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# Augmentation of Heat Transfer in Duct by Staggered Vortex Generators

Ahmed H. Yousif [a], Maher R. Khudhair [b] and Mohannad A. Kadhom [c]

*AL-Dewaniyah Technical Institute, AL-Furat Al- Awsat Technical University,Dewaniyah, Iraq*

[a] Corresponding author: Ahmed19690708@Gmail.com; dw.ahd1@atu.edu.iq
[b] maherrehaif@gmail.com, maher.khudhair@atu.edu.iq
[c] mohannad_a_kadhom@atu.edu.iq

**Abstract.** A numerical simulation is performed to study the effect of two types vortex generators (VGs) on heat transfer coefficient and pressure drop in duct. There are two types of V.G., one is concave V.G. and the other is rectangular. The aim of the study is observe effects of the shape and arrangement this V.Gs in channel to the increase of heat transfer with Reynolds number range from (300 to 1500). Both types of V.Gs were placed in 45° angle of attack, in an in line and staggered position. The results shows that the staggered position gives the high heat transfer coefficient enhancement and concave is better than rectangular V.Gs by 7-10%.

**Keywords***:* heat transfer, vortex generators, CFD, Nusselt number

*Nomenclature*

| Symbol | Description | Unit |
|---|---|---|
| $d$ | Distance between V.G.s | $m$ |
| $b$ | Long of V.G. | $m$ |
| $h$ | Height of V.G. | $m$ |
| $H$ | Height of channel | $m$ |
| $k$ | Thermal conductivity | $W/m^2. K$ |
| $L$ | Channel length | $m$ |
| $L_{in}$ | Inlet distance | $m$ |
| $Nu$ | Nusselt number | ------ |
| $P$ | Pressure | $Pa$ |
| $Re$ | Reynold number | ------ |
| $T$ | Temperature | $K$ |
| $u$ | Velocity in x-direction | $m/s$ |
| $v$ | Velocity in y-direction | $m/s$ |
| *2-D* | Two dimension | ------ |
| *V.G.* | Vortex generators | ------ |
| $\rho$ | Density | $kg/m^3$ |
| $\theta$ | Theta angle | *degree* |

## INTRODUCTION

In many industries involving gas to liquid or gas to gas heat transfer, vortex generators are used to enhance the performed heat exchanger the gas has thermal conductivity resulting in high thermal resistance causing a low rate of heat transfer [1]. In this review article, a vortex generator may divide into may type as ((delta wing rectangular wing, delta winglet, rectangular winglet with multi position and multi charges used to increase of heat transfer.

Syaiful, M. T. et.al [1] Using longitudinal perforated concave winglet vortex generator to enhanced heat transfer in channel, the results show that heat transfer compared with channel without V.Gs. A CFD simulated ware current

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out to investigate the effect of cured and plane trapezoidal vortex generator by Russi K. et.al [2], the results shows that curved winglet (V.Gs) of heat transfer augmentation that the plain V.Gs in laminar and turbulent flow. A numerical study was performed to investigate the effect of longitudinal (V.Gs) of heat transfer augmentation of laminar flow in rectangular channel mounted with rectangular winglet pair on the bottom wall done by Qiang Z. et.al [3]. The study Reynold number range (500 – 7000) and the results show that max. heat transfer is obtained when the angle of attack is $90^o$ due to max. value of secondary flow generated by winglets. Syaiful, G. S. et.al [4] studied the effect of rectangular (V.Gs) on convection heat transfer with angle of attack of $30^o$, experimentally the results shows that Nusselt number and j-factor increase up to 205 % while thermal resistance decreases up to 67 % compared to baseline for highest Reynold number. A numerical study to show the effect of two types of concave (V.Gs) arranged as a fish tail locomotion in rectangular channel done by Ahmed Hashim Y. et.al [5].

