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Research on underground local carbon dioxide transcritical refrigeration equipment

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Abstract: *Taking Zhujidong Coal Mine as an example, the cooling technology of mine working face is studied, and the required cooling capacity of driving working face is calculated. According to the principle of carbon dioxide phase change large temperature difference refrigeration, the carbon dioxide refrigeration cycle system is designed, which is composed of compressor, oil and gas separation, gas cooler, evaporator, oil separation, sensor and related pipelines. The equipment is applied in the 1331(1) Yunshun driving face of Zhujidong Coal Mine. The outlet temperature of the air cooler is stable between 15℃ and 18℃ when the air flow rate is 810m^3/min. The absolute humidity of the outlet of the working face decreases from 80% to 90% of the local fan inlet to 45% to 55%. The equipment solves the problem of controlling temperature and humidity of underground thermal environment and improves cooling and dehumidification effect.*

Keywords: *Local refrigeration; Carbon dioxide transcritical; Dehumidify; Equipment*

1. Introduction

With the deepening of mining depth, the high temperature and heat damage of mine are more and more serious. According to incomplete statistics, there are more than 1200 high-temperature surfaces in high-temperature and non-high-temperature mines in China's mining industry, and the problem of heat damage is very prominent [1]. Among them, the air flow temperature of the mining face exceeds 30 °C, and some mines even exceed 40 °C, which has exceeded the standard of "the air temperature of the mining face shall not exceed 26 °C" stipulated in the *Coal Mine Safety Regulations*. In terms of occupational hazards, the working environment of high temperature and humidity has seriously affected the health of underground operators, which is one of the main occupational hazards in China's coal mine production, just like coal dust hazards [2]. To solve the problem of temperature and humidity control in underground thermal environment is not only an urgent matter for shallow mining at present, but also the foundation for the mine to safely enter the deep mining stage.

2. Zhujidong refrigeration status and existing problems

2.1 Zhujidong refrigeration status

Zhujidong Mine of Huainan Mining Group is a typical 1000m deep mine in China, which belongs to high gas and high temperature mine. According to the temperature gradient, the temperature of the first-level -906m rock is 41.9°C. The rock temperature of -985m is 44.1°C, which belongs to the second high temperature region. In summer, the temperature of mined air flow can reach more than 35°C, and the relative humidity is more than 95%, resulting in serious heat damage [3].

According to the arrangement of mine cooling units, Zhujidong Mine adopts underground surface joint centralized refrigeration system [4]. According to the different wind speed and cooling load of each working face, the total cooling capacity of 16 heads on 3 faces reaches 13.4 MW. After considering the cold loss along the way, the temperature rise of the water pump and the additional coefficient of cooling load, the installed capacity of the ground refrigeration equipment is 18 MW, and three refrigeration units are designed to operate in parallel, and the cooling capacity of each refrigeration unit is 6 MW. Three centrifugal refrigeration units and one steam type lithium bromide refrigeration unit are installed in the central cooling station of Zhujidong Mine, with the power of 6000 kW, 6000 kW, 1744 kW and 5035 kW

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respectively. The refrigerant of centrifugal refrigeration unit is freon, and chilled water is used as the cooling medium to achieve underground cooling. Lithium bromide absorption and steam compression combined cycle units use waste heat or low-grade heat for cooling to produce cold water.

2.2 Deficiencies in Zhujidong refrigeration system

1) Steam type lithium bromide refrigeration unit is out of service

Model SD80C-TCU requires a steam pressure of 0.6 MPa and a steam consumption of 5.39 t/h. Due to the lack of steam, the steam type lithium bromide refrigeration unit has been discontinued.

2) The cold loss of the cooling pipeline is large

The cooling branch pipe of the existing cooling pipeline entering the working roadway is not insulated, and the cold water temperature of the pipeline rises from 7 °C to 14 °C, and the temperature rises by 7 °C, resulting in large cold loss.

3) Low unit efficiency

In the high temperature season in summer, the centrifugal unit is affected by the diffused cooling efficiency of the cooling tower, and the actual cooling efficiency is low. The actual output cooling capacity of 6000 kW unit only accounts for 48.07% of the theoretical design cooling capacity.

4) Underground cooling system

The air cooler copper pipe can be seen on a layer of cohesive coal ash layer, the air cooler exchange efficiency is low, the total exchange efficiency of 5~7℃ temperature difference, the cold capacity is not fully released into the hot air. The actual cooling capacity of 400 kW air cooler is 150-250 kW.

