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An experimental, computational and flow visualization study on the air-side thermal and hydraulic performance of louvered fin and round tube heat exchangers

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ABSTRACT

The aim of this study is to determine heat transfer and pressure drop characteristics in different louvered fin geometries for manufacturing of commercial louvered fin and round tube heat exchangers. Numerical simulations were carried out for various louver angles, louver lengths (pitches), fin pitches and frontal air velocities. The heat transfer and pressure drop characteristics of the louvered fin and round tube heat exchangers, Colburn and friction factors, were respectively normalized with Colburn and friction factors of the flat plate fin and round tube heat exchangers operating under the same conditions and they were presented as the relative Colburn factor j^* and the relative friction factor f^*. Thermal & hydraulic performance was presented as JF^*. Temperature and local Nusselt number contours, and streamline patterns were provided to reveal the mechanisms behind the heat transfer enhancement. Among different heat exchangers for which heat transfer and pressure drop characteristics were obtained, one was chosen to manufacture a real size heat exchanger. Flow visualization studies were also conducted with a PIV system in an open water channel to determine whether the flow structure is louvered directed or not. The louvered fin heat exchanger tested in the PIV system was a five times scaled up model of the real size louvered fin heat exchanger and made from a transparent plexiglas material. PIV results were presented and evaluated based on streamlines and velocity vectors. Furthermore, a numerical analysis was performed using exactly the same dimensions and conditions of the model tested in the PIV system. The comparison between numerical and experimental results was done to validate the numerical model. Consequently, the performance of the fabricated real size heat exchanger was tested at different air velocities in a wind tunnel in a conditioned room. The experimental results were compared with numerical analyses and found to be compatible with each other. Finally, thermal and hydraulic performance of the louvered fin and round tube heat exchanger was compared with a wavy fin and round tube heat exchanger with identical size and specifications. It was found that the thermal and hydraulic performance of the louvered fin and round tube heat exchanger is higher than that of the wavy fin and round tube heat exchanger. The Colburn factor *j*, friction factor *f* and *JF* of the louvered fin and round tube heat exchanger are higher about 16.8–7%, 19.9–8.2% and 10–4.3% than that of the wavy fin and round tube heat exchanger depending on the Reynolds number, respectively.

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1. Introduction

Heat exchangers are used in a wide range of industrial and everyday applications from air and sea to land vehicles, from power plants to air conditioning. Increasing the thermal and hydraulic performance of heat exchangers means saving energy and materials at a considerable amount. For this reason, researchers at universities and manufacturers have been conducting studies to increase the performance of heat exchangers for years. Louvered fins are a cost-effective method for increasing the thermal and hydraulic performance of heat exchangers. The louvered fins, which provide non-continuous interrupted surfaces, increase the air-side heat transfer coefficient in two ways. First, the discontinuous solid wall in contact with the fluid flow reduces thickness of the thermal boundary layer by stopping its growth. Second, air

