Cooling principle analysis of HEMS and numerical simulation analysis in cooling effect on Jiahe deep coal mine

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Abstract. At present, deep mine cooling is becoming more and more important because of seriously heat hazard. Based on the research of all cooling technologies in both China and abroad professor He Manchao proposed HEMS cooling technology, and it was applied in Jiahe coal mine successfully. In my paper, the reverse Carnot cycle and working process of HEMS in Jiahe coal mine was analysed. After the project was constructed, we tested temperature of key points on working face. FLUENT was adopted to simulate the heat exchange process in HEMS-II and in roadway. Compared with the monitored data, simulation on HEMS-II and roadway was proved correct. We can predict air temperature in roadway by Fluent simulation and it offers basis for optimization design in future.

1. Introduction

Coal has been the major energy source in China for a long time and it accounted for more than 70% of China’s total primary energy consumption. Due to long periods of exploitation, coal resources have become increasingly exhausted with exploitation depth less than 1 km. Therefore, deep exploitation of coal mines becomes very important [1]. As mining depth increases, rock temperature also increases and temperature on the working face in coal mine can reach up to 30~40 °C [2]. Coal mine safety law in China requests that miners are not allowed to work when air temperature at working face exceeds 30°C [3]. Consequently, it is urgent to reduce the temperature in deep coal mine.

There are in general two kinds of cooling technologies [4]; one is mine ventilation and the other is water or ice cooling systems. Practice has shown that ventilation provides only a low cooling ability and cannot meet the needs of deep mine cooling with serious heat hazards. Water cooling is usually applied in air-conditioning in deep coal mine. It uses compression equipment to cool the working face, with freon as refrigerant. The disadvantages of this system are the high operation cost and high power consumption [5]. In ice cooling system, ice is produced by an ice machine. Heat exchange occurs during process of ice melting into water [6-9]. The key problem is ice blockage in pipe during the ice transportation. The method requires high standard of operational management and control [10].

Based on the research above and given the existed problems in cooling technology at present, also considering the deep mine heat hazard in Jiahe coal mine of the Xuzhou Mining Company, the China
University of Mining & Technology (Beijing) in cooperation with the Xuzhou Mining Company proposed the high temperature heat exchange machinery system (HEMS) and key equipment were produced and successfully applied in the Jiahe coal mine, which has a good effect on controlling heat hazard in the coal mine.

2. Operation principle of HEMS

2.1. Working principle of HEMS

The working principle of HEMS is as follows: first, extracting cold energy from mine water inrush at all levels; then water stored cold energy exchanged with high temperature air at working face, and the air temperature and humidity is decreased at the working face. At the same time, heat energy obtained from HEMS can be used for building heating and showers. There are two circulations in HEMS, one is refrigeration and heat discharge system in deep coal mine, the other is building heating and heating system on the ground. These two systems form the entire circulation and production system, which is shown in Fig.1.

2.2. Reverse Carnot cycle of HEMS

The cooling principle of HEMS in Jiahe coal mine is reverse Carnot cycle, which is shown in Fig.2. The working process is as follows:

① Mine water with temperature of 29℃ from deep mine flows into condenser in HEMS-I station, the refrigerant releases heat and the water temperature is increased by 38℃.

② HEMS-I work station: the cooling reverse Carnot cycle: the low temperature low pressure liquid refrigerant in the evaporator absorbs heat and become high temperature low pressure gaseous; then the gaseous refrigerant flow to compressor, in the compressor, the low pressure refrigerant become high temperature high pressure gaseous refrigerant, then the refrigerant flows to the condenser, then the high temperature high pressure gaseous refrigerant become low temperature high pressure liquid when meet cold water, through the throttle, the refrigerant become low temperature low pressure liquid, then refrigerant flow into the evaporator again, and then flow to the compressor, so the refrigerant cycle in HEMS-I, more and more heat in the air will be transferred to mine water. The heat in water can be used for building heating.

③ HEMS-PT work station: reverse Carnot cycle work station (HEMS-I) is at the level of -600m, HEMS-II cooling station is at the level of -1010m, height difference between two station is 410m, the pipe pressure is so great that ordinary material will not meet the pressure needed, so HEMS-PT is set between HEMS-I and HEMS-II, it transfers pressure and heat in water from one side to another. The heat exchange parameters at both sides are shown in Fig.2.

