Mining Science and Technology (China) 21 (2011) 295–299

Contents lists available at ScienceDirect

Mining Science and Technology (China)

journal homepage: www.elsevier.com/locate/mstc

Progress of heat-hazard treatment in deep mines

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A R T I C L E   I N F O

Article history:
Received 2 August 2010
Received in revised form
1 September 2010
Accepted 30 November 2010

Keywords:
Heat hazard
Cooling technology
HEMS
Low-carbon
Production
Mine water

A B S T R A C T

Based on the urgency of thermal hazard control in deep coal mines, we studied the status of deep thermal damage and cooling technology both at home and abroad, summarized the causes of deep thermal hazard, analysed and compared the control technologies for deep thermal hazards. The results show that the causes of deep thermal damage can be attributed to three aspects, i.e., climate, geological and mining factors, of which the geological factors are deemed the major reasons for thermal hazards. As well, we compared a number of cooling technologies of domestic and overseas provenance, such as central air conditioning cooling technology, ice cooling technology and water cooling technology, with one other cooling technology, i.e., the HEMS cooling technology, which has a large and important effect with its unique "pure air" cooling technology, realizes the utilizing of heat resources from underground to the ground. This technology makes use of heat obtained underground; thus the technology can promote low-carbon environmental economic development in coal mines, in order to achieve low-carbon coal production in China.

1. Introduction

China is a big coal consuming country, accounting for 40% of global consumption [1]. Because of our long-term exploitation of shallow coal resources, most coal mines have successively entered into deep mining.

According to the 3rd prediction and evaluation of coal resources of China, the total coal resources in China are about 5.57 trillion tons. By the end of 1992, the estimated shallow coal resources, less than 2000 m deep, are shown in Fig. 1 [2]. Of this, 2.71 trillion tons of coal are buried at a depth of 1000–2000 m. According to incomplete statistics, 33 pairs of mine pits, with depths below 1000 m, have temperatures at the working face as high as 30–40 °C [3,4].

Some of the major coal-producing countries began deep mining in the 1960s. In 1986, 25% of the mines in the Soviet Union had mining depths exceeding 800 m, with a maximum of 1329 m [5]. At the end of 1987, the average mining depth in Germany reached 900 m; by 2000, the average mining depth of coal mines in the Ukraine had reached 800 m, with about 13.8% of coal mines with a mining depth between 1000 and 1300 m [6,7].

One of the difficulties encountered in deep mining is high temperature. Since the 1970s, the number of mines threatened by heat hazard has been growing, which has become a widespread problem in coal mines. In South Africa, the face temperature of the #1 well of Amandelbult is up to 55 °C [8,9]. At a depth of 3300 m the temperature of the western mines in South Africa can reach 50 °C because of hot water. At depths of 500 m, the temperature is up to 80 °C in the Japanese Fengyu Lead–Zinc Mine [3]. Coal production in China has generally been carried out at high temperatures. Some data about the temperature at working faces of a few mines in China are presented in Table 1 [10–12]. This table shows that the temperature at working faces is higher than 30 °C. According to incomplete statistics, the humidity at working faces with high temperature is usually up to 90–100%. According to a survey of the coal mines of Shandong, Jiangsu, Anhui and Henan provinces, there are 40 mines with working face temperatures higher than 26 °C.

Hot and humid environments not only affect production efficiency, but are harmful to the health of workers and affects safety in coal mines. Test data of the Donetsk Institute of Industrial Hygiene and Occupational Diseases in the former Soviet Union show that: when the wind speed is 2 m/s, the relative humidity 90%; with temperatures of 25, 30 and 32 °C the efficiency of human labor declined from 90%, to 72%, and 62% respectively [13]. Working in hot and humid environments will cause great harm to workers. Practice shows that a comfortable working temperature range is from 24 °C to 28 °C; temperatures outside this range cause discomfort to miners [14]. The Sanhejian Coal Mine is one of the high-temperature mines in China. During June, July and August,

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1674-5264/$ – see front matter
doi:10.1016/j.mstc.2011.02.015

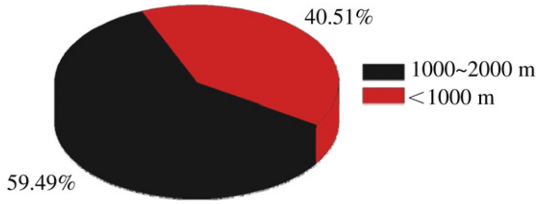

Fig. 1. Estimated coal resources in China buried up to 2000 m deep.

some workers at the mining area suffered from multiple skin diseases, covering more than 40% of their body surfaces [15]. Table 2 lists the numbers of workers suffering from heat stroke and other febrile conditions when the temperature is higher than 31 °C or lower than 30 °C [16]. At the Yongcheng Coal Mine, most accidents occurred at the working face with temperatures of more than 28 °C. During 2000 and 2001, seven people were seriously injured by high temperatures [17]. From June to September, production at the Suncun Mine came almost to a standstill [18]. High temperatures decrease efficiency of workers and greatly increase safety risks.

