International Journal of Heat and Mass Transfer 54 (2011) 2758–2764

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

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

Frosting and defrosting characteristics of a fin according to surface contact angle

Kyoungmin Kim, Kwan-Soo Lee *

School of Mechanical Engineering, Hanyang University, Sungdong-gu, Seoul 133-791, Republic of Korea

ARTICLE INFO

Article history:
Received 16 August 2010
Received in revised form 4 February 2011
Accepted 4 February 2011
Available online 7 April 2011

Keywords:
Frost formation
Defrost
Surface contact angle
Frost structure
Frost retardation

ABSTRACT

We investigated the characteristics of frosting and defrosting on a fin according to its surface contact angle under the winter operating conditions of a heat pump. The static contact angles were 2.5°, 75°, and 142° for hydrophilic, bare, and hydrophobic surfaces, respectively. The frost layer exhibited different frost formations for different surface contact angles during the early stages of frost formation. Frost retardation was observed on the hydrophobic fin, but the effect was not significant. The frost layer was thinner and the average frost density was higher on the hydrophilic surface than on the other surface-treated fins. The effect of surface treatment on defrosting time was found to be insignificant. However, the ratio of residual water on the hydrophilic surface was significantly smaller than those on the other surfaces. Because of this, in repeated frosting/defrosting experiments, the fin of the hydrophilic surface was found to show almost the same frosting/defrosting behaviors as those of the first run.

1. Introduction

The demand for heat pumps has been increasing, because they combine heating and cooling capacity in a single unit with high energy efficiency. Frosting, which occurs when a heat pump is used for heating during the winter season, degrades the efficiency of the heat exchanger. Defrosting induces larger energy consumption. These lead to lower overall heat pump efficiency. Thus, frosting and defrosting pose a major problem, and studies are needed on extending heat pump working time by frost retardation or reduction, and also on efficient defrosting operations.

Research on frost retardation or reduction can be divided into two categories, i.e., with and without surface treatment. The topics of frosting and defrosting on the untreated surfaces have been examined by several authors [1–4]. The previous papers related to frost retardation are as follows: heating the refrigerant by inserting the heater in the accumulator [1] and using the hot gas bypass method [2]. Studies on optimal defrosting period to increase the heat exchanger working time have also been conducted [3,4].

There have been some studies of frost formation and defrost of treated surfaces [5–11]. Jhee et al. [5] investigated the density of frost layer, blocking ratio, defrosting efficiency, and residual water with respect to surface treatment for a fin-tube heat exchanger with two rows and two columns, applied to a refrigerator. Liu et al. [6,7] divided a vertical plate into two parts, one part being hydrophobic, and the other part untreated. Frosting experiments were then conducted under natural convection conditions, and frost retardation was observed on the hyper-hydrophobic treated section [7]. However, the experimental operating conditions were quite different from the typical winter operating conditions of a heat pump. Huang et al. [8] coated the fins of a heat exchanger with novel anti-frosting paint, and reported that the pressure drop due to frosting was delayed in comparison with a heat exchanger with an untreated surface. However, properties of the frost layer were not investigated, and information of contact angle on the surface was not revealed. Wu and Webb [9] conducted frosting and defrosting experiments with hydrophilic and hydrophobic treated fins, and photographs of the frost layer were taken. Also, experiments were performed to remove the frost layer from a hydrophobic treated fin by surface vibrations. However, frost properties were not investigated in this work, either. Shin et al. [10] carried out frosting experiments with a hydrophilic surface, and the thickness, density and thermal conductivity of the frost layer were reported, but frosting/defrosting experiments were not repeated. Moreover, air temperature under frosting conditions was 12 °C, which may not match the actual winter operating conditions of a heat pump. Lee et al. [11] conducted frosting experiments with hydrophobic treated fins. Dynamic contact angles of 23° and 88° were measured, and frost maps were proposed. However, air temperature in the frosting conditions ranged from 10 to 20 °C. As indicated, frosting experiments with treated surfaces have mostly been carried out under natural convection conditions or operating conditions of refrigerators. There have been few studies of frost properties under the winter operating conditions of a heat pump, as well as under repeated frosting/defrosting tests.

In this paper, the effect of surface treatment for lessening performance degradation during frosting and defrosting was

---

* Corresponding author. Tel.: +82 2 2220 0426; fax: +82 2 2295 9021.
E-mail address: ksleehy@hanyang.ac.kr (K.-S. Lee).

