Study on the Characteristics of Spray Defrosting of Air Source Heat Pump Solution in High Humidity Areas

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Abstract: When an air source heat pump is used in a low temperature and high humidity area, frost on the surface of an outdoor heat exchanger will lead to the decrease of the heating performance of a whole unit. So periodically defrosting is very necessary. However, when the commonly used reverse cycle defrosting method is applied, the unit stop heating indoor and the temperature will drop. In this paper, the method of spraying solution with low freezing point is used to defrost in order to ensure the normal operation of the unit and provide continuous heat supply. The results show that the continuous heat supply can be provided during the defrosting process and the working unit doesn’t need to be stopped. Moreover, exhaust pressure of the prototype compressor is more than 3.0 MPa, while air outlet temperature of the indoor unit is more than 40°C. And the heat capacity of the unit is over 2000W, which enhances indoor thermal comfort. In addition, the influence of different outdoor ambient temperature on the performance of the air source heat pump is studied when the spray defrosting is in progress. It is found that the lower the outdoor ambient temperature is, the lower the heat capacity and COP of the unit will be.

1. Introduction

Compared with the traditional heating method, air source heat pumps are widely used because of their advantages such as energy saving, high efficiency and environmentally friendly performance. However, frosting is a common problem of an air source heat pump [1]. Frost layer will increase the heat transmission resistance and affect the heat transfer rate, leading to a significant decrease in both the heating capacity and coefficient of heating performance of an air source heat pump [2]. Moreover, it will also do harm to energy conservation and emission reduction.

At present, scholars at home and abroad have done some research on anti-frosting and defrosting methods. Gou et al. [3] carried out experimental research of frost formation on a magnetic surface. Compared with the surface without magnetic field, the size of the condensate on the magnetic surface is smaller and its distribution is more even. Furthermore, the structure of the frost layer is looser, which is easier to be removed. Tan et al. [4] found that high pulling torque generated by ultrasonic vibration could decline or even fracture the frost in a short time. Shen et al. [5] observed the frosting and defrosting processes on four surfaces with different microscopic characteristics. Compared with the untreated hydrophobic surface, a super-hydrophobic microstructure surface has better anti-frosting performance. Wang et al. [6] sprayed glass water on the surfaces of the multi-line outdoor evaporators, and they found that glass water could remove a frost layer and delay frost formation. As
for air source heat pumps used in high humidity areas, spraying solution with low freezing point to defrost can make them keep working and provide continuous heat supply, which can provide references for the defrosting process of air source heat pumps used in high humidity areas.

2. Experimental Principle

The chemical potential theory states that when there is no transfer of work between a substance and the outside world, the substance will spontaneously transfer from the phase with a higher chemical potential to one with a lower chemical potential under isothermal and isobaric conditions. And the process won’t stop until the substance reaches the chemical potential equivalence in the two phases.

During the defrosting process, the frost layer on a fin will transfer to the solution spontaneously when the solution containing solute is sprayed onto the surface of the fin, because the chemical potential of the water in the spray solution is lower than that of the frost layer (solid water). In this way, the frost layer will melt gradually and this is how the defrosting process works.

3. Method and Procedure of the Experiment

3.1 Experimental Facilities and Distribution of Measuring Points

The experiment is carried out in an artificial environment room. The parameters of the experimental unit are shown in Table 1.

| Parameters of the Air Source Heat Pump | Value          |
|--------------------------------------|----------------|
| Rated power                          | 1100W(200W-1250W) |
| Refrigerant/mass                     | R410A/810g     |
| Heating capacity                     | 700-3600W      |
| Maximum operating pressure at exhaust/suction side | 4.2/1.5MPa |

The main test parameters include: the suction and exhaust temperature of the compressor, the temperature and humidity of the inlet and outlet of the indoor machine, the surface temperature of the outdoor heat exchanger, the suction and exhaust pressure of the compressor, the air velocity of the inlet and outlet of the indoor machine. The principle of the system and the distribution of the measuring points are shown in Fig.1.

![Fig.1 Distribution Map of the Measuring Points](image)

- T1——Exhaust temperature of the compressor; T2——Suction temperature of the compressor;
- T3——Inlet temperature of the indoor machine; T4——Outlet temperature of indoor machine;
- T5——Surface temperature of the outdoor evaporator; P1——Exhaust pressure of the compressor;
- P2——Suction pressure of the compressor.
3.2 Experimental Design

The parameters of temperature and humidity inside and outside the laboratory are shown in Table 2.

| No | Outdoor Ambient Temperature (℃) | Outdoor Ambient Humidity (RH) | Moisture Content (G/Kg) |
|----|---------------------------------|------------------------------|-------------------------|
| 1  | -2～-1                           | 85%                          | 3.41                    |
| 2  | 0～1                             | 85%                          | 3.98                    |
| 3  | 1～2                             | 85%                          | 4.28                    |
| 4  | 3～4                             | 85%                          | 4.94                    |
| 5  | 4～5                             | 85%                          | 5.30                    |

3.3 Determination of the Spray Solution and Its Concentration

As for the defrosting system where a solution with low freezing point is used, which solution to choose is crucial, because it will affect the reliability and stability of the system and it’s closely related to the performance of defrosting. Ethylene glycol is non-volatile and low corrosive, which can dissolve with water in any proportion. Besides, it has low viscosity and good heat transmission performance, and its price is reasonable. So, ethylene glycol is used as the spray solution in this paper.

