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Research on the Defrosting System of Refrigerated Containers Combining Air and Electro-Thermal Energy and the Controlling Strategy

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Abstract. Considering the problems such as long duration of defrosting, low working reliability and high energy consumption of refrigerated containers, this paper put forward a new defrosting method combining air and electro-thermal energy, and designed a new defrosting structure system based on the structural features of refrigeration modules of refrigerated containers. The two-variable method of wind pressure change and temperature difference change on both sides of the evaporator was used to detect frosting, and the specific controlling strategy supporting the new defrosting system was provided to realize the effect of intelligent defrosting. It can provide references for fast defrosting, intelligent defrosting and low energy consumption defrosting of refrigerated containers.

1 Introduction

At present, the infrastructure and supervision system of cold chain logistics in China have been continuously perfected, and the cold chain circulation rate of perishable goods has been rapidly enhanced. As an important tool for transportation of cold chain logistics, refrigerated containers have also achieved steady growth. According to the data released by the 2018 Cross-border Food Supply Chain Forum of the China Federation of Logistics & Purchasing Cold Chain Logistics Committee, China's frozen and refrigerated containers will maintain a compound annual growth rate of about 7%, ranking the top in the world.

The defrosting system of refrigerated container plays an important role in ensuring the transportation quality of goods and reducing the transportation cost. The failure of the defrosting system will lead to the increase of equipment energy consumption or even the damage of transported goods. At present, the defrosting system designed for refrigerated containers of mainstream brands in the market still has problems such as long duration of defrosting, low working reliability and high energy consumption, which restrict the development of high-quality transportation, low-cost transportation and green cold chain transportation of refrigerated containers.

According to the features of running environment of refrigerated containers, this paper has designed a new defrosting system based on the combination of air and electro-thermal energy. With the corresponding controlling strategy, the system can enable refrigerated containers to defrost on demand, intelligently and efficiently, reduce the impact of temperature fluctuation in the refrigerated container caused by defrosting operation, increase the accuracy of temperature control in the refrigerated container, lower the odds of energy consumption in defrosting and the damage to perishable goods, and improve the quality of refrigerated transportation.

2 Design of the new defrosting system

2.1 Designing Ideas of the new defrosting system

As an important means of long-distance and long-span transportation of cold chain logistics, refrigerated containers are faced with the complexity of climate environment. Therefore, refrigerated containers are required to be applied to a wide range of environment temperature. Currently, the commercial brands of refrigerated containers (such as Carrier, Thermo King, Daikin, etc.) have been generally applied to the temperature range from -30 ℃ –to 50 ℃. Especially, when running in a high temperature, the refrigerated container has higher thermal load, and the refrigeration unit has longer running time. With higher moisture content in the environment, the evaporator has higher frequency of frosting, thus resulting in a higher demand for defrosting. At the same time, the environment with a higher temperature has higher heat in the air, which can provide free heat source for defrosting. Therefore, the high-temperature air introduced from the environment can flow through the evaporator of the refrigerated container, and the air after heat exchange can be discharged again, so that the evaporator of the refrigerated container can be circularly heated, the temperature of the evaporator itself can be increased, and the frost on the surface will melt through absorption of heat, completing the defrosting process. Because such a defrosting method has certain requirements for the environment temperature, in order to make up for the deficiency that the defrosting effect becomes weak when the refrigerated container is operated in low-temperature environment, an electrical heating system can be designed to assist the defrosting, thus forming a defrosting method combining air source and electric heat source.

2.2 Structural principles of the new defrosting system

At present, refrigerated containers mostly adopt modular design, which means that they are composed of picture-frame module of refrigeration unit and incubator module. Defrosting system is an important functional module of the refrigeration unit. Therefore, the defrosting system should be developed and designed on the basis of the refrigeration unit module.