0017-9310/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijheatmasstransfer.2011.02.065

Nomenclature

A	fin surface area [m^2]
m	mass [kg]
p	measured points [mm]
T	temperature [°C]
t	time [min, s]
u	air velocity [m/s]
w_a	absolute humidity ratio [kg/kg$_a$]
w_{re}	ratio of residual water mass [%]
x	measurement point coordinate in the direction of the airflow [mm]
z	measurement point coordinate in the direction perpendicular to the airflow [mm]

Greek symbols

ρ	density [kg/m^3]
θ	static contact angle [°]

Subscripts

a	air
ave	average
b	fin base
d	defrosting
f	frosting
fs	frost surface
re	water residual
s	static

investigated. The experiments on frost formation on a fin with different surface contact angles were conducted under winter operating conditions of a heat pump. Because the defrosting time and residual water affect the frosting behavior, experiments on frosting and defrosting were also performed repeatedly.

2. Experiments

Fig. 1 shows the experimental apparatus for frosting and defrosting experiments. This apparatus included a test section to perform the frosting and defrosting experiments, a climate chamber to control the temperature and humidity of the air, a refrigeration section to control the flow rate and temperature of the refrigerant, a recirculation section to connect the parts and recirculate the air [12], and a constant temperature bath for the defrosting experiments. Bypass valves were placed at the entrance and exit of the heat exchanger to alternately circulate cold refrigerant for the frosting experiments and warm refrigerant for the defrosting experiments. The capacity of the constant temperature bath was 0.03 m^3, and a solution of ethylene glycol and distilled water, mixed as a mass ratio of 1:1, was used as the refrigerant. The flow rate of the refrigerant for defrosting was 6.0 kg/min, measured by a turbine flow meter.

The test section was made of transparent acrylic plastic to allow for observation of frosting and defrosting behaviors [13]. Two flat plate fins were erect in the test section, and holes were drilled on the sidewalls of the test section to observe the frosting and defrosting, and to measure the properties of the frost layer. The fin length, height, and thickness were 60, 52.5, and 0.8 mm, respectively, and the fins made of aluminum. Experimental conditions are listed in Table 1, based on typical winter operating conditions of a heat pump. The plastic wrap covering the fins was removed after experimental conditions reached a steady state, and data were recorded [14]. When the frosting experiments were completed

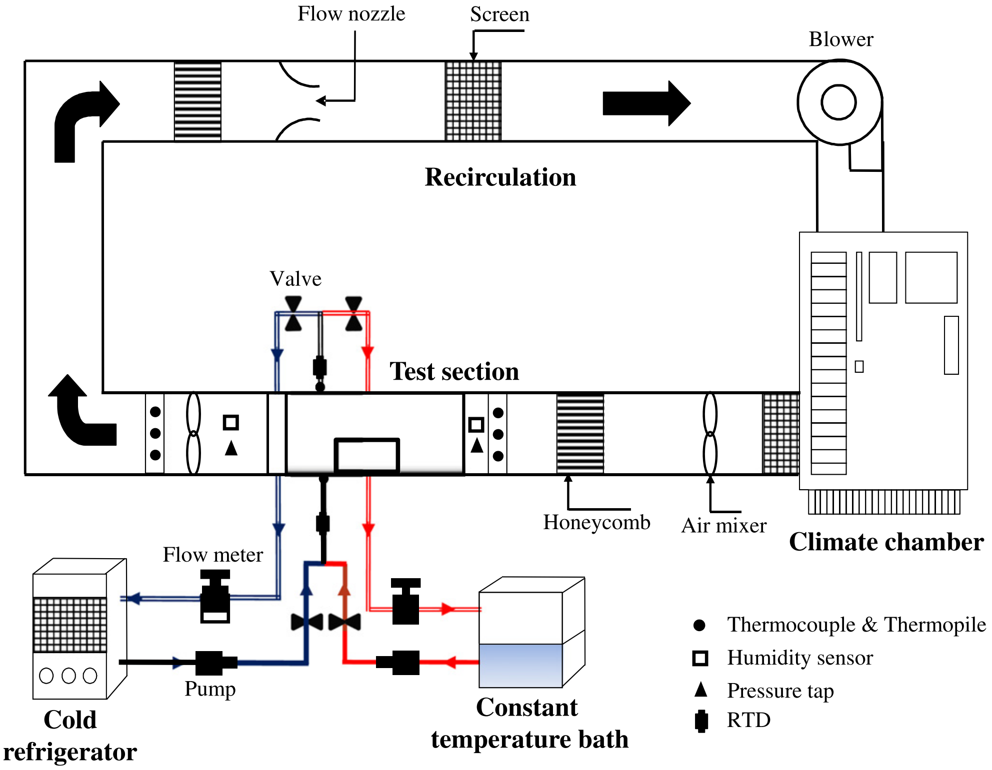

Fig. 1. Experimental apparatus.