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Optimal design of a corrugated louvered fin

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HIGHLIGHTS

- Optimal design of corrugated louvered fin.
- The optimal model increased the *JF* factor by 14–32%.
- The modified Suga–Aoki equation provided estimates of the optimal model.

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ABSTRACT

We carried out a parametric study and optimization procedure to improve the performance of a corrugated louvered fin. Based on the results of the parametric study, we selected the fin pitch, louver pitch, and louver angle as the three most important parameters in performance. A full-factorial design was applied to the three chosen parameters for our design of experimental technique. We used the Kriging method and a micro-genetic algorithm to design an optimal corrugated louvered fin. The *JF* factor of the resulting optimum model was increased by 14–32% compared to that of the base model for Reynolds numbers in the range $0 \le Re_{\mathrm{Lp}} \le 500$. In addition, we propose a modified Suga–Aoki equation that can be used to estimate the optimum shape of a louvered fin with a smaller error than that produced by the original Suga–Aoki equation.

1. Introduction

Louvered fins are widely used in fin-tube and flat-tube heat exchangers since their geometric properties and expanding heat transfer areas increase the heat transfer rate by regenerating the flow boundary layers. However, louvered fins also create a large pressure drop. These fins could be improved by simultaneously satisfying the conflicting physical requirements to reduce pressure drop and augment the heat transfer rate. Therefore, a study of the optimal design of louvered fins is necessary to overcome these conflicting physical phenomena under limited conditions.

Hsieh and Jang [1] optimized a louvered-fin round-tube geometry via the Taguchi method and numerical experiments. Ameel et al. [2] optimized an X-shaped louvered-fin and tube heat exchanger via the VG-1 method and investigated the influence of the Reynolds number. However, in the above studies, the round tubes had a strong effect on the flow around the louvered fins, which is not the case for corrugated louvered fins. Suga and Aoki [3] proposed an equation to estimate the optimum shape of a corrugated louvered fin. However, this equation does not include flow velocity terms; hence, an error occurs when the flow velocity changes. Qi et al. [4] used the Taguchi method and numerical simulation to study the effects of parameters on the performance of a corrugated louvered fin. However, they conducted only a parametric study and did not propose an optimal model.

In this research, we select important parameters and carry out optimization to improve the performance of a corrugated louvered fin. We compare the heat and flow characteristics of the optimal model with those of a reference model. In addition, we propose a modified Suga–Aoki equation with an additional velocity term to estimate the optimum shape of a louvered fin.

2. Model description

Fig. 1 shows a corrugated louvered fin. The geometric details of the reference model for this study were $F_{\mathrm{d}} = 25$ mm, $L_{\mathrm{p}} = 1.2$ mm, $F_{\mathrm{p}} = 1.33$ mm, $\delta = 0.08$ mm, and $\theta = 30°$. The louvered fin had a seven-layer stack, and periodic boundary conditions were used at the upper and lower boundaries.

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Nomenclature

F_d	fin depth
F_p	fin pitch
f	friction factor
JF	JF factor
j	Colburn factor
L_p	louver pitch
M	number of louvers
Re_{Lp}	Reynolds number ($=u_c L_p/\nu$)
T	temperature
u	velocity
Greek symbols	
δ	fin thickness
θ	louver angle
ν	kinematic viscosity
Subscripts	
c	minimum area
in	inlet
fin	fin
ref	reference

2.1. Governing equations

For the numerical analysis, the following assumptions were made.

(1) The flow was 2-D, transient, incompressible, and turbulent.
(2) The working fluid was air, and its properties were constant.
(3) Natural convection and radiation heat transfer could be neglected.

The flow was two-dimensional (2-D) and was affected by the louver between the flat tubes. Accordingly, we solved this problem in 2-D coordinates. Because of the size of the louvered fins and the flow velocity, a turbulence model was used.

