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Research Progress of Defrosting Methods for Air Source Heat Pump

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Abstract

With the proposal of the national "double carbon" strategic goal, air source heat pump (ASHP), as a high-efficiency and energy-saving product, will be more and more widely used. Frosting is one of the main factors to reduce the heating capacity of ASHP in winter. The main technical solution for the problem is delaying frosting and high efficient defrosting. The research of domestic and foreign scholars on restraining frosting technologies and defrosting methods for ASHP are summarized. The researches show that changing the inlet air parameters and the structure of evaporators can realize restraining frosting without or only consuming less energy; electric heating defrosting needs consuming additional electrical energy; for small scale refrigeration and heat pump equipment, reverse-cycle defrosting and hot gas by-pass defrosting are most commonly used; a new defrosting method with small energy loss, continuous heating and non-stop defrosting needs to be developed in the future.

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Keywords: ASHP; restraining frosting; defrosting;heating performance ;

1. Introduction

In recent years, with the implementation of the “coal-to-electricity” project in China, air source heat pump (ASHP) has been widely used in northern China. However, when the ASHP is running in winter, especially when the outdoor air humidity is high, when the outdoor temperature is lower than 0℃, Frost will grow on the fins of the evaporator. Frosting will not only increase the heat transfer resistance, but also increase the wind resistance, reduce the heat transfer efficiency and the performance of the unit, and even in case of severe frost, the unit will be shut down. Therefore, the frost layer on the fins of the outdoor heat exchanger must be removed periodically. Seeking a suitable defrosting method has been a hot topic of domestic and foreign scholars. This paper summarizes the research on frost suppression and defrosting technology of ASHP by domestic and foreign scholars. The existing problems of frost suppression and defrosting technology are analyzed. The defrosting technology of large and medium-sized ASHP has been prospected.

2. Study on restraining frosting for ASHP

The evaporator frosting is greatly affected by the surrounding environment. Air parameters, surface characteristics, cold surface temperature, and fin structure have significant effect on frosting process and frost layer characteristics [1]. At present, the main methods to inhibit frost growth are to reduce the relative humidity of air around the evaporator, increase air temperature and speed.

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2.1. Reducing the relative humidity of the air

Xia et al. [2] found that after 50 min of heat exchanger operation, the frost deposition was 1. 34 times higher at 80% RH than at 70%. The former evaporator heat exchange decreased by 23. 1% and the latter by 17. 2%. This indicates that the higher the inlet air humidity, the higher the thickness of frost formation, the greater the frost deposition, and the greater the impact on the evaporator performance. For the ASHP, using the solid or liquid desiccant is mainly used to reduce the air humidity around the evaporator. Wang et al. [3] proposed a novel frost-free heat pump water heater system incorporating an energy storage device and an auxiliary heat exchanger covered by a solid desiccant. Experimental results showed that the relative humidity increased from 75 % to 85 % at a temperature of 0 °C, and the average COP of the system decreased by 6.7 %. A novel frost-free air source heat pump (ASHP) combined with membrane-based liquid desiccant dehumidification and humidification is proposed and investigated by Su et al. [4]. Results demonstrate that the COP_{sen} and the COP_{tot} of the novel system are at least 37.7% and 64.3% higher than that of the $COP_{reverse}$ of conventional reverse-cycle defrosting ASHP system in the variation ranges of the analyzed parameters, respectively.

2.2. Raising the temperature of the air

Increasing the inlet air temperature of evaporator can restrain frost growth effectively. Chen [5] proposed of setting a plate collector at the inlet of the outdoor heat exchanger, using solar preheating inlet air can effectively improve the evaporative temperature, so as to improve the system coefficient of performance (COP). Liu et al. [6] pointed out that in order to ensure energy saving and improve the efficiency of heat pump, the wet air can be heated by heat recovery technology. Kwak et al. [7] set the electric heater at the outdoor heat exchanger air inlet and turned on the electric heater to increase the outdoor heat exchanger inlet air temperature when the outdoor environment reached the frost condition, and the experiment concluded that the heat supply increased by 38.0% and the COP increased by 57.0% compared with the conventional heat pump, and the heat supply could be continuous and stable throughout the defrost period.

