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Experimental study on concentration change of spray solution used for a novel non-frosting air source heat pump system

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ABSTRACT

Frost formation on the outdoor coil surface of an air source heat pump (ASHP) unit may occur when it is used for space heating at a low ambient temperature in winter. To reduce the impact of frosting on the operational performance and energy efficiency of ASHPs, a novel non-frosting air-source heat pump (NASHP) system was proposed. The detailed introduction of NASHP prototype was given, and its test rig was developed, as well as its operating principles and modes. Then the characteristics of some conventional dehumidification solutions were compared; the glycerol was selected as spray solution for NASHP system, due to its great influence on the operating performance of the system. The glycerol solutions with different concentration and different mass flow were investigated experimentally, and the best practice by which NASHP system has the most remarkable efficiency was found finally. Such results will provide helpful reference for the potential application of NASHP system and future research work.

1. Introduction

Environmental pressures have resulted in an increased importance being placed on the consumption of energy and energy efficiency. Air source heat pumps (ASHPs) have the potential to make an important contribution to make the transition to more sustainable energy systems since they utilize the low grade energy in the air as sources. Air source heat pump (ASHP) system as cooling and heating source for building heating, ventilating and air conditioning (HVAC) systems becomes increasingly popular in central and south China [1]. However, in the past ten years, a growing number of ASHPs were found unsatisfactory during practical operation. Professor Zhang had made an investigation on a project which used air-source heat pump heater/chillier unit as central air-conditioning. The result showed that only fifteen percent of these units work well [2]. Similar problems occur successively in cities such as Hangzhou, Chengdu and Changsha. The most significant cause of the poor performance of ASHP unit is that frost may form on the tube surface of its outdoor coil when an ASHP unit operates for space heating at a low ambient temperature in winter. Frost reduces the airflow passage area and acts as a thermal insulator, leading to the performance degradation of the outdoor coil, or even the shutdown of the ASHP unit [3–5]. Therefore, it is necessary to defrost periodically or delay frosting.

Currently, the most widely used standard defrosting method for ASHPs is reverse-cycle defrosting method [6,7]. However, there are a number of problems, including insufficient heat available, prolonged defrosting time, low stability of system and affected thermal comfort of occupants during defrosting for ASHPs [8,9]. To solve these problems, Hu et al. [10] proposed a novel thermal energy storage based reversed-cycle defrosting technology for ASHPs. It improved the stability of the system and took shorter time; however the fundamental problem of insufficient heat available during reverse-cycle defrosting remains unsolved. To solve these problems in essence, methods of avoiding or delaying frosting rather than defrosting after frost formation should be considered. There are several parameters that affect frost growth on outdoor coils, such as air velocity, air humidity, air temperature, surface temperature [11,12], surface energy (including coatings or roughness) [13,14], fin geometry and water retention [15]. According to these parameters, the research on preventing or delaying frosting can be classified to three types.

1.1. Change the outdoor air parameters

The experiments on different ASHP units showed that frost may form when the outdoor air temperature is between −12.8 °C and 5.8 °C; meanwhile its humidity is greater than 65%, which is also called frosting area [16]. Therefore, many studies were carried out to decrease the outdoor air humidity. Kondepudi et al. [17] utilized solid desiccant to dehumidify the air in the entrance of heat exchanger. It could prevent frosting effectively by reducing the humidity of the air at the initial time. However, the moisture absorption capability of desiccant as well as the performance of inhibiting frost would decline by time. Wang and Liu [18] fixed an adsorbent bed made of zeolite plates with an active carbon coat

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behind the outdoor unit of heat pump. In this way, not only did the air humidity reduce, but also the air temperature rose because of absorbing heat. However, the desiccant must be regenerated when the inhibition of frosting is decreased. In addition, the bed increased the flow resistance of air as well as the energy consumption of fan, which prevented this method from practical application.

1.2. Change the structure of evaporator

The influences of enlarging the heat exchange area of evaporator and fin span, as well as changing the structure of fin were mainly studied [19]. Besides, Gu et al. [20] found that delay frosting can be realized by adding the fin span. Therefore, the value of fin span should be different in areas with different humidity.

1.3. Change the surface energy of evaporator

The studies on the influence of hydrophobe and hydrophilic surface coating on the frost growth had been carried out; however, contrary results had been got. Nikulshina et al. [21] covered the evaporator with hydrophobe coating, and found it can change the structure of frost. However, there were opposite views on the influence of the surface energy. Seki and Hoke [22,23] thought that the frost on hydrophobe surface was more intensive than that on hydrophilic surface.