The system of air and electro-thermal defrosting is shown in Figure 1. At the front side of the refrigeration unit module of the refrigerated container, the air inlet and outlet are arranged in the upper and lower sides of the evaporator for air flowing in and out. At the same time, the supply air outlet and the return air inlet have automatic on/off function to ensure that hot air does not penetrate into the refrigerated container to affect temperature field fluctuation during air defrosting. In order to improve the reliability and applicability of defrosting of refrigerated containers, five groups of electrical heating U-tubes are used to assist defrosting, so that the defrosting system can function normally in harsh low-temperature environment.

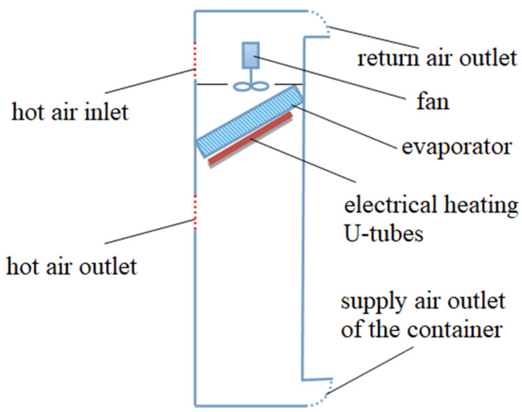

Fig. 1 Schematic diagram of the defrosting system combining air and electro-thermal energy

2.3 Principle of Intelligent defrosting electrical system

In order to realize the function of intelligent defrosting, in this system, a differential pressure sensor and a temperature sensor will be set in the evaporator of the refrigerated container to detect the frost formation of the evaporator. Then they transmit the data to the PLC, complete the analytical processing by setting a certain control strategy, output the processing result and let PLC control the execution. The schematic diagram of electrical components layout of the defrosting system combining air and electro-thermal energy is shown in Figure 2, and the circuit principle is shown in Figure 3.

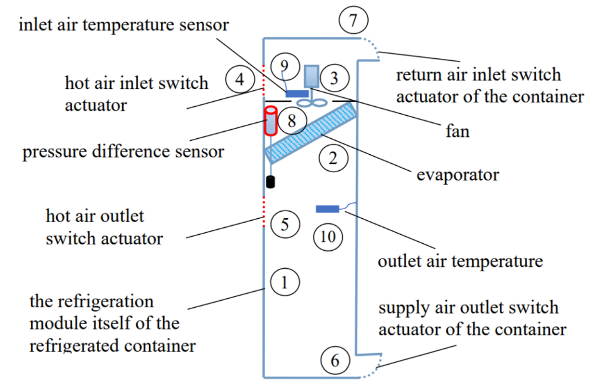

Fig. 2 Schematic diagram of electrical component layout of the defrosting system combining air and electro-thermal energy

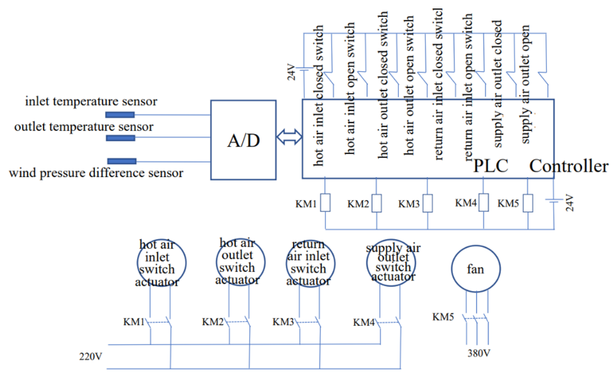

Fig. 3 Control circuit diagram of the defrosting system combining air and electro-thermal energy

3 Construction of the controlling strategy for the new defrosting system

3.1 Principle of intelligent defrosting control strategy

The frost formation on the evaporator of refrigerated containers will block the air flow channel, and the flow through the evaporator will decrease, which will lead to the rise of the pressure difference between the windward side and the leeward side of the evaporator. In addition, with the increase of frost formation, the blockage of the air flow channel is becoming severer, and the temperature of supply air outlet of the evaporator will gradually increase. If the refrigerated container is under chilled mode, the outlet air temperature controlled by the controller stabilizes near the set temperature. If the refrigerated container is under the frozen mode, the inlet air temperature controlled by the controller stabilizes near the set temperature, and the outlet air temperature will further decrease. Therefore, the temperature difference between the inlet air temperature and the outlet air temperature of the evaporator will continue to increase. The wind pressure difference P and the temperature difference (i.e., the inlet air temperature Tj-outlet air temperature Tc) are used together to evaluate the severity of the frost formation on the evaporator and are regarded as trigger conditions for starting/releasing defrosting.