The flow examined at range of Re. (200 – 2200), the result shows that the using of concave (V.G), at this type of arrangement enhanced heat transfer due to better mixing of secondary flow. There are a number of studies the effect of (V.Gs) on tubes in heat exchangers. Sandip B. K. et.al [6] studied enhanced of heat transfer in tube in tube type heat exchanger experimentally. In this study using are two types of V.G., one is concave V.G. and the other is rectangular with a wide range of Reynold number. The result shows that heat transfer enhanced with increasing in pressure drop. A two dimensional numerical investigation for forced laminar flow heat transfer over oral-tube bank in staggered arrangement with using rectangular vortex generator is done by Abdulmajeed A. [7]. The result shows that increasing in heat transfer with increasing skin friction coefficient and overall Nu. increases by (10 – 20 %) and by (10.4 – 27.7 %) with angle of attack of $30^o$ and $45^o$ respectively. Mohammad W. et.al [8] studied enhancement of heat transfer from rectangular duct with using trapezoidal vortex generators numerically of Reynold number range (7250 – 10300). The results show that thermal performance will be enhanced by (15 % – 45 %) with usage trapezoidal (V.G.s) at different Reynolds number.

The aim of this study is to investigate heat transfer and fluid flow in duct with using two type of V.Gs (concave and rectangular) and arranged this V.G. inline and staggered in laminar flow with deferent Reynolds number.

## *Geometry Model and Mathematical Description*

Figure (1) shows the geometry which has been considered in this study to show the effect of V.G. on heat transfer and pressure drop. The dimensions of this geometry are ($L/H = 60$), ($Lin/H = 1.4$), ($b/H = 0.6$), ($d/H = 0.7$), ($h/H = 0.5$), and $\theta = 45^o$.

The top and bottom wall channel is heated at 500 $^o$C

Two types of vortex generators, one is concave V.G.s and the other is rectangular V.G.s arranged in channel in line and staggered with Reynolds number range from (300 to 1500).

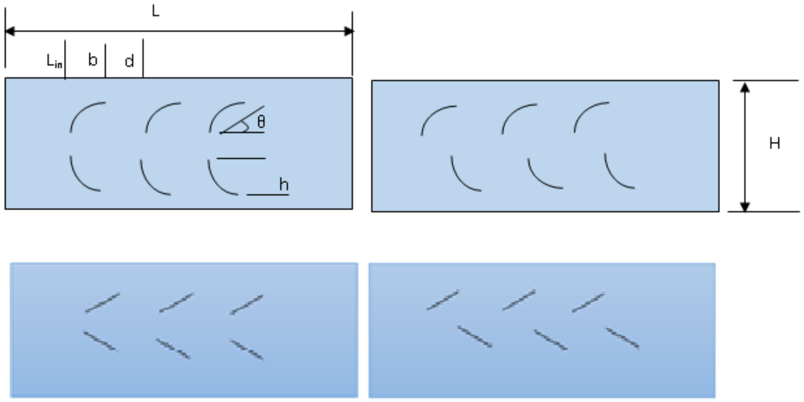

**FIGURE 1.** Geometry domain

$A_1$ – Concave inline, $A_2$ – Concave staggered V.G.s
$B_1$ – Rectangular V.G.s inline, $B_2$ – Rectangular V.G.s

The numerical simulation was conducted by a commercial CFD package FLUENT 16.1 for solving the following continue equations Hader Abdul H. L. [9].

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad \text{---------------} \ (1)$$

x- momentum equation

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{\partial p}{\partial x} + \frac{1}{Re}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) \quad \text{---------------} \ (2)$$

y- momentum equation

$$u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -\frac{\partial p}{\partial x} + \frac{1}{Re}\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) \quad \text{---------------} \ (3)$$

Energy equation

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{1}{P_r}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) \quad \text{---------------} \ (4)$$

The boundary conditions are

- Inlet (u= $U_{in}$ , v= 0, and $T_{in}$ = 300 °C

- Outlet $\frac{\partial u}{\partial x} = \frac{\partial v}{\partial y} = 0 \ \ and \ \frac{\partial p}{\partial x} = 0$

- Wall of the channel and V.G.s

(No slip, $T_w$ = 500 °C, TV.G. = 300 °C)

The parameters of this study are

Reynold number $R_e \frac{\rho u H}{\mu}$ --------------- (5)

Friction factor computed by pressure drop across The length of channel ($L$)

Nusselt number

$$N_u \frac{hH}{k} \quad \text{---------------} \ (7)$$

## RESULTS AND DISCUSSION

The non-uniform grids are generated for all numerical study, and a very fine mesh near the walls used to resolve the laminar sub-layer as shown in fig. (2). The average Nusselt number is almost constant after using grid of 160000 cells.

