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Developed correlations for heat transfer and flow friction characteristics of louvered finned tube heat exchangers

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ABSTRACT

3D turbulent flow numerical simulations were performed in order to develop correlations for heat transfer and flow friction characteristics in louvered fin and tube heat exchangers. A detailed sensitivity analysis was done on the effects of Reynolds number, fin pitch, longitudinal tube pitch and transversal tube pitch on parameters j/j_0 and f/f_0. Developed correlations are based on ratio of Colburn and friction factors of louvered fin heat exchanger to that of flat fin heat exchanger (j/j_0 and f/f_0) respectively which are much simpler than other correlations. Also, as it is expected, when louver angle approaches zero (flat fin), parameters j/j_0 and f/f_0 reach 1. This approach cannot be seen in previous developed correlations. The developed correlations can describe 100% and 86% of parameters j/j_0 and f/f_0 respectively among 186 numerical simulation data within ± 15%. Optimum louver angle was also obtained by genetic algorithm using the developed correlations.

1. Introduction

Heat exchangers are widely used in air conditioning systems, power generation, automobiles, and other applications. Air-cooled heat exchanger is one of the most important heat exchangers. Hot fluid flows inside the tubes and air flow outside the tubes acts as cold fluid. Fins are usually used in air side of air-cooled heat exchangers in order to increase heat transfer performance. Louvered fins are common fins which are widely used in air side of finned tube heat exchangers (Fig. 1). Louvers increase heat transfer by interrupting the flow on the surface and consequently stopping growth of boundary layer [1].

Kays and London [2] presented the first paper on heat transfer and flow friction characteristics of some compact heat exchanger surfaces including louvered fins in 1950. Davenport [3] proposed correlations for heat transfer and flow friction characteristics of corrugated louver fin in triangular channel experimentally. Sunden and Svantesson [4] presented correlations for Colburn and friction factors for corrugated multi-louvered fin with rectangular channel experimentally. Chang and Wang [5] presented a generalized correlation for heat transfer of louvered fin heat exchangers by performing experiments on 91 samples. Achaichia and Cowell [6] performed analysis on heat transfer and pressure drop characteristics of flat tube and louvered plate fin surfaces based on experimental data. They also presented some correlations for Stanton number and friction factor for this type of fin surfaces. Flow visualization study for the convex louver fin geometry was presented by Pauley and Hodgson [7] in order to determine maximum heat transfer conditions. Wang et al. [8,9] presented experimental study on non-redirection louver fin and tube heat exchangers which resulted in some correlations for Colburn and friction factors of this type of louvered fin surfaces. Chang et al. [10] developed a generalized friction correlation for louver fin geometry by experimental analysis of 91 samples in 2000. An amendment to their correlation was proposed by Chang et al. [11] in 2006. Kim and Bullard [12] performed experimental studies on the air-side heat transfer and pressure drop characteristics of multi-louvered fin and flat tube heat exchangers. Dong et al. [13] developed correlations for heat transfer and pressure drop characteristics of multi-louvered fin and flat tube heat exchangers by performing experimental analysis. Kim and Cho [14] reported correlations for Colburn and friction factors for low velocities and small fin pitches based on experimental studies. An experimental study on the air side heat transfer and pressure drop characteristics of brazed aluminum heat exchangers with multi-region louver fins and flat tubes was also conducted by Li and Wang [15] which resulted in correlations development. Vaisi et al. [16] proposed an investigation on air-side heat transfer and pressure drop characteristics of flow over louvered fins and flat tube heat exchangers experimentally. An experimental comparison of double row and triple row multi-louvered fin heat exchangers with flat tubes was performed by Dogan et al. [17].

The first papers on 2D numerical models of flow over louvered fins were published by Baldwin et al. [18] and Kajino and Hiramatsu [19] in

