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Experimental investigation of adverse effect of frost formation on microchannel evaporators, part 1: Effect of fin geometry and environmental effects

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ABSTRACT

This study experimentally investigated the frost growth on louvered folded fins in micro channel heat exchangers when used in outdoor air source heat pump systems. The effects of surface temperature, fin geometries, and air environmental conditions were studied. The overall aim was to isolate and quantify the effect of geometry from surface temper ature effects. Experimental data of frost weight, local frost thickness, air pressure drop across the coils, time of frost defrost cycles and heat transfer rates were recorded. Data showed that the frosting time and the frost growth rates depended mainly on the local fin surface temperature. Lower fin density was beneficial because it delayed the blockage of the air flow. The fin length and fin depth had minor effects on frosting performance. The air humidity had a fairly significant effect on rate of frost formation while air velocity seemed to have a small effect on the frost growth rate.

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Mots clés : Givre ; Microcanal ; Température de la surface ; Géométrie des ailettes ; Pompe à chaleur ; Réduction de puissance

1. Introduction

Air source heat pump systems are used for heating and cooling of residential and commercial buildings all year around. They are energy efficient, compact, and have low installation costs. An air source heat pump exchanges heat directly from the indoor environment to the outdoor ambient air, and during winter operation, the outdoor coil might accumulate frost on its surface. Frost forms on the surface of the outdoor coils when humid air comes in contact with the coil surface which has

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a temperature below the dew point temperature of entering air and also below freezing point of water (0 °C). Frost on the surface acts as an insulation, obstructs air flow, reduces the heat transfer rate and increases the air pressure drop of air passing through the coil. 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 accu mulated frost before the heating service is initiated again. Microchannel coils have been employed recently in heat pump applications to replace conventional fin and tube coils due to their compactness, lower coil weight and less refrigerant charge which could lower the direct contribution to global warming due to potential refrigerant leakage (Garimella, 2003; Kim and Groll, 2003; Kim and Bullard, 2002; Park and Hrnjak, 2007). 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. While in cooling mode, microchannel heat exchangers increase the energy efficiency 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 (Kim and Groll, 2003; Padhmanabhan et al., 2008). 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 formation on outdoor coils, such as air velocity, air humidity, air tempera ture, cold surface temperature (Kondepudi and O'Neal, 1989; Lee et al., 1997) surface energy and fin base surface microscopic characteristics (include coatings and roughness or brazing fluxes) (Na and Webb, 2003; Shin et al., 2003), fin geometry and coil water retention after defrost cycles (Xia et al., 2006).

Kim and Groll (2003) studied two microchannel geometries with different fin density and coil orientations under frosting condition and concluded that water drainage and refrigerant distribution in headers needed to be improved for achieving a better frosting performance. Xia et al. (2006) investigated five louvered fin flat tube microchannel evaporators experimen tally and observed that water retention has a significant effect on the air pressure drop in the next cycles. In another study, Zhang and Hrnjak (2010) investigated frosting performance of uncoated parallel flow parallel fin (PF^2) flat tube microchannel heat exchangers with horizontally installed tubes. The authors observed an improvement in frosting performance over a conventional serpentine fin which was attributed to better drainage capability of the PF^2 heat exchanger. Padhmanabhan et al. (2008), on the other hand, found that removing the water residual at the end of the defrost cycle by flushing the microchannel coil with pressurized nitrogen improved the next frost cycle time by only 4%. Results from a previous work (Padhmanabhan et al., 2008) and preliminary results of this study (Moallem et al., 2012a) showed that water retention, which was assumed to be one of the main reasons of faster frost growth on microchannels, was not the dominant factor affecting the frost, even though it seemed to have some effects on the air side pressure drop. The key parameters that affected frost nucleation and growth were observed to be fin surface temperature (Moallem et al., 2012a) and the fin geometry. Air face velocity also affected frost formation but, in the range of heat pump applications, the effect of air velocity was minor. The effects of outdoor air temperature and air humidity were also studied. However they are the environmental conditions and are independent from the system of the heat pump unit. Between the main factors that affect the frost, surface temperature increase is a parameter that depends on evapo rating refrigerant temperature and is mostly controlled by the system designers to provide good heating capacity. The effect of fin surface temperature was partly analyzed in the literature by changing the refrigerant saturation temperature. The chal lenge was the various coil geometries were not directly comparable to each other with this approach. Each coil had a different internal geometry that made different flow regime and different hydraulic and thermal entry lengths inside tubes and ports. So even with the same entering refrigerant temper ature, the surface temperature of various coils has a consider able difference, not only between different coils, but also in different locations of a single coil between inlet and outlet header. This was also the challenge in the present study. In our initial work (Moallem et al., 2010), experimental data showed that the frost in fin and tube coils grows non uniformly from inlet to outlet header. Even for microchannel coil, this effect was less noticeable but still existed and frost accumulates more near inlet header rather than outlet even for a 1ft by 1ft coil custom made for laboratory testing. In other previous micro channel studies, the geometries were changed to search for the best option for thermal performance but surface temperature was not investigated or independently controlled. As a result, the effect of geometry modification was coupled with the effect of surface temperature change. To overcome this difficulty a new methodology was developed to measure and control the fin surface temperature independently which will be described in detail next.

The scientific merit of this paper is a fundamental under standing of frost growth on folded louvered fins with micro channel tubes. The main goals of this paper are first to investigate the effect of fin geometry on the frosting perfor mance of different microchannel coils and to determine the geometry that could minimize the frost formation. Also drop in microchannel coils with new fins might be able to replace the conventional fin and tubes coils in heat pump applications.

2. Experimental setup

2.1. *Sample preparation and construction*

In the present work, the fin samples were made of one column of louvered fins cut from commercially available microchannel coils. The fins were made of uncoated aluminum. The tube of this one column of louvered fins was machined until a thin wall of metal attached to each side of the folded fins remained. Since conduction heat transfer was employed in cooling the sample to the desired surface temperature, presence of tubes was not necessary in the present study. The removal of microchannel tube was also to eliminate the effect of different internal tube designs or microchannel ports. In addition the