Energy Conversion and Management 110 (2016) 494–500

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

A novel louvered fin design to enhance thermal and drainage performances during periodic frosting/defrosting conditions

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ARTICLE INFO

Article history:
Received 9 September 2015
Accepted 12 November 2015

Keywords:
Frost formation
Defrosting
Water retention
Drainage
Louvered fin
Air source heat pump

ABSTRACT

The retention water on fin surface can significantly degrade the thermal performance of heat exchangers under periodic frosting/defrosting conditions, which also leads to a decrease in the energy efficiency of air-source heat pumps. A novel louvered fin design was suggested to improve the drainage and the thermal performance of heat exchanger. The novel louvered fin had an asymmetric louver arrangement by flattening two louvers on the leading edge. The retention water formed on fin surface markedly decreased the heat transfer rate of the conventional symmetric louvered fins in re-frosting cycles. On the other hand, the asymmetric louvered fins improved the drainage performance of the retention water, which enhanced the heat transfer rate. To identify the reason of the difference in drainage performance between two fin geometries, additional experiments were carried out with enlargement models. The improvement in drainage performance of the asymmetric fin design originated from the lowered surface tension between the fin surface and water droplet.

1. Introduction

Air source heat pumps (ASHPs) have been used extensively for heating and cooling both the commercial and residential spaces because they utilize the renewable and sustainable energy source. In spite of the advantages of ASHPs, there are still several challenges to overcome. One of the challenges is the degradation of the thermal performance and energy efficiency of ASHPs under frosting/defrosting conditions [1,2]. Accordingly, there have been many studies to improve the performance of ASHPs in terms of the frosting retardation by using surface treatments [3–5], the prevention of frosting by using additional devices [6,7], and the developments of an efficient defrosting method [8,9]. Particularly, the importance of the drainage of retention water has been highlighted for the consistent performance of ASHPs in periodic frosting/defrosting conditions. Li et al. [10] investigated the influences of retention water on the performance of ASHP. As the frosting–defrosting cycles repeated, the quantity of retention water gradually increased, which led to the decrease of the heating capacity by 11% and the corresponding decrease of the energy efficiency by 10%. They pointed out that the development of efficient means for better drainage of the retention water from fin surface was required.

Louvered fin microchannel heat exchangers (LFMCs) are widely used in ASHPs due to their excellent thermal performance under dry condition (i.e., non-frosting condition) [11,12]. However, their poor drainage of retention water leads to the significant degradation of the thermal performance of LFMCs under frosting/defrosting conditions [13,14]. Although the fin surface treatments, including hydrophilic or hydrophobic coatings, could improve the drainage of the fin surface [15,16], applying the functional coatings over the LFMCs is still challenging due to the complex shape of fins. Therefore, designing the geometries of LFMCs has been attempted to improve their drainage performance. Xu et al. [17] investigated the drainage of the LFMC depending on the arrangement of tubes. In their study, the vertical arrangements of tubes performed the better drainage of the retention water than the horizontal arrangement. Furthermore, they emphasized that the thermal performance of LFMC decreased mainly due to the retention water on the leading edge of fins.

In this paper, we suggested a novel louvered fin (i.e., asymmetric louvered fin) design to improve the drainage of the retention water on the leading edge. The thermal performance of the novel design was compared with the conventional design (i.e., symmetric louvered fin) during periodic frosting/defrosting cycles. To identify the reason of the difference in drainage between two fin geometries, we carried out an additional experiment using enlargement models of the fin geometry.

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http://dx.doi.org/10.1016/j.enconman.2015.11.028
0196-8904/

Nomenclature

c	specific heat, kJ kg^{-1} °C^{-1}
F	force, N
g	acceleration of gravity, m s^{-2}
L_h	latent heat of sublimation, kJ kg^{-1}
$\dot{m}$	mass flow rate, kg s^{-1}
Δp	pressure drop, Pa
$\dot{Q}$	heat transfer rate, kW
T	temperature, °C
V	volume, m^3
w	humidity ratio, kg kg$_{DA}^{-1}$

Subscripts

||	parallel
a	air
g	gravity
in	inlet
lat	latent heat
out	outlet
r	refrigerant
sen	sensible heat
tot	total

