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Air-side performance of a parallel-flow parallel-fin (PF^2) heat exchanger in sequential frosting

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ABSTRACT

The thermal-hydraulic performance in periodic frosting conditions is experimentally studied for the parallel-flow parallel-fin heat exchanger, henceforth referred to as a PF^2 heat exchanger, a new style of heat exchanger that uses louvered bent fins on flat tubes to enhance water drainage when the flat tubes are horizontal. Typically, it takes a few frosting/defrosting cycles to come to repeatable conditions. The criterion for the initiation of defrost and a sufficiently long defrost period are determined for the test PF^2 heat exchanger and test condition. The effects of blower operation on the pressure drop, frost accumulation, water retention, and capacity in time are compared under the conditions of 15 sequential frosting cycles. Pressure drop across the heat exchanger and overall heat transfer coefficient are quantified under frost conditions as functions of the air humidity and air face velocity. The performances of two types of flat-tube heat exchangers, PF^2 heat exchanger and conventional parallel-flow serpentine-fin (PFSF) heat exchanger, are compared and the results obtained are presented.

Performance côté air d’un échangeur de chaleur à écoulement parallèle aux ailettes parallèles sous des conditions de givrage séquentiel

Mots-clés : Échangeur de chaleur ; Tube aileté ; Écoulement parallèle ; Givrage ; Dégivrage ; Transfert de chaleur ; Chute de pression ; Performance

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Nomenclature

A	air-side heat transfer area (m^2)
C_P	specific heat ($J\,kg^{-1}\,K^{-1}$)
dP	pressure drop (kPa)
h	enthalpy ($J\,kg^{-1}$)
$\dot{m}$	mass flow rate ($kg\,s^{-1}$)
M	mass (g)
NTU	number of transfer units
Q	heat transfer rate (W)
RH	relative humidity (%)
t	time (min)
T	temperature (°C or K)
U	overall heat transfer coefficient ($W\,K^{-1}\,m^{-2}$)
v	air face velocity ($m\,s^{-1}$)

Subscripts

air	moist air (i.e., dry air plus water vapor)
d	defrost
dp	dew point
in	inlet
out	outlet
ref	refrigerant

1. Introduction

Microchannel heat exchangers are becoming widely accepted, but mostly as condensers. There is a perception that their performance as evaporators is not as good. Special concerns are related to condensate removal and drainage, in the dehumidification mode and in defrosting.

Several studies of frost properties and the frost growth mechanism in finned-tube heat exchangers and microchannel heat exchangers have been reported in the past. Martinez and Aceves (1999) conducted research on the effect of frosting on the heat pump system with a round tube-plate fin heat exchanger. The authors developed a model for a heat exchanger with frost build up and integrated it into a heat pump system simulation model. Characteristics of the heat pump, such as COP, pressure drop, frost thickness and frosting time were studied.

Kim and Groll (2003) reported a comparison between microchannel and fin-tube heat exchangers when used as an outdoor coil in a heat pump system. The study included both cooling and heating tests. The authors reported frosting/defrosting time and the heating capacity of the heat pump with both coils. The effects of other variables such as heat exchanger inclination and fins per inch were also studied. The authors concluded that microchannel heat exchangers have a shorter frosting time compared to fin-tube heat exchangers and that the frosting time decreased even further with each cycle due to residual water retained at the end of each defrost cycle.

Xia et al. (2006) studied the effects of frost, defrost, and refrost on the air-side thermal-hydraulic performance of louvered-fin, flat-tube heat exchanger which resembled a microchannel heat exchanger. An overall heat transfer coefficient was obtained for the heat exchanger for a realistic range of temperatures and flow rates. Frost thickness was measured using images captured with a CCD camera and frost weight was obtained by using a high precision scale. They developed a numerical model, which was also experimentally validated, to predict the frost thickness and blockage ratio.

Additional studies include Carlson et al. (2001) who focused on understanding how environmental conditions, air temperature and relative humidity, refrigerant temperature, and air and refrigerant temperature glide, affect the deposition and distribution of frost on heat exchangers, specifically of those found in refrigerated display cases. Padhmanabhan et al. (2008) compared frost and defrost cycling performance between a microchannel heat exchanger with louvered fin and a fin-tube heat exchanger with straight fins employed as outdoor coils of a heat pump system. Local surface temperature and weight of the coil were taken in real time during the experiment. The mass of frost accumulation during heating tests was obtained by using load cells.

There is a growing interest for application of microchannel heat exchangers in outdoor units of the air conditioners because of their excellent performance. Cost and manufacturing reasons drive design to horizontal orientation of the tubes because of smaller and thus less expensive header in addition of easier bending of the tubes than headers. In that case, drainage of condensate or water after defrost is difficult because of obstruction that horizontal tube makes. Due to the well known drainage mechanism in the serpentine-fin structure through the louvers and to some extent down the trailing edge of the microchannel tube, all successful evaporators that use conventional folded fins are with vertical tubes. This was and still is especially important when horizontal orientation of tubes is desired. One of the excellent potential features of the PF^2 design is that it extends fins beyond the tube and uses that part of the fins as a “downspout”, a drainage facilitator for the condensate or defrost water. PF^2 offers great improvement in water removal either in dehumidification or defrost mode compared to a folded (serpentine) fin type heat exchanger where the flat tube is horizontal (Zhang and Hrnjak, 2009).

To our best knowledge the new design, parallel-louvered fin with flat tubes, has not been widely reported in open literature. The comparison of FP^2 heat exchanger to a conventional round-tube-plate fin heat exchanger (RTPF) and parallel-fin serpentine-fin (RTPF) with flat-tube heat exchanger was presented earlier, in Zhang and Hrnjak (2009). This paper focuses on evaluating the air-side performance characteristics of PF^2 heat exchanger under frosting conditions, with attention to defrost and refrost effects. We will address: (1) characteristics of periodic frosting and determi-