④ HEMS-II work station: hot air exchanges heat with cold water, air temperature is decreased to 18℃ from 32℃, cold water temperature is increased to 19℃ from 14℃.
3. Numerical simulation of HEMS-II and roadway

Fluent is a large fluid software, it can simulation from air flow over an aircraft wing to combustion in a furnace, from bubble columns to oil platforms, from blood flow to semiconductor manufacturing and from clean room design to wastewater treatment plants. In this paper, HEMS-II cooling process and heat exchange between rock and air in roadway are simulated by FLUENT. The numerical simulation process is as follows:

(1) Building model by GAMBIT: give assumptions of model; build model; meshing the model; set the boundary condition; save, export mesh file.

(2) Simulation process of FLUENT: ① read the mesh file, check the mesh, and decide whether it is need to rectify the side of the model, smooth and swap the mesh. ② Definition: set the solver; activate energy equation; set the turbulence model; define physics properties of the materials; set the working condition; define the boundary condition in detail; ③ set the solving: setting the control equation; initialize the initial condition; open the residual monitor; start iteration; post processing once the iteration is converged. ④ display results: air temperature, pressure, velocity and velocity vectors.

3.1. Numerical simulation of HEMS-II

3.1.1 Model establishment

In Jiahe coal mine, we adopt 9 HEMS-II for deep mine cooling, Every HEMS-II consist two surface air coolers. Every cooler has four pipes, and there are 32 pipes for 9 HEMS-II. Stack two coolers to form a HEMS-II. Based on this structure, we can choose a half of the HEMS-II as the calculated model. In order to build the model easily, distance between HEMS-II can be shortened. Finally, the size of the model is 1221mm*638mm, the layout and model is shown in Fig.3.

Figure 3 The key points on working face and layout of HEMS-II in Jiahe coal mine

Figure 4 The model and mesh of HEMS-II
3.1.2 Simulation results of water temperature

![Figure 5 Air temperature in HEMS-II](image1)

![Figure 6 Air temperature after every HEMS-II](image2)

(x axis is number of HEMS, and y axis is temperature)

From Fig.5-6, we know air temperature change is obvious, colour gradually turn green from red and air temperature is decreased to 19℃ from 32℃. Air temperature is decreased by 1℃ when it flow through one HEMS-II. The tested temperature is 20~21℃ at the end of HEMS-II and the simulation results is 19℃, which shows that simulation result is correct.

3.2. Numerical simulation of roadway

3.2.1 Model establishment

![Figure 7 Model and mesh of the roadway](image3)

The model and mesh is shown in Fig.7, the left picture is draw in proportion, the size of roadway and the temperature of air and rock is shown in the second figure from left, the air velocity is 2m/s. After built the model, we meshed the model, which is shown in Fig.7.

3.2.2 Simulation results of air temperature

![Figure 8 Air temperature of whole and key cross section of roadway](image4)
From figure 8, we can see air temperature is increased along the roadway, the colour turn green from blue, and from figure 10, we know air temperature at the beginning of roadway is 18℃, but at the control point C, the temperature is 28.5℃, which is less than 30℃ and meet state regulation. From figure 9 (b), we can see the temperature is increased by 1 degree per 100 meters in the roadway.

3.2.3 Comparison between simulation results and tested results

The tested temperature on the key points (F1, F2, A, B, C, as is shown in figure 3) on working face is shown in figure 10-13. In all figures, the x axis is date, and y axis is temperature, the working time of HEMS is in summer, which is July, August, September and October, that is from 7.30 to 9.28.

From simulation results and tested data, we can get table 1.

| Points | F1/℃ | F2/℃ | A/℃ | C/℃ |
|--------|------|------|------|------|
| Tested data | 32   | 22.5 | 26   | 28   |
| Simulation data | 32   | 18   | 27.2 | 28.5 |

Compared with the tested data and simulation result, the two data are consistent, which proved simulation correct of HEMS-II and roadway, and we can predict the air temperature before cooling in future.
4. Conclusions
The main conclusions are:

(1) Reverse Carnot cycle and working process of HEMS in Jiahe coal mine is analysed. In HEMS cooling technology, HEMS-I is the key equipment, cold energy is extracted by HEMS-I from mine water inrush underground. Refrigerant flows circulation in HEMS-I, it absorbs heat when it flows into evaporator, and it releases heat when it flows into condenser. Based on the recirculation of refrigerant, more and more heat in deep coal mine is extracted and stored in water mine inrush for building heating. This is the reverse Carnot cycle.

(2) FLUENT is adopted to simulate heat exchange process in HEMS-II and in roadway. Compared with the monitored data, simulation on HEMS-II and roadway is proved correct. We can predict air temperature in roadway by fluent simulation and it offer basis for optimization design in future.

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