International Journal of Frontiers in Engineering Technology
ISSN 2706-655X Vol. 7, Issue 4: 6-16, DOI: 10.25236/IJFET.2025.070402

Research on Underground Mobile Carbon Dioxide Transcritical Green Refrigeration Technology and Equipment

Li Xing

Huainan Donghua Industrial (Group) Co., LTD., Huainan, Anhui Province, 232001, China
Ping'an Kaicheng Intelligent Safety Equipment Co., LTD., Huainan, Anhui Province, 232001, China

Abstract: *This study delves into various factors contributing to mine heat hazards and the cooling technologies applicable to mine working faces. The research focuses on the development of mobile carbon dioxide transcritical green refrigeration technology and equipment for underground applications. Specifically, a mobile precision refrigeration device is developed, tailored for deep mining scenarios such as mines and tunnels, especially in regions plagued by severe heat hazards. Leveraging liquid carbon dioxide as both the refrigerant and the secondary coolant, this system capitalizes on the unique property of carbon dioxide. When transitioning from the supercritical state under high temperature and pressure to the subcritical state at low temperature and pressure, and particularly during the phase change from liquid to gas, carbon dioxide exhibits rapid and substantial heat absorption capabilities. This innovative approach enables swift cooling and dehumidification with a significant temperature differential. It not only minimizes energy consumption and operational losses but also markedly enhances the efficiency of cooling and dehumidification processes. As a result, the comfort of on-site workers is greatly improved, thereby optimizing the working environment in these challenging settings.*

Keywords: *Underground Mobile Carbon Dioxide Transcritical Precision; Refrigeration Dehumidification*

1. Introduction

From the perspective of actual mine production, as the depth of mining continues to increase, the problem of high-temperature heat hazards in mines is becoming increasingly severe. According to incomplete statistics, there are as many as 1,200 high-temperature and non-high-temperature underground working faces in China's mining industry, and the problem of heat hazards is very prominent. The air temperature in the working faces of mining and excavation exceeds 30℃, and in some mines, it even exceeds 40℃, far exceeding the standard stipulated in the "Coal Mine Safety Regulations" that "the air temperature in the working faces of mining and excavation shall not exceed 26℃". In terms of occupational hazards, heat hazards have seriously affected the physical health of underground workers. Like coal dust hazards, it is one of the main occupational hazard factors in China's coal mining industry. Conducting heat hazard prevention and control work is also an important part of coal mine occupational health, which is of great significance for improving the level of coal mine occupational health.

2. Technical Background

2.1 Research Status of Mine Cooling Technology

At present, there are mainly two types of mine cooling technologies in the world: non-refrigeration cooling and refrigeration cooling. For high-temperature mines, the effect of non-refrigeration cooling is not obvious and it is no longer used alone. Mine cooling air conditioning systems can be classified according to the working medium as: cold water refrigeration mine air conditioning systems, ice refrigeration mine air conditioning systems, absorption refrigeration air conditioning systems, etc. According to the layout of the mine cooling unit, they can be mainly divided into: underground centralized, ground centralized, underground and ground combined centralized, and underground local

ISSN 2706-655X Vol. 7, Issue 4: 6-16, DOI: 10.25236/IJFET.2025.070402

systems[1].

2.2 Current Problems of Commonly Used Cooling and Cooling Systems in Mines

At present, the commonly used cooling systems in mines have the following problems:

1) Low efficiency of the cooling system

2) Difficult control of thermal environment humidity and lack of effective research on dehumidification in underground conditions

3) High cold consumption in the dehumidification process

4) Problems of condensation heat utilization and emission

2.3 Selection of Refrigerants

2.3.1 Requirements in terms of safety

The refrigerant should not burn, not explode, be non-toxic; have weak permeability and be easy to detect leaks; in case of partial leakage, it should have no irritating smell and cause no harm to human health, and have no pollution to the environment[2].The refrigerant analysis is shown in Fig.1.

Refrigerant		ODP Ozone attenuation index	Global warming potential value	Security level
HCFC	R22	0.055	1700	A1
HFC	R134a	0	1300	A1
	R404A	0	3850	A1
	R407C	0	1370	A1
	R410A	0	1370	A1
	R507A	0	3900	A1
Natural fluids	R717 (ammonia gas)	0	<1	B2
	R290 (propane)	0	3	A3
	R600a (isobutane)	0	3	A3
	R744 CO_2	0	1	A1

Fig.1 Refrigerant Analysis

2.3.2 Requirements in terms of environmental impact

The lifespan of refrigerants in the atmosphere should be short to reduce their impact on the environment on which human beings rely. ODP is an indicator representing the potential degree of a refrigerant's consumption of atmospheric ozone molecules, and it is a relative comparison value based on CFC-11 being 1.0. As an environmentally friendly refrigerant, the ODP value should be zero or as small as possible to reduce damage to the atmospheric ozone layer; GWP is an indicator measuring the impact of refrigerant substances on global climate warming, and it is a relative comparison value based on CO_2 having an effect of 100 years as 1.0. As an environmentally friendly refrigerant, the GWP value should be as low as possible to reduce the impact on global greenhouse effect; in addition, there should be no photochemical fog reaction, and the impact on the atmosphere, water sources, and soil should be minimal[3].The trend of environmental impact is shown in Fig.2.