2.3. Increasing the speed of inlet air

Increasing air velocity can suppress frosting. Gu et al. [8] studied to compare the evaporation temperature of coils at windward velocity of 3m/s and 1.2m/s and found that the decrease in wind speed led to a rapid decrease in evaporation temperature, which resulted in faster frosting of the coils. Guo et al. [9] studied the influence of wind speed on frost layer growth. The results showed that the frost layer growth rate of outdoor heat exchanger increased with the decrease in air speed. Sheng et al. [10] concluded that increasing the flow rate may delay the formation of the early frost layer. When some frost layers appear, increasing the flow rate will lead to an increase in the density of the frost layer and promote the frost formation process.

2.4. Changing the structure of evaporator

Domestic and foreign scholars mainly studied increasing the evaporator area, changing the structure and spacing of fins, and the number of tube rows along the airflow direction to restrain frosting on the evaporator surface. Huang et al. [11] used three outdoor units with different fins to compare the performance of ASHP, and found that flat fins had the best thermal properties. A defrost-free heat exchanger that has fin surfaces with fine irregularities was proposed by Yajima et al [12]. It could be confirmed that the heat pump, fitted with the defrost free heat exchanger where the fine irregularities were formed only on the fin-ends. The use of the defrost-free heat exchanger has made it possible to achieve a higher COP. Cheng et al. [13] simulated the air-side heat exchanger of air-source heat pump chiller and hot water unit with different fin spacing, tube diameter and tube spacing. The study shows that the fin spacing: 2 mm for light frost zone, 2.5 mm for general frost zone, and 3.5 mm for heavy frost zone is the optimal value; tube diameter 8 mm is better than 10 mm and 12 mm; tube spacing 27.4 mm is better than 25.4 mm.

2.5. Changing evaporator surface characteristics

Some scholars in China and abroad have studied the inhibition of frosting by surface treatment technology (hydrophobic coating or hydrophilic coating). He et al. [14] prepared a superhydrophobic aluminum-based fin with a contact angle of 158.3°, and the experimental study results showed that the superhydrophobic surface exhibited good frost inhibition and rapid frost melting properties.

Shan [15] conducted a theoretical and simulation study on fins with a superhydrophobic composite coating of epoxy resin + 2 wt% graphene and found that the coated fins could provide frost suppression, shorten defrosting time, and improve heat transfer efficiency.

2.6. Changing the temperature of cold surfaces

The effect of cold surface temperature and air humidity on frosting is more obvious than air temperature, flow rate and heat exchanger structure [16]. Wang et al [17] found that when air temperature is 10.5℃, relative humidity is 80%, wind speed is 3m/s, cold surface temperature is -3.5℃~-19.7℃, the temperature of cold surface has a significant influence on frosting rate, defrosting frequency and frosting height.

3. Study on defrosting technology for ASHP

Common defrosting methods include reverse cycle defrosting (RCD), hot-gas bypass defrosting (HGBD), and electric heating defrosting (EHD). In recent years, researchers have proposed a variety of new ASHP defrosting methods for reverse RCD and HGBD technology, and studied the defrosting effect, system performance and indoor comfort. In addition, in recent years, scholars have proposed energy storage defrosting (ESD), liquid defrosting (LD) and so on.

3.1. Study on Reverse Cycle Defrosting

3.1.1. Conventional reverse cycle defrosting

RCD is an effective defrosting method widely used at present. RCD is mainly used in small household air conditioning, heat pump and refrigeration equipment.

A large number of theoretical and experimental studies on RCD methods have been carried out in China and abroad. Song et al. [18] proposed that the distribution of chillers in the circuit has an effect on the reverse cycle defrost performance, and that the defrost efficiency of vertically installed multi-circuit heat pump units was improved by 7.4% compared to the uneven distribution of refrigerant in each circuit. Reverse cycle defrosting will cause the room temperature to decrease by about 2~5℃, and it will take about 10min for the system to return to normal heating state after defrosting [19].

