Experimental study on the effect of heat transfer temperature difference on frosting characteristics of air-cooled heat exchanger

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Abstract: In this paper, the frosting experiment was carried out by the wind tunnel experimental device in the single experimental section of the closed-mouth return flow. Through the experimental study on the influence of heat exchange temperature difference on the growth characteristics of the frosting layer in the finned evaporator under the experimental conditions of different initial head wind speeds, the following conclusions were drawn: At 2m/s, the frost thickness of finned tube evaporator increases gradually with the frosting time at different heat exchange temperature differences. At 3, 4, 5m/s initial face wind speed, the frost thickness of finned tube evaporator grows in a three-stage pattern at different heat exchange temperature differences. The cooling capacity of the evaporator at different face wind speeds and different heat transfer temperature differences increases first and then decreases with the frosting time.

1. Introduction

Cold storage is an important refrigeration product, and the average annual electricity consumption of cold storage in China is 15 billion kWh, with an average energy consumption of 30-50 kWh per cubic meter. The future development direction of cold storage is sustainable, green and efficient "energy-saving cold storage". During the actual operation of the cold storage, the heat exchange temperature difference has a great relationship with the relative humidity in the storage. The larger the heat exchange temperature difference, the larger the difference between the dew point temperature of the wet air in the storage and the fin surface temperature of the heat exchanger, that is, the greater the temperature difference force of frosting, and the more water vapor in the wet air in the storage will condense on the fin surface of the heat exchanger. However, the actual use of large temperature difference heat exchange cold storage relative humidity is also difficult to achieve more than 85%, it is also difficult to achieve good preservation storage effect.

Through the study to reduce the evaporation temperature of finned tube heat exchanger and the heat transfer temperature difference between the library temperature, so as to maintain a high relative humidity in the library, in high temperature conditions to reduce the heat exchanger condensation water outflow, low temperature conditions to delay the heat exchanger or table cooler frost cycle or even no frost, will help reduce the amount of cold storage humidification or even do not need to humidify. At the same time, the reduction in the number of defrosts, the power consumption when defrosting and the power consumption when the temperature fluctuations need to turn on the compressor to lower the temperature will also be reduced, the cold storage operating costs will also be
saved; cold storage temperature fluctuations will be reduced, so that the freezing and thawing process of food more stable, better food quality. Therefore, the construction of green and energy-efficient cold storage has important positive significance.

Yang et al. [1] used the turbulence model and the diffusion equation of the frost layer to obtain the results that turbulence is more conducive to the heat transfer and growth of frost layer than laminar flow, wet air velocity had no obvious effect on the mass transfer under turbulence, and the frost thickness increased with the increase of wind speed under laminar flow. Amini et al. [2] conducted frosting experiments with finned tube heat exchangers under natural convection flow, and the results showed that in the initial frosting stage, the frost thickness grew rapidly, and then the frost thickness growth rate gradually decreased. Kandula et al. [3-4] studied the experiments what are performed concerning frost growth and densification in laminar flow over a flat surface under conditions of constant and variable humidity. Barron et al. [5-6] studied the effect of parameters such as mass flow rate of air, moisture content, and cold surface temperature on the growth rate of frost layer on cold surfaces by experimental methods. They concluded that at the initial stage due to several factors the formation of frost layer will increase the heat transfer rate, but with the increasing thickness of frost layer the overall heat transfer coefficient will decrease. When the whole heat and mass transfer process enters the relative steady state stage, although the frost crystal deposition, thickness increases but the heat transfer rate does not change much.

