Numerical study of heat transfer enhancement in fin and tube heat exchangers using curved semi wavy vortex generators.

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Abstract. This paper deals with a three dimensional numerical study of heat transfer and pressure drop for fin and tube bank heat exchanger with a vortex generator. A new type of vortex generator, curved semi-wavy vortex generators (CSWVGs) is introduced and compared its performance. The computational domain consists of a small portion between two adjacent fins and air is used as the working fluid. The vortex generators are punched out from the fin surface. The analysis show that with the use of new vortex generators convective heat transfer rate has been increased by increasing the solid to fluid interaction through delaying the boundary layer separation, directing the working fluid to the wake region and bringing vortices into the working fluid. The most favourable position and geometric parameter of the new CSWVGs are found by studying the average Nusselt number and friction factor at various Reynolds ranging from 800 to 2000.

1. Introduction

Fin and tube bank heat exchangers are mainly employed in engineering application such as vehicle radiators, heating, ventilation, air conditioning etc. M.Fiebig et al.[4] studied about different vortex generators found that longitudinal vortices can enhance heat transfer compared transverse vortices. The author also mentioned that heat transfer rate enhances with rise in Re accompanying with a pressure drop. Seong et al.[5] concluded that fin flat tube heat exchanger has an enhanced heat transfer rate and lesser pressure drop compared to fin circular tube heat exchangers. Also observed an increase of 75% and 45% heat transfer rate with vortex generator in flat fin tube and circular fin tube heat exchangers respectively. P.Chu et al.[6] investigated on rectangular winglet pair vortex generator and found an intensification in heat transfer coefficient from 28.1% to 43.9% which compensates the additional pressure drop generated. The staggered arrangement of tubes b delivers an improved heat transfer coefficient compared to inline arrangement. The author suggested that vortex generator array produces additional vortices but these vortices interact each other which declines the swirling of fluid. Z.M.Lin et al.[7] investigated the annular groove on fin surface and found that at low Reynolds number there is no significant change in heat transfer rate. But at higher Reynolds number the Nusselt number has improved by 10 to 40% than in plain fin.

Uddip et al[9] numerically analysed the heat transfer over a flat plate with a rectangular vortex generator. Multiple shapes of VGs were analysed in FVM based solver and concluded that multi concave profile on the leading face of the VGs considerable enhances the Nusselt number. Zhiming et al[10] also analysed the effect of VGs shape with five novel types of vortex generators. Winglet type vortex generators are more effective than other vortex generators in the sense of less pressure drop. It is important to find an optimum angle of attack to lower pressure drop and boost heat transfer. Wijayanta et al[11] experimentally examined the effect of angle of attack in a Punched Delta Winglet VG and suggested an angle of attack 70° for the optimum thermal performance. Mohammad et al[12] suggested a new a winglet VG called inclined projected winglet pair (IPWP), which shows better thermal performance than classical delta winglet pair combination. Zouqin et al[13] made a numerical investigation by incorporating k-ε turbulence model to inspect the impact of VG on the heat transfer and
resistance characteristics. A non-conventional curved delta wing vortex generator was introduced by Deshmukh et al [14] which is capable to augment local heat transfer upto 4-15 times in tube heat exchanger.

The present study focus on the improvement which could be obtained by introducing CSW vortex generator in a heat exchanger. Here the three dimensional modelling is done on ANSYS Design modular and the solver used is Ansys Fluent 14.

2. Methodology
A fin and tube heat exchanger with four tubes which are arranged in staggered manner was used for the present study. The curved semi wavy vortex generator is punched out of the fin surface close to the circular tube as shown in figure 1. The geometrical parameters that defines the curved semi wavy vortex generator and the computational domain are longitudinal tube pitch $S_1$, transverse tube pitch $S_2$, tube diameter $D_t$, fin pitch $T_p$, fin thickness $\delta_f$, vortex generator’s height, radii and circumferential angle as $H$, RVG and $\beta$. The vortex generator has a curved and a wavy part. The wavy part of the Vortex generator has been modelled for 2, 4 and 6 wavy patterns. The parameter of the wavy pattern is defined by a dimensionless factor $RW/R$ and $R_w$ is the radii of the wavy shape. All parameters are purposefully made dimensionless, so that this model can be incorporated even if the dimensions are changed for specified industrial application.