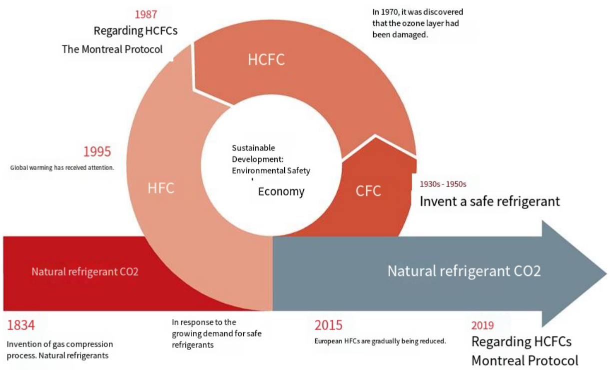


Fig.2 Trend of Environmental Impact

ISSN 2706-655X Vol. 7, Issue 4: 6-16, DOI: 10.25236/IJFET.2025.070402

2.3.3 Requirements in Thermodynamics

The standard boiling point of the refrigerant should be low to meet the requirement of obtaining a lower evaporation temperature for refrigeration; the working pressure should be appropriate to reduce the compression power consumption and the number of compression stages; the latent heat of vaporization should be large, and the unit volumetric refrigeration capacity should be higher, to reduce the circulation volume of the refrigerant and thereby reduce the size of the refrigeration compressor; the thermal conductivity should be high to improve the heat exchange efficiency of the heat exchange equipment[4].

2.3.4 Requirements in Physical Chemistry

The density and viscosity of the refrigerant should be small to reduce the flow resistance of the refrigerant in the refrigeration system; it should be able to dissolve well with lubricating oil to ensure adequate lubrication of all parts of the compressor; it should have certain water absorption capacity to avoid ice blockage in the low-temperature part of the system and not corrode metals, have good chemical stability and insulation properties, and good thermal stability, and not decompose at high temperatures.

2.3.5 Requirements in Economic Aspect

Liquid carbon dioxide can be used as a refrigerant with a simple production process, low cost, and easy availability.

2.4 Principle of CO2 Refrigeration Cycle

When the critical pressure of CO_2 is 7.3 MPa, the critical temperature is 31.1℃. Based on the external conditions of the cycle, three cycle modes can be achieved: subcritical cycle, transcritical cycle, and supercritical cycle. Among them, the supercritical cycle of CO_2 is completely different from the ordinary vapor compression refrigeration cycle. The cycle process of the working medium has no phase change, and this cycle mode is not adopted in the refrigeration application; the subcritical cycle of CO_2 is shown as 1→2→3→4→1, at this time, the suction and exhaust pressures of the compressor are lower than the critical pressure, the evaporation temperature and condensation temperature are also lower than the critical temperature, the heat exchange process mainly relies on latent heat to complete, currently, the subcritical cycle of CO_2 is mainly used in the low-temperature refrigeration equipment of the low-temperature stage of the cascade refrigeration system.

The process of the transcritical cycle of CO_2 is slightly different from that of the ordinary vapor compression refrigeration cycle, the cycle process is shown as 1→2'→3'→4'→1. At this time, the suction pressure of the compressor is lower than the critical pressure, the evaporation temperature is also lower than the critical temperature, the heat absorption process of the cycle is carried out under subcritical conditions, but the exhaust pressure of the compressor is higher than the critical pressure, the heat exchange process of the working medium on the high-pressure side is completed through sensible heat exchange, this is completely different from the condensation process of the ordinary vapor compression refrigeration cycle, at this time, the high-pressure heat exchanger is called an air cooler[5].

3. Research Contents

For the difficult problems of controlling the temperature and humidity of the underground thermal environment, an in-depth study was conducted, replacing the traditional refrigerant with CO_2 for the research of underground mobile cooling technology, and developing an underground mobile CO_2 transcritical refrigeration dehumidification integrated machine.

1) Based on the actual situation on site, the engineer analyzed various factors of the sources of heat damage in the mine, and calculated the cooling load required for the excavation working face;

2) According to the principle of CO_2 phase change large temperature difference refrigeration and related calculation formulas, the engineer designed the CO_2 refrigeration cycle system, which includes CO_2 gas compression, heat exchange, evaporator, air cooler, automatic control, data acquisition, etc. subsystems;

3) The engineer developed an underground transcritical refrigeration dehumidification integrated machine, select the components of the equipment, collect data on pressure, temperature, etc. of the equipment, and control the valves;

4) Operators conduct ground test experiments to verify the stability of the underground mobile CO_2 transcritical refrigeration dehumidification integrated machine.

