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Numerical simulation of heat transfer and fluid flow characteristics of composite fin

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ABSTRACT

The composite fin is presented based on the advantage of longitudinal vortex generator and slit fin, respectively. The performance of air-side heat transfer and fluid flow is investigated by numerical simulation for Reynolds number ranging from Re = 304 to 2130. Stepwise approximation method is applied on the mesh generation for the irregular domains of delta winglets and slit fins. The mechanism for augmenting heat transfer is also analyzed based on the local fluid field, field synergy principle and entransy dissipation principle. The computational results show that some eddies are developed behind the X-shaped slit and delta winglet, which produce some disruptions to fluid flow and enhance heat transfer; compared with plain fin and slit fin, it shows the composite fin has better heat transfer performance. By applying on the field synergy principle and entransy dissipation principle to analyze the composite fin, the computational results show that composite fin can improve the synergy of temperature gradient and velocity fields, and its equivalent thermal resistance is smaller and its irreversibility of heat transfer is lower.

1. Introduction

Fin-and-tube heat exchangers are widely used in many fields, such as power engineering, petrochemical engineering, air-conditioning engineering and refrigeration system et al. The air-side thermal resistance generally is 5–10 times of the liquid, which significantly increases the energy consumption [1]. In order to improve the performance of fin-and-tube heat exchanger, enhanced fins surface including wavy fin, interrupted (slit) fin and dimpled fin have been developed. As an interrupted fin, slit fins are paid more attention because of the diversity of structure and complexity of principle.

The experiment and numerical simulation had been widely used to investigate the heat transfer and fluid flow characteristics of slit fin. Nakayama and Xu experimentally studied the heat transfer coefficient for two-row staggered slit fin-and-tube heat exchanger, the result revealed that the heat transfer coefficient was about 78% higher than that of the plain fin [2]. Wang et al. also experimentally investigated the airside performance of slit-fin-and-tube heat exchanger [3]. Yun and Lee applied the Taguchi method to systematically analyze the effect of various design parameters on the heat transfer and fluid flow characteristics of slit fin. Kang and Kim [4] experimentally and Qu et al. [5] numerically investigated the location effect of X-strip fin on the heat transfer and pressure drop characteristics. Their investigated results indicated plain fin at front row and strip fin at rear row was more effective to enhance heat transfer than that of the whole strip fin under the same fan power. Li et al. analyzed the heat transfer and fluid flow characteristics of slit fin by numerical simulation, their conclusions showed that the proposed structure of slit fin based on "front coarse and rear dense" was optimized for the heat transfer and fluid flow characteristics [6].

In present, many studies focused on the longitudinal vortex generator (LVG, and different forms of wing-type longitudinal vortex generator had developed (shown in Fig. 1), which were used to mount on the fin surface with "common flow down" configuration or "common flow up" configuration, as shown in Fig. 2. In general, LVGs might involve three kinds of heat transfer mechanisms, such as destroying the boundary layers, producing swirl and flow destabilization, and lasting over long distances in the flow direction, so which had high heat transfer coefficient and low pressure loss. Fiebig et al. experimentally studied the effect of wing-type vortex generators on a three-row fin-and-tube heat exchanger, four configurations were tested for an inline and a staggered arrangement. The highest heat transfer enhancement due to the vortex generators was found with the inline tube arrangement, which increased 55–65% heat transfer and 20–45% the friction factor for Reynolds

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Nomenclature

A_c	area at minimum cross section, m^2
A_f	fin surface area, m^2
A_o	total area, m^2
C_p	specific heat capacity, j/(kg k)
D_c	tube outside diameter, mm
F_p	fin pithc, mm
f	friction factor
j	Colbum j factor
h	heat transfer coefficient,w/(m^2 k);or the height of lvgs, mm
H	height of slit, mm
l	delta winglet length, mm
L	fin length, mm
Ls	width of slit, mm
Nu	Nusselt number
Δp	Pressure drop, Pa
P_l	longitudinal tube pitch, mm
P_t	transversal tube pitch, mm
Pr	Prandtl number
Q	heat transfer rate ,w
Re_{Dc}	Reynolds number
R_h	equivalent thermal resistance,(k m^2)/w
Tw	tube wall temperature, K
u	velocity, m/s
u_m	velocity at minimum cross section, m/s
W	the width of slit, mm

