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Experimental investigation of frost and defrost performance of microchannel heat exchangers for heat pump systems

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HIGHLIGHTS

- ▶ Cycle frosting performances of two microchannel heat exchangers were studied.
- ▶ The vertical-tube sample with less water retention had better performance.
- ▶ Water retention impact on frosting time and performance was studied quantitatively.
- ▶ Growing of ice crystals had three periods, observed by image processing method.
- ▶ The impact of water retention on the frost crystal formation was analyzed.

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ABSTRACT

The cycle frosting and defrosting performance of two types of microchannel heat exchangers were investigated. All the processes were observed using a CCD camera to better understand the cycle frost mechanism. Ice blockage formed in the fin root gaps of the horizontal-tube sample because of water retention. Cycle operation increased the blockage severity until the fin space was completely blocked. The amount of water retained and its impact on frosting time, pressure drop, and capacity were investigated. With increasing water retention, frosting time decreased, air pressure-drop and capacity could not return to the initial value after each defrosting time. Approximately 800 g of water was retained on the heat exchanger after four operating cycles, causing the ice blockage that shortened the effective operating time by 40 min compared with that of the vertical-tube sample at the end of the test. At the beginning of the fifth frost cycle, air pressure-drop had reached thrice the initial pressure drop, even when no frost was on the surface. The capacity decreased by 27% compared with the initial value. However, the vertical-tube sample exhibited no obvious water retention on the surface; as such, pressure drop and capacity experienced a similar degradation process during each cycle. The distribution of ice crystals on the fin surface was also studied, and the frosting process was divided into three periods: initial, developing, and fully grown. With increasingly serious water retention, frost only formed at the fin front-end surface, and could only reach the initial period because the ice blockage rapidly increased the pressure drop, thereby causing the defrosting process.

1. Introduction

Microchannel heat exchangers are a new kind of highly efficient and compact heat exchangers. Saving on space, weight, and refrigeration charge, microchannel heat exchangers have been widely used in automotive air-conditioning systems in the past few years. Recently, such heat exchangers have been increasingly used in other refrigeration devices, especially in heat pump systems, where they must operate under wet and frost conditions. The low conductive thermal resistance of the microchannel tubes makes the fin base temperature closer to the local saturation temperature of the refrigerant. This condition leads to a relatively high rate of frost growth and an increase in defrost cycles during heating-mode operations [1]. Thus, condensate-draining performance and frost–defrost processes must be seriously considered.

Numerous research has focused numerically and experimentally on frost formation. Yang and Lee [2,3] experimentally studied frost formation on flat plates and suggested correlations for frost thermal conductivity. Dyer et al. [4] experimentally studied frost growth on five different substrate plate surfaces. Frost grows 13% thicker in hydrophilic-coated surfaces compared with bare aluminum plates. Yan et al. [5] investigated the performance of frosted finned-tube heat exchangers of different fin types. The heat

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exchanger with re-direction louver fins has the highest amount of frost. Tso et al. [6] developed a distributed model considering the uneven wall and air temperature distribution inside the coil to predict the dynamic behavior of a finned-tube heat exchanger under both frost and non-frost conditions. Shao et al. [7] similarly researched on developing a distributed model of microchannel heat exchanger used in commercial heat pump systems and the frost-formation processing of fin tube evaporators. Wu et al. [8] studied frosting characteristics on a microchannel heat exchanger with louver fins, and provided the frost height correlation. Moallem et al. [9,10] investigated surface temperature, surface coating, and water retention effects on the frosting performance of microchannel heat exchangers. Surface temperature has a larger impact on the frost growth rate and frosting time compared with surface coating and water retention.

Several other studies have focused on the performance of the frost–defrost cycle of heat exchangers, which is much more important to the actual design of heat pump systems. Xia et al. [11] experimentally studied five louvered-fin microchannel heat exchangers, and found that condensate droplets significantly affect the air pressure drop and heat transfer in the re-frost cycles. Zhang and Hrnjak [12] investigated frosting performance of parallel-flow parallel-fin (PF2) flat tube microchannel heat exchangers with horizontally-installed tubes. Compared with a conventional serpentine fin, the frosting performance improved, which was attributed to better drainage capability of the PF2 heat exchanger. Padhmanabhan et al. [13], on the other hand, found that removing the water residual by flushing the microchannel coil with pressurized nitrogen at the end of the defrost cycle improved the next frost cycle time by only 4%.

