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Heat transfer enhancement in a parallel, finless heat exchanger using a longitudinal vortex generator, Part B: Experimental investigation on the performance of finless and fin-tube heat exchangers

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A B S T R A C T

The air-side pressure drops and overall heat transfer coefficients of a finless heat exchanger with and without a vortex generator, as well as those of five all-aluminum parallel multi-port heat exchangers, were experimentally measured and compared under dry, wet, and frosting/defrosting conditions. The multi-port heat exchangers included three exchangers with louvered fins featuring fin pitches of 1.2 mm, 1.4 mm, and 1.6 mm, and two exchangers featuring slit fins with pitches of 1.2 mm and 1.4 mm. For the fin-tube heat exchangers, the effects of fin pitch and type on the air-side pressure drop and overall heat transfer performance were discussed. Under the dry condition, the heat transfer performance of a finless heat exchanger with a longitudinal vortex generator (LVG) is still approximately 40% less than that of a fin-tube heat exchanger. However, the pressure drop is similar. Under wet conditions, due to the excellent drainage performance of the finless heat exchanger, the heat transfer coefficient reached the same level. However, the pressure drop is lower. Under the frosting/defrosting condition, the heat transfer coefficient is similar, but the pressure drop is much lower. It only reaches 50 Pa at the end of each frosting period. Overall, the performance of a finless heat exchanger with a vortex generator is still lower than that of a fin-tube heat exchanger in dry conditions, but it demonstrates superiority in wet and frosting/defrosting conditions.

1. Introduction

All-aluminum parallel multi-port heat exchangers are generally used as condensers in car air conditioning, but are rarely used in household air conditioners. In household air conditioners, during the summer the indoor heat exchanger works as an evaporator, while the outdoor heat exchanger works as a condenser. The opposite occurs in winter. The all-aluminum parallel multi-port heat exchanger consists of vertically set flat tubes and horizontally mounted fins. When working as an evaporator in humid conditions, condensed water easily accumulates on the fins, resulting in lower heat transfer performance and a higher pressure drop. In winter, the drainage problem is more serious for evaporators in the outdoor units, which may have an evaporating temperature below 0 °C. Under such conditions, frosting and defrosting will periodically occur on the surface of the heat exchanger. If defrosting water accumulates on the fins, ice will form rapidly during the next frosting period, resulting in dramatically reduced performance. To investigate this problem, research on air-side thermal performance under wet and frosting/defrosting conditions has been performed by several investigators.

Webb and Jung [1] investigated the application of brazed aluminum heat exchangers to a residential air conditioner and reported that the heat transfer rate was 50% higher than that of a conventional heat exchanger. Moreover, they observed that the condensation could be effectively removed from the heat exchanger surface so that it can be applied in the air conditioner system. Zhang and Hrnjak [2] studied the performance of three types of heat exchangers that use louver fin geometry: parallel flow parallel fin with extruded flat tubes heat exchanger (PF2), parallel flow serpentine fin with extruded flat tubes heat exchanger (PFSF), and round tube wave plate fin heat exchanger (RTPF). All three have been experimentally studied under dry, wet, and frost conditions. Owing to the fact that the air-side pressure drop in the PF2 heat exchanger increased at a slower rate, it can be used for a longer refrigeration cycle. Kim and Bullard [3] experimentally investigated the air-side thermal-hydraulic performance of 30 samples of louvered-fin, brazed, aluminum heat exchangers under dehumidifying conditions. The test results are compared with those

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Nomenclature

A_a	total air-side surface area, m^2
A_w	tube inner wall area, m^2
b_a, b_w	slopes of saturated air enthalpy, defined in Eq. (11), J/kg K
c_p	specific heat, J/kg K
C_r	capacity ratio
h	heat transfer coefficient, W/m^2 K
i	enthalpy, kJ/kg
m	mass flow rate, kg/s
NTU	number of transfer unit, refer Eqs. (5) and (8)
Q	heat transfer rate, W
T	temperature, K
U_o	overall heat transfer coefficient, W/m^2 K
U_{ow}	overall transport coefficient based on enthalpy difference, kg/m^2 s

