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Frost distribution characteristics of laminar airflow on cold surface of mini-channels ☆

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ABSTRACT

This study was performed for simulating frosting characteristics that occurred on the surface of plate fins of the outside heat exchanger. Test section with local cooling modules at the central part was made as the rectangular cross sectional passage to imitate the outside heat exchanger. Local frost thickness distributions for test conditions having three experimental parameters (plate wall temperature, air humidity and velocity) were presented. Leading edge effect of the plate was clearly confirmed from the measured frost thickness distributions. The central part of the plate had the highest frost thickness because cooling devices were installed at the center of the plate. Due to different heat and mass transfer characteristics of upstream flow and downstream flow, the frost thickness of upstream area was much higher than that of downstream. The effects of plate surface temperature, humidity and velocity of inlet flow on frost thickness, and sensible and latent heat fluxes were analyzed.

1. Introduction

When a humid air stream comes in contact with a cooled surface at a temperature below the freezing temperature, frosting will occur on the surface. This frosting phenomenon often happens on refrigerated surfaces as in a heat exchanger of heat pump systems. Then the thermal performance of the heat exchanger becomes lower due to the thermal resistance of the frost layer as well as the increase of airside pressure drop. Relevant to the frost research, O'Neal and Tree [1] reviewed some frost research and classified them into three categories: the frost properties, the frost growth process, and heat transfer measurement in simple geometries or in overall heat exchangers. They pointed out that there were no data available for flows in laminar regions for internal flow. Because the flow between the fins of heat exchanger is often laminar, these kinds of research are very important. Hayashi et al. [2] investigated the frost formation and classified three types of frost growth period: the crystal growth period, the frost layer growth period, and the frost layer full growth period. Sami and Duong [3] reported the frost growth model by using frost thermal conductivities of Brian et al. [4] for crystal growth period, and of Yonko and Sepsy [5] for full growth frost layer. Lee et al. [6] presented their frost formation model by using the effective thermal conductivity developed by their experiment. Other researchers such as Schneider [7], Dietenberger [8], Sahin [9], Yun et al. [10], and Lee and Ro [11] used frost properties such as frost density and frost conductivity to develop frost growth models or to propose frost property correlations. But, most of the conditions, such as inlet air temperature and plate wall temperature, were quite different from that of the so-called standard frosting condition for heat pump in winter season. In other words, the study on frosting of laminar airflow with locally being cooled down has been lacking, especially for air temperature to be near 0 °C which would be the standard test conditions for evaporator of heat pump in winter season. Therefore, the objective of this study is to investigate the frost thickness characteristics of laminar airflow in a small duct having local cooling devices under the standard frosting test conditions. Also, the effects of the root temperature of the aluminum plate, air humidity and velocity on heat flux were presented.

2. Experimental apparatus and test conditions

Fig. 1 shows the experimental apparatus for the present frosting study. The humid air for frosting test was controlled by using a constant temperature and humidity chamber, and then the air was supplied to the inlet of the test section. The test section shown in Fig. 2 has 4 mm × 100 mm rectangular cross sectional passage. The cooling surface of aluminum was installed at the bottom side of the test section. Nine Peltier cooling modules (each has 4 W maximum power)

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