Cold storage air-cooled finned tube heat exchanger frost problem is affected by many factors, such as high humidity working environment in the cold storage, frequent access to the cold storage, take a large temperature difference in the heat transfer mode will worsen the heat exchanger frost. How to make the cold storage air-cooled finned tube heat exchanger in low temperature and high humidity environment to delay the cold storage chiller frost, reduce the number of cold storage defrost is the focus of this paper, through frost experiments to study the heat transfer temperature difference, real-time head-on wind speed on the fin surface frost growth characteristics of the law, as well as different frost conditions under the conditions of frost growth characteristics of the finned tube heat exchanger heat transfer impact. The analysis of the change law of frost performance provides practical support for optimizing the design of cold storage chillers and defrosting control methods in the future, and improving the operating performance of cold storage chillers under high humidity and frost-prone operating conditions.

2. Experimental system

2.1. Closed-port reflow type single test section wind tunnel experimental device

Low-temperature air-cooled heat exchanger performance experimental device is a closed-port reflow type single test section wind tunnel as the main body, and is equipped with air treatment system, fan system, being tested system. The outline of the structure of the closed-port reflow type single test section wind tunnel is shown in Figure 1.

![Figure 1. The outline of the wind tunnel structure in the single experimental section of closed-loop return flow](image)
The system has used multi-point anemometer, Pitot tube with micro differential pressure sensor to measure the uniformity of airflow velocity, dynamic pressure stability, and flow field measurement in the experimental section of the closed-loop return flow wind tunnel, and the turbulence of the experimental section has been numerically calculated using empirical equations. The measurement of the flow field performance in the experimental section of the wind tunnel can provide accurate and uniform air field for the air-cooled finned tube heat exchanger frosting experiments, which provides a basis for reliable frosting experimental results and better research on the frost growth characteristics of finned tube heat exchangers.

2.2. Air-cooled finned tube evaporator test and experimental system
When the finned tube evaporator is installed in the wind tunnel test section, the performance and reliability test system of the low temperature wind tunnel heat exchanger is selected as the finned evaporator test system through the test software of the wind tunnel test bench. When air-cooled finned tube evaporator frosting experiments, wind tunnel experimental section of finned tube evaporator heat exchange with wind tunnel of wet air, the inside of the finned tube evaporator liquid refrigerant heat evaporates into gas into the gas and liquid separator, the compressor suction gas from gas liquid separator compressed into the high temperature and high pressure gas refrigerants, after the access to the oil separator for oil and gas separation, And then through the shell and tube condenser with cold water from the cooling tower heat into liquid refrigerant, after entering the water supercooler into supercooled liquid refrigerant, again after liquid lens, refrigerant mass flowmeter into electronic expansion after throttling depressurization into wind tunnel finned tube evaporator absorbs heat wind tunnel, so repeated cycle. The principle of low-temperature wind tunnel air-cooled finned tube evaporator test system is shown in Figure. 2.

![Figure 2. Air-cooled finned tube evaporator test system](image)

1-Oil separator; 2-Compressor; 3-gas-liquid separator; 4-Pitot tubes; 5-Differential pressure transmitter; 6-Shell and tube condenser; 7-over cooler; 8-Electric heating; 9-liquid test mirror; 10-Mass flowmeter; 11-Electronic expansion valve; 12-Frequency conversion fan; 13-Air handling unit; 14-Finned tube heat exchanger
3. Results and discussion

3.1. Effect of heat transfer temperature difference on frost layer thickness of finned tube evaporator at different head-on wind speeds

In order to study the effect of heat transfer temperature difference on the frost layer growth characteristics of finned tube evaporator under different initial head-on wind speeds, a finned tube evaporator with a flat fin pitch of 9 mm was selected for frost experiments, and the experimental conditions were controlled under initial head-on wind speeds of 2, 3, 4 and 5 m/s in the wind tunnel experimental section, and the temperature and humidity of the evaporator inlet were set to -18°C and 80%. The frost growth characteristics of the finned tube evaporator were analyzed and compared under different heat transfer temperature differences (3, 4, 5, 6 and 7°C).