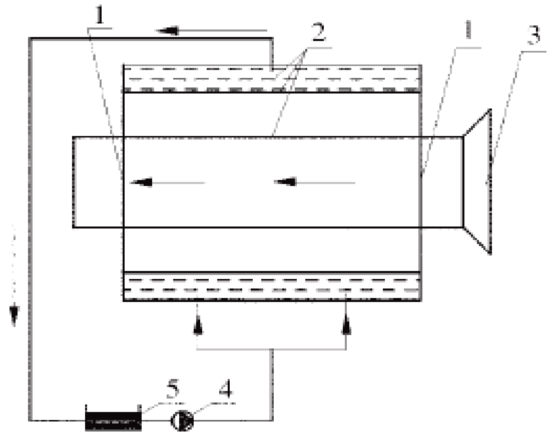
3.1 Research on Phase Change Refrigeration Mechanism

The gas, liquid, and solid are the three states of matter. The change of the base state of matter is called phase change. During the phase transition process, due to the rearrangement of the molecules and the change in the speed of molecular thermal motion, heat is absorbed or released. When a substance undergoes a phase transition from a dense state to a sparse state, it absorbs latent heat; conversely, when it undergoes a phase transition from a sparse state to a dense state, it releases latent heat. Phase change refrigeration is achieved by utilizing the heat absorption effect of the former.

3.2 Heat Damage Sources and Degree of Impact

1) Distribution Characteristics of Temperature Field of Surrounding Rock in Shaft and Tunnel

Through on-site data collection, laboratory experiments, and the method of combining theoretical research with model comparison analysis, the changes in the temperature at the entrance and exit of the simulated roadway under different surrounding rock temperatures and air volumes are explained. Based on different air volumes and different simulated surrounding rock temperatures, the characteristics of heat transfer of the simulated roadway surrounding rock are studied; based on the same surrounding rock temperature, the changes in the inlet and outlet temperatures and the changes in the heat transfer coefficient of the surrounding rock under different simulated air volumes are studied; based on the same surrounding rock temperature, the changes in the inlet and outlet temperatures and the heat transfer coefficient of the surrounding rock under different simulated air volumes are studied.The test system for the thermal exchange characteristics of unstable rock masses is shown in Fig.3.



1- Thermal resistance, humidity-sensitive resistance; 2- Liquid-type thermal resistance; 3- Variable-frequency fan; 4- Water pump; 5- Hot water storage tank

Fig.3 Test System for Unstable Rock Mass Heat Exchange Characteristics

2) Analysis of typical heat sources in mines

The typical heat sources in mines mainly include heat dissipation from surrounding rocks, self-compression of air, heat dissipation from electrical and mechanical equipment, and heat dissipation from transported coal and gangue.

3) Multi-field coupling model of speed field, temperature field and humidity field in working face thermal environment

Establishing a calculation model for the unstable coefficient of heat diffusion due to the coupling effect of the temperature field of surrounding rocks and the airflow field, the engineer simulated the dynamic evolution process of temperature, and through the construction of an overall correlation model of thermal environment medium coefficients, we can determine the boundary conditions of the deep well thermal environment model, as shown in Fig.4.

Using the basic coefficients to set the boundary conditions, the engineer combined the previous theoretical experience to establish the temperature equation and the airflow velocity equation, establish

ISSN 2706-655X Vol. 7, Issue 4: 6-16, DOI: 10.25236/IJFET.2025.070402

a mathematical model of multi-field coupling effect, and use the ANSYS software to simulate the distribution and diffusion of heat through theoretical calculation and solve the multi-field coupling model, as shown in Fig.5.

