----------------------------------------|----|----|----|----|
| Industrial injury frequency            | 0  | 150| 300| 450|

In the hot environment, the central nervous system of people is restrained, the excitement course of the pallium becomes weak, the conditioned reflex latency is extended, and the miner’s ability of the work and the control descends. Therefore the accident is easy to happen in mine. The survey data show that the accident rate of the working spot with the temperature of 30 ºC ~ 34 ºC is more than 3.6 times the accident rate under the temperature of less than 30 ºC. The survey of South Africa showed that when the air wet-bulb temperature of the working spot reaches 28.9 ºC (or the dry-bulb temperature reaches 30 ºC), the accident of the sunstroke or the death will happen in mine. Table 2 is the relation between the accident rate and the temperature in South African gold mines\[5\].

5. Evaluation index of heat hazard

Now, the WBGT, as an experience index, is widely used to evaluate the degree of heat hazard in mine, which means the heat harm degree to human body by dry bulb thermometer \((t_a)\), wet bulb thermometer \((t_w)\), and bulb globe temperature \((t_g)\). This method scientifically synthesized 4 factors that include the temperature, the humidity, the wind speed and the radiating heat.
The WBGT index of the hot environment in mine is represented by [3]:

\[ WBGT = 0.7t_w + 0.3t_g \]  \hspace{2cm} (1)

Because the miners are in different underground workplaces with various thermal environments, a WBGT index cannot denote the degree of heat hazard in whole mine. When the formula (1) is improved, the synthesis-reduced temperature \((SRT)\) can be used to comprehensively denote the degree of heat hazard as follows.

\[ SRT = \frac{(WBGT_1)\tau_1 + (WBGT_2)\tau_2 + \cdots + (WBGT_n)\tau_n}{(\tau_1 + \tau_2 + \cdots + \tau_n)} \]  \hspace{2cm} (2)

Where \(WBGT_1\)——the WBGT index Measured at the 1st workspace.

\(WBGT_2\)——the WBGT index Measured at the 2nd workspace.

\(WBGT_n\)——the WBGT index Measured at the \(n\)th workspace.

\(\tau_1, \tau_2, \ldots, \tau_n\)——the actual working time of miner at the 1st, 2nd \(\ldots\) \(n\)th workspace.

The actual working time of miner is the total exposure time that the miner actually works at the high-temperature spot in a working day.

The synthesis-reduced temperature \((SRT)\) corresponds to the standard thermal sensation in mines, as shown in table 3. According to the value of SRT, the degree of heat hazard can be determined.

| \(SRT\) \(({}^\circ C)\) | Thermal sense | The hot-harm degree |
|---|---|---|
| >35 | Very hot, no acceptable | Very severity |
| 32~35 | Hot, no comfort | Severity |
| 28~32 | Warm, acceptable | Moderation |
| 25~28 | Slightly hot, comfort | Mild |
| 23~25 | Comfort, acceptable | No thermal damage |
| <23 | Slightly cool | cool |

The WBGT index can be measured with the comprehensive hot index measurement instrument \((WBGT-101)\). Some hot environment parameters in Tianchen Mine were measured on August 16, 2004, as shown in Table 4.

By calculating with formula (2), when the synthesis-reduced temperature \((SRT)\) reaches 28.1 \(^\circ C\), miners will begin to feel uncomfortable, which belongs to moderate heat harm but acceptable.

| Measure location | A | B | C | D | E | F | G | H | J | K |
|---|---|---|---|---|---|---|---|---|---|---|
| Measure time | 8:30 | 8:50 | 9:50 | 10:00 | 10:20 | 10:40 | 11:25 | 11:40 | 12:00 | 12:35 |
| \(t_w\) \(({}^\circ C)\) | 24.5 | 26.6 | 27.5 | 28.4 | 30.7 | 29.6 | 29.3 | 31.3 | 32.4 | 32.0 |
| \(t_g\) \(({}^\circ C)\) | 24.5 | 25.6 | 27.4 | 28.4 | 30.5 | 30.1 | 29.4 | 31.6 | 32.2 | 31.8 |
| RH(%) | 74.2 | 81.4 | 91.9 | 91.6 | 94.2 | 91.4 | 86.8 | 91.6 | 93.6 | 83.3 |
| \(WBGT\) \(({}^\circ C)\) | 22.6 | 24.8 | 26.9 | 27.8 | 30.2 | 29.6 | 28.4 | 30.8 | 31.9 | 31.3 |

\(A——the\ well\ mouth;\ B——the\ bottom\ station;\ C——532-orbit\ lane\ fanner\ head;\ D——the\ right\ station;\ E——No.40\ section\ air\ tube\ of\ the\ 532-orbit\ lane;\ F——532-orbit\ lanes\ head-on;\ G——533-orbit\ lane\ fanner\ head;\ H——the\ contact\ lane\ between\ the\ North\ 5\ pedestrian\ lane\ and\ the\ North\ 5\ transport\ lane;\ J——the\ entrance\ of\ the\ 533\ conveyance\ lane;\ K——533-orbit\ lane\ head-on.\)
6. Conclusions

Some conclusions are gotten in this paper:

1) There are four heat sources in the high-temperature mines, which are the calorific radiation of wall rock, the digging machine-electricity equipments, the disposal of coal gangue and mineral, and the air self-compression heat.

2) Hot environment have some influences on the body temperature adjusting of miners. The miners may be subjected to the heat attack, the heat cramp, the heat exhaustion and other injuries.

3) The high temperature environment mainly influences the safe production in mine in the following aspects: lowering labor efficiency, causing the fire, eroding equipments and materials, reducing the service life of the electromechanical equipments, and resulting in the accident rate increase, etc.

4) The concept of the synthesis-reduced temperature (SRT) and its evaluation criteria are put forward to evaluate the degree of heat hazard in high-temperature mine.

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