5) The thermal humidity is not controlled

After the air cooler cools the hot air and condenses and dehumidifies, the relative humidity of the air outlet is 100%.

3. CO_2 refrigeration system design

In view of the shortcomings of the refrigeration system in Zhujidong, if the refrigerant is replaced, the compressor unit needs to be replaced. The cost is expensive, and the cold loss in the transportation process can not be avoided. To this end, the local refrigeration equipment is designed to be linked with the existing refrigeration system, and the carbon dioxide with better refrigeration effect is selected as the refrigerant, and the cold water of the original refrigeration system is connected to the heat exchanger, and the refrigeration effect is well enough to ignore the heat source generated by hot water.

3.1 Refrigerant

When the critical pressure of CO_2 is 7.3 MPa, the critical temperature is 31.1 ℃. According to the external conditions of the cycle, sub-critical cycle, trans-critical cycle and supercritical cycle can be realized. The pressure enthalpy relationship of CO_2 is shown in Figure 1.

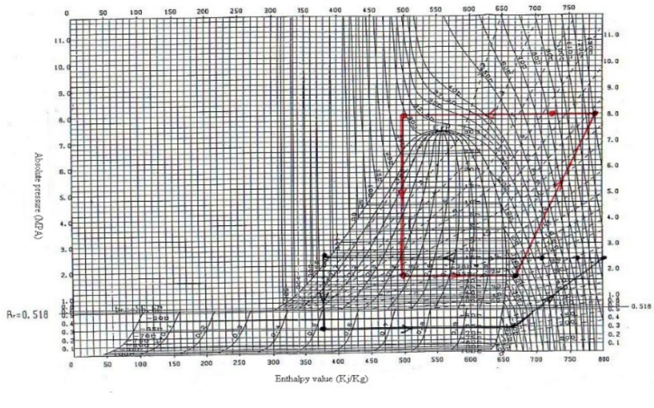

Figure 1: CO_2 pressure enthalpy performance diagram

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CO_2 supercritical cycle is completely different from ordinary vapor compression refrigeration, there is no phase change in the cycle process of working medium, and this cycle method is not used in refrigeration applications. Compared with the traditional subcritical refrigeration cycle, the transcritical CO_2 does not undergo phase transition during the cooling process, and the entire heat release process is above the critical point, which is the heat removal of non-condensing phase transition and has a larger temperature slip [5-6]. Taking into consideration, the cross-critical cycle of CO_2 is selected.

3.2 System working principle

The CO_2 refrigeration system is connected by a compressor, oil and gas separation, gas cooler, evaporator, oil separation, sensor and related pipelines [7].

System working principle: gaseous CO_2 forms high temperature and high pressure supercritical fluid through two compressors; It flows into the gas cooler, at this time, the other pipe of the cooler uses the cold water of the previous refrigeration system to heat exchange the compressed high temperature and high pressure CO_2. At this time CO2 is low temperature and high pressure; The low temperature and high pressure CO_2 is reduced through the pressure reducing coil, and CO_2 is the low temperature and low pressure liquid. Finally, it flows into the evaporator and air for convective heat transfer. CO_2 evaporates into gas, enters the gas storage tank for buffering, and finally the compressor for circulation. The working principle of CO_2 is shown in Figure 2.

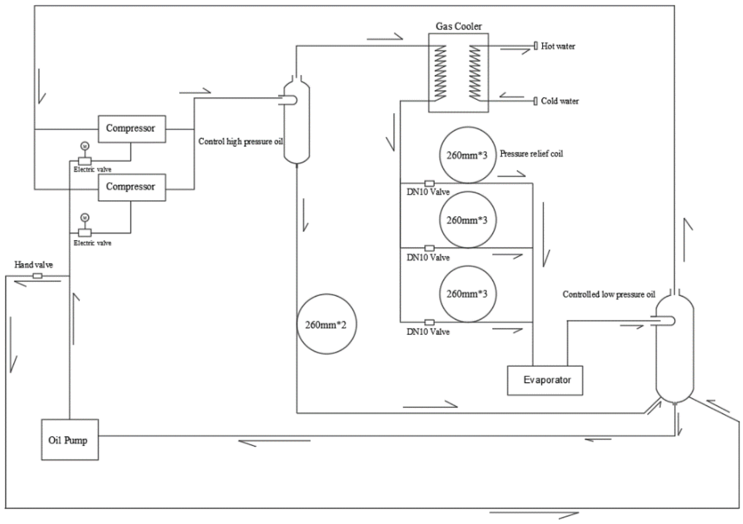

Figure 2: Schematic diagram of CO_2 refrigeration

3.3 Compressor selection

The standard cooling capacity of each original underground air cooler is 400 kW. One for the driving face can meet the demand, and five for the mining face is 2000 kW cooling capacity, which can meet the demand of the mining face. The mobile refrigeration unit with a maximum cooling capacity of 450 kW is designed to meet the cooling requirements of a drilling face.