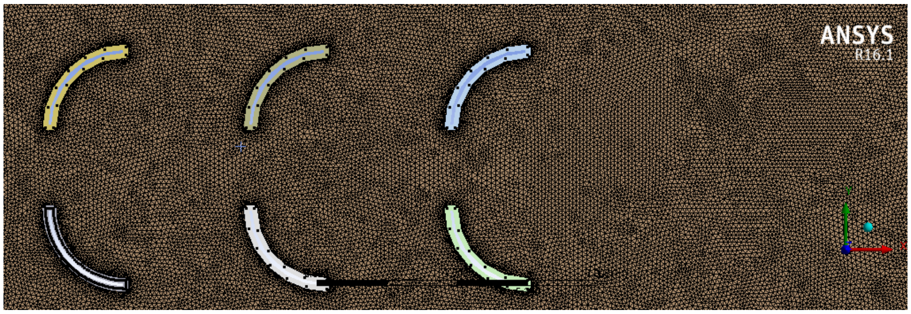

**FIGURE 2.** Mesh generation for concave vortex generators

Verification of Nusselt number and friction factor for smooth channel without vortex generators is performed by comparing the present study with Tariq Amin Khan et.al [10] under similar condition as shown in figures (3 & 4) respectively. The figures show good agreement between the current study and the result of Tariq Amin Khan [10] and The average deviation of the measured are within 8% for Nu and 7% for *f*.

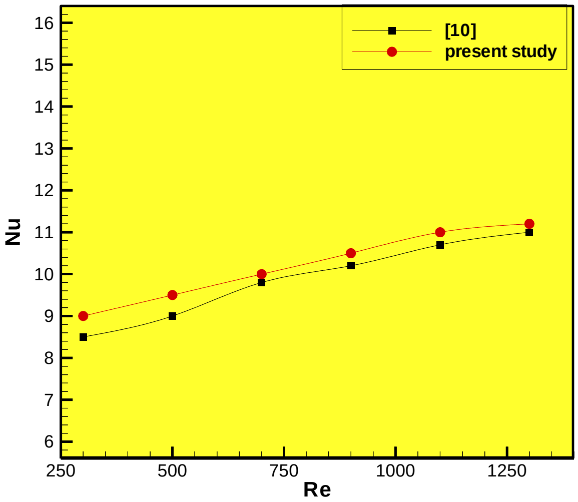

**FIGURE 3.** Comparison of $N_u$ for present study with [10]

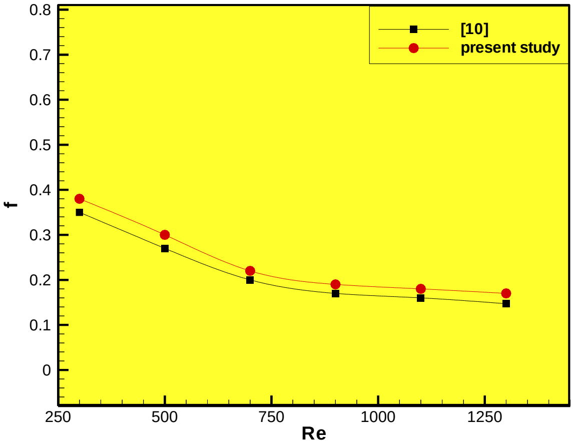

**FIGURE 4.** Comparison of friction factor for present study with [10]

Fig. (5) shows heat transfer in term of Nu along the channel with and without using V.G.s for two types staggered arrangement (Re = 800). The local Nu increases near V.G.s due to sweeping the heat from the walls and maximum heat transfer obtained when using concave vortex generator because more fluid move towards the heated walls and more heat remove from wall and mixing with cold fluid.