It can be seen that the conventional RCD inevitably needs to absorb heat from the room. It causes a large fluctuation of indoor temperature and causes discomfort to human body. In addition, when the four-way valve is switched. In addition, when the four-way valve is switched, it has a great pressure impact on the compressor and pipeline.

Hu et al. [20] developed a novel reverse cycle hot gas defrost method for air source heat pumps. The experimental results suggested that the use of the novel reverse-cycle hot gas defrosting method for the experimental ASHP unit was able to help shorten the defrosting time by 3 min or 38%, and minimize the risk of shutting down the ASHP unit due to low suction pressure through increasing the compressor's suction pressure by about 200 kPa, when compared to the use of the traditional standard reverse-cycle hot gas defrosting method.

3.1.2. Reverse cycle defrosting with new heat dissipation terminal

In order to reduce the influence of RCD on indoor thermal comfort and improve the heating performance of the heat pump system, some scholars proposed an ASHP system with radiation heat dissipation terminal [21-24].

Xu et al. [25] effectively coupled the condenser of the heat pump system with the radiation heat pipe. The refrigerant medium is filled inside as the heat dissipation medium. Experimental studies showed that the heating apparatus of heat pump-driven heat pipe has a fast start-up speed. After defrosting, the surface temperature of radiator recovered quickly and distributed evenly. Qu et al. [26] proposed a thermal storage based reverse cycle defrost method, stating that the optimal defrost strategy is to keep the low-level cycle compressor frequency at 90 Hz and the high-level cycle expansion valve opening at 80%. This method can reduce the energy consumption of air source heat pump defrosting. The principle is shown in Fig.1.

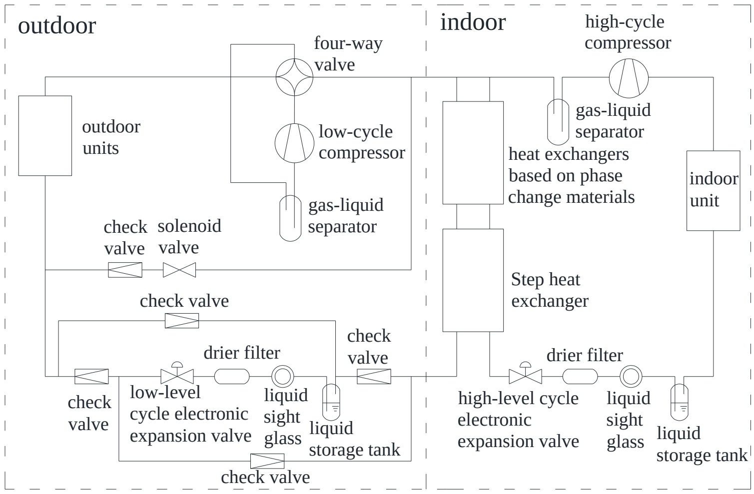

Fig. 1. Reverse circulation defrosting system based on regenerative [26].

3.2. Study on hot-gas bypass defrosting

3.2.1. Conventional hot-gas bypass defrosting

The HGBD is to set a bypass pipeline between the compressor discharge pipe and the evaporator inlet pipe. When defrosting, the solenoid valve on the bypass pipeline is opened, and the compressor discharge vapor was directly discharged into the frosting evaporator.

Lai et al. [27] concluded that the most influential factors of bypass defrost efficiency are the bypass volume, the point of entry into the defrost, and the defrost frequency, and the optimal time entry point for defrost can be determined by the frost inflection point. Xi et al. [28] proposed a new intelligent control strategy based on the maximum heating capacity of the hot gas bypass defrost system and designed a suitable defrost start-stop point. The results showed that the heating capacity of the hot gas bypass defrost was increased by 10.17 % and the overall energy efficiency was improved by 4.06 %. Huang et al. [29] pointed out that the time of HGBD is 2.89 times of RCD. The superheat in suction of compressor is always around 0℃ during defrosting. The discharge temperature and superheat of the compressor continuously reduce, and the safe operation of the compressor is threatened. For heat pumps and water heaters with trans critical CO_2, the power consumption of RCD is lower than that of HGBD, and the average heating COP is higher [30-32].

