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Airside heat transfer and friction characteristics for enhanced fin-and-tube heat exchanger with hydrophilic coating under wet conditions

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Abstract

The airside heat transfer and friction characteristics of 14 enhanced fin-and-tube heat exchangers with hydrophilic coating under wet conditions are experimented. The effects of number of tube rows, fin pitch and inlet relative humidity on airside performance are analyzed. The test results show that the influences of the fin pitch and the number of tube rows on the friction characteristic under wet conditions are similar to that under dry surface owing to the existence of the hydrophilic coating. The Colburn *j* factors decrease as the fin pitch and the number of tube rows increase. For wavy fin, the Colburn *j* factors increase with the increase of the inlet relative humidity, but for interrupted fin, the Colburn *j* factors are relatively insensitive to the change of the inlet relative humidity. The friction characteristic is independent of the inlet relative humidity. Based on the test results, heat transfer and friction correlations, in terms of the Colburn *j* factor and Fanning *f* factor, are proposed to describe the airside performance of the enhanced fin geometry with hydrophilic coating under wet conditions. For wavy fin, the correlation of the Colburn *j* factor gives a mean deviation of 7.6%, while the correlation of Fanning *f* factor shows a mean deviation of 9.1%. For interrupted fin, the correlation of the Colburn *j* factor gives a mean deviation of 9.7%, while the correlation of Fanning *f* factor shows a mean deviation of 7.3%.

Keywords: Heat exchanger; Cooler; Humid air; Finned tube; Enhanced surface; Heat transfer; Coefficient; Friction; Coating

Transfert de chaleur côté air et caractéristiques de frottement d'un échangeur à tubes ailetés muni d'un enrobage hydrophile sous des conditions mouillées

Mots clés : Échangeur de chaleur ; Refroidisseur d'air ; Air humide ; Tube aileté ; Surface augmentée ; Transfert de chaleur ; Coefficient ; Frottement ; Revêtement

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Nomenclature

a	coefficient defined by Eq. (14)
A_1	outside surface area of tubes (m^2)
A_2	surface area of fin (m^2)
A_{fr}	frontal area (m^2)
A_{min}	minimum free-flow area (m^2)
A_0	total airside surface area (m^2)
b	coefficient defined by Eq. (14)
C_p	specific heat ($J\,kg^{-1}\,K^{-1}$)
D_c	fin collar outside diameter (mm)
f	friction factor
F_p	fin pitch (mm)
F_s	fin spacing (mm)
G_c	mass flux of the air based on the minimum flow area ($kg\,m^{-2}\,s^{-1}$)
h_m	mass transfer coefficient ($kg\,m^{-2}\,s^{-1}$)
h_s	sensible heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
i	enthalpy ($J\,kg^{-1}$)
i_{fg}	saturated water vapor enthalpy ($J\,kg^{-1}$)
I_0	modified Bessel function solution of the first kind, order 0
I_1	modified Bessel function solution of the first kind, order 1
j	the Colburn factor
k	thermal conductivity ($W\,m^{-1}\,K^{-1}$)
K_0	modified Bessel function solution of the second kind, order 0
K_1	modified Bessel function solution of the second kind, order 1
Le	Lewis number
m	mass flow rate ($kg\,s^{-1}$)
m^*	coefficient defined by Eq. (22)
M_{fb}	coefficient defined by Eq. (10)
M^*	coefficient defined by Eq. (9)
N	number of longitudinal tube rows
P_l	longitudinal tube pitch (mm)
Pr	Prandtl number
P_t	transverse tube pitch (mm)
ΔP	pressure drop of airside (Pa)
Q	average heat transfer rate (W)
Q_s	sensible heat transfer rate (W)
Q_l	latent heat transfer rate (W)
r	fin radius (m)
Re_{Dc}	Reynolds number based on tube collar diameter
RH	relative humidity
T	temperature (°C)
$T_a{*}$	coefficient defined by Eq. (11)
V	velocity ($m\,s^{-1}$)
W	humidity ratio of moist air ($kg\,kg^{-1}$)

Greek symbols

β	coefficient defined by Eq. (12)
δ	fin thickness (mm)
$\eta_{f,wet}$	wet fin efficiency
η_o	overall surface effectiveness
ξ	boundary line between dry region and wet region
ρ_i	inlet air density ($kg\,m^{-3}$)
ρ_m	mean air density ($kg\,m^{-3}$)
ρ_o	outlet air density ($kg\,m^{-3}$)
σ	contraction ratio of the fin array

Subscripts

a	air
d	dew point
dry	dry bulb temperature
f	fin
fb	fin base
ft	fin tip
i	inner
in	inlet
o	outer
out	outlet
s	saturated
w	water

1. Introduction

Enhanced fins including wavy fin and interrupted fin are widely used to improve the performance of fin-and-tube heat exchangers. The wavy fin enhances heat transfer by lengthening the air flow channel and causing better mixing of air flow. The interrupted fin, including louver fin and slit fin, enhances heat transfer by renewing the boundary layer and reducing the thickness of the boundary layer. In practical application of fin-and-tube heat exchangers, condensation phenomena will occur on the fin surface when the surface temperature is below the dew point temperature of incoming air. The presence of condensate water makes the heat/mass transfer process more complicated. In recent years, airside performance research of enhanced fin-and-tube heat exchangers in wet conditions was performed gradually. Mirth and Ramadhyani [1,2] presented test results for five smooth wavy fin patterns. Their results showed that the Nusselt numbers are very sensitive to the change of inlet air dew point temperature, and the Nusselt numbers decrease with the increase of inlet air dew point temperature. Wang et al. [3–5] analyzed the effects of the number of tube rows, the fin pitch and tube size etc. on airside performance for herringbone wavy fin patterns in wet conditions, and developed the airside heat transfer and friction correlations. For slit fin, only Wang et al. [6] presented test results for three slit fin-and-tube heat exchangers under wet conditions. The