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Effect of surface modification of a rectangular vortex generator on heat transfer rate from a surface to fluid: An extended study

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ABSTRACT

For many industrial applications, cooling of a hot surface is of greater importance for an improved performance of the system. The wetted surface area plays a vital role in heat transfer process. Increase of the wetted surface may improve the heat transfer rate from the hot surface to the flowing fluid. Further, the optimisation of the shape of the extended surface may promote superior thermal interaction between the surface and the fluid. These extended surfaces are responsible for creating an abrupt pressure difference across it. This results in formation of longitudinal vortices downstream of the surfaces. The induced longitudinal vortex may interact with the boundary layer, which in turn enhances the convective rate of heat transfer. In the current work, the vortex generators with surface textures are studied numerically, which is an extension of previous work performed by same group of authors Kashyap et al. (2018). The CFD results show that multiple textures on the leading and the trailing faces of the vortex generator enhances the strength of the primary vortex, downstream of the vortex generator. As a result, the heat transfer from the heated surface increases to about 14.4%. The phenomenon is realised by increment in the surface average skin friction coefficient along with the surface average Nusselt number of the plate. The surface temperature distribution of the plate downstream of the vortex generator show a downfall due to the stretching of the primary vortex with a minimal pressure drop.

1. Introduction

The need for cost effective, sustainable, and energy efficient systems are increasing with rise in energy prices. The existing systems can be modified in low cost ways to deliver high savings. Advancement in the field of engineering and technology help the systems to get miniaturised. As a result, an economic as well as efficient system is the need of today. Almost all systems while operating releases energy in the form of heat. The heat generated by these systems demand an efficient cooling mechanism to maintain its efficiency. Therefore, to maximise the efficiency, an improved heat transfer mechanism is hunt for.

Surface cooling is a process that witnesses a wide applications in many industries, viz., power, electronics, electrical, automobiles, aerospace, etc. Extended surfaces like fins and vortex generators are usually used in such applications. Fins increases the overall wetted surface area for heat transfer and assist in cooling of the base system. On the other hand, vortex generators (VG) improve the heat transfer rate by inducing convective circular flow patterns in the cooling fluid domain. Important geometrical parameters like shape characteristics, surface coating and patterns, surface temperature, material composition, etc. influence the heat transfer mechanism in such cooling systems.

The design of a thermal system may be improved by allowing a liquid or a gas to flow through it, to extract the thermal energy. However, due to lower thermal diffusivity of fluids, compared to solids, it lead to a poor heat dissipation of the system. The main goal is to reduce the thermal resistance of the fluid medium. It may be achieved by installing VGs on the effective surfaces of the thermal system. A VG is responsible for inducing vortices (circulating zones) when it is placed in a flow. A work by Ref. [12] reveals that heat transfer rate is enhanced by using VGs on a flat surface. The authors also found that with increase in pressure drop various recirculation zones are produced behind the trailing edge of the VGs [18]. studied experimentally, the effect of longitudinal and latitudinal vortices. An enhancement in the heat transfer rate have been observed for the longitudinal vortices in comparison to latitudinal vortices. In a numerical comparison between wing type VG and bare plate [3], the former showed a 34% increase in the surface average Nusselt number ($\overline{Nu}$).

The influence of Reynolds number (Re) and geometrical shape over thermo-physical properties of a conjugate heat transfer system has been studied by Ref. [5]. Further, the influence of longitudinal vortex over thermo physical parameters has been studied by Ref. [6]. The study

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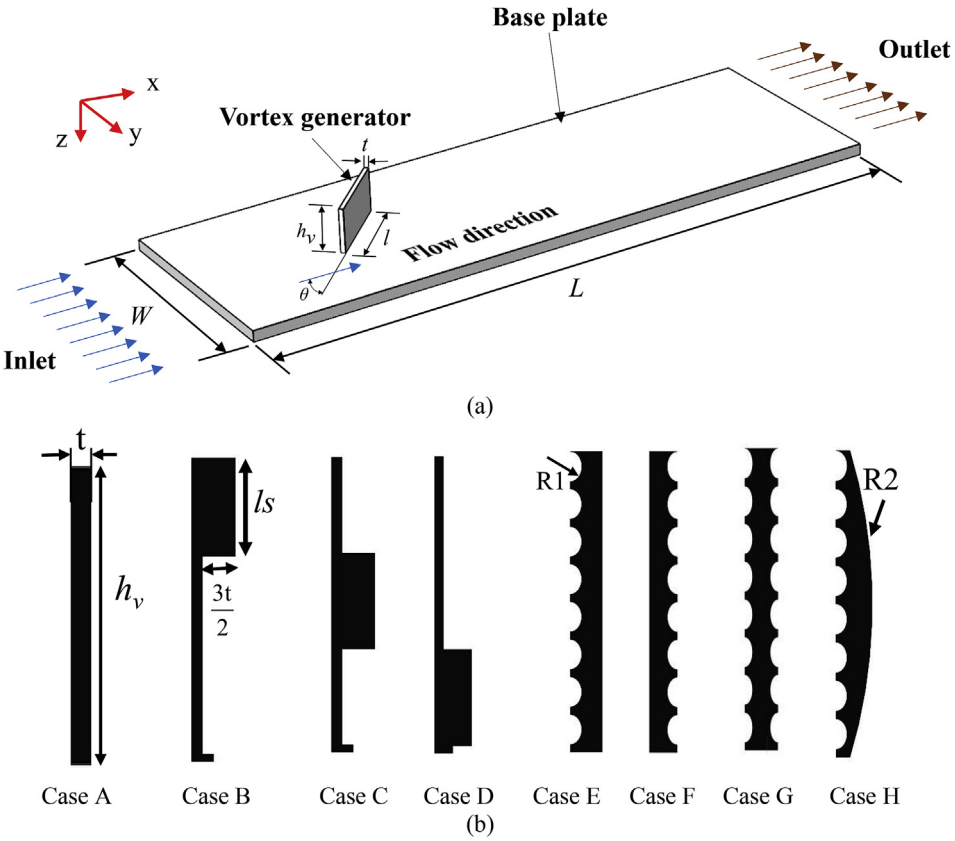

