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On the heat and mass analogy of fin-and-tube heat exchanger

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Abstract

This study examines the heat and mass analogy of the fin-and-tube heat exchanger under dehumidifying process. A total of 36 fin-and-tube heat exchangers having plain fin geometry are experimentally examined. It is found that the ratio of $h_{c,o}/h_{d,o}C_{p,a}$ is in the range of 0.6–1.1 and is insensitive to change of fin spacing at low Reynolds number. However, it is noted that this ratio is not a constant throughout the test range. A slight drop of the ratio of $h_{c,o}/h_{d,o}C_{p,a}$ is seen with the decrease of fin spacing and with the rise of the Reynolds number. This is associated with the more pronounced influence during condensate removal. Moreover, during the dehumidifying process, the temperature gradient is directly responsible for establishing the concentration gradient, suggesting the heat transfer and mass transfer are not independent. Based on a simple analysis, one can easily find that the increasing rate of $\left(\frac{dc}{dT}\right)\big|_i$ slightly exceeds that of $\frac{\Delta c}{\Delta T}$. As a result, the ratio of $h_{c,o}/h_{d,o}C_{p,a}$ can be proved to be slightly decreased with the rise of the Reynolds number.

Keywords: Fin-and-tube heat exchanger; Heat and mass analogy; Dehumidifying

1. Introduction

Plate fin-and-tube heat exchangers are composed of a plurality of heat transfer tubes that are inserted into respective bores of fins, and are closely fitted and fixed to the latter by means of tube expansion or the like method. The fin-and-tube heat exchangers are employed in a wide variety of engineering applications like air-conditioning apparatus, process gas heater, and cooler. For typical applications of exploitation the fin-and-tube heat exchangers, the air-side resistance generally comprises over 90% of the total thermal resistance. Hence enhanced fin patterns such as wavy, louver, slit, and convex-louver are adopted for augmentation. However, plain fin geometry is still the mostly commonly used for its reliability when comparing to other enhanced fin patterns.

The fin-and-tube heat exchangers can be applicable to both condenser and evaporators. In the evaporators which typically operated at a surface temperature below the dew point temperature. Hence, simultaneous heat and mass transfer occurs along the fin surfaces. In general, the complexity of the moist air flow pattern across the fin-and-tube heat exchangers under dehumidifying conditions makes the theoretical simulations very difficult. Accordingly, it is necessary to resort to experimentation.

Many experimental studies have been carried out to study the heat and mass transfer characteristics of the fin-and-tube heat exchangers under dehumidifying conditions. For instance, McQuiston [1,2] presented experimental data for five plate fin-and-tube heat exchangers, and developed a well-known heat transfer and friction correlation applicable to dry and wet surfaces. Mirth and Ramadhyani [3,4] investigated the heat and mass characteristics of wavy fin heat exchangers. Their results showed that the Nusselt numbers were very sensitive to change of inlet dew point temperatures, and the Nusselt number decreases with an increase of dew point temperatures. Similar results were reported by Fu et al. [5] in dehumidifying heat exchangers having a louver fin configuration. They reported a pronounced decrease of the wet sensible heat transfer coefficients with increases of inlet relative humidity. On the contrary, the experimental data of Seshimo

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Nomenclature

c	concentration
D	diffusivity
D_{i}	inside diameter of tube
F_{p}	fin pitch
$h_{\mathrm{c,o}}$	sensible heat transfer coefficient
$h_{\mathrm{d,o}}$	mass transfer coefficient (based on W)
N	number of tube row
P_{l}	longitudinal tube pitch
Pr	Prandtl number
Q_{a}	heat transfer rate at the air-side
Q_{w}	heat transfer rate of the water side
$Re_{D_{\mathrm{i}}}$	Reynolds number based on D_{i}
Sc	Schmidt number
Sh	Sherwood number
T	temperature
c_{∞}	ambient concentration
$C_{\mathrm{p,a}}$	heat capacity
D_{c}	tube collar diameter
k	thermal conductivity
k_{m}	mass transfer coefficient (based on c)
L	characteristics length
Nu	Nusselt number
P_{t}	transverse tube pitch
$Re_{D_{\mathrm{c}}}$	Reynolds number based on D_{c}
t	fin thickness
T_{∞}	ambient temperature
W	humidity ratio

et al. [6] indicated that the Nusselt number was relatively independent of inlet conditions. Wang et al. [7] studied the effect of the fin pitch, the number of tube row, and inlet relative humidity on the heat transfer performance under dehumidification, and concluded that the sensible heat transfer performance is relatively independent of inlet humidity. The difference in the existing literatures is attributed to the different reduction methodology as shown by Pirompugd et al. [8].