Greek symbols

α	attack angle of the delta winglet, deg.
β	field synergy angle, deg.
δ_f	fin thickness, mm
μ	dynamic viscosity, kg/(m s)
θ	angle of slit, deg.
η_f	fin efficiency
η_o	total efficiency
λ	thermal conductivity, W/(m^2 K)

Subscripts

a	airside
f	fin
in	inlet
m	mean value
out	outlet

numbers from 600 to 2700. The corresponding increases for the staggered tube arrangement were found to be lower [7]. Zhu et al. [8] investigated influences of four types of longitudinal vortex generators (delta wing, rectangular wing, delta winglet pair and rectangular winglet pair) on heat transfer and flow loss, their results showed that the mean heat transfer rate could increase by 16–19% with the vortex generators for an area of channel wall which was 30 times larger than the vortex generator area. Torii et al. [9] experimentally investigated delta winglets in a plain fin-and-tube heat exchanger at a relatively low Reynolds number. The winglets were not only completely located on the upstream or downstream region of the tubes, but also placed more on the sides of the tubes. Their investigated results showed winglet type vortex generators could increase the overall heat transfer coefficient. Their results also revealed the augmentation was more important for the case of the common-flow-up configuration. The similar experimental study by Jaordar and Jacobi [10] and Sommers and Jacobi [11] also proved that delta winglet LVGs could improve the heat transfer rate in many thermal systems. Pesteei et al. [12] experimentally studied the effect of winglet location on heat transfer enhancement and pressure drop in the fin and tube heat exchangers. Allison and Dally [13] analyzed the effects of delta-winglet vortex generators on the performance of fin and tube radiator. Compared to a standard louver fin surface, experimental results showed that the winglet surface had 87% of the heat transfer capacity but only 53% of the pressure drop of the louver fin surface. Joardar and Jacobi also experimentally studied the effectiveness of a vortex-generator alternate-tube inline array of vortex generators. They found that the air-side heat transfer coefficient increased from 16.5% to 44% for the single-row winglet arrangement with a corresponding increase less than 12% in the pressure drop. For the three-row vortex generator array, the heat transfer coefficient increases with Reynolds number from 29.9% to 68.8% with a pressure drop penalty from 26% at Re = 960 to 87.5% at Re = 220. Their results indicated that vortex generator arrays could evidently enhance the performance of fin-and-tube heat exchanger [14]. Akbari et al. [15] studied the effects of two different configurations of delta-winglet pair vortex generators on heat transfer enhancement. Wu and Tao [16,17] applied the field synergy principle to analyze the mechanism of heat transfer enhancement in fin-and-tube heat exchanger in aligned arrangement with longitudinal vortex generator. Chu et al. [18] analyzed the heat transfer characteristics and fluid flow structure of fin-and-oval-tube heat exchangers with longitudinal vortex generators (LVGs). Their results showed that the average Nu for the three-row fin-and-oval-tube heat exchanger with longitudinal vortex generators increased by 13.6–32.9% over the baseline case and the corresponding pressure loss increased by 29.2–40.6%. Lei et al. [19] investigated the effects of vortex generators on heat transfer and pressure drop of heat exchanger, they found that the delta-winglet vortex generator with an attack angle of 20° and an aspect ratio of 2 could provide the best integrated performance over the range of

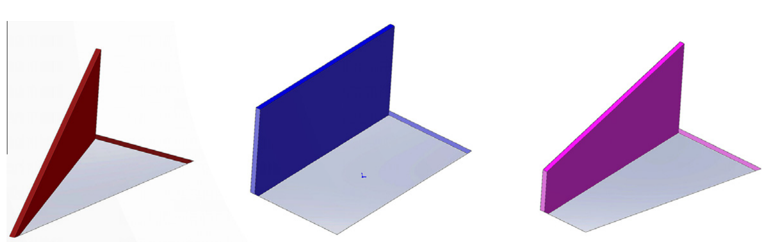

Fig. 1. Different types of longitudinal vortex generators.