Fig. 1. (a) Schematic diagram of the considered rectangular vortex generator fixed over a base plate and (b) Schematic diagram of cross sections of various VGs.

reveals higher rate of heat transfer from the surface to the fluid under the influence of longitudinal vortex. The flow behaviour and heat transfer effect of longitudinal vortices produced by delta winglets in a laminar flow has been explained by Ref. [4]. This work is carried out numerically as well as experimentally. The heat transfer enhancement and the pressure drop is very much sensitive to the angle of attack offered by the VGs. It has been concluded by the experimental work of [7] [15]. shows that using of baffle in a heat exchanger tube can enhance the heat transfer rate to about 84%, when compared tube without baffle.

The analysis of winglets of different types, sizes and locations that produces longitudinal vortices has been observed and studied by Ref. [22]. It has been concluded that the delta winglets have an edge over the rectangular winglets [22]. It shows an increment in heat transfer rate under the influence of delta winglet in the channel. The experimental work of [19] shows that the influence of counter rotating vortices downstream may enhanced the overall Nusselt number of the system and thereby increase the heat transfer rate. The flow and thermal behaviour of fin and-tube heat exchanger with longitudinal VGs on the fin are numerically studied by Ref. [23]. An increment in Nusselt number by 20% is reported by the authors with the modified system. The increase in number of VG does not necessarily increases the heat transfer rate [17].

[9] numerical performed a study to combine vortex rods with a heat exchanger tube. The results show that the use of the vortex rods prompts a considerable heat transfer enhancement. The noble VGs has shown a better heat transfer characteristics when compared to the existing VGs. An innovative compact design of heat exchanger by Ref. [20] showed that high swirling of the primary secondary flow in the bend promotes better mixing and thereby increases the heat transfer rate [25]. studied the thermo physical properties of plane and curved longitudinal VGs based on field synergy principle. The results show that the best thermo-hydraulic performance is achieved for curved trapezoidal winglet pairs. In a laminar channel flow, the mechanism of heat transfer using longitudinal vortex is investigated by Ref. [21]. The results prompted that the local convection is greatly enhance due to the longitudinal vortices. As a result, the local transport of heat flux in span direction is improved.

[14] investigated the effect on heat transfer rate with modified VG. The result showed that wavy fin VG registers inferior heat transfer rate compared to the simple rectangular VG. It may be due to the fact that the wavy nature of the model does not actively participate in modifying the induced vortices behind. Therefore, an intelligent surface modification on the VG is highly desirable to enhance the heat transfer rate. Such novel modification was performed by the present group of authors [8]. In this work, the authors discussed the effect of modifications on the leading and trailing surfaces of a rectangular VG placed over a horizontal base-plate. The concave or convex modifications are used in the study. The modifications are oriented perpendicular to the base plate unlike the work performed by Ref. [14]; which are oriented parallel. It has been found that increment in the thickness of the VG at its vertical middle portion shows a favourable effect on heat transfer rate and fluid flow characteristics. The present work is an extension of the previous work performed by the authors [8] using multiple concave modifications on a surface. Here, a set of cases is studied altering the surface of the rectangular VG. The computational domain consists of VG placed over a heated flat plate. No such work on a rectangular VG with surface modification has been found during the literature survey. In the following section the details of the geometry and the formulations are described in detail.

2. Geometry and formulations

An extended surface from a body and its configuration influences the heat transfer characteristics in the system. The effect of surface modifications of a rectangular VG in heat transfer rate from a plate to