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Research and application of methods for effectiveness evaluation of mine cooling system

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ABSTRACT

Regarding the complexity and inconsistency of results in existing evaluation methods of mine cooling system, this paper clarifies the advantages, disadvantages and application of various mine cooling systems through principle analysis, and divides all the cooling systems into air-cooling, ice-cooling and water-cooling according to the transportation of cold energy. On this basis, the paper proposes a simple and efficient evaluation method for mine cooling system. The first index of this method is the air temperature at point *C* which is 15 m away from the return wind corner at working face. A cooling system will be judged ineligible if the air temperature at point *C* is above 30 °C during operation, because in this case, the combustible gases in coal will sharply overflow, inducing gas incidents. Based on the preliminary judgment of the first index, another two evaluation indexes are proposed based on the cooling ability and dehumidification of an airflow volume of 1000 m^3/min at point *C* to evaluate the investment and operation cost of mine cooling system. This evaluation method has already been successfully applied in the cooling system design of Zhangshuanglou coal mine.

1. Introduction

With the increasing of coal mining depth, heat hazard becomes more and more common and has already become one of the major obstacles for deep mining [1–3]. Various cooling technologies have been used to prevent heat hazards and ensure safe and efficient mining. Yet, in recent years, cooling technologies have been prospering in China and other countries. According to the phase of the refrigerant system, these cooling systems can be divided into: icy refrigeration, water refrigeration and compressed air refrigeration. Meanwhile, according to the location of refrigerators, they are divided into surface cooling and underground cooling. The systems can still be classified according to the different cold sources, namely mine inflow, underground return air, surface air and mixed cold source. There are both advantages and disadvantages for each of these technologies which therefore are applied in different circumstances [4,5]. It is necessary to evaluate the efficiency of the cooling technique and to build a unified index system to evaluate the effectiveness of a cooling system.

The effectiveness evaluation method is drawing more and more attention from domestic and foreign scholars. Based on the comprehensive consideration of technology, economy and environmental impact, Miao Sujun et al. introduced an assessment index system for decision-making which consists of 10 indexes. They also used the multi-objective decision-making method for cooling scheme optimization [6]. Qiao Hua et al. proposed a simple economic analysis method for icy cooling systems by analyzing the mechanism and process of ice-melting [7]. Zhang Hui et al. used a thermodynamic energy method to analyze the thermal economy of cooling systems. Technological economics was also used in investment feasibility analysis [8].

In all these studies, every mine cooling system is evaluated as a simple thermal system. However, the underground situation is complex and influenced by various factors. Therefore, the evaluation method for normal surface thermal systems cannot fully reflect the efficiency of underground cooling systems [9–15]. This paper establishes an effective assessment index system which provides a scientific basis for the selection of cooling systems and the criteria for completion acceptance of mines.

2. Mine cooling systems and their classification

Mine cooling systems can be classified according to the status of heat-transfer medium, namely gas, solid and liquid. Therefore, they can be divided into air-cooling, ice-cooling and water-cooling

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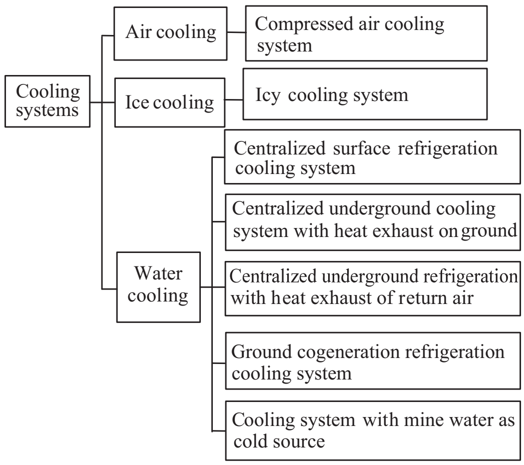

Fig. 1. Classification of mine cooling systems.

(Fig. 1). According to the location of workstations and the access of cold source, the water-cooling type can be further divided into a centralized surface cooling system, centralized underground cooling system with ground heat discharge, centralized underground refrigeration with heat discharge of return air and a cooling system with mine water as the cold source.