Greek symbols

θ	angle
ρ	density, kg m^{-3}

2. Experiments

2.1. Experimental set-up and test heat exchangers

Fig. 1 shows a schematic diagram of the experimental set-up, which consisted of a constant-climate chamber, circulation duct, test section, and refrigerant chambers. The constant-climate chamber was used to maintain the air at a constant temperature and humidity, and the air was transferred using a blower operated at a constant speed. The circulation duct was divided into a main duct and a bypass duct. The bypass duct was closed during the frosting cycle, which allowed the airflow to be transferred to a test section through the main duct. The main duct was closed during the defrosting cycle to obstruct the airflow into the test section, so that the air circulated through the bypass duct. A multi-port pitot tube was installed on the top of the main duct to measure the average velocity of the airflow during frosting cycles. The louvered-fin heat exchanger was installed in the test section. Grids of T-type thermocouples (±0.15 °C) and humidity sensors (±1%) were installed at the inlet and outlet of the test section to measure the temperature and humidity of the air, respectively. Pressure tabs connected to differential pressure transducers (±0.5% of rdg ±1 Pa) were installed on the duct wall of the test section. Rigid scopes were placed into the inlet and outlet of the test section to visualize the frosting process, as well as the defrosting and drainage characteristics. Two refrigerant chambers were prepared: a cold chamber for the frost-

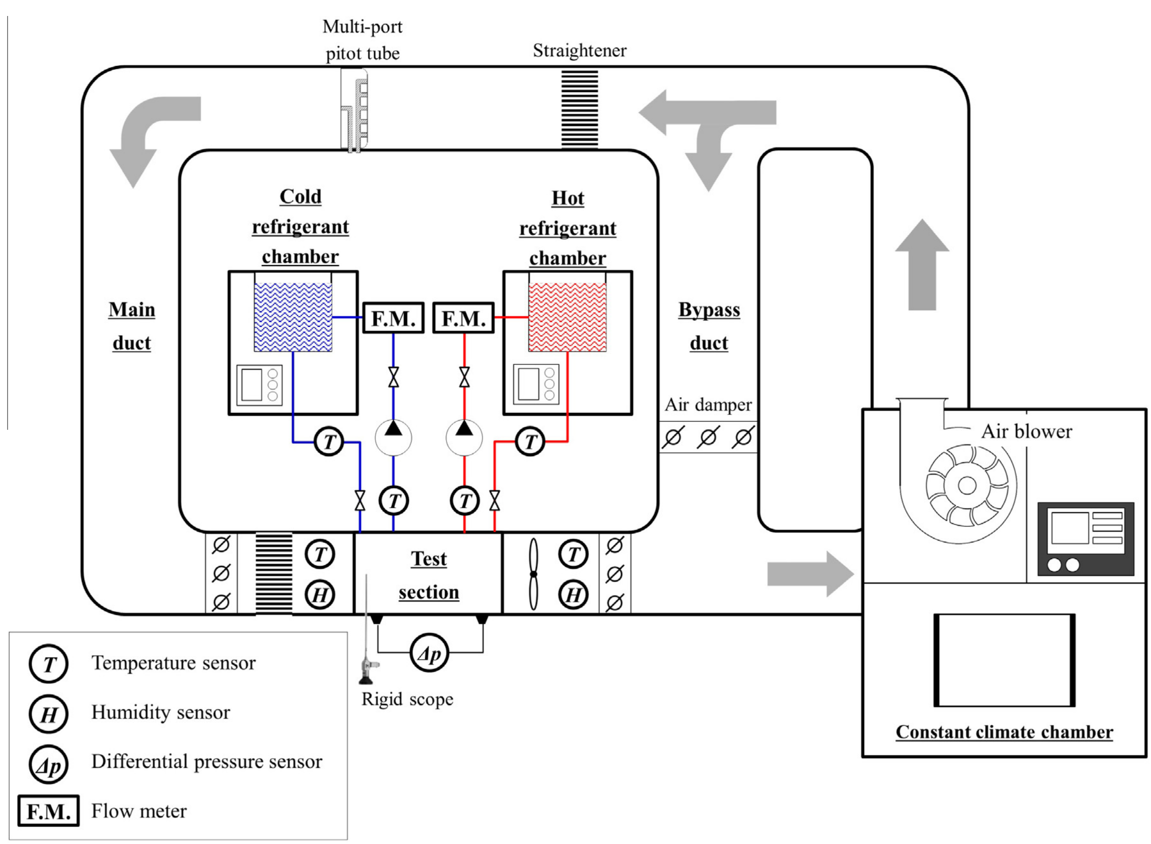

Fig. 1. A schematic diagram of the experimental setup.