3.2.2. Hot-gas bypass defrosting with continuous heating

In view of the problem that the system heating is insufficient or even stopping heating during defrosting, some scholars upgraded the defrosting method of hot-gas bypass with double/multiple circuits hot-gas bypass defrosting to achieve continuous heating.

Si et al. [33] proposed a double-loop bypass defrosting technology, in which the indoor unit keeps continuous heating operation under experimental conditions, and as the outdoor temperature decreases, the amount of frosting decreases, the heating operation time is extended, and the proportion of heating time in the whole defrosting/heating cycle keeps increasing. Liu et al. [34] proposed an ASHP system with continuous heating in defrosting. The system has at least two outdoor heat exchangers, one is defrosting, the other one continues to absorb heat from the outdoor air. Part of the heat is used for heating and the other is used for defrosting the outdoor heat exchanger to achieve defrosting while continuing to heat. The system principle is shown in Fig.2 and it is still part of the discharge defrosting of the bypass compressor.

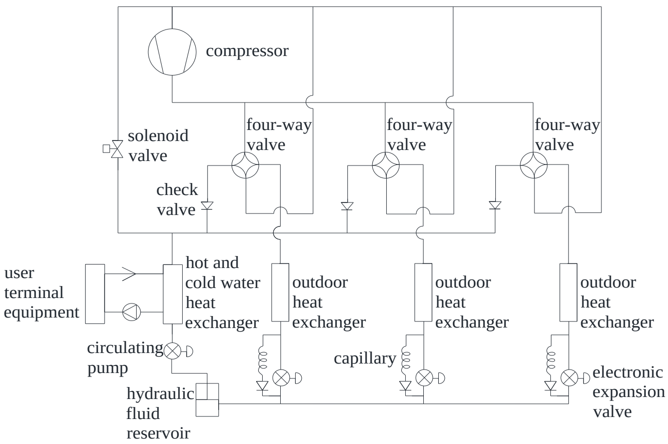

Fig. 2. ASHP with continuous heating and defrosting [34].

Fu et al. [35] proposed a new grouping throttle defrosting method based on the HGBD method. The principle is shown in Fig. 3. The outdoor heat exchanger is divided into two rows, the parallel capillary and solenoid valve are connected in the middle. In defrosting the front and rear heat exchange tubes are used as condenser and evaporator respectively, and the four-way valve is used to defrost them respectively. Under the working condition of outdoor temperature of 2℃ and relative humidity of 80%, the defrosting time of reverse cycle is about 440s, and the defrosting time of this system is about 430s, which is slightly shorter than the defrosting time of reverse cycle method.

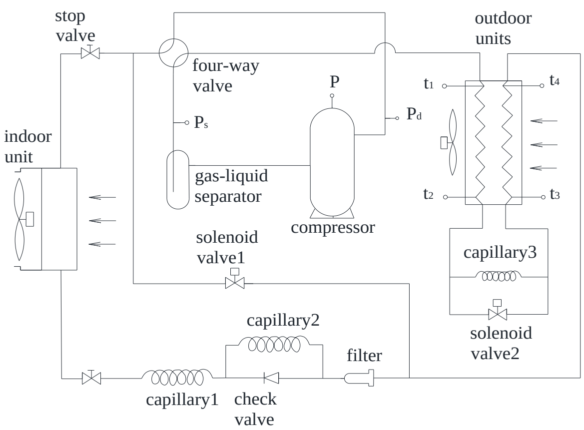

Fig. 3. Principle of group throttle defrosting system [35].