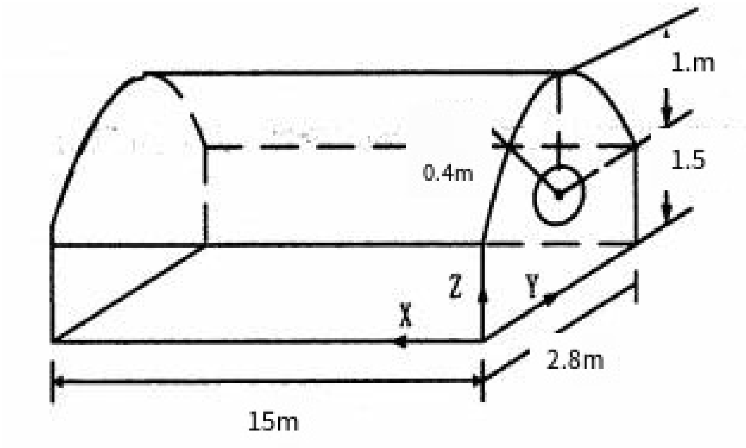


Fig.4 Geometric Model of the Mining Workface

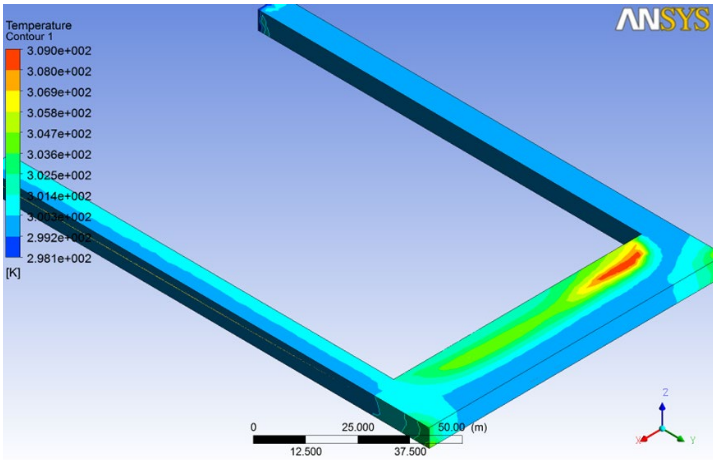


Fig.5 Three-dimensional simulation diagram of temperature field

3.3 Cooling Demand Analysis

The original underground air-cooler has a standard cooling capacity of 400kW per unit. One unit can meet the demand for the excavation face, and five units with a cooling capacity of 2000kW each can meet the demand for the mining face. The designed maximum cooling capacity is a 450kW mobile refrigeration device, which can meet the cooling demand of one excavation working face in the mine.

3.4 System Principle

The underground mobile carbon dioxide transcritical refrigeration dehumidification unit consists of a compressor, oil separation system (high-pressure oil control device and low-pressure oil control device), gas cooler, oil replenishment system (oil pump and solenoid valve), and depressurization system. The equipment system diagram is shown in Fig.6.

ISSN 2706-655X Vol. 7, Issue 4: 6-16, DOI: 10.25236/IJFET.2025.070402

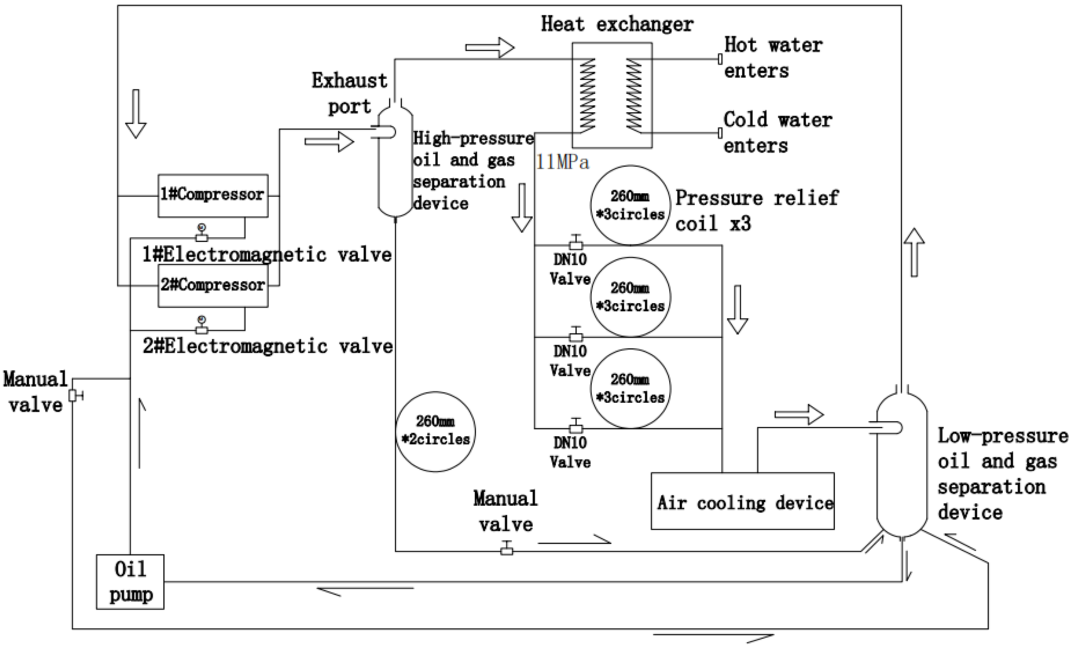


Fig.6 Equipment System Diagram

During operation, gaseous carbon dioxide is compressed by the compressor to form a supercritical vapor fluid at high temperature and high pressure, which flows into the gas cooler and undergoes heat exchange with cold water. At this time, the carbon dioxide is a low-temperature and high-pressure subcritical liquid fluid; the depressurization module reduces the pressure of the low-temperature and high-pressure carbon dioxide, as the pressure decreases, the temperature of the liquid carbon dioxide continues to drop until it reaches a low-temperature and low-pressure (4-3.5MPa, 5-0°C) liquid state; finally, it flows into the air cooler and the air duct airflow for heat exchange, where the carbon dioxide undergoes phase change and evaporates into gas, returning to the gas-liquid (oil) separator for separation and then entering the compressor for circulation.