Even though many efforts have been devoted to the study of the wet-coils, the available literature on the dehumidifying heat exchangers still offers limited information especially in association with mass transfer. This can be made clear from the reported data were mainly focused on the study of the sensible heat transfer characteristics, very few attention was paid to the mass transfer characteristics. Most of the investigators simply used heat-mass analogy to estimate the corresponding mass transfer coefficient from available heat transfer coefficient. Therefore, the objective of the present study is to examine the applicability of the heat and mass analogy based on experimental data.

2. Experimental apparatus and reduction method

The schematic diagram of the experimental air circuit assembly and related data reduction method had been addressed in some previous studies such as those by Wang et al. [7], Pirompugd et al. [8,9]. Readers who are interested in this may be referred to these studies. Details of the test samples can be seen from Table 1. Notice that no hydrophilic treatment was made to all the test heat exchangers.

Table 1
Geometric dimension of the sample plain fin-and-tube heat exchangers

Nos.	F_{p} (mm)	t (mm)	D_{c} (mm)	P_{t} (mm)	P_{l} (mm)	N
1	1.19	0.115	8.51	25.4	19.1	1
2	1.75	0.120	10.34	25.4	22.0	1
3	2.04	0.115	8.51	25.4	19.1	1
4	2.23	0.115	10.23	25.4	19.1	1
5	2.50	0.120	10.34	25.4	22.0	1
6	1.20	0.115	6.93	17.7	13.6	1
7	1.21	0.115	6.93	17.7	13.6	1
8	1.98	0.115	6.93	17.7	13.6	1
9	1.99	0.115	6.93	17.7	13.6	1
10	1.23	0.115	8.51	25.4	19.1	2
11	1.70	0.120	8.62	25.4	19.1	2
12	2.06	0.115	8.51	25.4	19.1	2
13	2.24	0.130	10.23	25.4	22.0	2
14	3.20	0.130	10.23	25.4	22.0	2
15	1.22	0.115	7.53	21.0	12.7	2
16	1.22	0.115	7.53	21.0	12.7	2
17	1.23	0.115	10.23	25.4	19.1	2
18	1.78	0.115	7.53	21.0	12.7	2
19	1.79	0.115	7.53	21.0	12.7	2
20	1.82	0.130	10.23	25.4	22.0	2
21	3.13	0.120	8.62	25.4	19.1	2
22	1.23	0.115	10.23	25.4	19.1	4
23	1.55	0.115	10.23	25.4	19.1	4
24	2.03	0.130	10.23	25.4	22.0	4
25	2.23	0.130	10.23	25.4	22.0	4
26	3.00	0.130	10.23	25.4	22.0	4
27	1.21	0.115	8.51	25.4	19.1	4
28	1.22	0.115	7.53	21.0	12.7	4
29	1.60	0.115	8.51	25.4	19.1	4
30	1.70	0.120	8.62	25.4	19.1	4
31	1.78	0.115	7.53	21.0	12.7	4
32	2.31	0.115	10.23	25.4	19.1	4
33	3.13	0.120	8.62	25.4	19.1	4
34	1.85	0.130	10.23	25.4	22.0	6
35	2.21	0.130	10.23	25.4	22.0	6
36	3.16	0.130	10.23	25.4	22.0	6

3. Results and discussion

The dehumidifying process involves heat and mass transfer simultaneously, if mass transfer data are unavailable, it is convenient to employ the analogy between heat and mass transfer. The existence of the heat and mass analogy is because the fact that conduction and diffusion in a liquid are governed by physical laws of identical