3.3. Study on electric heating defrosting

EHD usually installs an electric heater in the evaporator shell, or installs a heater element on the evaporator fin to defrost. Wang et al. [36] proposed an air-source heat pump system with auxiliary heating from an external heat source, with an additional electric heater between the expansion valve and the condenser. The principle is shown in Fig. 4. The system can extend the operating time of the air-source heat pump for heating under low temperature and high humidity conditions and achieve continuous heating during defrost, but the COP under each condition will be reduced, resulting in increased power consumption.

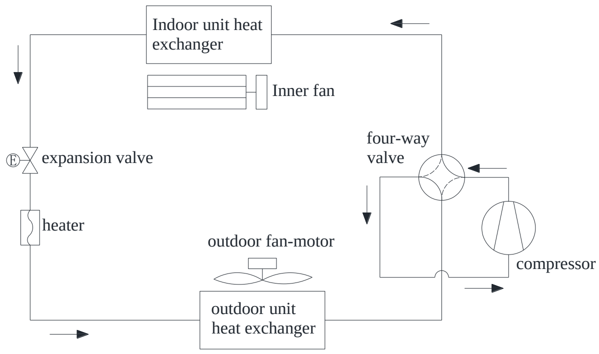

Fig. 4. Heating / defrosting flow chart of new external heat source assisted heating air source heat pump system [36].

The EHD control is convenient, and the electric heating system is relatively independent of the heat pump system. The defrosting ability is not limited by environmental conditions, and the reliability is high [37]. EHD is easy to control, but at the cost of additional power consumption, it is generally only applicable to small window air conditioning [38] and refrigerators [39-40]. The heat requirement of EHD is determined by the thickness of the frost layer and the surface temperature of the evaporator. However, the EHD not only has low defrosting efficiency, but also increases power consumption.

3.4. Study on energy storage defrosting

The ESD method can fundamentally solve the problem of energy shortage of the traditional defrosting method [41], and improve the running stability of the ASHP to a certain extent.

Liu et al. [42] designed a phase change heat storage exchanger through an air source heat pump defrost system with compressor housing heat storage combined with hot gas bypass circulation, and the experimental results showed that the defrosting time and energy consumption were reduced by 10s (9%) and 12.1kJ (21.7%), respectively, compared to reverse cycle defrosting. Zhao et al. [43] used paraffin wax as the heat storage medium and adopted the idea of "waste heat storage and waste heat defrost" to achieve the "frost-free effect", and the system suction and discharge pressure and compression ratio changed smoothly compared with RCD. Chen et al. [44] used the heat storage module with electric heating layer matrix structure to realize VRV system defrosting with heating without shutdown. Zhu et al. [45] proposed a new air source heat pump thermal storage heating system using peak and valley electricity and variable flow operation to achieve economical operation. Through simulation calculation and analysis, the results showed that the operating cost of the system in the heating season can be reduced by more than 50% compared with the annual cost of central heating. Zhao et al. [46] proposed an energy storage air source heat pump system for rapid heating and defrosting, as shown in Fig. 5. Tests were conducted under experimental conditions, and the results showed that the defrosting time of the new system was 68% shorter and the defrosting energy consumption was 51.4% less than that of the conventional system.

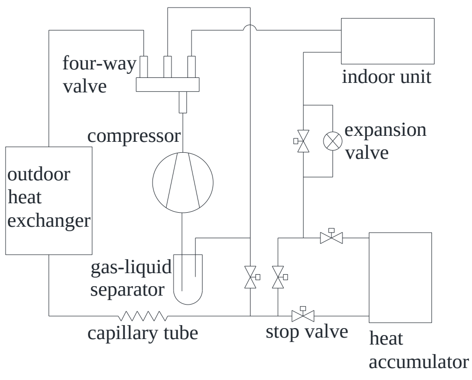

Fig. 5. Principle diagram of storage type air source heat pump system [46].

