

Application Research on Energy Saving Technology of Waste Heat Recovery and Defrosting for Low Temperature Cold Storage

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Abstract. In this paper, a glycol defrosting system using waste heat exhaust from refrigeration compressor is designed. The defrosting numerical model, heat transfer model and frost growth model were established. The frost thickness, defrosting heat consumption and ethylene glycol flow rate were calculated, and the ethylene glycol pipeline was designed. The project solves the problems of traditional defrosting of cold storage, such as high power consumption, fluctuation of storage temperature, hidden danger of safety, high condensation temperature and low efficiency of refrigeration system.

1 Introduction

As a low temperature refrigeration equipment, cold storage is widely used in cold chain logistics equipment[1], which is the key to ensure the storage quality of food and medicine. In the cold storage, when the surface temperature of the cooler heat exchanger is lower than the dew point temperature, the surface of the heat exchanger will form condensation, and frost will be formed when the temperature is lower than the freezing point of water[2]. With the increase of time, the whole surface of the heat exchanger will form a dense frost layer[3]. Due to the low thermal conductivity of the frost layer and the large flow resistance of the air, the heat transfer resistance of the heat exchanger increases and the heat transfer coefficient decreases, which greatly reduces the performance of the heat exchanger and increases the energy consumption of the system. Defrost is necessary to improve the performance of the system.

This paper intends to use the refrigeration compressor to exhaust waste heat and develop the ethylene glycol defrosting system in view of the problems such as high

power consumption, fluctuation of storage temperature, safety risks, high condensing temperature and low efficiency of refrigeration system in the traditional defrosting of cold storage. The project mainly solves the key technical problems of system matching and coordination, and carries out practical application verification, in order to obtain a safer and more efficient energy-saving cold storage system.

2 Principle of hot refrigerant defrosting cycle

Hot refrigerant defrost is to introduce the refrigerant steam discharged from the compressor into the evaporator, and melt the frost layer on the surface of the evaporator by using the heat released when the superheated steam condenses. The original accumulated ammonia liquid and lubricating oil in the evaporator are discharged into the defrosting drain bucket or low pressure circulation reservoir under the action of pressure difference[4].

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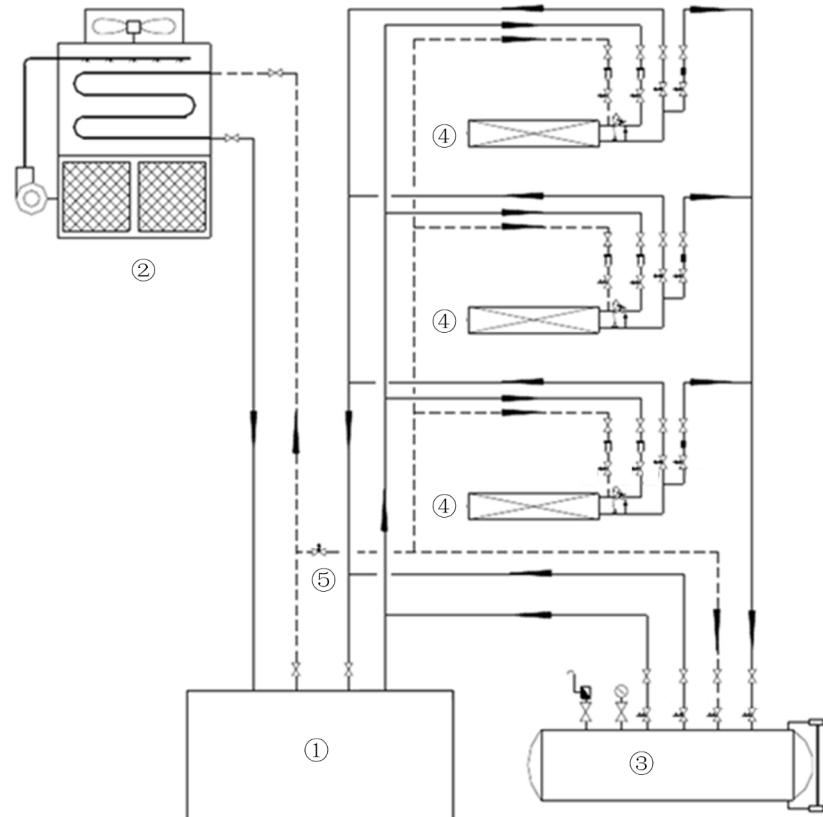


Figure 1. Principle of hot refrigerant defrosting cycle.