4. Scheme Design

Based on the working principle of the mobile underground carbon dioxide transcritical refrigeration dehumidification unit, the parameters such as pressure, temperature and oil level of the system are collected and analyzed through the programmable controller.

4.1 System Control

The programmable controller collects and monitors the pressure, temperature and oil level parameters at the key points of the system. The distribution map of the control points is shown in Fig.7.

ISSN 2706-655X Vol. 7, Issue 4: 6-16, DOI: 10.25236/IJFET.2025.070402

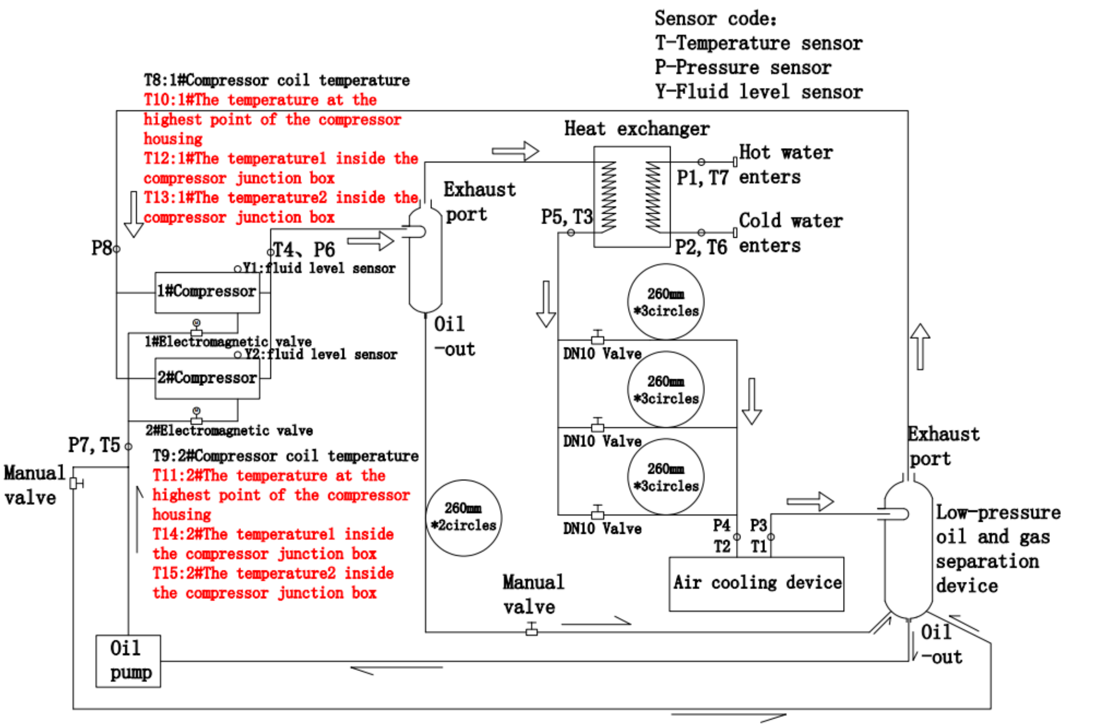


Fig.7 Distribution figure of control points

4.1.1 Startup Control

When the control system detects that the startup conditions are met, it will first open the cooling water supply valve to ensure the normal operation of the cooling water system; then start the oil pump. Once the oil pressure difference meets the startup conditions, one compressor will be started and run for 10 seconds. After that, the control system estimates whether the inlet and outlet pressures of the compressor meet the operation conditions (inlet pressure≥2.6 MPa,≤5.0 MPa;outlet pressure≥7.0 MPa,≤10.5 MPa). When the outlet pressure approaches 7.0 MPa, the second compressor will be started. The parameters of the device will stabilize approximately after 5 minutes.

4.1.2 Shutdown Control

First, the control system stops the compressor, then stops the oil pump after 3 minutes. After 20 minutes, when the outlet water temperature of the cooling water is consistent with the inlet water temperature, the control system stops the water supply valve. Fault shutdown: If any of the shutdown conditions is met, the device will automatically shut down.

4.1.3 Startup Conditions

1) The power supply system is normal;

2) The oil pump starts, and the oil pressure difference is greater than 0.04 MPa;

3) The pipeline pressure of the compressor system is greater than 2.6 MPa, less than 10.5 MPa;

4) The cooling water system is operating normally, and the inlet and outlet pressures of the cooling water pipeline (P1, P2) are greater than 0.05 MPa;

5) The inlet water temperature of the cooling water pipeline is less than 35℃;

6) There are no other fault information.