2.1 Geometry and domain discretization.
The computational domain is the space between two adjacent fins. Air is passed through the computational domain and upper and lower fins are the two boundaries. The tube and fin material is taken as copper.

![Figure. 1 Geometry of curved semi wavy vortex generators.](image-url)
Figure 2 Three dimensional view of computational domain

Table 1: Geometrical parameters

| Case | A | B | C | D | E |
|------|---|---|---|---|---|
| S₁ (mm) | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 |
| S₂ (mm) | 25.3 | 25.3 | 25.3 | 25.3 | 25.3 |
| R (mm) | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| δ₀ (mm) | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| β (°) | 90° | 90° | 90° | 95° | 105° |
| R₀₀/R | 1.35 | 1.35 | 1.35 | 1.35 | 1.35 |
| H (mm) | 1.683 | 1.683 | 1.683 | 1.683 | 1.683 |
| R₀/R | 0.0623 | 0.0935 | 0.1853 | 0.0935 | 0.0935 |
| Waves number | 6 | 4 | 2 | 4 | 4 |

3. Numerical method and analysis

3.1 Governing Equations
In the computational domain continuity, momentum and energy equation are considered. The fluid flow is assumed to be laminar, incompressible and heat transfer is at steady state. The air is considered to have a flow with constant physical properties.

3.2 Boundary conditions
An inlet velocity boundary condition is given at the inlet with Reynolds number varying from 800 to 2000. The outlet of the computational domain is given with a pressure outlet boundary condition. The circular tube is specified as wall boundary condition with a constant temperature. The upper and lower part of the computational domain that is the two fin surface is also specified with wall as boundary condition. The inlet and exit of the computational domain is extended to get a uniform velocity and to avoid reverse flow. The extended regions are connected to the computational domain by giving interface as the boundary condition and the rest of the extended computational domain is given symmetry boundary condition.

3.3 Validation
Experimental values by Y Wang et al [8] has been taken for validation which uses flat tube bank plain fin heat exchanger. Nusselt number and friction factor were plotted against Reynolds number and maximum deviation was found to be 8.08%.
3.4 Grid independence

Various grid elements numbers were tried by changing the mesh pattern to confirm the accuracy and validity of the numerical results. After increasing elements size above 206619 there in no variation in the results obtained. In figures 3 and 4, friction factor ($f$) and Nusselt number ($Nu$) are defined as:

Friction factor, $f = \frac{\nu p D_e}{0.5 \rho U m S_t}$  \hspace{1cm} (1)

Nusselt Number, $Nu = \frac{hD_e}{k}$  \hspace{1cm} (2)
4. Results and discussion
Curved wavy VG is a novel design of VG to improve heat transfer in a tube bank heat exchanger. In this work the CWVG is again modified to improve thermal performance. Figure. 5 shows that there is a significant increase in the average Nusselt number as compared to conventional fin and tube bank heat exchanger. Different geometries of CSWVGs was analysed and avg Nusselt number for various Reynolds number were plotted for comparison. It was observed that geometrical model with 2 wavy vortex generator has highest average Nusselt number. Geometry with 4 and 6 wavy vortex generator are observed in the decreasing order of average Nusselt number.

![Figure 5](image1.png)

**Figure. 5** Variation of average Nu with Re

From the figure.6 of Nusselt number contour it is clear that flow is getting separated from the top section of the circular tube when there is no VG. By using the CSWVGs it was observed that the flow was directed towards the wake region and also separation delay was observed.

![Figure 6](image2.png)

**Figure. 6** Nu contour at Re 1600 with and without VG’s
Figure 7 shows the variation of friction factor with increasing Reynolds number. It is observed that friction factor for geometry with 4 wavy vortex generator is minimum when compared with other. As the friction factor increases the pumping power required to for the flow through the heat exchanger will be higher. Thus an optimum design for the vortex generator was required which was fulfilled by geometry with 4 wavy vortex generator.

![Figure 7 Variation of friction factor with Re](image)

5. Conclusions
The fluid flow and heat transfer characteristic are numerically studied on a new type of VG by varying the geometrical parameter at different Re and an optimal design was selected. The results shows that the wake region present behind the circular tube has reduced by delaying the flow separation. Due to the wavy shape of the VG more turbulence created thus resulting in enhanced solid to fluid interaction. From the analysis it can be concluded that geometry with 4 wavy vortex generator offers the maximum heat transfer.

6. References
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