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Enhancement of heat transfer in a fin-tube heat exchanger using rectangular winglet type vortex generators

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ABSTRACT

The present study simulates the air flow through fin-tube type heat exchangers with rectangular winglet pairs (RWP) of half the channel height as vortex generators (VG). The heat exchanger is approximated as a periodic rectangular channel with heated walls and three rows of built-in tubes placed at an appropriate interval. Two different orientations of the tubes in the heat exchangers are considered here – one with inline arrangement of three tube rows and the other with staggered arrangement of three tube rows. Further, the angles of attack in each orientation are varied. The heat transfer characteristics of the heat exchangers with vortex generators located near the tubes have been compared among the cases with varied angles of attack and orientations of tubes. The Navier–Stokes and energy equations along with the appropriate boundary conditions are solved using the ANSYS FLUENT 14.5 solver. Performance parameters in terms of Nusselt number, vorticity and quality factor (a ratio between the Colburn factor to apparent friction factor, also refer to as area goodness factor with slight modification) were evaluated. The results show significant improvement in the heat transfer performance due to the nozzle-like flow passages created by the winglet pair and the region behind the circular tube which promote accelerating flow. There is an increasing trend of the above for the in-line row of tubes; whereas with the staggered row of tubes, there is slight deviation of this trend. Due to the alternate CFD–CFU orientations of the VG, the performance improves with increase in angle of attack up to a certain point and afterwards it is going down.

1. Introduction

In energy transfer related applications, heat exchanger performance is of great importance in meeting today's stringent energy efficiency standards with low cost and less environmental impact. In the liquid-to-gas and phase-change heat exchangers, typical to many Heating, Ventilating and Air Conditioning & Refrigeration (HVAC&R) systems, the gas-side thermal resistance contributes heavily to the overall thermal resistance. The vortex generators have shown great promise in enhancing air/gas-side heat transfer coefficient. With increasing energy costs and new regulations aimed at achieving higher efficiency and better environmental protection, heat exchanger performance will continue to play very important role. Achieving overall performance enhancement in the above mentioned heat exchanger geometry is expected to have profound implications on the energy conversion and HVAC&R systems. Vortex generators (VG) induce streamwise longitudinal vortices in the flow field. Such vortices impart strong swirling action causing destabilization of thermal boundary-layer and in some cases leading to unsteady oscillatory motion. Apart from these well-known mechanisms of heat transfer enhancement, the placement, shape and orientation of the VGs can yield additional augmentation through management of wake structure behind the tubes.

It was shown experimentally by Jacobi and Shah [1] and Tiggelbeck et al. [2] that the longitudinal vortices generated by surface-mounted delta-wings and winglet pairs are indeed very effective for heat transfer enhancement. Over the years, various researchers had shown that VGs are capable to enhance heat transfer for both fin-tube and plate-fin heat exchangers. In case of plate-fin heat exchangers, protrusions can be mounted on the channel surfaces to enhance heat transfer between flowing fluid and closely placed parallel plate channels [3–5]. The two most commonly reported VG placement strategies are the so called "common-flow-down" (CFD)

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Nomenclature

B	channel width
c_p	specific heat
h	heat transfer coefficient
k	thermal conductivity
Nu	Nusselt number
p	pressure
Pr	Prandtl number
q	heat flux
f_{app}	apparent friction factor
Q_f	quality factor
Re	Reynolds number
T	temperature
u_i	local velocity
U_{av}	average velocity
x_i	tensor coordinate direction

Greek symbols

α	thermal diffusivity
β	angle of attack
μ	dynamic viscosity
ν	kinematic viscosity
ρ	density
Γ	vorticity

Subscripts

av	average
b	fluid bulk quantity
i, j	tensor notations
in	at inlet
pl	plane channel without VG
sa	spanwise
w	the channel wall (fin surface)