4.1.4 Automatic Shutdown Conditions (The following are logical "OR" relationships)

1) The oil pressure difference ≤0.04 MPa;

2) The inlet pressure of the compressor ≥5.0MPa,≤2.6MPa;

3) The inlet pressure of the air cooler ≥5.0MPa;

4) The outlet pressure of the air cooler ≥5.0MPa,≤2.6MPa;

5) The outlet pressure of the compressor ≥10.5MPa,≤7.0MPa;

6) The outlet pressure of the air cooler ≥10.5 MPa,≤7.0MPa;

7) The vacuum electromagnetic starter detects a compressor fault (overvoltage, undervoltage, short circuit, leakage lockout, overload, etc.);

8) The temperature of the compressor housing ≥130℃;

9) The outlet temperature of the compressor pipeline ≥130℃;

10) The temperature of the connection cavity of the compressor ≥70℃;

11) The winding temperature of the compressor ≥130℃;

12) The inlet water temperature of the cooling water ≥35℃;

13) The outlet water temperature of the cooling water ≥80℃;

14) The outlet temperature of the air cooler ≥40℃;

15) The outlet temperature of the air cooler ≤0℃;

16) The outlet temperature of the oil pump ≥50℃;

17) Human shutdown signal, emergency stop button action.

4.2 Compressor Control

One explosion-proof and intrinsically safe dual-loop vacuum electromagnetic starter is designed to supply power and perform related protection and monitoring for the two compressors; the mine-used explosion-proof and intrinsically safe programmable control box is equipped with a programmable controller to achieve data collection of temperature, pressure, oil level, etc., and control the start and stop of the compressors and protection according to the changes in relevant parameters.

The project designed one mine-used intrinsically safe and explosion-proof programmable control box to be used as a vacuum electromagnetic starter, which realizes power supply for the oil pump and related protection monitoring. The mine-used intrinsically safe and explosion-proof programmable control box is equipped with a programmable controller, which enables data collection of the oil pump outlet temperature, pressure, and oil level, and controls the start and stop of the oil pump and protection based on changes in relevant parameters.

The intrinsically safe oil level sensor is associated with the monitoring of the compressor oil level, using a switch input, five-core wire connection (red - 24V, black - GND, green - oil replenishment output, yellow - low oil alarm, white - no oil), to achieve control of the oil replenishment system. The logic diagram for oil quantity replenishment control is shown in Fig.8.

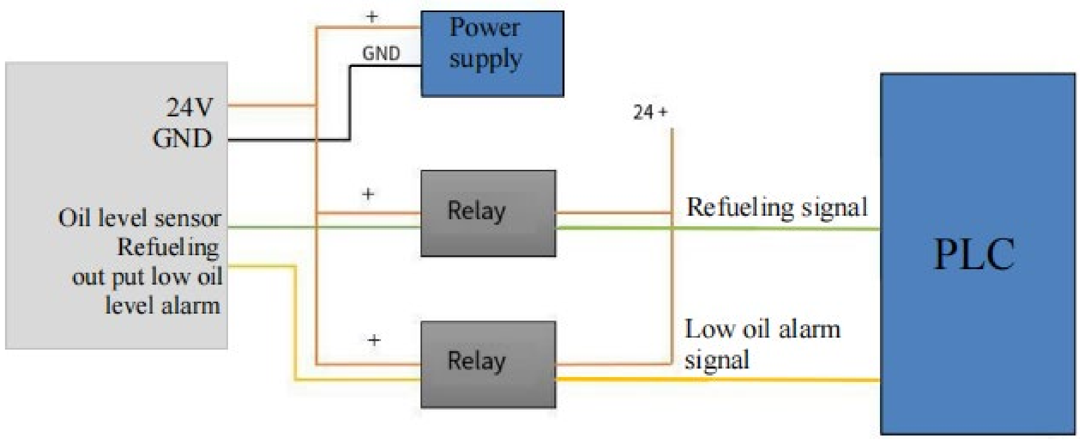


Fig.8 The logic diagram for oil quantity replenishment control

ISSN 2706-655X Vol. 7, Issue 4: 6-16, DOI: 10.25236/IJFET.2025.070402

4.3 Refrigeration System

The device conducts closed-loop control of carbon dioxide, and after filling, it circulates internally. Through the compressor's continuous pressurization, it passes through the oil separation component, heat exchange component, gas-liquid separation component, pressure control component, etc., and is sent to the air-cooled unit for air cooling exchange, absorbing heat and vaporizing the carbon dioxide back to the unit.

5. System Functions

The system is equipped with a mine-used explosion-proof and intrinsically safe programmable control box, which has functions such as display, setting, control, alarm, and emergency stop. It can display the operating status and various parameters in real time, and can promptly consult data records and alarm records.The parameter display interface is shown in Fig.9.