1- Compressor 2- Evaporative condenser 3- Circulating drum 4-Air cooler 5- Defrost stop valve

3 Ethylene glycol solution heat recovery defrosting device

3.1 Establish mathematical model, determine air circulation, wet bulb temperature, and calculate frosting amount

The air cooler is a kind of evaporator used to cool the air. All kinds of aluminum or copper fins are often installed on the air side to increase the area of the heat exchanger. It has the advantages of compact structure and good heat transfer performance, so it is widely used in refrigeration equipment. The object studied in this paper is the air cooler used in cold storage[5]. Its structural parameters are as follows: the fin thickness is 0.35mm, the fin

spacing is 4mm, the total number of fins is 288, the number of tube rows is 5 rows, the number of branches is 6, the number of main pipes is 72, and the spacing of tubes perpendicular to the direction of air flow is 33mm. The fan has two, the diameter of the blade is 530mm, the motor voltage is 380V, the power is 170W.

3.1.1 Numerical model of frosting in finned tube heat exchangers

Figure 2 shows the finned tube heat exchanger structure, which has a copper tube jacket and aluminum fins to maintain a relatively low temperature as a cold body, through the cooling air flow of relatively high temperature and high relative humidity to provide heat.

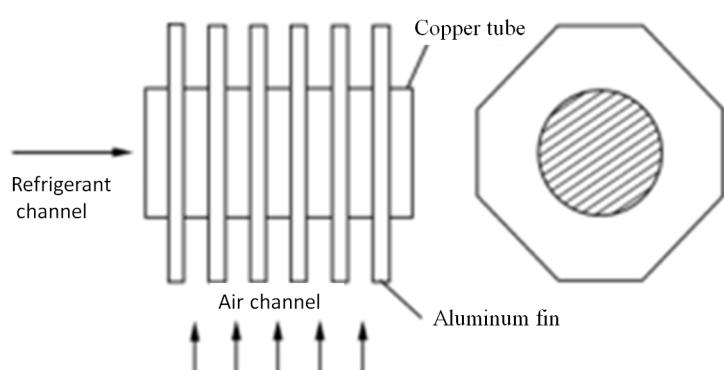


Figure 2. Principle of hot refrigerant defrosting cycle.

The finned surface frost model is a one-dimensional transient model, which is used to describe the energy and mass migration within the frost layer. The basic governing equations and boundary conditions are described below.

Vapor diffusion equation:

$$\frac{\partial(\varphi_a \rho_v)}{\partial t} - m = \frac{\partial}{\partial z} \left(D_{eff} \frac{\partial \rho_v}{\partial z} \right)$$

Here, D_{eff} is the actual vapor diffusion coefficient inside the frost layer (m/s).

Energy conservation equation:

$$\rho_f c_p \frac{\partial y}{\partial x} + m h_{sg} = \frac{\partial}{\partial z} \left[k_{eff} \frac{\partial T}{\partial z} \right]$$

Frost continuity equation:

$$\frac{\partial \varepsilon_\beta}{\partial t} + \frac{m}{\rho_i} = 0$$

The mass transfer boundary condition is

$$h_{mf} [W_0 - W_{(z=\delta_{f,t})}] = D_{eff,s} \frac{\partial \rho_v(z=\delta_{f,t})}{\partial z} + \rho_f \frac{d\delta_f}{dt}$$

Where, $D_{eff,s}$ is the actual vapor diffusion coefficient at the frost layer interface (m/s).