Considering the special properties of CO_2, the compressor adopts a closed structure [8]. The refrigerating capacity of this system is 450 kW, so the DORIN compressor produced in Italy is selected. The mechanical diagram of the compressor is shown in Figure 3; Model: CD6 801-45H. DORIN can achieve 200KW+ for CO_2 transcritical compression, and the two compressors work at the same time to meet the refrigerating capacity demand.

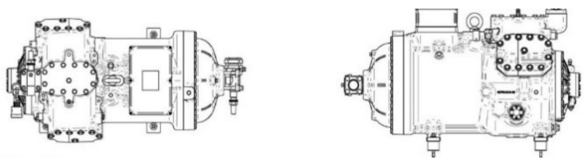

Figure 3: Compressor mechanical structure diagram

3.4 Gas cooler

The plate structure of the system gas cooler is selected, and the plate structure heat exchanger is also generally used in the CO_2 refrigeration system. The plate structure cooler is shown in Figure 4. The gas cooler is made of 150 corrugated plates stacked with a spacing of 3.5 mm and sealed by welding. The structure is compact and the flow of fluid in the flow channel is independent of each other [9].

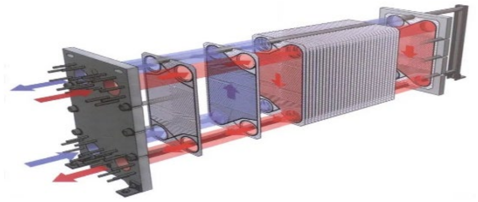

Figure 4: Plate cooler structure drawing

The local refrigeration equipment is linked with the original system, and the cold water generated is connected to the gas cooler of the local refrigeration equipment, and the heat is exchanged with the compressed high temperature and high pressure carbon dioxide, and the hot water generated enters the cooling tower.

3.5 Evaporator

To calculate the total heat transfer area required by the evaporator of the heat exchanger, the material of the evaporator is to choose a "straight" crossed copper tube [10-11], perpendicular to the flow direction, tube spacing S1=25.4 mm, row spacing S2=22 mm. Copper pipe selection φ10*0.6 copper pipe (d_0=10 mm). The dimensions of the evaporator are shown in Figure 5.

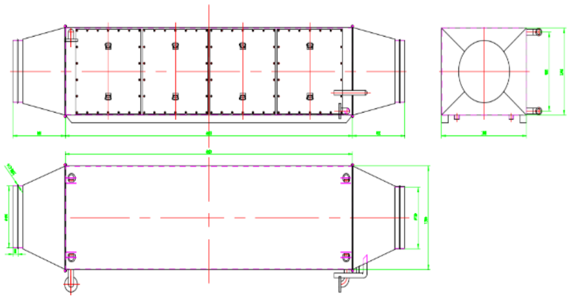

Figure 5: Evaporator exterior mechanical drawing

3.6 Pressure relief coil

The system uses adiabatic capillaries instead of throttle valves for reference to small CO_2 refrigeration systems. Outlet flow rate and outlet velocity affect the heat transfer efficiency of the evaporator, so the selection of an appropriate pipe diameter is of great significance to the refrigeration effect [12]. After simulation and experiment, DN73 copper pipe is selected for the decompression coil, and its mechanical structure is shown in Figure 6. The pressure of the pipe is 10 MPa. The thickness of the pipe wall and the design strength meet the requirements of the specification. The experimental verification shows that the flow rate is less affected by the inlet pressure and temperature.

