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Non-identical shaped vortex generators with triangular and cylindrical fins to control in the heat transfer

Suresh Kumar Muthusamy[1], N.Sankar Ganesh[2]

[1]Lecturer, Madha Institute of Engineering & Technology, Sadhanathapuram, Thandalam Post, Chennai – 600 122.
[2]Research Engineer, Skill TeQ, Adambakkam, Chennai – 600 088.

Abstract. In this paper, a novel heat transfer enhancement mechanism is deployed, which improves the performance of heat transfer using longitudinal vortices generator in weak regions. Instead of plain fine, the fins embedded with vortex generator are used to reduce the fin area. This mechanism generates less drop in pressure with increasing heat transfer fluid flow. Further, this research aims to study the heat transfer over three row plate fin. Further, tube heat exchangers without and without vortex generators of pair different shape mounted behind a tube is studied through computational fluid dynamics model in a wake re-circulation zone. The proposed mechanism is tested through numerical simulation with different span angles for triangular and cylindrical shaped vortex generator for Reynolds number ranging from 400 to 3000.

1. Introduction

The increasing prices of energy in industries started to focus on cost effective solutions to reduce the cost of energy using efficient designs. The cost effective solution is a better way to trade-off between sustainability and efficiency using the upgraded systems. One such way is the intelligent system design with the existing system, which helps to improve the energy utilization. Such miniaturized devices improve the usage of energy with reduced system weight, cost and volume. In order to attain optimal rate of efficiency, the heat in system should be controlled with optimal cooling rate. However, if the system gets too much heated up, performance of the system gets affected. Hence, it is very essential to consider reduced size components in a system that should support well effective cooling rate in the system. The demand on these systems mainly aims to reduce the overall size of cooling equipment with optimal rate of heat transfer.

Some of the earlier works includes various shapes of vortex generators to improve the rate of heat transfer, this includes: rectangular [1, 4, 6], rectangular trapezius [1], angular rectangular [1], wishbone [1], intended [1], wavy [1], delta winglet [2], rectangular winglet [2], spanwise-varying passive [3], lateral sweep [5], half-cylinder [7], flapping [8], low-profile [9] and quadrilateral [10]. These studies provide necessary information about enhancing the heat transfer rate in vortex generation through slight modifications in its overall geometry. This work aims at modifying the shape of vortex generator cross section through convex and concave textures. Here, two or more textures are considered in trailing and leading faces of vortex generators. The domain is placed with vortex generator over heated plate and this is studied using computational fluid dynamics. The volume of the vortex generator is made constant. The major parameters considered for the proposed study involves the position, span angles and size of vortex generator, which is not considered in conventional literatures. In spite of this, the present study aims at the evaluation of modification in thermal effects due to span angle effects.

The present study considers three span angles α = 30°, 45° and 60° for various vortex generation geometries like aerofoil, elliptical and semi-circular. The investigations are carried out by setting the range of Reynolds number between 400 and 3000. A three row tube is used for performing the numerical simulation and the turbulence effect is simulated using CFD. Further, the conjugated convective heat transfers in the flow field and heat conduction in the fins are also considered. This paper mainly aims at maintaining reduced pressure drop to attain high rate of heat transfer using aerofoil, elliptical and semi-circular shaped vortex generator.

2. Materials and methods

To tackle the fluid flow problem in vortex generator, the structuring of CFD codes is carried out around numerical algorithm. The codes in CFD include its main elements like solver, post and pre-processor. These codes aim to reduce the time for solving the problem using its urbane user interfaces to its parameters for determining the results.

3. Geometry and formulations

The characteristic of heat transfer over the surface is influenced by the configuration of extended surface. This study focuses on surface pressure when the heat is transferred from plate to fluid. The vortex generator produces different pressured area zones, where there is a drop in pressure flow and it induces circular flow along the direction of flow to form vortices.