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Nomenclature

A_c	flow cross sectional area (m^2)
A_f	fin surface area (m^2)
A_{fin}	flat fin area in zero louver angle (m^2)
A_{louver}	louvered area (m^2)
A_o	total surface area (m^2)
C	heat capacity (J/kg.K)
D_c	tube collar outside diameter (m)
f	friction factor
f/f_0	ratio of louvered fin to flat fin friction factors with the same geometry
F_p	fin pitch (m)
G	air mass flux based on minimum flow area ($kg/m^2.s$)
G_k	generation of turbulence kinetic energy due to the mean velocity gradients (J/kg)
j	Colburn factor
j/j_0	ratio of louvered fin to flat fin Colburn factors with the same geometry
k	turbulent kinetic energy (J/kg)
k_f	fluid thermal conductivity (W/m.K)
K_c	entrance loss coefficients
K_e	exit loss coefficients
L	length of louvered region (m)
$LMTD$	logarithmic mean temperature difference (K)
m	thermo geometry parameter (m^{-1})
Nu	Nusselt number
P	pressure (Pa)
P_l	longitudinal tube pitch (m)
P_t	transversal tube pitch (m)
Pr	Prandtl number
$\dot{Q}''$	heat transfer rate to the fluid per surfaces area (W/m^2)
r	radial distance from tube center (m)
r_f	circular fin radius (m)
Re_{Dc}	Reynolds number based on tube collar outside diameter
T	temperature (K)
t	fin thickness (m)
u	velocity (m/s)
W	width of louvered region (m)

Greek symbols

α_k	inverse effective Prandtl numbers for k
α_ε	inverse effective Prandtl numbers for ε
ΔP	pressure drop (Pa)
ε	dissipation rate (m^2/s^3)
η	fin efficiency
η_o	surface efficiency
θ	louver angle (radian)
μ	dynamic viscosity (kg/m.s)
μ_t	turbulent dynamic viscosity (kg/m.s)
ρ	density (kg/m^3)
σ	ratio of the minimum flow area to frontal area
ψ	fin efficiency parameter

Subscripts

i, j, k	tensor index
in	inlet
m	mean
out	outlet
R	reference
s	solid wall

1987. Airside performance of fin and tube heat exchangers having circular and oval tubes was investigated numerically by Leu et al. [20] and Han et al. [21]. Hsieh and Jang [22] performed 3D thermal hydraulic analysis for louvered fin heat exchangers with variable louver angle. They also did parametric study and optimization of louver finned-tube heat exchangers by Taguchi method [23]. Atkinson et al. [24], Malapure et al. [25] and Carija et al. [26] made numerical investigation of fluid flow and heat transfer over louvered fins in compact heat exchangers with flat tubes. T'Joen et al. [27] studied inclined louvered fin by CFD simulations. Optimization of louvered fin heat exchanger with variable louver angles was performed by Jang and Chen [28] both experimentally and numerically. Ryu and Lee [29] studied heat transfer and pressure loss of corrugated louvered fin heat exchangers which resulted in developing correlations. Karthik et al. [30] performed experimental and parametric studies of a louvered fin and flat tube compact heat exchanger using computational fluid dynamics. CFD analysis was carried out by Srinivasu et al. [31] in order to predict heat transfer performance of louvered fin radiator with water/Eg & Al_2O_3 nano fluid. Sparrow et al. [32] performed numerical simulations of heat transfer and fluid flow through an array of offset fins with conjugate heating in the bounding solid. They also investigated the design of cold plates for thermal management of electronic equipment [33].

Developed correlations in papers are too complicated and functions of numerous parameters. When louver angle in louvered fin correlation approaches zero it shall have same result as flat fin correlation, since louvered fin with zero louver angle is the same as flat fin. This cannot be seen in the developed correlations in different papers [5,8–10]. Also, the number of researches done on louvered fin heat exchangers with flat tube is much more than researches on louvered fin heat exchangers with circular tube. In this study, louvered fin heat exchanger with circular tube was simulated by three dimensional turbulent simulations. Wide ranges of louver angle from 0° to 60° were investigated. Sensitivity analyses were done on several parameters. These studies led to development of correlations for Colburn factor and friction factor which are much simpler than previous proposed correlations in papers. Here, similarities between zero louvered fin heat exchanger with flat fin heat exchanger were found.

2. Numerical analysis

Physical model and computational domain of the simulated louvered fin and tube heat exchanger are illustrated in Fig. 1. Basic parameters of this geometry for two cases of validation and sensitivity study are tabulated in Table 1.

2.1. Governing equations

The following assumptions were made for numerical simulation:

- Working fluid is air with constant properties.
- The flow is three dimensional, incompressible, steady and turbulent.
- Natural convection and radiation are ignored.
- Solid walls have constant temperatures.

Governing equations for continuity, momentum (RANS), and energy are described as follows respectively:

$$\frac{\partial \overline{u_i}}{\partial x_i} = 0 \tag{1}$$