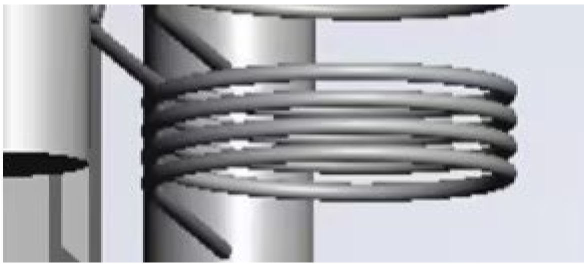

Figure 6: Mechanical picture of decompression coil

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3.7 Electronic control system

It is necessary to collect part of the pressure parameters and part of the temperature parameters of the system. Since the outlet gas temperature is too high and the pressure is large, the customized pressure sensor and temperature sensor of West AVIC are selected. The oil level of the compressor, the oil level of the oil separator and the intake pressure tank are monitored, and the oil level sensor designed by Ping An Kecheng intelligent safety equipment is selected. The sensor is a five-wire system. When there is a lack of oil, the oil level alarm signal and oil filling signal can be detected to achieve oil filling control. The equipment is equipped with two solenoid valves for the two compressors to control the oil supply, and the other valves are manual control valves. The electrical principle is shown in Figure 7.

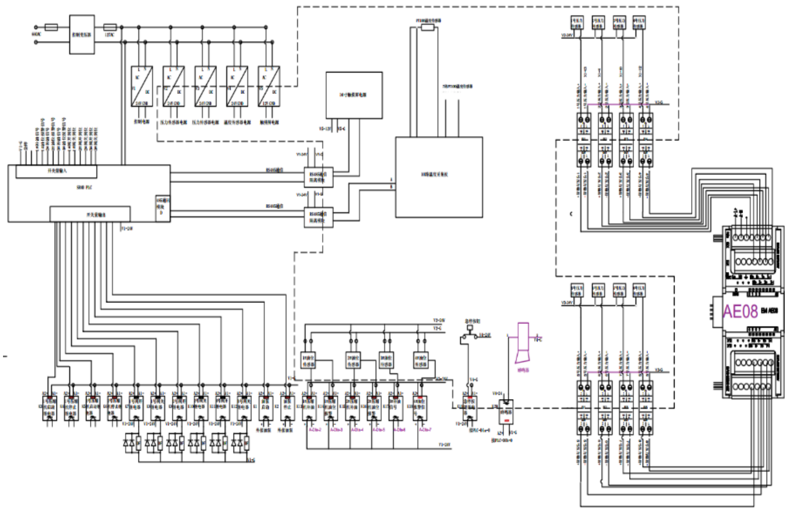

Figure 7: Electric control schematic

When the PLC oil shortage alarm input terminal detects a low level signal, the oil valve opens. At this time, it starts to fill the compressor oil, 45s later we close the oil valve. Since the oil shortage alarm signal detection error is easy to occur during the oil replenishment process, the valve is closed for 20 s, and then determine whether to open the oil valve again.

If the following problems occur, the system stops running:

1) Oil pressure difference ≤0.04 MPa;

2) Compressor inlet pressure ≥5.0 MPa, ≤ 2.6 MPa;

3) Evaporator inlet pressure ≥5.0 MPa;

4) Evaporator outlet pressure ≥5.0 MPa, ≤ 2.6 MPa;

5) Compressor outlet pressure ≥10.5 MPa, ≤7.0 MPa;

6) Air cooler outlet pressure ≥10.5 MPa, ≤7.0 MPa;

7) Compressor outlet pipe temperature ≥130 ℃;

8) Compressor connecting cavity temperature ≥70 ℃;

9) Compressor winding temperature ≥130 ℃;

10) Pump outlet temperature ≥50 ℃.

4. Conclusion

Underground mobile CO_2 cross-critical refrigeration and dehumidification integrated machine was applied in 1331(1) Yunshun driving face of Zhujidong Coal Mine under Huaihe Energy Group. During the downhole application, the unit operated normally, the liquid CO_2 of the air inlet cooler was below 5℃, and the outlet temperature of the air cooler was stable between 15℃ and 18℃ when the air flow rate was 810 m^3/min. The absolute humidity of the outlet of the working face is reduced from 80% to

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90% of the local fan inlet to 45% to 55%, which meets the project design index and greatly improves the human comfort of the working face operators.

The introduction of CO_2 refrigeration technology into the underground to solve the needs of large temperature difference refrigeration dehumidification, in improving the underground working environment, ensuring the occupational health of workers, improving production efficiency, reducing operating costs, energy saving and emission reduction will have significant economic and social benefits. It has a great demonstration significance and widespread promotion value in the mining industry, and contributes to the utilization of "carbon peaking and carbon neutrality goals" in China.

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