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Experimental study of the effects of fin surface characteristics on defrosting behavior

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HIGHLIGHTS

- The effect of surface characteristics on defrosting behavior of fins was reported.
- A fin frosting/defrosting experimental system was constructed to realize the visual research of defrosting process.
- The characteristics of frost melting and molten water retention were analyzed and compared.
- Results indicate that the hydrophobic fin can improve the defrosting efficiency.

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ABSTRACT

The defrosting behavior of an air source heat pump includes melting, drainage and evaporation, which shows different characteristics on fins with different surface characteristics. This paper presents an investigation of the effects of surface characteristics on the defrosting behavior of a fin. A frosting/defrosting experimental system was constructed to implement visual research of the defrosting process on fins with different surface characteristics. The characteristics of frost melting and molten water retention were analyzed and compared. The effects of the surface characteristics on the melting time and melting process were significant. There were obvious differences in molten water retention among different fins. Retained water formed a thin water film on the hydrophilic fin, while only a few spherical droplets with small sizes stayed on the super hydrophobic fin because the frost layer was released from it. The retained water mass on the super hydrophobic fin was the least, which reduced the energy for evaporation. Repeated experiments showed almost the same defrosting behavior as those of the first run.

1. Introduction

Air source heat pumps (ASHPs) have been widely used because of their advantages such as combining heating and cooling capacity, energy saving, environmental protection, flexibility and convenience [1]. The ASHP used as cooling or heating sources for heating, ventilation and air conditioning installations has found wide applications over the recent decades in many parts of the world [2], such as in America and China [3]. However, the phenomenon of frosting on the outdoor heat exchanger is unavoidable when the ASHP is used for heating in winter. The frost layer may reduce the efficiency of the heat exchanger and even result in the mechanical failure of the ASHP unit [1,4]. Therefore, exploring effective defrosting technologies are focused on by researchers worldwide.

So far, researchers have put forward some defrosting methods, such as reverse-cycle defrosting [5], hot-gas bypass defrosting [6], energy storage defrosting [7] and sensible heat defrosting [8]. Obviously, the defrosting process consumes much energy, which leads to lower efficiency of the ASHP in periodic frosting–defrosting cycles. An effective anti-frosting technology may delay frosting and reduce the frost quantity, thereby reducing the energy consumption for defrosting and improving the efficiency of the ASHP.

With the development of various kinds of new materials, surface treatment has become an effective technology to restrain frost growth. The study of the hydrophilic surface on delaying and suppressing frosting started from the early 80s. Okoroafor [9] tested the restrained frost ability of a hydrophilic surface in over 2 h, and results indicated that the reduction in the frost growth rate

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and subsequently frost thickness lied in the range, 10%–30%. Lee et al. [10] developed two surfaces with different hydrophilic characteristics and found ambient conditions associated with the formation of frost structures. Huang et al. [11] developed a fin-tube heat exchanger with hydrophilic coating thickness of 30 μm and conducted a series of comparative experiments to test its effectiveness in restraining frosting, where the results demonstrated that the anti-frosting duration of the coated heat exchanger was longer compared with the uncoated heat exchanger. A more interesting candidate, which is currently being investigated for anti-frosting applications, is the use of the hydrophobic surface [12]. Liu et al. [13] prepared a super hydrophobic surface whose contact angle was 162°. The super hydrophobic surface had a strong ability to restrain frost growth and the frost on the surface was delayed for 55 min compared with the plain copper surface under the tested conditions. Cai et al. [14] studied the growth characteristics of the frost layer on a hydrophobic surface by means of experiments. Jing et al. [15] performed experiments to investigate the frosting on the rigid super hydrophobic surface and found it had advantage of anti-frosting. These works mainly focused on the effects of surface characteristics on the frosting behavior rather than on the defrosting behavior.

There have been a few studies of the defrosting behavior on treated surfaces. Rahman et al. [16,17] investigated the drainage of frost melt water from a number of micro grooved brass surfaces experimentally and found that micro grooved surfaces drained up to 70% more condensate than the flat baseline did. Kim et al. [18] studied the characteristics of frosting and defrosting on a fin according to its surface contact angle under the winter operating conditions of a heat pump, and put forward the concept of the ratio of the retained water mass. Jhee et al. [19] investigated the effects of the heat exchanger surface treatment on the frosting/defrosting behavior in a fin-tube heat exchanger, and the results revealed that the amount of retained water on the surface treated heat exchangers was shown to be smaller than that of the bare heat exchanger. However, the defrosting behavior of the ASHP includes melting, drainage and evaporation. The characteristics of above processes are different on fins with different surface characteristics, which greatly influence the performance of the ASHP during periodic frosting–defrosting cycles. Therefore, studying the effects of surface characteristics on the defrosting behavior including above processes are necessary. In this paper, a frosting/defrosting experimental system was constructed to implement the visual research of the defrosting behavior on fins with different surface characteristics, and the characteristics of frost melting and molten water retention were systematically analyzed and compared.

