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Research paper

Condensing droplet behaviors on fin surface under dehumidifying condition. Part II: Experimental validation

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HIGHLIGHTS

- A visualization experimental rig for observing the droplet behaviors was built.
- The predicted droplet behaviors agree well with the visualization images.
- The predicted j_m and j_h agree well with the experimental data.

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ABSTRACT

The objective of this paper is to validate the numerical model of condensing droplet behaviors proposed in Part I of the present study. An experimental rig for visualizing the droplet behaviors from the front view of the fin surface was built, and the visualization images of the condensing process was captured by employing a newly designed test section and sample. Experimental conditions cover inlet air velocity over a range from 0.5 m/s to 3.5 m/s, Re_{Dc} over a range from 500 to 3500, inlet air temperature over a range from 27 °C to 35 °C, inlet air *RH* over a range from 50% to 90%, and inlet water temperature over a range from 6 °C to 18 °C. The visualization images as well as the experimental data of heat and mass transfer characteristics obtained in the present study were used for the model validation. The validation results show that, the predicted droplet behaviors can qualitatively agree with the visualization images; the predicted mass transfer j factor agrees with 89% of the experimental data within a deviation of ±25%, and the predicted heat transfer j factor agrees with 94% of the experimental data within a deviation of ±20%.

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1. Introduction

For the real operation conditions of fin-tube heat exchanger employing in air conditioners, the condensation of water vapor in the moist air occurs on the cold fin surface, and the condensing droplets behaviors (formation, growth and movement) may result in the complicated influence on the air side performance of the fin-tube heat exchanger [1–7]. In order to quantitatively evaluate the influence of the droplet behaviors on the air side performance of fin-and-tube heat exchanger, a model of the condensing droplet behaviors on the fin surface was developed in Part I of the present study [8]; based on the proposed model, the condensing droplet behaviors were discussed, and the effects of operation conditions and fin geometry on the heat and mass transfer characteristics were analyzed. For validating the proposed model, the experimental data of visualization for the condensing droplet behaviors on the fin surface during dehumidifying process are needed.

The existing research on the experimental investigation of the air side condensation in fin-tube heat exchangers under the dehumidifying conditions mainly focuses on the macroscopic measurement of heat and mass transfer characteristics and the visual analysis of condensates. For the macroscopic measurement, the heat and mass transfer characteristics of the fin-tube heat exchanger with the four types of fins were investigated, covering the plain fin [9,10], the wavy fin [11–14], the slit fin [15,16] and the louver fin [17–19], and the prediction correlations were also developed based on the experimental data. For the visual analysis, the condensates between the fin surfaces were observed from the view of windward side [7,20,21], and the images of water bridges

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Nomenclature

A	surface area, m^2
b'_p	slope of the air saturation curved between the outside and inside tube wall temperature, J/kg K
b'_r	slope of the air saturation curved between the mean water temperature and the inside wall temperature, J/kg K
$b'_{w,m}$	slope of the air saturation curved at the mean water film temperature of the fin surface, J/kg K
$b'_{w,p}$	slope of the air saturation curved at the mean water film temperature of the tube surface, J/kg K
C_p	specific heat at constant pressure, J/kg K
D	tube diameter, m
f_i	friction factor
G_{max}	mass velocity based on the minimum flow area, kg/m^2 s
h	heat transfer coefficient, W/m^2 K
I_0	zero-order modified Bessel function of the first kind
I_1	first-order modified Bessel function of the first kind
i	enthalpy, kJ/kg
j_h	Chilton–Colburn *j* factor for the heat transfer
j_m	Chilton–Colburn *j* factor for the mass transfer
K_0	zero-order modified Bessel function of the second kind
K_1	first-order modified Bessel function of the second kind
k	thermal conductivity, W/m K
m	mass flow rate, kg/s
Pr	Prandtl number
Q	heat transfer rate, W
RH	relative humidity, %
r	radius, m
Sc	Schmidt number
T	temperature, K
$U_{o,w}$	wet surface overall heat transfer coefficient based on enthalpy potential, kg/m^2 s
W	humidity ratio, kg/kg
y_w	thickness of condensate water film, m
Greek	
η_f	fin efficiency
δ_f	fin thickness, m
Subscript	
a	air
c	extended tube diameter, condensate
f	fin
i	tube inside
in	inlet, tube inside
m	mean value, mass
o	total, tube outside
out	outlet, tube outside
p	tube wall
s	sensible, saturated
w	liquid water
wet	wet

formed between the fin surfaces were captured by the camera installed in the wind tunnel. For validating the droplet behaviors on the fin surface, the experimental images from the front view of the fin surface are needed. However, no study concerning the observation from the front view of the fin surface was reported.

The difficulty for observing from the front view of the fin surface lies in the narrow fin pitch, which is too small to install the camera in front of fin surface. In order to capture the real-time images of the droplet behaviors from the front view of the fin surface, a new test sample of heat exchanger which can be observed from the front of the fin surface will be designed in Part II of the present study, and the experimental rig with the new test sample will be established. Based on the experiments, the model of droplet behaviors developed in Part I will be validated.

2. Design of experiments for model validation

2.1. Experimental parameters and conditions needed for model validation

The verification for the whole model of condensing droplet behaviors on the fin surface requires the validations of the droplet formation, growth and movement, respectively. In the existing literature [22], the model of droplet movement has been validated by the key influncing factors of velocity and contact angles. Until now, there is no available experimental data for validating the model of water droplet formation and growth, and new experimental data are needed.

For qualitatively validating the model of the droplet formation and growth, the visualization images of the condensing process from the front view of fin surface will be captured in the present study; for quantitively validating the model, the experimental data of heat and mass transfer coefficients, which govern the droplet behaviors, will also be obtained.

During the experimental validation, the experimental data should be obtained under various test conditions, covering various inlet air velocities, temperature, relative humidity and inlet water temperature. The frontal average air velocity ranges from 0.5 m/s to 3.5 m/s ($500 < Re_{Dc} < 3500$, $25 < Sh < 75$); the dry-bulb temperatures of incoming air flow are chosen as 27 °C and 35 °C; the relative humidity of incoming air flow ranges from 50% to 90% with a step size of 10%; the inlet temperature of cold water ranges from 6 °C to 18 °C with a step size of 6 °C. The detailed test parameters for total 24 test conditions are shown in Table 1.

2.2. Test section

For the observation of the condensing process on the fin surface, the transparent test section is needed, and the test sample of heat exchanger can be observed from the front of the fin surface.

The test section is made of transparent plexiglass, and the fin surface of test sample installed in the test section is easy to be observed, as shown in Fig. 1(a). The size of the cross section is designed as 140 mm × 60 mm. The test section is split into two parts, as shown in Fig. 1(b). One part is used for guiding the moist air through the fins of test sample; the other part is a closed cavity, which is used for guiding the cold water through the back of the test heat exchanger to supply the cooling capacity.

The closed cavity consists of a acrylic jacket and a seal, as shown in Fig. 2(a) and (b), respectively. The acrylic jacket and the seal are used to form an enclosed space in order to circulate the cold water at the back of the test sample, as shown in Fig. 2(a). On the acrylic jacket, the test sample is installed by several screws, as shown in Fig. 2(b).

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