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Nomenclature

A	area (m^2)
A_c	inlet frontal flow area (m^2)
A_f	fin surface area (m^2)
A_o	total outside surface area (m^2)
A_i	tube inside surface area (m^2)
$c_{p,c}$	specific heat of cold fluid (J/kg °C)
$c_{p,h}$	specific heat of hot fluid (J/kg °C)
d_i	inside tube diameter (m)
d_o	outside tube diameter (m)
f	the Fanning friction factor
f^*	the relative Fanning friction factor
F_L	flow length (m)
H	fin pitch (m)
h	heat transfer coefficient (W/m^2 °C)
h_o	air side heat transfer coefficient (W/m^2 °C)
h_w	water level in open water channel (mm)
j	the Colburn factor
j^*	the relative Colburn factor
k	turbulent kinetic energy
L_p	louver pitch (m)
L_T	tube length (m)
Nu	Nusselt number
U	overall heat transfer coefficient (W/m^2 °C)
P_l	longitudinal tube pitch (m)
P_r	Prandtl number
P_t	transverse tube pitch (m)
r	radius of tube diameter, with collar fin thickness (m)
Re	Reynolds number
Re_H	Reynolds number based on fin pitch
Re_{L_p}	Reynolds number based on louver pitch
Re_{d_o}	Reynolds number based on outside tube diameter
R_{eq}	equivalent radius for circular fin (m)
St	Stanton number
T	temperature (°C)
ΔT_m	logarithmic mean temperature difference (°C)
$T_{c,in}$	inlet temperature of cold fluid (°C)
$T_{c,out}$	outlet temperature of cold fluid (°C)
$\dot{m}_c$	cold fluid mass flow rate (kg/s)
$\dot{m}_h$	hot fluid mass flow rate (kg/s)
$T_{h,in}$	inlet temperature of hot fluid (°C)
$T_{h,out}$	outlet temperature of hot fluid (°C)
T_w	wall temperature (°C)
$U_{frontal}$	frontal air velocity (m/s)
X_L	geometric parameter (m)
X_M	geometric parameter (m)
W_λ	wave length of wavy fin (m)
W_h	wave height of wavy fin
ΔP	pressure drop (Pa)
$\dot{Q}_h$	hot fluid heat transfer rate (W)
$\dot{Q}_c$	cold fluid heat transfer rate (W)
$\dot{Q}$	averaged heat transfer rate (W)

Greek symbols

μ	dynamic viscosity (kg/m s)
δ_f	fin thickness (m)
η_f	fin efficiency
η_o	surface efficiency
θ	louver angle (°)
λ	thermal conductivity (W/m °C)
ρ	density of fluids (kg/m^3)
υ	kinematic viscosity (m^2/s)

Subscript

a	air
c	cold fluid
h	hot fluid
i	inside
in	inlet
k	turbulent kinetic energy
o	outside
out	outlet
ref	reference
t	tube
f	fin

circulates between the different fins by increasing the mixture of cold and hot fluids due to the effect of the louvers. It is necessary that the air follows the louvers yielding heat transfer enhancement. This kind of flow is called louver-directed flow, which is dependent on the Reynolds number and geometric parameters. On the other hand, louvered fins increase the pressure drop as they allow the flow to circulate between fins increasing the flow length. For this reason, the maximum possible heat transfer enhancement should be achieved with the lowest pressure drop possible. Some of the studies in the literature related to louvered fin heat exchangers are grouped as experimental, numerical and correlation studies and summarized below.

Experimental studies about louvered fin heat exchangers can generally be divided into two groups. Studies investigating in detail the effect of flow structure on heat transfer and pressure drop may be included into the first group. In such studies, scaled models of real size heat exchangers were investigated. To conduct this kind of experimental studies, Springer and Thole [1] developed a methodology to design an experimental model which was scaled up by a factor of 20 for two-dimensional louvered fin geometries. They concluded that a total number of 19 louvered fin rows must be used to simulate a full-scale louvered fin heat exchanger. Lyman et al. [2] proposed a method to determine heat transfer coefficients of louvered fin heat exchangers. They performed experiments using large-scale louvered fin models with different fin pitches and louver angles and determined convective heat transfer coefficients using the bulk flow temperature and adiabatic wall temperature as reference temperatures. DeJong and Jacobi [3] conducted a complementary flow visualization study and naphthalene sublimation technique to investigate the relation between flow structure and heat transfer characteristics on louvered fins in the effect of bounding walls. T'Joen et al. [4] and Huisseune et al. [5] used a dye injection technique to visualize the flow structure around louvered fins.

In the other group, experiments were conducted using full-scale commercially available heat exchangers. In such studies, the total effects of fluid properties, operating conditions and geometrical parameters on heat transfer and pressure drops were investigated.

Wang et al. [6] developed a correlation for heat, momentum and mass transfer with mean deviations of 5.94%, 6.10%, and 7.89% based on their experimental data, respectively. Kim and Bullard [7] concluded that flow depth is a dominant parameter on pressure drop, and that the effect of louver angle on heat transfer rate depends on the flow depth, fin spacing and Reynolds number. Qi et al. [8] reported that there are three main geometrical factors, such as ratio of fin pitch, fin thickness and the number of louvers

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