3.2 Design of intelligent defrosting control strategy

Refrigerated containers can be divided into chilled mode (TSet⩾-5 ℃) and frozen mode (TSet< -5 ℃) according to the temperature set by the user. Since these two modes are quite different, they should be treated separately when defrosting control strategies are formulated. In addition, the use of air energy for defrosting requires a higher air temperature to ensure sufficient energy during defrosting and shorten the duration of defrosting as much as possible. When the environment temperature is low, defrosting with air energy may be too slow and lasts too long, which will affect the temperature fluctuation in the refrigerated container. Therefore, in this paper, when the environment temperature is lower than 10 ℃, the electro-thermal defrosting method will be directly adopted.

The intelligent defrosting control strategy will be composed of the selection of defrosting methods, the running modes selection of refrigerated containers, the trigger conditions of starting defrosting (i.e. intelligently determining whether defrosting is needed), defrosting preparation and defrosting process, the trigger conditions of ending defrosting (i.e. intelligently determining whether defrosting is finished), ending defrosting and the preparation process for returning to the refrigeration state, etc.

In normal use, elements such as the differential pressure sensor 8, the inlet air temperature sensor of evaporator 9 and the outlet air temperature sensor of evaporator 10 are jointly responsible for detecting the frost formation of the evaporator. Before the refrigerated container is put into use, the evaporator is in a frost-free state. At this time, the PLC controller collects the wind pressure difference between the windward surface and the leeward surface of the evaporator, which is taken as the reference value of the frost-free state of the evaporator, that is, Pb. When the refrigerated container is put into use afterwards, considering the possible filth blockage of the evaporator, calibration can be made during the regular maintenance to ensure that the wind pressure sensor of the evaporator can truly and accurately reflect the filth blockage state of the evaporator.

In the process of determining the frost formation of the evaporator, the wind pressure difference is taken as one of the important bases. The specific arrangements are as follows. Under the chilled mode, the evaporator fan runs at a high speed, and the supply air volume of the inlet in the refrigeration container is measured. When the supply air volume is reduced by 50%, the collected wind pressure difference P is recorded as the calibration value P50% for trigger conditions of refrigeration defrosting. Under the frozen mode, the evaporator runs at a low speed and the supply air volume of the inlet in the refrigerator is measured. When the supply air volume is reduced by 65%, the collected wind pressure difference P is recorded as the calibration value P65% for trigger conditions of refrigeration defrosting.

The specific design of intelligent defrosting control is shown in Table 1.