The thermal conductivity boundary condition is

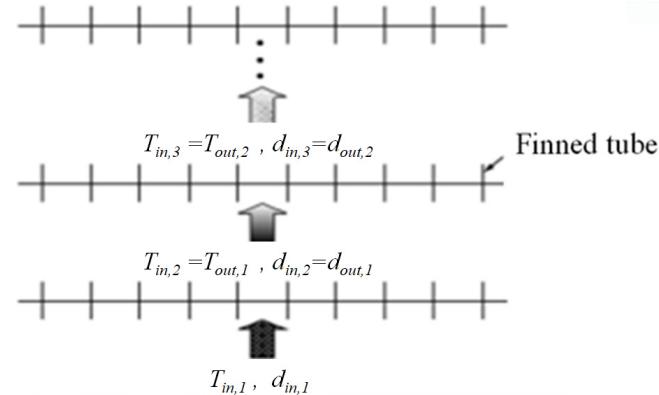


Figure 3. Heat transfer model of finned tube.

According to the conservation equation of mass and energy in the fin region:

$$\rho_a Q(c_{pa}\Delta T + 2500\Delta W) = q_{total}$$

$$\rho_a Q\Delta W = \int h_{mf} \rho_a (W_0 - W_{fs}) dA$$

and

$$\Delta T = T_{in} + T_{out}$$

$$\Delta W = W_{in} + W_{out}$$

3.1.3 Frost growth model

$$q_{m,fr} = h_m A_T (d_{a,i} - d_{fr}) = q_{m,\rho} + q_{m,\delta}$$

$$h_f [T_0 - T_{(z=\delta_{f,t})}] = K_{eff} \frac{\partial T_{(z=\delta_{f,t})}}{\partial z} - h_{sg} \rho_f \frac{d\delta_f}{dt}(t)$$

$$T_{(z=0, t)} = T_c(x, y)$$

Where, T_c is the fin surface temperature, T_0 and W_0 are the average airflow temperature and humidity in the fin area.

According to the conservation equation of mass and energy in the fin region:

$$\rho_a Q(c_{pa}\Delta T + 2500\Delta W) = q_{total}$$

$$\rho_a Q\Delta W = \int h_{mf} \rho_a (W_0 - W_{fs}) dA$$

3.1.2 Heat transfer model

Along the direction of air flow, the evaporator is divided into each control body according to the tube row. Each row of tubes and its fins are taken as a control unit, and the air outlet state of the previous control unit is taken as the air inlet state of the next control unit, as shown in Fig.3. After dividing the control body in this way, the model can consider the influence of heat exchanger structure, frost layer thickness and wet air state change along the passage.

$$q_{m,\rho} = A_T D_S \left(\frac{1 - \rho_{fr}/\rho_{ice}}{1 + (\rho_{fr}/\rho_{ice})^{0.5}} \right) \left(\frac{d\rho_v}{dx} \right)_s$$

Energy balance form is:

$$Q = A_T D_S \frac{dT_V}{dx} + d_{fr} \rho h_{fr}$$

According to the above mathematical model and boundary conditions, it is assumed that in common working conditions of cold storage air cooler, that is, the evaporation temperature of cold storage is -30°C, the air inlet temperature of cold air cooler is -18°C, the relative humidity in the cold storage is 60%, and the air inlet velocity is 3m/s. It is calculated that after four hours of cumulative operation of the compressor, the frost thickness is 3mm and the frosting amount is 2000g.

3.2 The calculation method is used to determine the heat consumption of defrosting and the circulating amount of ethylene glycol

The total heat input in evaporator defrosting $Q=Q_1+Q_2+Q_3+Q_4$, where Q_1 is the heat required for the frost layer to dissolve into water at 0°C , Q_2 is the heating heat of evaporator, water plate and metal frame, Q_3 is the heat absorption of the residual refrigerant working medium in the evaporator coil tube, Q_4 is the heat added to the surroundings.

In order to achieve good defrosting effect and the purpose of energy saving, Q_1 is necessary, the smaller the value of Q_2 , Q_3 and Q_4 , the better the energy saving effect. This is because when the warehouse is put into normal operation, this part of the heat must consume cooling capacity to offset, which will pay unnecessary energy consumption. In order to reduce this additional energy consumption, a series of corresponding measures can be taken. There are two measures taken in this paper, one of which is the return air delay. After the defrosting instruction is issued, the liquid inlet solenoid valve of the evaporator is closed, but the return air solenoid valve is delayed and closed to reduce the refrigerant working

medium remaining in the evaporator. The other is to stop running the forward fan when defrosting to reduce the heat added to the surrounding environment.