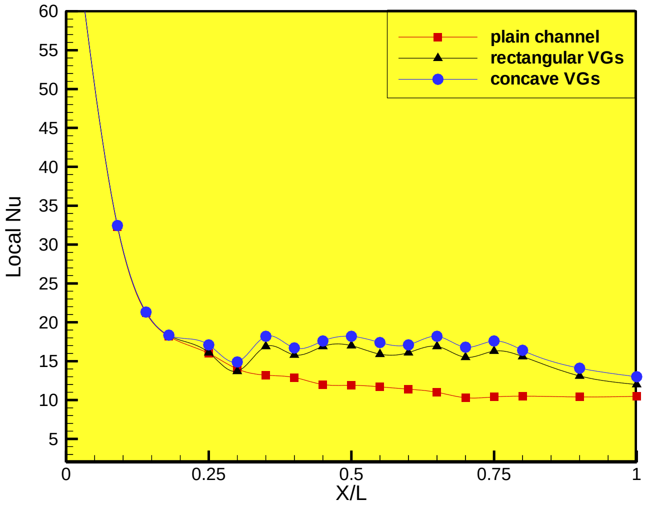

**FIGURE 5.** Local Nu with and without using V.G.s

The temperature contours with using concave and rectangular V.G.s with different Reynolds number can be shown in figures (6 and 7) respectively, it can be clearly shown that vortex generator effects, the temperature distribution along the channel and temp. gradient increases also. The boundary layer thickness decreases due to increasing mass flow rate toward the wall. Also it can be shown that the effect of concave V.G.s in the process of sweeping the heat from heated wall. The effect of VGs on channel continues for long distance when increasing Reynolds number

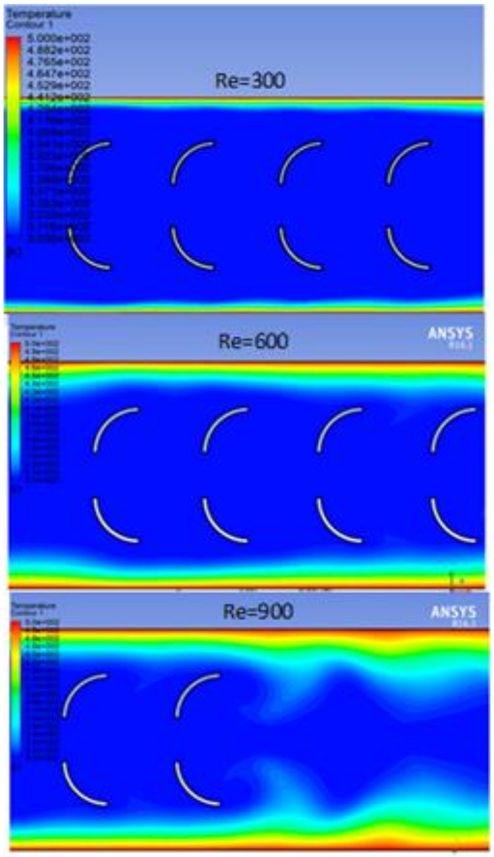

**FIGURE 6.** Temperature contour with using concave V.G.s at different Re

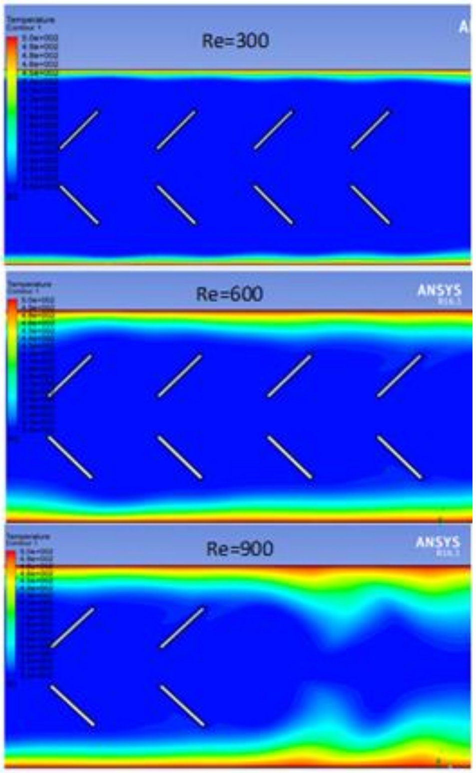

**FIGURE 7**. Temperature contour with using rectangular V.G.s at different Re

Fig. (8) shows the temp. contour with using concave and rectangular V.G.s with staggered arrangement at (Re = 600). It is clearly shows that affected temp. distribution along the channel and the temperature gradient increase with using V.G. at staggered arrangement due to effect at longer distance in channel and good mixing between hot and cold fluid.