In this study, we used the *JF* factor of Yun and Lee [5] to represent the performance of a louvered fin. Higher values of the *JF* factor indicate good performance. The *JF* factor is defined as follows:

$$JF = \frac{j/j_{ref.}}{\left(f/f_{ref.}\right)^{1/3}} \tag{1}$$

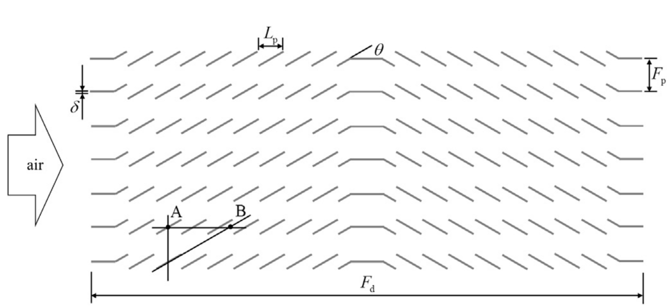

Fig. 1. Illustration of the geometrical parameters of a louvered fin.

Table 1
Comparison of results.

		$Re_{Lp}=50$		$Re_{Lp}=250$		$Re_{Lp}=450$	
		JF	Err. (%)	JF	Err. (%)	JF	Err. (%)
2-D steady-state model	Kim and Bullard [6]	1	–	1	–	1	–
	Std. $k-\varepsilon$ model	1.28	28	1.14	14	1.05	5
	RNG $k-\varepsilon$ model	1.49	49	1.32	32	1.20	20
	Real. $k-\varepsilon$ model	1.05	5	1.04	4	0.98	2
	Std. $k-\omega$ model	0.93	7	0.65	35	0.58	42
	SST $k-\omega$ model	0.93	7	0.65	35	0.57	43
2-D unsteady model (realizable $k-\varepsilon$ model)		1.05	5	1.04	4	0.98	2
3-D steady-state model (realizable $k-\varepsilon$ model)		1.02	2	0.98	2	0.98	2

2.2. Validation of results

To validate the turbulence model and the results, the test conditions $T_{in} = 21$ °C, $T_{fin} = 45$ °C, and $Re_{Lp} = 50$, 250, and 450 were chosen for comparison. The *JF* values were compared with the results of Kim and Bullard, and the reference values of *j* and *f* were calculated using their correlation [6]. Table 1 summarizes the results of the comparison; the realizable $k-\varepsilon$ model produced the smallest deviations from the previous study. To determine the effect of a three-dimensional (3-D) flow around a louvered fin, we compared a steady-state 2-D model with a steady-state 3-D model. The steady state 3-D model generated an error less than 2% with respect to the reference model. However, the steady-state 2-D model generated an error less than 5%. Therefore, we chose the steady-state 2-D model since its computational time was 1/20th that of the steady-state 3-D model. In addition, we compared the steady-state model with an unsteady model to determine the effect of flow vibration around a louvered fin. The results of the unsteady model were the same as those of the steady-state model; thus, flow vibration was not observed.

3. Results and discussion

We carried out a numerical analysis to investigate the effects of the design parameters on the performance of a corrugated louvered fin, which was represented by the *JF* factor. We used the design of the experimental technique to optimally design a corrugated louvered fin. In addition, we proposed a modified Suga–Aoki equation to estimate the optimum shape of a louvered fin.

3.1. Optimization

We investigated the effects of various parameters on the optimal design of a corrugated louvered fin and selected the fin pitch, louver pitch, and louver angle as the three most important parameters affecting the *JF* factor. The fin thickness was excluded because the associated performance change was less than 0.5%. Table 2 shows the selected parameters and their levels observed in

Table 2
Levels of each factor used in this study ($F_d = 25$ mm).

Factor (unit)	Level		
	−1	0	1
Fin pitch, F_p (mm)	1.20 (21 fpi)	1.33 (19 fpi)	1.49 (17 fpi)
Louver pitch, L_p (mm)	0.98	1.2	1.54
Louver angle, θ (°)	20	30	40
Fin thickness, δ (mm)	0.06	0.08	0.1