2. Experiments

The aim of the experiments was primarily to investigate and compare the defrosting behavior of fins with different surface characteristics. Therefore, an experimental system including a frosting/defrosting platform and an air supply system was designed. Fig. 1 is the schematic diagram of the frosting/defrosting platform. A cold platform with the semiconductor thermoelectric refrigeration, was used to adjust the temperature of the fin surface. The surface temperature can be controlled from −20 °C to 150 °C by using a temperature controller. The cold platform was placed vertically in the experiments. The largest size of a sample fixed on the cold platform is not more than 94 mm × 94 mm. The visual research of the defrosting behavior was performed by using an image acquisition system. The image acquisition system included a CCD video camera, an asana microscope and image acquisition cards. The side and front photographs were recorded by the CCD video camera and the asana microscope, respectively, and then were transmitted to the computer.

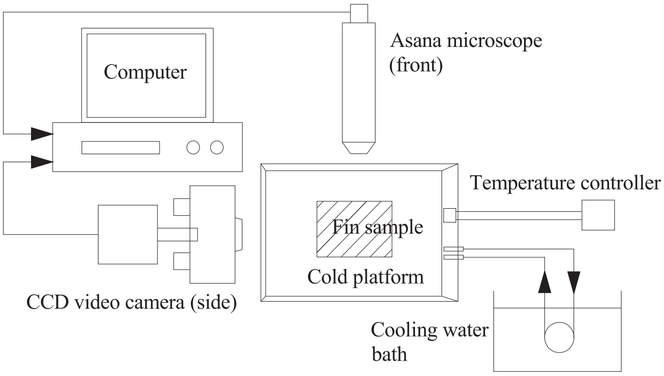

Fig. 1. Schematic diagram of frosting/defrosting platform.

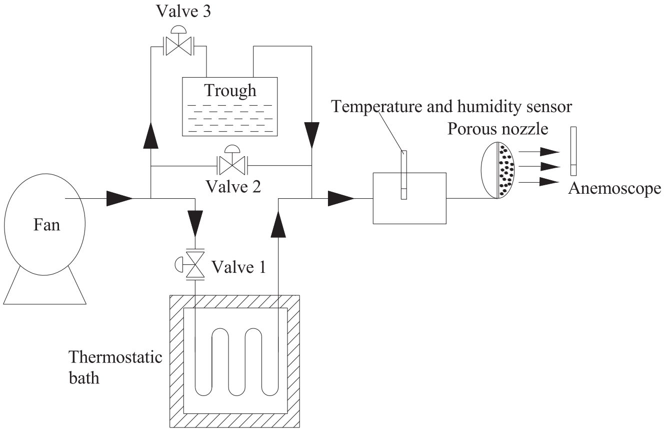

Fig. 2. Schematic diagram of air supply system.

Fig. 2 is the schematic diagram of the air supply system, which was used to adjust the temperature and humidity of the frosting and defrosting environment. A thermostatic bath was used for cooling and dehumidifying the supply air and a trough was used for humidifying the supply air. The supply air inhaled by the fan was divided into three branches. One branch was cooled and dehumidified by the thermostatic bath, one branch was humidified by the trough, and another branch was in the by-pass pipe. The temperature was controlled by adjusting the opening of valve 2 to adjust the air flow into the thermostatic bath. Similarly, the humidity was controlled by adjusting the opening of valve 3. The air flowing through the three branches mixed and reached the surface of the fin sample through a porous nozzle. The porous nozzle was similar to a shower nozzle, which ensured the uniform air distribution around the fin surface. Temperature and humidity sensor was used to measure the condition of the supply air. An anemoscope was used to measure the velocity of supply air. Table 1 shows the measurement parameters and instrument performances. The

Table 1
Measurement parameters and instrument performances.

Measurement parameter	Instrument	Range	Accuracy
Fin surface temperature	K-type thermocouple	−200–350 °C	±0.1 °C
Air temperature/air relative humidity	Temperature and humidity sensor	−40–120 °C, 0–100%RH	±0.2 °C, ±1%RH
Air velocity	Anemoscope	0.05–30.0 m/s	4%