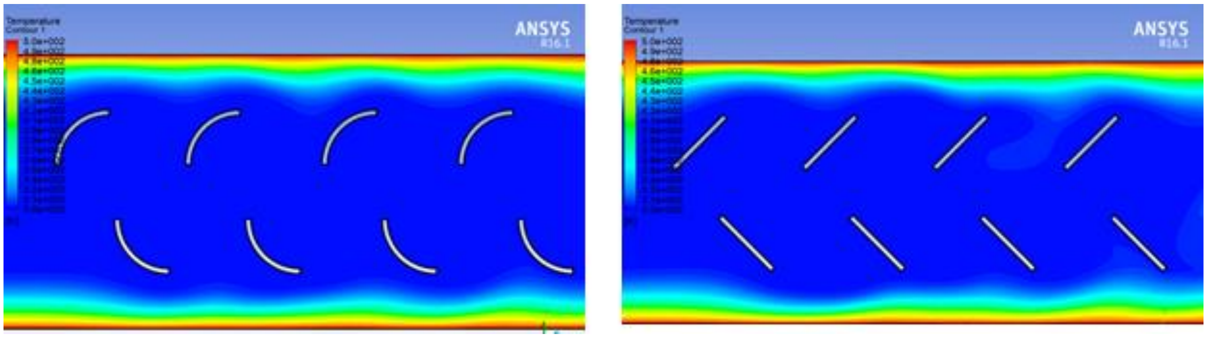

**FIGURE 8**. Temperature contour with using concave and rectangular V.G.s at staggered arrangement at Re=600

Figure (9) shows the velocity vector of the flow in channel with using concave and rectangular vortex generators with two types of arrangement at (Re = 600). It is clearly shows that the flow moves toward the wall and also shows vortexes behind the V.Gs. vortices done as a mixture of fluid and sweeping heat from heated walls.