The studies on the frost and defrost performance of microchannel heat exchangers are quite limited and sometimes inconsistent. As such, this paper aims to investigate the frost and defrost performance of two types of microchannel heat exchangers and the impact of condensate draining on the cycle performance. At present, the digital image processing method has been applied to analyze frost formation [8,14]. Thus, the method is also introduced in our study. The frosting, condensate draining, as well as cycle frosting and defrosting processes are observed by a CCD camera, which will provide insights into the cycle frosting and defrosting mechanism in microchannel heat exchangers.

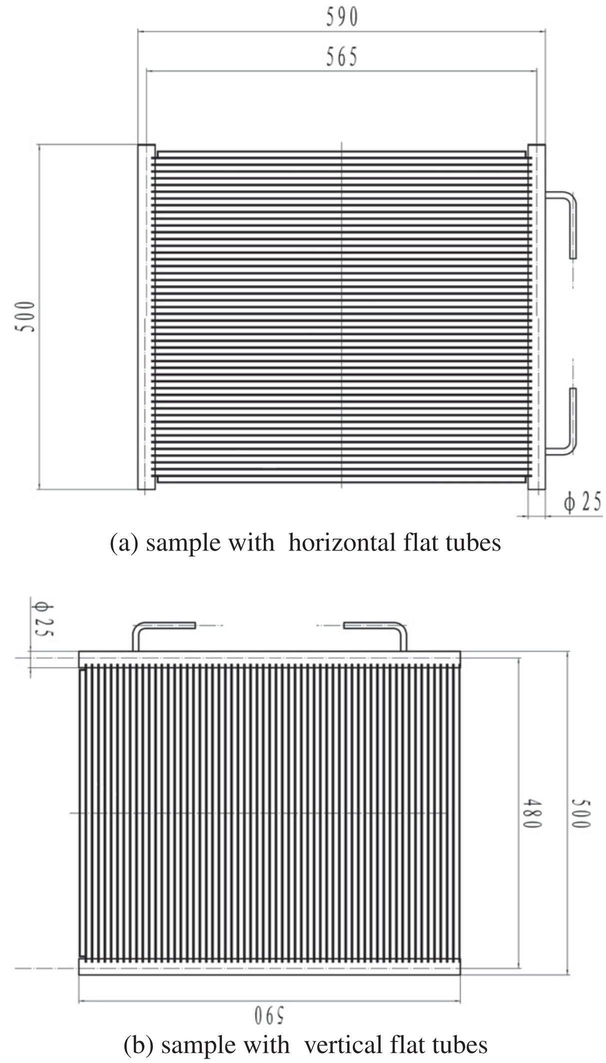

Fig. 1. Schematic diagram of the test samples.

2. Experimental test set up

2.1. Test samples

Microchannel heat exchangers with aluminum flat tubes and folded louver fins, typically used in air conditioning systems, served as test samples. Considering the defrost and drainage features, two types of samples were compared, as shown in Fig. 1. The first type was a conventional microchannel heat exchanger, with horizontal flat tubes and louver fins, used in mobile and commercial air conditioning systems. This type is often used as condenser, with wet and frost performance that have not been fully studied when used as an evaporator in heat pump systems. The second type consisted of vertical flat tubes and louver fins, considered to possibly possess better drainage and defrost features. The two samples had the same dimensions and tube and fin geometry, as provided in Table 1.

Table 1
Microchannel sample geometries.

	Sample 1	Sample 2
Face area (m^2)	0.27246	0.27246
Coil depth (mm)	20	20
Coil length (mm)	590	590
Coil height (mm)	500	500
Fin height (mm)	8	8
Fin pitch (mm)	1.3	1.3
Fin thickness (mm)	0.1	0.1
Tube height (mm)	1.8	1.8
No. of ports in each tube	12	12
Tube position	Horizontal	Vertical

2.2. Test facility and procedures

The performances of the two heat exchangers were evaluated in a psychrometric calorimeter test facility composed of an evaporator room, a condenser room, a compressor box, an auxiliary unit and a control panel, as shown in Fig. 2. The temperature and humidity of each room were controlled. The air flow through the sample was provided by a blower, and measured by the nozzles in the wind tunnel. The compressor was driven by a variable speed electrical motor, clutched with a torque meter to measure the compressor torque. Both air side and refrigerant side parameters were measured and controlled. Table 2 shows the accuracy of the measured parameters. The accuracy of air pressure drop is ±2 Pa. The performances of the test samples could be evaluated from the parameters of air passing through the exchangers. Based on the uncertainty calculation method proposed by Moffat [15], the