The concentration of a spray solution directly affects defrosting speed and anti-frosting effect. If the concentration of a solution is too low, it will lower the speed of defrosting and the solution may freeze on the surface of a fin. However, if the concentration of a solution is too high and its viscosity is also relatively large, the transmission resistance of the solution will increase. And it will also lead to the increase of energy consumption. Therefore, it’s necessary to figure out an optimal concentration to ensure the performance of defrosting and anti-frosting.

![Fig.2 Diagram of Freezing Point-Concentration Curve of the Ethylene Glycol Solution](image1)

![Fig.3 Surface Temperature of the Outdoor Heat Exchanger during the Heating Stage](image2)

**Fig.2** shows the relation between the freezing point and the mass concentration of the ethylene glycol aqueous solution. It can be seen that the higher the concentration of the ethylene glycol aqueous solution is, the lower its freezing point temperature will be. However, they are not correlated linearly. When the concentration of ethylene glycol is over 60%, its heat transmission efficiency will be significantly reduced, but its freezing point temperature will not be lower. So, the concentration of the solution should be lower than 60%.

In addition, the freezing point of the spray solution should not be higher than the surface temperature of the outdoor heat exchanger so that the spray solution wouldn’t freeze on the surface of the outdoor heat exchanger. **Fig.3** shows the surface temperature of the outdoor heat exchanger of the air source heat pump at different outdoor ambient temperatures under heating conditions. From Fig.3, it can be seen that the surface temperature of the outdoor heat exchanger will decrease continuously when the unit is supplying heat. And when the outdoor temperature is 0-5℃, the
minimum surface temperature of the outdoor heat exchanger is \( T_3 = -7.7 \, ^\circ C \). It can be seen from Fig. 2 that the freezing point of the ethylene glycol aqueous solution is \( T_{i1} = -7.8 \, ^\circ C \) when its concentration is 20%. At this time, \( T_3 > T_{i1} \), so, when the outdoor temperature is 0-5 \( ^\circ C \), the concentration of the ethylene glycol solution should be 20%. When the outdoor environment ranges from -2 to -1 \( ^\circ C \), the minimum surface temperature of the outdoor heat exchanger reaches -9.7 \( ^\circ C \), which is lower than the freezing point of the 20% ethylene glycol solution. So, the concentration of the solution should be increased to prevent itself from freezing. According to the relationship between its freezing point and the concentration, when the ambient temperature ranges from -2 to -1 \( ^\circ C \), the concentration of the solution should be increased to 25% to ensure the effective defrosting performance of the system.

3.4 Experimental Operations

It is necessary to maintain the suction pressure at an appropriate level so that the heat capacity of the unit won’t drop. According to the situation of the unit used in this experiment, suction pressure of the unit should be set over 0.540 MPa. So, in this paper, the drop of the compressor suction pressure is regarded as the basis for the startup of the defrosting system. When the compressor suction pressure drops by 0.05 MPa, the spray system starts to defrost. Suction pressure will continue to rise with the melting of the frost layer. When the frost layer completely melts, suction pressure will rise to where it was before defrosting. The spray system should be turned off at this time, and the defrosting process is done. What should be done practically is to start the spray system when the unit begins to work. And the spraying process should last for 30s to prevent the solution from frosting on the surface of the heat exchanger. Whether the suction pressure is 0.05 MPa lower than its initial value, that is, below 0.490 MPa, should be closely observed when the unit starts to supply heat. If it is below 0.490 MPa for 30s, the spray system will be opened for defrosting. The change of suction pressure should be observed during defrosting. When it’s over 0.540 MPa, the spray system should be turned off and the defrosting process is finished.

4. Results and Discussion

4.1 Changes of Characteristic Parameters of the System

In this section, how suction/exhaust pressure, temperature at each measuring point, input power of the compressor, system heat capacity and performance coefficient (COP) of the air source heat pump system when a solution is sprayed to defrost change will be discussed.
drops rapidly due to the instant working of the compressor after the unit starts to supply heat. When the unit works for 3 minutes, suction pressure drops to 0.457 MPa and then it starts to rise. When the unit works for 13 minutes, suction pressure reaches the maximum value, 0.585 MPa. At this time, suction pressure begins to fall, because the frost layer formed on the finned tube of the outdoor heat exchanger. However, suction pressure starts to rise again when spraying begins. And that’s why suction pressure of the compressor fluctuates. Exhaust pressure rises gradually when the unit starts to work, and it reaches the maximum value, 3.126 MPa when the unit works for 43 minutes. After that, the fluctuation of exhaust pressure is small, and exhaust pressure remains at 3.048 MPa at the end of the whole process.