The melting heat of frost is

$$Q_1 = G_f \times [C_{pf}(0 - t_f) + r_f] = 775\text{kJ}$$

Where, G_f is the weight of the frost layer to be melted, 2kg. C_{pf} is the average specific heat of frost layer, $2050\text{J}/(\text{kg}\cdot\text{K})$. T_f is the average temperature of the frost layer, which is -25°C between the evaporation temperature and the cold storage temperature according to the situation. r_f is the melting heat of the frost $3.36\times105\text{J}/\text{kg}$.

The total heat increased by 30% margin on the basis of the frost melting heat, the result is 1007 kJ.

3.3 According to the structure of the air cooler, determine the ethylene glycol pipeline, calculate the flow resistance of ethylene glycol solution

The structure of the air cooler selected for this system is shown in Figure 4.



Figure 4. The structure of the air cooler.

According to the size of the air cooler is 1200×400 , ethylene glycol defrosting is arranged on a one-way pipeline, under and out. In order to ensure defrosting, the temperature of ethylene glycol solution entering the air cooler is set at 30°C , the temperature difference between inlet and outlet is set at 5°C , and the defrosting time is set at 10 minutes. The circulating amount of ethylene glycol was 0.101kg/s .

Selection of ethylene glycol pipe material: considering the heat exchange effect, ethylene glycol pipe is still copper pipe.

The selection of ethylene glycol pipe diameter: in the design of pipe diameter, under the condition of a certain flow, the diameter of the pipe is thicker, the flow resistance is smaller, but the waste of pipe material. On the contrary, the smaller the pipe diameter, the greater the flow resistance, but save space and pipe material. Therefore, when choosing the diameter of the pipe, both should be taken into account. According to the circulating amount of ethylene glycol calculated in the front, the copper tube of DN10 should be preselected.

4 Technical advantages of waste heat recovery defrost system design

The project is the first time to carry out the application research on the recovery of compressor exhaust heat in low temperature cold storage. The exhaust temperature of the compressor is relatively high, which has a great impact on refrigerant, lubricating oil and pipeline system. As for this part of heat energy, this project puts forward reasonable utilization for the first time.

The use of ethylene glycol as a heat medium, transported to the side of the air cooler for defrosting, can fill the gap in domestic related technology. In view of the problem of defrosting uniformity and process, the reversible fan is set up to control the rotation of the fan, so that the rotation direction is opposite to that of refrigeration, so as to speed up the defrosting process. Through the matching of refrigeration equipment and the optimization of the system, the performance of the unit can be significantly improved.

4.1 Energy conservation and environmental protection

This system can reduce the energy consumption of small cold storage by 20% ~ 30%, reduce emission (equivalent to CO₂ emissions) by 10% ~ 20%, and save energy by 10% ~ 20% for medium and large cold storage. The construction investment is equivalent to that of traditional cold storage, and the operation cost can be significantly reduced.

4.2 Safe and reliable

This system makes full use of the waste heat of the compressor, solves the hidden danger of fire caused by the temperature control of the electric frost, and the ethylene glycol used is also a non-toxic and harmless organic solvent, which finally realizes the green defrosting. At the same time, the system has little impact on food, no pollution to the food, fully ensure the quality of goods, safe and reliable operation.

4.3 Wide application prospect

It is estimated that the defrosting technology developed in this project can save 100,000 kWh of electricity and 120,000 yuan of electricity per year compared with the defrosting technology of electric heating for a 2,000-ton cold storage. The construction investment only increased by more than 50,000 yuan. Moreover, the temperature and pressure of ethylene glycol in the whole cycle are far below the allowable value, so it has a reliable safety guarantee, so it has a broad prospect of popularization and application.

The technical achievements of this project can also be transformed into logistics cold chain, refrigeration and air conditioning, industrial refrigeration and other industrial fields, which will generate greater market demand.

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