Table 1 Table of Intelligent Defrosting Control Strategy

Defrosting Method	Mode Selection	Trigger Conditions of Starting Defrosting	Execute	Trigger Conditions of Ending Defrosting
Air Defrosting ($T_{Environment}$≥ 10 ℃)	Chilled Mode (T_{Set}≥-5 ℃)	Condition 1: when P ≥ $P_{50\%}$, and stabilizes for 10 minutes; Condition 2: when Tc-Tj ≥ 4 ℃, and stabilizes for 10 minutes.	1. Close the supplying valve and shut down the refrigeration system; 2. Close the supply air outlet in container 6 and the return air inlet in container 7; 3. Open hot air inlet 4 and hot air outlet 5; 4. Start the fan to run at high gear.	Condition 1: when P_b⩽ P ⩽ 1.05*P_b and stabilizes for 5 minutes; Condition 2: when Tj-Tc ⩽ 2 ℃ and stabilizes for 5 minutes.
	Frozen Mode (Test<-5 ℃)	Condition 1: when P ≥ $P_{65\%}$, and stabilizes for 10 minutes; Condition 2: when Tc-Tj ≥ 6 ℃, and stabilizes for 10 minutes.	1. Close the supplying valve and shut down the refrigeration system; 2. Close the supply air outlet in container 6 and the return air inlet in container 7; 3. Open hot air inlet 4 and hot air outlet 5; 4. Start the fan to run at high gear.	Condition 1: when P_b⩽ P ⩽ 1.05*P_b and stabilizes for 5 minutes; Condition 2: when Tj-Tc ⩽ 2 ℃ and stabilizes for 5 minutes.
Electro-Thermal Defrosting ($T_{Environment}$<10 ℃)	Chilled Mode (T_{Set}≥-5 ℃)	Condition 1: when P ≥ $P_{50\%}$, and stabilizes for 10 minutes; Condition 2: when Tc-Tj ≥ 4 ℃, and stabilizes for 10 minutes.	1. Close the supplying valve and shut down the refrigeration system;2. Close the supply air outlet in container 6 and the return air inlet in container 7; 3. Start the electrically heated rod.	Condition: Tj ≥ 10 ℃
	Frozen Mode (Test<-5 ℃)	Condition 1: when P ≥ $P_{65\%}$, and stabilizes for 10 minutes; Condition 2: when Tc-Tj ≥ 6 ℃, and stabilizes for 10 minutes.	1. Close the supplying valve and shut down the refrigeration system;2. Close the supply air outlet in container 6 and the return air inlet in container 7; 3. Start the electrically heated rod.	Condition: Tj ≥ 10 ℃

4 Conclusions

Considering the problems such as long duration of defrosting, low working reliability and high energy consumption of refrigerated containers, this paper put forward a new defrosting system combining air and electro-thermal energy. After theoretical analysis, system designing and formulation of controlling strategies, the following conclusions are drawn:

The new defrosting method combining air and electro-thermal energy can make full use of the free heat source in the environment and greatly reduce the energy consumption of defrosting. In addition, the defrosting system can well meet the defrosting requirements of refrigerated containers in high-temperature environment. Therefore, the new defrosting method combining air and electro-thermal energy is theoretically feasible.

According to the structural features of refrigeration unit module of the refrigerated container, a new defrosting system combining air and electro-thermal energy is designed, the corresponding layout of key sensors and design of actuators are completed, and the electric control diagram of the new defrosting system is designed, which provide a scheme reference for the hardware design of the new defrosting system.

The two-variable detection method including wind pressure change and the temperature difference change on both sides of the evaporator is adopted to accurately determine the frost formation of the evaporator of the refrigerate container, guaranteeing the intelligent defrosting of the new defrosting system. The intelligent defrosting control strategy can provide guidance and reference for the control of new defrosting systems in the future.

References

1. F. R. Ameen. Experimental study of warm-air defrosting of heat-pump evaporators. International Journal of Refrigeration, 2013, 16(1): 13-18.
2. Hua Kaitai, Liang Fei, Chen Jinjun. Study on Defrosting Scheme of the Mechanical Refrigeration System in Refrigerated Container. Energy Conservation, 2020, 77-81.
3. Yu Chaoqun, Zang Runqing, Wu Guoqiang, etc. Study on frosting and defrosting performance of centralized air supply cold storage. Cryogenics & Superconductivity, 2018, 46(5): 88-92.
4. YANG Ming-liang, LIN Hua-jiang, CHEN etc. The Design of Control Device for Marine Reefer Containers Based on PLC. Journal of Jimei University, 2016, 21(4): 287-292.
5. Song Mengjic，Wang Xuanjie，Liao Liyuan，Deng Shiming. Termination Control Temperature Study for an Air Source Heat Pump Unit During Its Reversc Cycle Defrosting[J].Energy Procedia ,2017:335 -342.