Although previous research relating to both frosting and inhibition of frosting for ASHPs have been carried out and reported, none of the above methods have been found efficient enough and the fundamental problem of defrosting remains unsolved. To avoid frosting in essence, a novel non-frosting air-source heat pump (NASHP) system as well as its operating principles and modes have been proposed, and the best practice by which NASHP system has the most remarkable efficiency is found experimentally. The NASHP system can avoid frosting, delay frosting and defrosting timely and efficiently with sufficient heat available.

2. Experimental apparatus and prototype

2.1. NASHP system

Frost formation on the outdoor heat exchanger of an ASHP unit occurs when the surface temperature is below both the dew point of the moist air and the freezing point. The mechanism of NASHP system proposed in this paper is to avoid these two essential elements to appear simultaneously. Fig. 1 shows the schematic of NASHP system.

As Fig. 1 shows, the NASHP system is composed of a solution spray subsystem and a conventional ASHP subsystem. The solution subsystem consists of a solution pump, two solution tanks, sprayers and the corresponding piping and valves. The working fluid is solution. This subsystem is installed on the outdoor unit of the ASHP subsystem.

When the frost accumulates to a certain thickness (frost affects slightly when it is thin), the solution spray subsystem starts to work and it sprays the liquid desiccant windward to the finned tube of the outdoor heat exchanger. The operational principles are as follows: firstly, outdoor air is dehumidified by contacting in a large area with the liquid droplet, thus the dew point temperature reduces. Secondly, the sprayed liquid desiccant has the effects of brushing the surface of heat exchanger and defrosting. Finally, the dehumidified air transfers heat and moisture with the liquid desiccant retained on the surface of outdoor heat exchanger, and the frost-proof liquid membrane formed could lower the freezing point. Thereby, the elements of frosting are avoided. After spraying for a while, close the solution spray subsystem and run the NASHP system in a traditional way. And when the monitored parameter

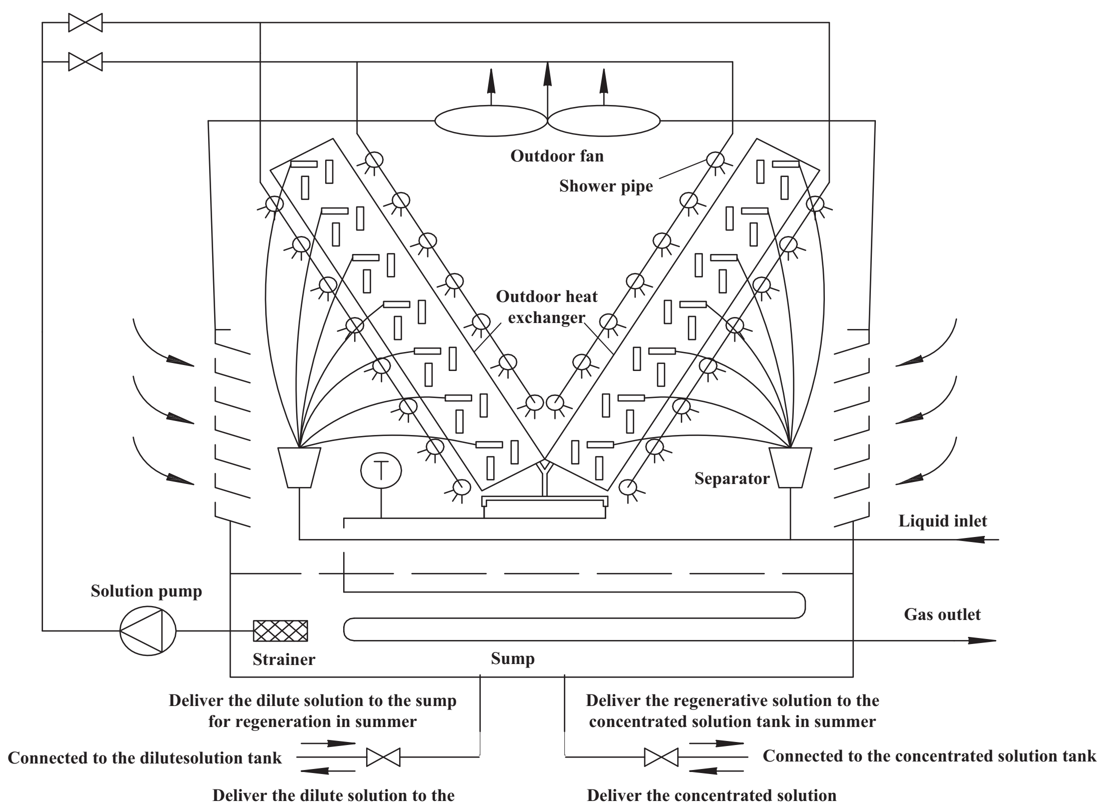

Fig. 1. Schematic of NASHP system (for heating).