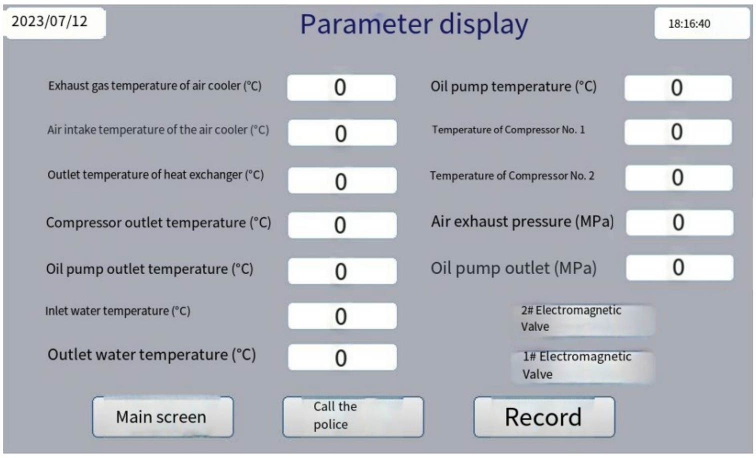


Fig.9 Parameter display interface

5.1 Air Cooler Protection

The air cooler uses cooling water to conduct heat exchange with the high-temperature and high-pressure gaseous carbon dioxide to control the temperature during the phase change of carbon dioxide liquefaction. According to the requirements of cross-critical refrigeration of carbon dioxide, the air cooler cools the high-temperature and high-pressure gas to keep the outlet temperature below 31.1℃. To meet the control needs, a PT100 temperature sensor is installed in the outlet pipeline of the air cooler to monitor the outlet temperature in real time; at the same time, a temperature protection value is set to monitor the water supply status of the cooling water to prevent the device pressure from rising.

At the inlet and outlet pipelines, a pressure sensor is installed respectively. When the detected pressure value is less than 0.05MPa, it is determined that the cooling water of the device is insufficient, an alarm signal is issued, and the machine is stopped to prevent the device from remaining under high pressure; a PT100 temperature sensor is installed at the outlet of the cooling water to monitor the temperature of the cooling water. When the outlet temperature exceeds 75℃, an alarm signal is issued, and when the outlet temperature reaches 80℃, an alarm signal is issued and the machine is stopped to prevent the device from remaining at high temperature.

5.2 Oil Temperature Protection

To prevent the oil temperature from being too high, the oil circuit is monitored for temperature. A PT100 temperature sensor is installed at the outlet pipeline of the oil pump to prevent the oil temperature from exceeding the flash point of PAG68 lubricating oil. Considering the viscosity index of the oil, the system lubrication effect, and the impact of adding lubricating oil to the compressor on the liquefaction of carbon dioxide, an alarm signal is set to be issued when the oil temperature exceeds 50℃, and the device is stopped.

ISSN 2706-655X Vol. 7, Issue 4: 6-16, DOI: 10.25236/IJFET.2025.070402

5.3 Dual and Failure Protection

1) Two PT100 temperature sensors are pre-buried in the wiring cavity of the compressor and connected to the programmable controller control system to achieve dual protection of the compressor wiring cavity. When any one set of data exceeds the limit, an alarm signal is issued and the machine is stopped.

2) One PT100 sensor is pre-buried at the highest heat surface of the device, and one PT100 sensor is pre-buried in the outlet pipeline of the compressor. Both are connected to the programmable controller control system to achieve dual protection of the highest heat surface. When any one set of data exceeds the limit, an alarm signal is issued and the machine is stopped.

3) One pressure sensor is installed in the compressor inlet pipeline, and one pressure sensor is installed in the outlet pipeline of the air cooler. Both are connected to the programmable controller control system to achieve dual protection of the compressor inlet pipeline. When any one set of data exceeds the limit, an alarm signal is issued and the machine is stopped.

4) One pressure sensor is installed in the outlet pipeline of the compressor and one pressure sensor is installed in the outlet pipeline of the air cooler. Both are connected to the programmable controller control system to achieve dual protection of the compressor outlet pipeline. When any one set of data exceeds the limit, an alarm signal is issued and the machine is stopped.

5) One pressure sensor is installed in the inlet pipeline of the air cooler and one pressure sensor is installed in the outlet pipeline of the air cooler. Both are connected to the programmable controller control system to achieve dual protection of the air cooler water shortage. When any one set of data exceeds the limit, an alarm signal is issued and the machine is stopped.

6) One pressure sensor is installed in the outlet pipeline of the oil pump and one pressure sensor is installed in the inlet pipeline of the compressor. Both are connected to the programmable controller control system to monitor the oil supply pressure difference of the compressor; the compressor is equipped with an oil level sensor, forming dual protection of the compressor supply oil state. When any one set of data exceeds the limit, an alarm signal is issued and the machine is stopped.

