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Experimental investigation of the surface temperature and water retention effects on the frosting performance of a compact microchannel heat exchanger for heat pump systems

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ABSTRACT

Frost formation on a louvered fin microchannel heat exchanger was experimentally investigated in this paper with the aim of determining the dominant factors affecting the time of frosting and frost growth rate. A novel methodology was developed to measure frost thickness and frost weight at intervals during the frosting period. Frost mass and thickness growth rates, corresponding coil heat transfer, capacity degradations and air pressure drop are measured and discussed. The experimental data showed that at a given air dry bulb temperature, the fin surface temperature and air humidity are the primary parameters that influence the frost growth rates. Water retention and air velocity had a secondary impact on the frosting performance. From digital images of the frost growth it was observed that frost does not nucleate from the water droplets retained in between fins but it developed from the leading edges of the fins.

Etude expérimentale sur les effets de la température superficielle et de la rétention d'eau sur le givrage d'un échangeur de chaleur compact à microcanaux pour les systémes à pompe à chaleur

Mots clés : Givrage ; Microcanal ; Température superficielle ; Chute de pression ; Pompe à chaleur ; Réduction de puissance

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Nomenclature

C_d	Coil depth (mm)
d	distance (mm)
ERT	Entering Refrigerant (coolant) Temperature (°C)
F_h	Fin height (mm)
H	Coil height (mm)
L	Coil length (mm)
l_l	Louver length (mm)
l_p	Louver pitch (mm)
$\dot{Q}$	Heat transfer (W)
t	thickness (mm)
T	Temperature (°C)
T_t	Tube thickness (mm)

Greek letters

δ	dimensionless thickness ( )

Subscripts

0	at initial time ($t = 0$)
f	frost
fin	fin
surf	surface
t	at time t
T	Temperature (°C)

1. Introduction

In modern heat pump systems, heat exchangers use enhanced heat transfer surfaces for both air and refrigerant sides. Conventional fin and tube coils are slowly being replaced by microchannel heat exchangers, which use flat multi port tubes and louvered fin design. These heat exchangers are usually made of aluminum and because of the low conductive thermal resistance of the microchannel tubes, the fin base temperature is closer to the local saturation temperature of the refrigerant in comparison to conventional fin and tube type heat exchangers. Moreover, they reduce the volume and weight of condensers and evaporators and their reduced refrigerant charges could potentially lower the direct contribution to global warming due to refrigerant leakage (Garimella, 2003; Kim and Groll, 2003; Kim and Bullard, 2002; Park and Hrnjak, 2007). In heat pump applications, microchannel heat exchangers are usually mounted with their tubes oriented vertically to promote drainage of water condensate in the corrugated fin bends. While in cooling mode the increase in energy efficiency is in the range of 6–10% compared to spine fin or plate fin and tube coils with similar face area, during heating mode the energy performance of heat pump systems with microchannel outdoor coils are generally low due to a higher frequency of defrost cycles (Garimella, 2003; Kim and Groll, 2003; Padhmanabhan et al., 2008; Subramaniam and Garimella, 2005). Defrost cycles are periodically executed in between the heating times to melt the ice, drain the water from the outdoor coil, and free its surface from accumulated frost before the heating service could start again. Because frequent defrost cycles penalize the heating seasonal energy efficiency, it is crucial to understand the characteristics of frost growth on outdoor coils and develop heat exchangers that would minimize, if not eliminate, defrost cycles.

There are several parameters that affect frost growth on outdoor coils, such as air velocity, air humidity, air temperature, surface temperature, surface energy (including coatings or roughness), fin geometry and water retention (Kondepudi and O'Neal, 1989; Lee et al., 1997; Na and Webb, 2003; Shin et al., 2003; Xia et al., 2006). Frost thickness influences the heat transfer resistance and reduces the free flow area, ultimately causing a capacity degradation of the outdoor coil (Kondepudi and O'Neal, 1989; Padhmanabhan et al., 2010).

Studies of frost growth on microchannel heat exchangers with surface temperatures just below freezing point are rather sporadic and sometimes inconsistent in the literature. The complexity of the phenomena makes the theoretical analysis problematic and most of the results are based on a limited range of experimental tests in which the effects from the operating parameters and geometry are difficult to isolate and quantify (Kim and Groll, 2003; Xia et al., 2006; Yang et al., 2006). Other studies focused on simplified geometries, such as flat plates or channel flows between parallel flat plates (Lenic et al., 2009; Lüer and Beer, 2000; Na and Webb, 2004b).

Various techniques have been used in the literature to measure frost thickness such as mechanical methods with micrometers by Lee et al. (2003), Na and Webb (2004a) and Fossa and Tanda (2010); optical or laser methods by Kennedy and Goodman (1974) and Chen et al. (1999); and image analysis by Xia et al. (2005). With mechanical measurements methods, accurate measurements of frost build up might not be possible due to the fact that it is necessary to stop the experiment to obtain the measurement or the micrometer might interrupt the local air stream and hinder the onset of frost growth. Researchers reported laser beam methods to be impractical in most cases due to high roughness of the frost surface (Na and Webb, 2004a). Image analysis proved to be successful in measuring the frost thickness with good accuracy but the data reduction is a very lengthy process.

Different methods for measuring the frost weight were also proposed in the literature. The direct weight measurements using precision scales in air flow wind tunnels or load cells in psychrometric chambers generally yield more accurate results. Scraping the frost from the coil and measuring its weight at the end of the test (Hosoda and Uzuhashi, 1967), or melting the frost and weighting the water condensate (Kondepudi and O'Neal, 1989; Song et al., 2002), or adopting sophisticated scale mechanism to balance the frost weight (Yonko and Sepsy, 1967) are examples used in past studies but are not suitable to determine the onset of frost nucleation and the instantaneous frost growth rate in compact microchannel coils. A more promising method to measure frost growth is described by Verma et al. (2002) and more recently by Xia et al. (2005) for compact heat exchangers. The authors proposed to weigh directly small coil samples placed on a digital balance and compare the final weight with the amount of condensate. An experimental investigation of