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Numerical investigations on heat transfer characteristics of curved rectangular winglet placed in a channel

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ABSTRACT

Flow and heat transfer characteristics of curved rectangular winglet vortex generators (RWVGs) are investigated numerically. Three-dimensional numerical computations have been carried out for flow through a channel with curved RWVG mounted on its bottom wall. Effect of curvature of RWVG having concave and convex shapes with respect to the flow facing surface, has been addressed in terms of arc angle which is varied in the range from 15° to 120° for fixed arc length. Effect of curvature in concave and convex RWVG on flow and heat transfer characteristics has been compared with that of plane RWVG. Temperature and flow field characteristics near the plate surface have been presented and discussed with the help of temperature contours and streamline plots. Enhancement in heat transfer and pressure loss are examined by using Nusselt number and friction factor respectively. Maximum enhancement in heat transfer is found to be 22% for concave shape RWVG having arc angle equal to 75° as compared to channel in absence of RWVGs. The mechanism of heat transfer enhancement is explored with the help of secondary flow intensity and field synergy principle. Thermodynamic performance of various RWVGs has been analysed by calculating entropy generation rate caused by heat transfer and friction. Finally, overall thermo-hydraulic performance of various curved RWVGs has been reported and compared with that of plane RWVG.

1. Introduction

Limitation of energy sources has raised the need of energy saving in many industries that has formed most important area of research in recent times. Many industrial applications require efficient energy transfer by high performance heat exchange, such as refrigeration and air conditioning, electronic cooling, aerospace engineering, chemical engineering and automobile industry. In present thermal industries, energy saving can be achieved by enhancing heat transfer and reducing pumping power. In heat exchanger devices, thermal resistance of gas side is much higher than that of liquid side and contributes heavily to overall performance. Thus, enough scope exists towards improvement of thermal performance of these devices on gas side.

Augmentation in heat transfer can be achieved by disruption in the growth of thermal boundary layer and enhanced fluid mixing that can be accomplished by producing secondary flow [1]. Vortex generator (VG) as 'wing' or 'winglet' mounted on fin surface is one of the effective methods for secondary flow generation. Biswas et al. [2] numerically and Valencia et al. [3] experimentally investigated and reported that use of VGs on the flat fin surfaces are beneficial in terms of augmentation of heat transfer with less penalty in pressure drop. Longitudinal vortices are generated by the VGs in the main flow direction that disrupt the growth of thermal boundary layer and enhance fluid mixing thereby higher heat transfer is achieved [4–6]. VGs are usually mounted as protrusions on a surface at an angle of attack (β) with respect to the flow direction either as external devices or by punching out from the surface itself. Four basic configurations of VGs are widely known, such as delta wing [5,6], rectangular wing [5–7], delta winglet (DW) [5,6,8–10] and rectangular winglet (RW) [5,6,11,12]. Wings and winglets are distinguished based on attachment of edges of a VG to the plate. If the trailing edge of VG is attached to the plate, it is referred to as a 'wing' and if the chord length is attached it is named as a 'winglet'.

Heat transfer and flow field characteristics have been investigated experimentally by Fiebig [6] in a rectangular channel with four different types of VGs (delta wing, rectangular wing, DW and RW). It has been reported that for the same heat transfer rate, pressure drop is lower for winglet type VGs as compared to wing-type VGs. Tiggelbeck et al. [5] performed flow and heat transfer experiments with these four different types of VGs and reported that for higher angles of attack ($\beta > 30^o$) and higher Reynolds number (Re $>$ 3000), winglet type VGs perform better than wing type VGs. The mounting arrangement of VG in the form of winglet pair is identified as common flow up (CFU) or

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common flow down (CFD) configuration as proposed by Pauley and Eaton [13] and has significant effect on its heat transfer performance. Numerical investigations on heat transfer enhancement have been carried out by Tian et al. [14] for RW and DW for both CFD and CFU configurations. They observed that the effect of mounting configuration on overall performance is lower for channel mounted with DW than RW. Moreover, CFU configuration gives higher heat transfer augmentation with higher friction factor. However, in case of channel with RW, CFD configuration shows better overall performance than CFU configuration. Similarly, comparison of thermal performance for winglet type VGs has been carried out by Zhu et al. [15], Ferrouillat et al. [16], Biswas et al. [17] and Saha et al. [18].

Numerous studies have been carried out to investigate the effect of geometric parameters of VGs on flow and heat transfer characteristics as well as thermal performance. Wu and Tao [19] investigated experimentally as well as numerically the effect of location and spacing between RWVGs in a channel. Reduction in heat transfer enhancement has been observed when the location of RWVG is shifted away from channel inlet and also when spacing between RWVGs is reduced. Naik and Tiwari [20] numerically investigated the effect of Reynolds number (Re) and geometric parameters such as length and angle of attack of surface mounted RWVG. Augmentation in heat transfer has been reported with increase in length and angle of attack of RWVG and also with increase in Re. Similar studies that investigate effect of geometric parameters on heat transfer and pressure drop characteristics have been carried out by Yuan et al. [21], Ebrahimi et al. [22] and Zhang and Wang [23]. Heat transfer characteristics of modified RWVGs have been investigated experimentally by Min et al. [24] for angle of attack ranging from 25° to 65° and Re in the range of 5000–17500. It has been reported that surface-averaged Nusselt number (*Nu*) increases with increase in angle of attack of VG and maximum value appears for an angle of attack equal to 55°. Effect of winglet shape and angle of attack on heat transfer and pressure drop characteristics in a rectangular channel has been studied by Abdollahi and Shams [25]. They reported that effect of angle of attack on heat transfer is significant only at higher values of Re. Moreover, shape effect is such that the rectangular VG provides maximum heat transfer enhancement and pressure drop followed by trapezoidal VG and delta VG.

