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Air-side performance evaluation of three types of heat exchangers in dry, wet and periodic frosting conditions

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ABSTRACT

The performances of three types of heat exchangers that use the louver fin geometry: (1) parallel flow parallel fin with extruded flat tubes heat exchanger (PF^2), (2) parallel flow serpentine fin with extruded flat tubes heat exchanger (PFSF) and (3) round tube wave plate fin heat exchanger (RTPF) have been experimentally studied under dry, wet and frost conditions and results are presented. The parameters quantified include air-side pressure drop, water retention on the surface of the heat exchanger, capacity and overall heat transfer coefficient for air face velocity 0.9, 2 and 3 m/s, air humidity 70% and 80% and different orientations. The performances of three types of heat exchanger are compared and the results obtained are presented. The condensate drainage behavior of the air-side surface of these three heat exchanger types was studied using both the dip testing method and wind tunnel experiment.

Evaluation de la performance côté air de trois types d’échangeurs fonctionnant sous des conditions sèches, humides et de givrage

Mots clés : Conditionnement d’air ; Échangeur de chaleur ; Refroidisseur d’air ; Tube aileté ; Géométrie ; Mesure ; Transfert de chaleur ; Chute de pression ; Rétention d’eau ; Comparaison

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Nomenclature

A	air-side heat transfer area (m^2)
C_p	specific heat ($J\,kg^{-1}\,K^{-1}$)
h	enthalpy ($J\,kg^{-1}$)
$\dot{m}$	mass flow rate ($kg\,s^{-1}$)
dP	pressure drop (kPa)
Q	heat transfer rate (W)
T	temperature (°C or K)
UA	heat transfer ($W\,K^{-1}$)
U	overall heat transfer coefficient ($W\,K^{-1}\,m^{-2}$)
ν	air face velocity ($m\,s^{-1}$)
t	time (min)
V	heat transfer volume (dm^3)
ϕ	relative humidity (%)
L_p	louver pitch (mm)
F_p	fin pitch (fpi)
θ	louver angle (°)

Subscripts

r	refrigerant
a	moist air (i.e., dry air plus water vapor)
in	inlet
out	outlet
f	defrost
dew	air dew point
0	initial value
dry	dry condition
wet	wet condition

1. Introduction

The louvered fin, flat tube heat exchangers are finding wider application as performance, compactness and cost concerns continue to drive heat exchanger design. Many investigators have studied air-side heat transfer and pressure drop characteristics of louvered fin and flat tube heat exchangers. Davenport (1980) reported a comprehensive study of a non-standard variant of the flat tube and louvered corrugated heat exchangers. Totally, 32 samples of louver fin samples were tested. Achaichia and Cowell (1988) measured air-side performance using 15 samples with flat tube and louvered plate and found the same flow pattern proposed by Davenport. Two types of flow structure exist in the louver fin array: louver directed flow and duct directed flow. DeJong and Jacobi (1999) presented flow visualization, pressure drop, and mass transfer data for five louvered fin geometries, focused on the understanding of physical processes rather than the development of correlations. Webb and Jung (1992) studied the application of brazed aluminum heat exchangers to the residential air-conditioner and showed that the heat transfer rate of the brazed aluminum heat exchanger was 50% higher than that of a conventional heat exchanger and condensate could be removed well from its surface. Chang and Wang (1996) performed experimental studies on the air-side characteristics of louvered fin heat exchangers and developed correlations for j and f factors. Kim and Bullard (2002) and Kim et al. (2000) measured air-side heat transfer and pressure drop data using 30 different brazed aluminum heat exchangers with different louver fin geometrical parameters under dehumidifying conditions. Sunden and Svantesson (1990) concluded that the louvered surfaces are more efficient than the corresponding smooth surface. Aoki et al. (1989) performed an experimental study on heat transfer characteristics of different louver fin arrays such as louver angles, louver fin pitches. Zhong et al. (2005) introduce a new method, dynamic dip testing, to assess the condensate drainage behavior of the air-side surface of compact heat exchangers. The new method is shown to provide highly repeatable data for real-time drainage.

The studies on the thermal hydraulic performance for the louvered fin heat exchangers have been performed by many investigators, but very few data exist on the study of folded louvered fin-flat tube heat exchangers under wet and frosting conditions. Most louvered fins they tested are plate-and-tube louver fin and corrugated louvered fin with triangular channel or with rectangular channel. The new design, parallel louvered fin with flat tubes was not reported in open literature to our best knowledge. This paper presents experimental results of the air-side pressure drop, capacity and heat transfer coefficient for three types of heat exchanger, which fins are parallel louver fin, serpentine louver fin and plate louver fin, under dry, wet, and frosting conditions with discussion. The effect of the tube orientations of PF^2 and PFSF heat exchangers on the drainage performance under wet and frosting conditions is also addressed.

2. Experimental facility and test conditions

The experimental facility used to test the heat exchangers under frosting and defrosting conditions is shown in Fig. 1. Ethyl alcohol (99.9%) supplied by a pump was used as the secondary refrigerant in the experimental loop. The alcohol flow was cooled by a R404A chiller system. A pre-cooler was included in the chamber to set the chamber to the desired temperature prior to the initiation of the experiment. The air temperature in the chamber is controlled using the first PID controller to regulate the power supplied to the heater located in the chamber according to a thermocouple sensor placed inside the chamber. Air humidification is provided by a steam, and the air inlet dew point is measured and controlled using a General Eastern model D-2-SR chilled-mirror dew point sensor (±0.2 °C) and the second PID controller to regulate a solenoid valve in the steam line. Two chilled-mirror sensors of the same model were used to obtain humidity data upstream and downstream of the tested heat exchanger. Airflow is provided using a blower with a variable frequency drive so that three face velocities can be provided: 0.9 m/s; 2 m/s; 3 m/s. The pressure drop across the nozzles can be measured using a Setra model 239 pressure transducer (±0.25 Pa) connected to pressure taps upstream and downstream of the nozzles and converted into the air mass flow rate. The pressure drop across the heat exchanger is