As shown in Figure 3, the curves of frost thickness of finned tube evaporator with time change at different heat transfer temperature difference under the initial head-on wind speed of 2, 3, 4 and 5 m/s. From Figure 3-a, it can be seen that the thickness of the frost layer on the fin surface increases gradually with the frosting time at the initial head-on wind speed of 2m/s. At the same time, the greater the heat transfer temperature difference, the faster the growth rate of the frost layer thickness, this is due to the greater the heat transfer temperature difference, the lower the temperature of the fin surface, the greater the driving force of the phase change, more water vapor in the wet air condensed into frost crystals on the fin surface, and because the greater the heat transfer temperature difference
the faster the frost rate, at this time the evaporator head-on wind speed due to the frost layer blockage air circulation area decay is also faster, small wind speed, the water vapor in the wet air more easily in the Frost layer surface condensation increase thickness. Therefore, the greater the heat exchange temperature difference, the faster the frost layer thickness growth rate. There is almost no difference in the frost cycle at different heat transfer temperature difference at the initial head-on wind speed of 2m/s, and the frosting time lasts about 42min. From Figure 3- (b, c, d), it can be seen that the trend of frost thickness on the surface of the fins with time is basically the same, and the thickness of the frost layer is experiencing "rapid growth - almost constant - slowly decreasing "

3.2. Effect of heat transfer temperature difference on the cooling capacity of finned tube evaporator at different head-on wind speeds

Figure 4- (a, b, c, d) is the change curve of refrigerating capacity of finned tube evaporator with time under different heat transfer temperature difference at 2m/s, 3m/s, 4m/s and 5m/s, respectively. From the figure 4, with the growth of frost layer on the evaporator fin surface, the cooling capacity is nearly first up and then down trend. This is because in the process of frosting at the beginning, the frost crystal growing on the surface of the fins will enhance the disturbance of the airflow. So as to strengthen the effect of heat transfer, but with the aggravation of frosting, frost layer blocking the fin spacing, head-on wind speed is reduced, thus causing the cooling capacity is down trend.

From Figure 4, it can be seen that the cooling capacity increases with the increase of heat transfer temperature difference, which is because in the case of constant heat transfer area, head-on air speed and superheat, the heat transfer temperature difference can only be changed by adjusting the speed of
the compressor, and the high speed of the compressor will also bring a larger refrigerant flow, which leads to the increase of cooling capacity. At the same time, under the same heat transfer temperature difference, the cooling capacity gradually increases with the increase of the head wind speed, because the increase of the head wind speed will strengthen the air side heat transfer effect, and in order to maintain the evaporator outlet superheat, it is necessary to increase the expansion valve opening, which leads to the increase of the refrigerant flow rate with the decrease of the compressor suction specific volume under the condition of the compressor suction volume remains unchanged and causes the increase of the cooling capacity.

4. Conclusion
In this paper, the frost growth characteristics of finned tube evaporators are experimentally studied. The effect of heat transfer temperature difference on the frost growth characteristics under different initial head-on wind speed experimental conditions is obtained through experiments and the conclusions are as follows:

- When the finned tube evaporator in the windward surface speed at 2m/s, the thickness of the frost layer gradually increases with the frosting time at different heat exchange temperature difference. The thickness of the frost layer of the evaporator at 3, 4 and 5m/s initial head wind speed shows a three-stage growth pattern of "rapid growth - almost constant - slowly decreasing" at different heat transfer temperature difference.

- When the evaporator is under different wind speed, the cooling capacity of different heat transfer temperature difference is increasing first and then decreasing with the frost time. The evaporator in the frost layer thickness "slowly reduce" period and the head wind speed "first rise then fall" period, will bring the heat transfer coefficient increases, and at this time the cooling capacity of the finned tube evaporator are decreasing trend, fully indicating that the heat exchanger in front of the rows of tubes of frost layer is collapsed blowing To the back of the heat exchanger several rows of tubes, resulting in blockage of the heat exchanger circulation area, the air flow through the evaporator is reduced, and the air side of the heat transfer coefficient is reduced on the impact of greater refrigeration capacity.

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