Fig. 5 shows how air outlet temperature of the indoor machine changes. Indoor temperature is 20.9 °C when the unit starts to work. Air outlet temperature of the indoor machine rises slowly at the beginning, and it rises to 22 °C four minutes after the startup of the unit. Why the temperature rises slowly is that compression frequency of the compressor is low in the initial stage, and the heating process is slow. Then the exhaust temperature starts to rise rapidly over time. When the unit works for 19 minutes, air outlet temperature of the indoor machine has exceeded 40 °C. When it rises to the maximum value, 44.3 °C, people indoor will feel comfortable. When frost forms at the surfaces of fins, the spray system starts to defrost. After that, the solution with a low freezing point remains on the surfaces of the fins, which can prevent frost from forming. When the unit stops supplying heat, air outlet temperature of the indoor machine can still be over 43 °C.

Fig. 6 shows how surface temperature of the outdoor heat exchanger changes. It can be seen that when the surface temperature is below 0 °C, frost begins to form at the surfaces of fins. At the beginning, the frost layer doesn’t cause the drop of suction pressure of the unit and the spray system doesn’t start to defrost. As a result, surface temperature of the outdoor heat exchanger will continue to decrease. When the temperature drops to initiate the startup of the spray system, the system will start to spray solution to defrost. And that’s when surface temperature of the outdoor heat exchanger starts to rise, showing a fluctuation trend. As can be seen from Fig. 6, minimum surface temperature of the outdoor machine is -3.4 °C when the unit is supplying heat. And it rises to 1.1 °C, the maximum value, after the spray system starts to work. When the unit is working, the spray system works to defrost intermittently. So, the exhaust pressure of the compressor maintains at a relatively high level, inevitably leading to a high input power of the whole unit. Fig. 7 shows how input power of the unit changes when the spray system is working. It can be seen from the diagram that input power increases rapidly, almost showing linear growth. When the unit works for six minutes, input power rises to 1.02 kW and then it will increase slowly. When the unit works for 35 minutes, input power reaches the maximum value, 1.29 kW. Moreover, it doesn’t fluctuate until the unit stops working.
Fig. 8 Heat Capacity and Performance Coefficient (COP) of the Unit

Fig. 8 shows how heat capacity and COP of the unit change when it works. As can be seen from the figure, heat capacity remains above 2000 W when the unit starts to work. And the reason is that intermittently spraying solution can defrost and decrease the frost on the surface of the outdoor heat exchanger, and the air between the refrigerant and the fins transfer well. The evaporation volume of refrigerant in the evaporator is enough, so both suction and exhaust pressure of the compressor are relatively high. Heat capacity is large, and it maintains a high level until the unit stops working. COP is stable when the unit works for 11 minutes, and its values are over 1.5. Input power of the unit is increasing with the increase of heat capacity, so COP doesn’t change greatly when the unit is working stably.

4.2 Effect of Ambient Temperature on the Performance of the Solution Spray System

Fig. 9 shows the variation of heat capacity of the unit under different working conditions. It can be seen from the figure that heat capacity of the unit increases gradually when it starts to work. When outdoor ambient temperature is 0°C, maximum heat capacity of the unit can reach 2082 W. When outdoor temperature is 4°C, maximum heat capacity of the unit can reach 2893 W, which is 38.9% higher than that at 0-1°C. So, it can be clearly seen that maximum heat capacity of the unit is over 2000 W under all working conditions. Moreover, the higher the outdoor ambient temperature is, the larger the heating capacity will be larger as the unit is working. Therefore, even though the spray system is used to defrost, outdoor ambient temperature still has influence on heating capacity of the
unit. However, when the heating capacity reaches its maximum under different working conditions, it doesn’t drop greatly but fluctuates slightly. It can be seen from Fig. 10 that the higher the outdoor ambient temperature is, the greater the COP will be when the unit is working stably. When the outdoor ambient temperature is 4 - 5 °C, the maximum COP is 2.12. When the outdoor ambient temperature is 0-1 °C, the maximum COP is 1.76, which is 20.4% lower than that at 4-5 °C. Therefore, COP of the air source heat pump reduces with the decrease of outdoor ambient temperature when the spray system is working to defrost.

5. Conclusion
When the spray system is working to defrost in this experiment, suction pressure and surface temperature of the outdoor machine will fluctuate. Intermittently spraying solution can defrost and decrease the frost on the surface of the outdoor heat exchanger, and the air between the refrigerant and the fins transfer well. When the unit stops supplying heat, exhaust pressure is over 3.0 MPa, outlet temperature of the indoor machine is higher than 40 °C, and heat capacity of the unit is over 2000W, which can definitely ensure the thermal comfort for the people indoor. In addition, outdoor ambient temperature will affect the performance of an air source heat pump when the spray system is working to defrost. The lower the outdoor ambient temperature is, the lower heat capacity and COP of the unit will be. In general, the defrosting method mentioned in this paper can work well as the air source heat pump is still supplying heat continuously, which can improve indoor thermal comfort.

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