The device has failure protection function. When any one sensor of the dual protection sensors fails or has abnormal data, the device immediately stops running and issues an alarm signal.

6. Conclusion

This research on the control system of the mobile carbon dioxide transcritical refrigeration dehumidification unit for underground use has constructed the control framework of the mobile local refrigeration dehumidification device and developed a centralized remote control system based on a programmable controller. This system can collect parameters such as pressure, temperature, and oil level, monitor the operating status of the mobile carbon dioxide transcritical refrigeration dehumidification unit in the underground, and can promptly start or stop the unit in case of faults. It can simplify the operation process, provide centralized start and stop functions, improve the automation level of the refrigeration system, realize real-time centralized monitoring of the underground refrigeration system in the mine, collect real-time data, promptly detect problems in the equipment operation process, and promptly trigger alarms and handle them to avoid major equipment accidents.

Compared with traditional coal mine refrigeration, the underground mobile carbon dioxide transcritical green refrigeration equipment has the following advantages:

Low energy consumption and low loss: The total power of the unit is 110kW (with a single compressor running at only 55kW), and the maximum water consumption under double compressor operation is approximately $15m^3/h$. Under standard conditions, the system's single-cooling energy efficiency ratio (COP) can reach above 4, and the cold heat matching efficiency ratio can reach above 8. At the same time, it effectively solves the problem of large heat loss in the long-distance transportation of refrigerants in traditional refrigeration devices.

Low investment: The refrigeration capacity of the device can meet the local refrigeration needs of one or two mining sections, and no long-distance refrigerant transportation pipelines need to be arranged.

Strong mobility, reusable: This device is specifically provided for local refrigeration and

ISSN 2706-655X Vol. 7, Issue 4: 6-16, DOI: 10.25236/IJFET.2025.070402

dehumidification in high-temperature face, with the characteristics of repeated use and flexible mobility. It can follow the comprehensive mining machine or shield machine platform to move forward in real time, meeting the demand for synchronous forward movement of the underground mining section refrigeration device.

Safe refrigerant: Short-distance refrigeration can effectively reduce the leakage risk in intermediate links such as long-distance refrigerant pipelines, thereby reducing the failure rate; in addition, the usage of CO_2 refrigerant is less, and the safety risk is controllable under the condition of normal ventilation in the roadway.

Small volume: Due to the physical properties of CO_2, with the same refrigerant dosage, the volume of this device is significantly reduced compared to other units.

Large temperature difference refrigeration and heat exchange: During the phase change from supercritical liquid state to subcritical gas state in the transcritical state of CO_2, due to the high latent heat characteristics and strong heat absorption and release performance of the refrigerant in the critical state, it can present excellent effects of rapid cooling and heat release with large temperature differences, and is in line with the national "dual carbon" policy goals.

Easy on-site installation: The equipment layout and pipeline design are simple, integrating a vacuum starter and an electrical control box, facilitating overall movement, data monitoring, and equipment maintenance on site. At the same time, a water pre-treatment device for pipelines is added to reduce the requirements for the water quality of the underground water supply.

Introducing CO_2 refrigeration technology underground to solve the demand for large temperature difference refrigeration and dehumidification can improve the underground working environment, ensure the occupational health of workers, improve production efficiency, reduce operating costs, and achieve energy conservation and emission reduction. It will have significant economic and social benefits in the mining industry and has significant demonstration and wide promotion value, contributing to the realization of the "dual carbon" goal of our country. At the same time, the successful application of this technology in the underground of coal mines will play a leading and exemplary role in converting mature technologies to the coal mining field.

References

[1] Cai Shengjia, Zhang Yanling, Hu Zhanchao, Zhang Xinrong. Molecular Dynamics Simulation of Carbon Dioxide Diffusion in Supercritical Water. Science Bulletin, Vol. 2, 2019.

[2] Cui Zengguang, Li Ning, Zhang Xinrong. Utilization of Wastewater Heat from Large-scale Carbon Dioxide Heat Pump Power Plants for Heating. Electric Power Journal, Issue 3, 2014.

[3] Li Feng, Si Chunqiang, Ma Jin. Research and Application Progress of Carbon Dioxide Transcritical Refrigeration System. Refrigeration Technology, Issue 3, 2010.

[4] Liu Jia, Shang Xingyu, Zhang Xinrong. A Review of International Applications of Transcritical Carbon Dioxide Heating and Cooling Supply Technology. Energy Conservation and Environmental Protection. Issue 08, 2023.

[5] Du Y, et al. Organic solvent-free process for the synthesis of propylene carbonate from supercritical carbon dioxide and propylene oxide catalyzed by insoluble ion exchange resins. Green chemistry, 2005, 7.7:518- 523.