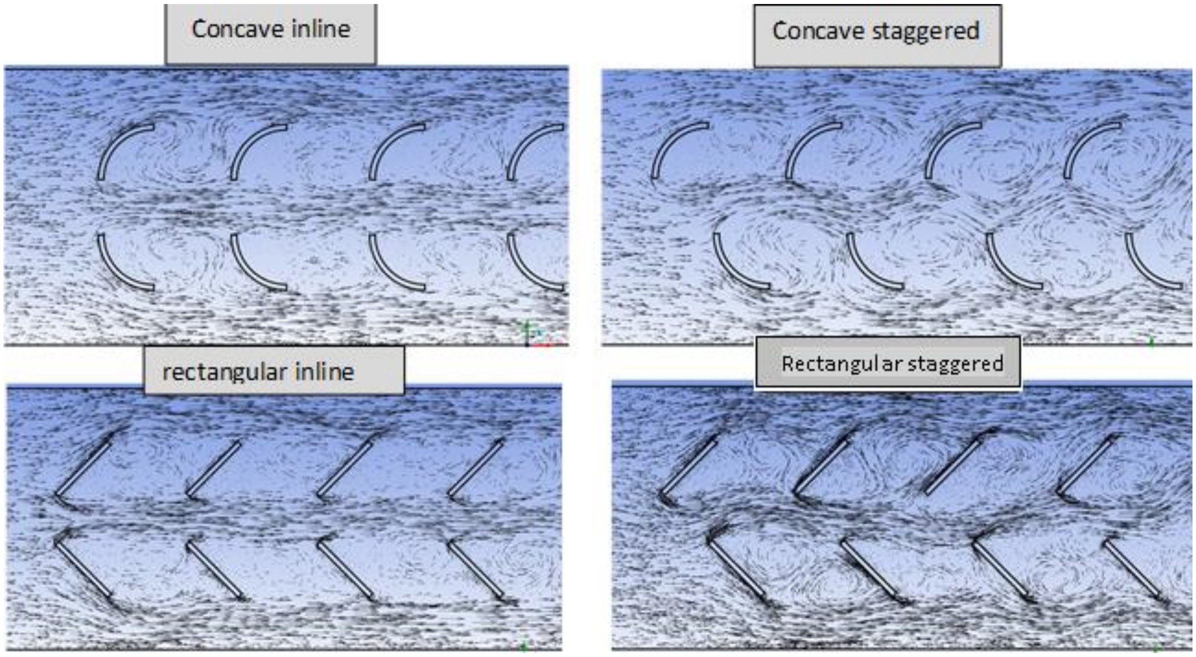

**FIGURE 9**. velocity vectors in channel with using different types of V.G.s with different arrangement at Re=600

Figure (10) show the compares of heat transfer with using concave and rectangular V.G.s with plane channel with different Reynolds number. The figure shows that the staggered concave V.G. is more affected than the others also the staggered rectangular have good affected after concave V.G.s and more than the other due to good directed the flow toward the wall and Nu enhanced by 16-28% with using V.Gs. Also from figure (11) shows that concave V.G.s inline arrangement has higher friction factor than the other due to long area facing the flow and friction factors increasing by 18-35%. With using V.Gs.

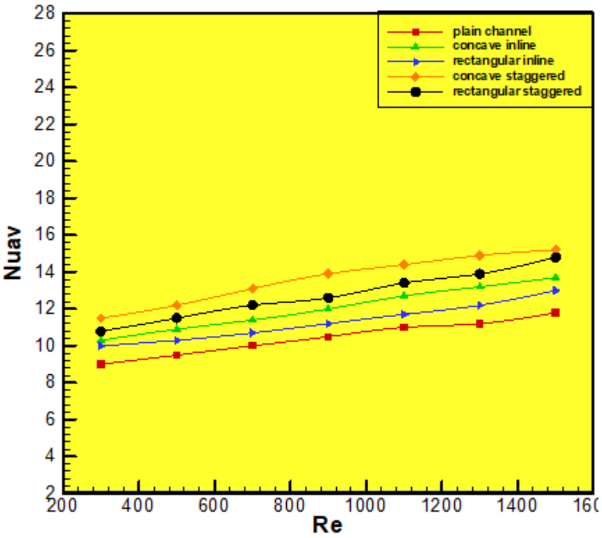

**FIGURE 10**. effect of two types of V.G.s with at arrangement on heat transfer with Re

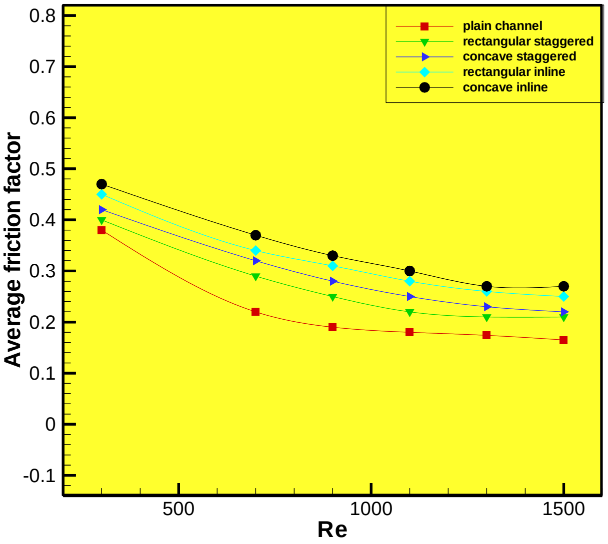

**FIGURE 11.** effect of two types of V.G.s with at arrangement on friction factor with Re

## CONCLUSION

2D Simulation were performed to investigate the effect of two types the effect of two types of vortex generator with (concave and rectangular) with two arrangements (inline and staggered) placed in channel to channel heat transfer.

A commercial CFD package FLUENT 16.1 was using for compute continuity, momentum, and energy equations using SIMPLE method at different Reynold number. The results show that $Nu_{av}$ with using V. Gs is seen to be higher than that of the plain channel around 16-28% also the staggered arrangement give maximum heat transfer from the channel wall. Also friction factor increasing with all types and arrangement of vortex generators by 18-35%. and concave is better than rectangular V. Gs by 7-10%.

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