Greek letters

ε	effectiveness
η	surface effectiveness

Subscript

1	inlet
2	outlet
a	air-side
max	maximum value
min	minimum value
s	saturation state of moisture air
w	water side

for dry surface heat exchangers, in terms of a sensible *j* factor and friction factor f as functions of Reynolds number based on louver pitch. The correlations for the *j* and *f* factors are then developed. Furthermore, they studied the effect of inclination on the air-side performance of a brazed aluminum heat exchanger under dry and wet conditions [4]. They reported that the heat transfer performance for both dry and wet conditions was negligibly influenced by the inclination angle ($-60° < \theta < 60°$), while the pressure drops increased consistently with the inclination angle. In addition, they investigated the effect of air inlet humidity conditions on the air-side heat transfer and pressure drop characteristics for an inclined brazed aluminum heat exchanger, [5] and reported that the heat transfer and pressure drop characteristics under wet conditions were not influenced substantially by the air inlet humidity for $\theta \leqslant 45°$. Wu et al. [6] experimentally studied the frosting process of a folded-louvered-fin, parallel-flow microchannel evaporator in a heat pump central air-conditioning system. Mesoscale frost formation processes on its front view surface for three different test conditions were observed using a Charge Coupled Device (CCD) camera, and the frost height correlation was provided. Moallem et al. [7] investigated the influence of surface temperature, water retention, and surface coating on the frosting performance of parallel microchannel heat exchangers. The results showed that temperature and air humidity are the primary parameters that influence the frost growth rates, whereas water retention and air velocity had a secondary impact on the frosting performance. Hydrophobic and hydrophilic coatings on microchannel coils slightly affected the heat transfer capacity in frosting conditions. Xia et al. [8] investigated the thermal-hydraulic performance of folded-louvered-fin microchannel heat exchangers under conditions of an initial frost growth on the air-side surface, and for subsequent 'refrosting' after a defrost period. They found that the air pressure drop and heat transfer in the re-frost cycles were significantly influenced by condensate droplets. Xu et al. [9] studied the cyclic frosting and defrosting performance of two types of microchannel heat exchangers, and all the processes were observed using a CCD camera. Ice blockage formed in the fin root gaps of the horizontal-tube sample because of water retention. Cycle operation increased the blockage severity until the fin space was completely blocked. The amount of water retained and its impact on frosting time, pressure drop, and capacity were further investigated. Moreover, they investigated the frosting and defrosting performance of microchannel heat exchangers used in a heat pump system, and found that the vertical-tube sample outperformed the horizontal-tube sample because the water retention in the horizontal-tube sample rapidly increased as the cycle progressed [10].

Compared to plain fins, slit and louver fins provide better heat transfer performance by breaking boundary layers and mixing airflow. Dejong et al. [11] and Cowell et al. [12] visualized the flow pattern for the louver and slit fins, respectively. The visualization suggested that the louver fin may provide a better mixing of the airflow, which was further supported by Achaichia's research [13]. In this study, the heat transfer and pressure drop performance of five all-aluminum parallel multi-port heat exchangers (including two with slit fins featuring fin pitches of 1.2 mm and 1.4 mm, and three with louver fins featuring fin pitches of 1.2 mm, 1.4 mm and 1.6 mm, were experimentally investigated under dry, wet, and frosting/defrosting conditions.

In the companion study, the design of a parallel, finless, flat-tube heat exchanger is proposed for air conditioners, wherein a longitudinal vortex generator (LVG) is placed before the heat exchanger in the air flow path, thus resulting in better heat transfer. Compared to the fin-tube parallel heat exchanger that has horizontally set fins, the finless heat exchanger, consisting of only vertically set flat tubes, provides much better drainage performance. Therefore, it may be an appropriate solution for a household air conditioning application. In this study, following the fin-tube heat exchangers, the heat transfer and pressure drop performance of a finless heat exchanger with and without a longitudinal vortex generator were also experimentally tested under dry, wet, and frosting/defrosting conditions. Finally, the performances of these two types of heat exchangers were comprehensively compared.

2. Experimental setup and methodology

2.1. Experimental setup

Fig. 1 shows the experimental apparatus used for measuring the air-side heat transfer performance of the all-aluminum, parallel multi-port heat exchangers. The tested heat exchanger was placed in the wind tunnel, where the temperature, humidity, and velocity of the air flow were precisely controlled. In the dry and wet conditions, water was circulated between the heat exchanger and the temperature-controlled baths as a heating or cooling source. In the frosting/defrosting condition, the water was replaced with brine. Air from a hydrothermal chamber supplied by an inverter-controlled fan was passed to the test section through a rectifier.