3.5. Study on liquid defrosting

The LD was first used in the cold storage refrigeration system [47]. This system includes two parallel evaporators. Through valve switching, the sub-cooling liquid after refrigerant defrosting can be evaporated and cooled in another evaporator. Although the system can realize defrosting without stopping cold storage refrigeration, defrosting will also lead to temperature rising for the cold storage.

Niu et al. [48] proposed a heat pump system with multi-outdoor units in parallel defrosting in turn, which principle is shown in Fig. 6, and carried out detailed theoretical and experimental research. The results showed that the system performance achieve best when 4 outdoor units are used for defrosting, and the heating capacity of the system can still reach 60% of that without frost. This method can achieve defrosting with heating at the same time, but for the multiple evaporators, the distribution of refrigerant flow becomes a key factor affecting the operation stability of the system during defrosting.

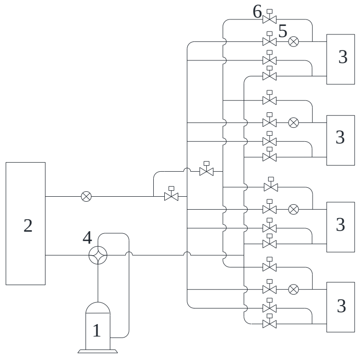

Fig. 6. Principle of sub-cooling defrosting with multi-outdoor units [48].

3.6. Other defrosting methods

Lin et al. [49] put forward hot water defrosting. The defrosting device that can produce hot water is placed on the condenser of the outdoor unit. Through this device, the defrosting is carried out, and the systematic frosting and heating of the air conditioning are carried out at the same time. The defrosting device is an independent additional system with high reliability.

A new defrosting strategy through injecting medium-pressure vapor refrigerant into compressor during defrosting process was proposed by Wei et al. [50]. For the ASHP in the experiment, with the injected electronic expansion valve opening less than 50%, the experimental unit can run safely and defrosting performance improve gradually with the opening increase.

Cai [51] found through simulation studies that the morphology of the frost layer changed significantly after the electric field intensity was applied to the environment, and the individual areas of frost aggregation gradually showed elongated morphological changes, and the frost layer was significantly suppressed.

Tan et al. [52] found through experiments that ultrasonic waves can remove the frost in a certain area of the evaporator surface, and the energy consumption is less than 50% of the energy consumption of the reverse defrost, and the defrosting efficiency is 7~29 times higher than the reverse defrost.

4. Conclusions

In view of the problem of frosting/defrosting in the ASHP system, the research on restraining frosting and defrosting technology is analyzed and reviewed, the conclusions are as follows:

1) Changing air parameters, evaporator structure and surface conditions can play an important role in restraining frosting. However, it can only delay frosting to a certain extent, once the evaporator getting frosting, a certain defrosting method must be used to remove the frost layer.

2) Reverse cycle defrosting and hot-gas bypass defrosting are the most common methods. At present, the research is more focused on the combination of new heat dissipation terminals to improve indoor comfort for reverse cycle defrosting. Based on hot-gas bypass defrosting, multiple evaporators are used to realize non-

stopping heating operation. Due to part of discharge vapor of the compressor is used for defrosting, the system heating capacity decreases and the heating performance deteriorates.

3) Electric heating defrosting is widely used in refrigerators at the cost of extra electric energy. Energy storage defrosting is in the experimental and simulation stage, and has not been applied widely yet. The application of the liquid defrosting method in the defrosting of the evaporator of the cold storage will lead to a temperature increase in the cold chamber. Four outdoor units are used in the ASHP to obtain the optimal defrosting performance.

4) Restraining Frost Formation has attracted much attention due to no energy consumption or low energy consumption. If frost can be restrained or delayed from the source, it will further promote the development of ASHP. At present, the commonly used defrosting methods are mainly used for small-sized ASHP. For large or medium-sized ASHP, due to the excessive thermal inertia of the system, the heat loss of cold and hot fluid mixing cannot be ignored. In the future, it is necessary to develop a defrosting method with small energy loss, continuous heating and uninterrupted defrosting.

Acknowledgements

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