Zhou and Ye [26] experimentally studied the performance of curved trapezoidal winglets and compared with that of RW, DW and trapezoidal winglets. It has been reported that thermo-hydraulic performance of curved trapezoidal winglet pair is better than other VGs in fully turbulent region. Zhou and Feng [27] investigated experimentally and Lu and Zhou [28] numerically the effect of curved winglet type VGs (curved RW, curved DW and curved trapezoidal winglet) with plane winglet type VGs (RW, DW and trapezoidal winglet). It has been reported that curved winglet type VGs show better thermal performance with lower flow loss than plane winglet type VGs. Apparently, the effect of geometric parameters of VG has been well studied by researchers. Also, few of the above studies presented a comparison of performance of curved VGs having fixed curvature. However, effect of surface curvature of a VG on mechanism of enhancement of heat transfer is rare and needs to be investigated. The motivation for the present study has been derived from this gap in literature.

Present work deals with three-dimensional numerical investigation to study the effect of surface curvature of RWVG on heat transfer and fluid flow characteristics. For the curved RWVG, both concave and convex shapes have been considered with different arc angles for fixed arc length. Effect of non-zero curvature of RWVG on flow and heat transfer characteristics is compared with that of plane RWVG. In addition, mechanism of heat transfer enhancement has been studied using concepts of secondary flow intensity and field synergy principle. Overall performance of curved RWVGs has been estimated using thermodynamic and thermo-hydraulic analysis and results are compared with those for plane RWVG.

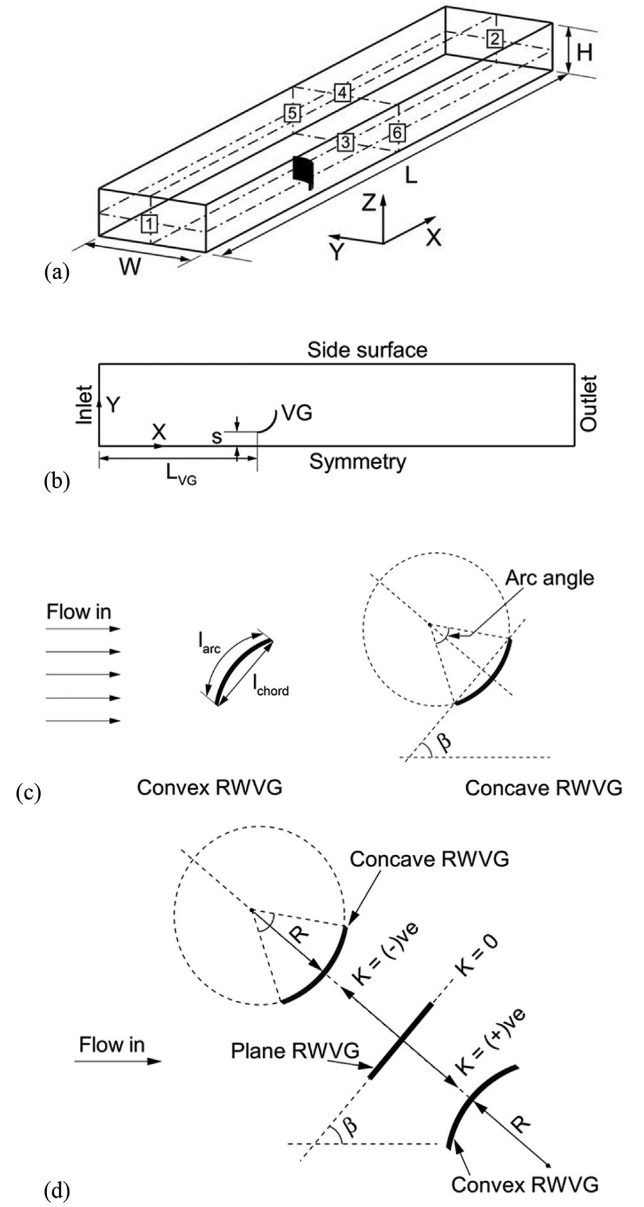

Fig. 1. Schematic diagram of the computational domain (a) three-dimensional view (b) top view (c) parametric view of VG (d) K notation for different RWVGs.

2. Problem formulation

Three-dimensional numerical simulations in a channel flow have been carried out using the finite volume based commercial software ANSYS Fluent 17.2. Obstacles in the form of plane and curved rectangular winglet type vortex generators (RWVGs) are mounted on the bottom wall of the rectangular channel. Fig. 1(a) and (b) show the three-dimensional and top view of the flow domain. Height of the channel (H) is fixed and is equal to 20 mm, length (L) is 15H and width (W) is 2.5H. The distance between leading edge of vortex generator and inlet of channel (L_{VG}) is fixed equal to 5H. The height of vortex generator is 0.5H and thickness is assumed to be less than 10% of its height. Flow is described in Cartesian coordinate system (x, y, z), where x, y, z represent streamwise, spanwise and normal to plate directions respectively. The considered configuration of RWVGs mounted on the bottom wall of the channel is common flow down configuration. Effect of angle of attack (β) of plane RWVG on heat transfer enhancement has been analysed and further studies for curved RWVGs have been carried out