2.1. Compressed air cooling system

Fig. 2 shows the principle of a compressed air cooling system. In this system, air is first compressed into high temperature and high pressure liquid on the ground, which is an isentropic process; then the liquid air is cooled down while maintaining a high pressure, which is an isobaric process; thirdly, the liquid air is transported underground and adiabatically expanded to low temperature air in an expander. In the end, the cold energy of the low temperature air is transported to the working surface for cooling. This is a simple and convenient system using small diameter pipes, yet there are some disadvantages, including the limited amount of cold energy and high requirement on equipment strength.

2.2. Ice cooling system

The principle of an ice-cooling system is shown in Fig. 3. First, granular ice or a mixture of ice and water are produced by an ice-making machine on the ground and then transported underground into a melting pool, releasing the cold energy when melting into cold water which is used for the working face cooling by cooler. Since part of this system is on the ground, it demonstrates obvious advantages, such as convenience for maintenance and large cold source. The disadvantage is that pipes are easily blocked

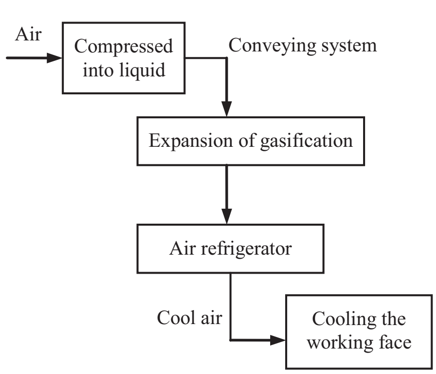

Fig. 2. Principle of compressed air cooling system.

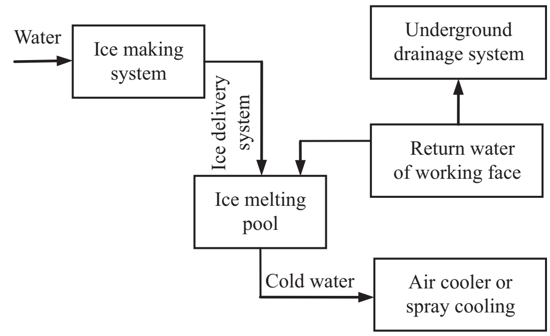

Fig. 3. Principle of ice cooling system.

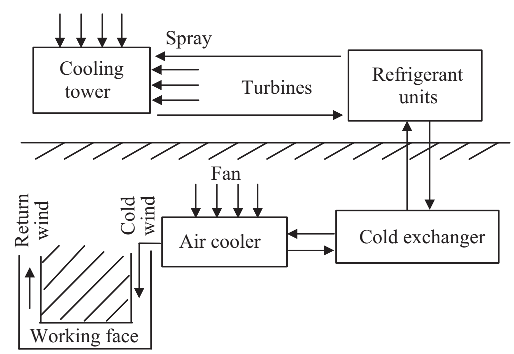

Fig. 4. Principle of centralized ground refrigeration cooling system.

due to the mixed flow of solid and liquid. Cold loss of this system is also large due to the long distance of cold energy transportation.

2.3. Centralized ground refrigeration cooling system

Fig. 4 shows the principle of a centralized surface cooling system. In this figure, low temperature water is delivered through the refrigeration cycle into the mine with cold energy obtained from the high pressure water by heat exchanger and delivered as low pressure water by convection. The low temperature and low pressure water is then used for working face cooling. This system is mainly located on the ground therefore convenient for maintenance, but the large height difference and the long transportation distance lead to high pressure and large loss of cold energy.

2.4. Centralized underground cooling system with ground heat discharge

Fig. 5 shows the principle of centralized underground refrigeration cooling system with ground heat discharge. The refrigerator is placed underground and transformed to adapt to the mine, while the cooling tower is installed on the ground to discharge heat. As the refrigerator is located underground, the transport distance is shortened and the quantity of cold energy loss reduced. At same time, the cooling tower on the ground avoids the difficulty of heat discharge. Nevertheless, the high pressure problem remains unsolved.

2.5. Centralized underground refrigeration with heat discharge of return air

Fig. 6 shows the principle of a centralized underground refrigeration cooling system with heat discharge of return air, which is used to provide a centralized surface refrigeration cooling system in the underground environment. The cooling water is cooled by