As well, an environment of high temperature and humidity changes the physical properties of rocks [19,20], when more and more accidents can easily occur, for example in the form of rock bursts.

Section 102 of China's "Coal Mine Safety Regulations" provides as follows: "when the mine temperature at the working face exceeds 26 °C, the working hours under the high temperature must be reduced and high temperature health treatment must be given. If it exceeds 30 °C, mine exploitation must be stopped". Therefore, heat hazards have greatly restricted deep mining, a problem that needs to be solved urgently.

2. Analysis of deep mine heat damage

Heat hazards are produced under many conditions, including climate, geological and mining factors.

2.1. Climate

Climate has a direct impact on underground temperatures. If the ground temperature is high, so is the underground temperature. In southern and northern China, ground temperatures at −1000 m are different. In the south, the ground temperature at −1000 m is higher than 45 °C, which is 3.3 times that of the north, when the temperature is 35–45 °C, the below ground temperature in the south is 1.5 times than that of the north [21].

At the same mine, working temperatures change with the seasons. At the −700 m level of the Baiji Mine, the temperature at the working face in the summer is 2–3 °C higher than that in the winter [22].

Table 1
Statistics on work face temperature of some mines in China.

Coal mine	Mining level (m)	Working temperature (°C)
Sanhejian	−1300	56
Jiahe	−800	32–34
Zhangshuanglou	−1000	34–36
Zhangxiaolou	−1125	30
Jisan	−785	31.51
Wobei	−640	35–36
Yongchuan	−800	29.3–31.5

Table 2
Number of workers at Sanhejian Mine suffering from febrile disease caused by high temperature [16].

Year	Lower than 30 °C		Higher than 31 °C	
	Skin rash	Heat stroke	Skin rash	Heat stroke
2000		0		2
2001		0		1
2002		0	About 400	5
2003		0	About 500	17
2004		0	About 85	1
2005		0	About 78	

2.2. Geological factors

Geological factors are the major reasons for heat hazards, consisting of lithology, geological structures and groundwater activities.

The air temperature at the working face is decided by the temperature of adjoining rocks. The distribution and formation of geothermal fields is related to lithology and structure. The temperature of strata with high thermal conductivity and of positive structural areas, such as anticlines, is generally high. For example, in the Longgu anticline of the Sanhejian Mine, the core geothermal gradient reaches 3.4 °C/100 m. With its two wings extended, the geothermal gradient is reduced to 2.8 °C/100 m from 3.2 °C/100 m. Fig. 2 shows the geothermal profile of the Longgu anticline.

The impact of groundwater activity on the geothermal field is as follows. ① Infiltration of groundwater in recharge areas and strong lateral runoff cool the deep geothermal field; ② The upwelling of deep water along the fault produces additional heat sources [23]. In the mine, the upwelling of water raises the air temperatures at the working faces. Hence, this kind of mine was defined by Yan Rusui (1981) as a hot water mine [24]. The temperature of the water at the #21102 coal face is 50 °C, which increased the temperature of the nearby rock to 38 °C. The hot water (39–45 °C) gushing from the #102 face of the Wu Tongzhuang Mine resulted in an air temperature of 41 °C [24,25].

2.3. Mining factor

The increment of temperature caused by mining can be called the mining factor and include such sources as oxidation heat, mechanical and electrical equipment radiation, mining and transport heat and body heat.

Heat is generated by oxidation of coal mining, pit props, filling material during exploitation; heat produced by mechanical and electrical equipment due to friction and thermal dissipation of equipment. Simultaneously, thermal dissipation occurs during ore transportation and ore peeling off from the roadway. By working underground, the high intensity of labor makes people speed up their metabolism and sweating, which is a part of the heat source that should not be ignored.

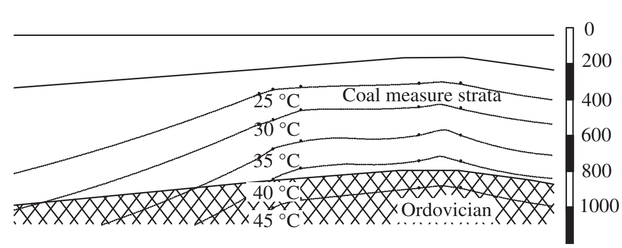

Fig. 2. Geothermal profile of the Longgu anticline.