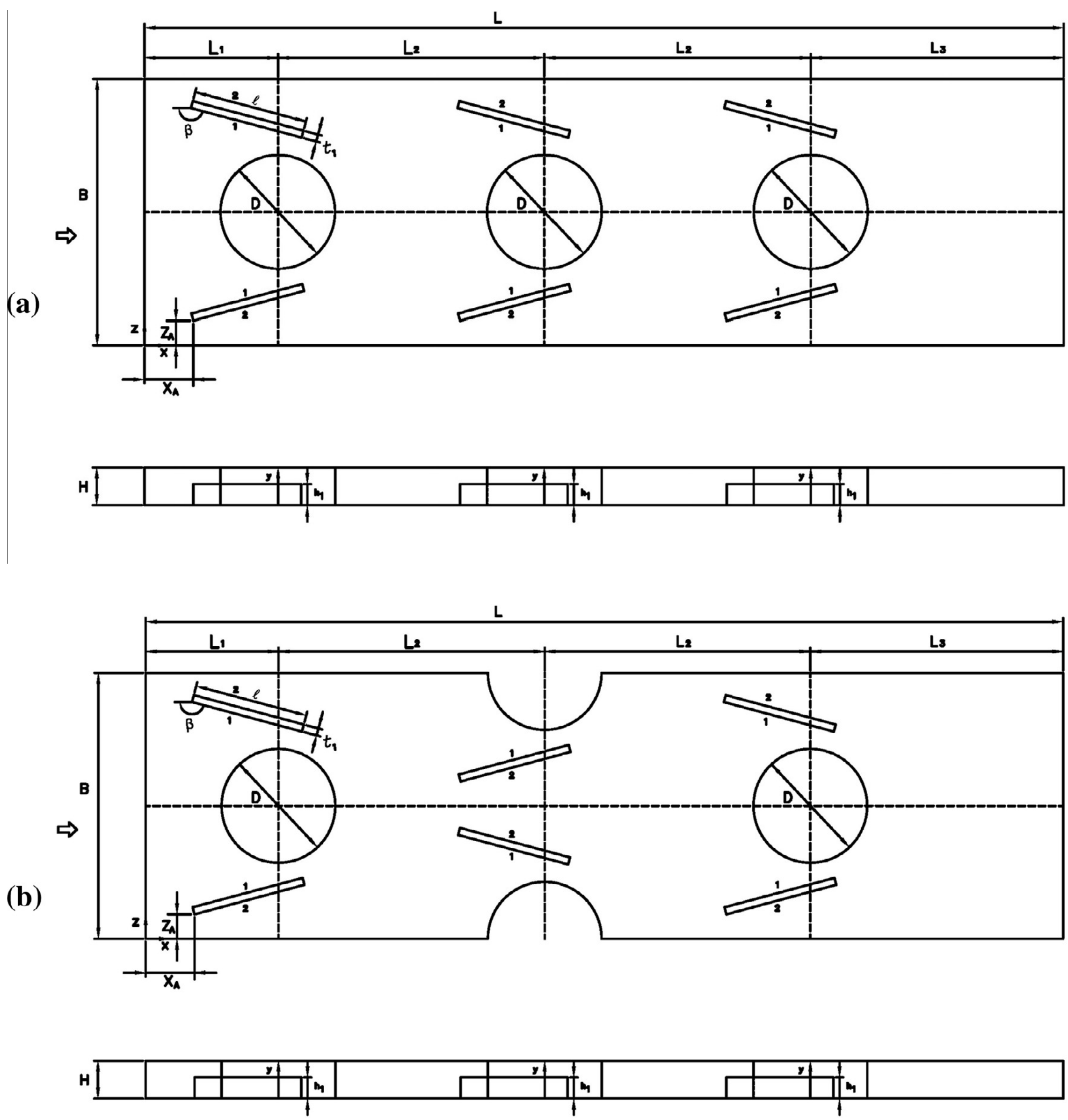

Fig. 1. Computational domain: (a) in-line rows with winglets, (b) staggered rows with winglets (angle of attack = 165°) (1 and 2 in figures denotes pressure side and non-pressure side, respectively).