This study involves the analysis of thermal characteristics of vortex generation with various shapes like convex and concave surface with trailing and leading surface in vortex generator. An energy equation is used in heat flow of vortex generator, where thermal radiation is eliminated. Here, the convection dominates the heat transfer but this is neglected easily. The movement of thermal energy is prompted by thermal potential difference in vortex generator. This is realised in terms of temperature difference, which helps to study the thermal behaviour and temperature distribution by solving the energy equation. By eliminating the volumetric heat generation rate, the energy equation in coordinate independent form [29] is given by

$$\frac{\partial T}{\partial t} + \left(\vec{V} \cdot \nabla\right) T = k \nabla^2 T \tag{1}$$

Where, t is the time of vortex generator medium, k is the thermal conductivity of vortex generator medium, T is the temperature of vortex generator medium and is the velocity vector, which depends on coordinate axes. From the above equation, the computation of temperature involves the velocity vector and this involves momentum and mass for its perfect estimation, which is given respectively in following equation.

$$\nabla \cdot \vec{V} = 0 \tag{2}$$

$$\frac{\partial \vec{V}}{\partial t} + \left(\vec{V} \cdot \nabla\right) \vec{V} = \frac{\nabla P}{\rho} + \nu \nabla^2 \vec{V} \tag{3}$$

where, ρ is density, ν is kinematic viscosity and P is pressure.

A set of boundary condition is used for solving these equations [9]. This is used to validate the present work and the main aim is to find the thermal structure of vortex generator. To solve the thermal convection, heat transfer co-efficient (h) and Nusselt number (Nu) are considered. The relative strength of convection to conduction is expressed as follows,

$$Nu = \frac{hD_w}{k} \tag{4}$$

where, Dw defines the length and it is estimated as volumetric ratio of computational domain to the heat transfer area and it is set as 0.04 m. k is the fluid thermal conductivity and the heat transfer coefficient (h) is given by,

$$h = \frac{q''}{T_w - T_m} \tag{5}$$

where, q″ defines the heat flux, Tw is the temperature of wall and Tm is the temperature of mean inlet.

Finally, the Reynolds number is used to find the water's flow velocity, which is given by,

$$\mathrm{Re} = \frac{\rho u D_w}{\mu} \tag{6}$$

where, μ is the fluid's dynamic viscosity and u is the fluid velocity.

4. Physical model

The vortex generator performance is estimated based on its size, position and span angles. The present study aims at evaluation of effects of span angles on thermal characteristics. Here, the Reynolds number ranging from 400 to 3000 is used to investigate the three span angles, namely 300, 450and 600. The numerical simulation is performed in a turbulent manner for heat transfer and fluid flow over three row tubes and the turbulence effect is simulated through CFD. This study further takes into account the heat conduction and heat transfer of the flow in fins. The three different span angles are shown in figure 1 to figure 3.

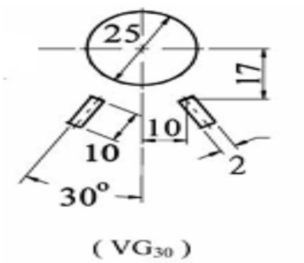


Figure 1. Span angle α = 30°.

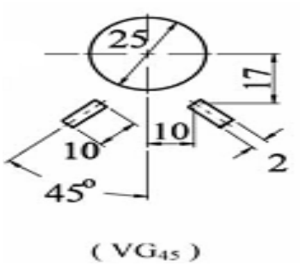


Figure 2. Span angle 45°.

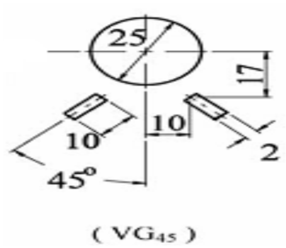


Figure 3. Span angle 60°.

5. Boundary condition

The fluid taken for study is incompressible with perpetual properties and the flow of fluid is turbulent, no viscous dissipation and steady. The velocity of fluid flow is assumed uniform at the boundary with inlet temperature of 200C. The turbulence intensity at inlet is set as 3%.The Neumann boundary condition or stream wise gradient for variables is zero. At the downstream end, the tube diameter is seven times the last downstream row tube. The temperature of constant tube wall, no slip condition is specified at solid surface. Between the boundary planes of XY and XZ, the cyclic match is found. The device for pressure drop has three tube row placed inside an inline array. Finally, the comparison of pressure drop and heat transfer over elliptical, aero foil and semi-circular generators is studied with and without wings.

6. Heat exchanger solving procedure

Gambit 2.0 solves the problem in pre-processor and Fluent 6.2 is used to solve the problem in solver and post-processor. Gambit is used to form geometries and meshes are generated to solve the post-processor problem. The heat exchanger model and test section is shown in figure 4 and 5, respectively.

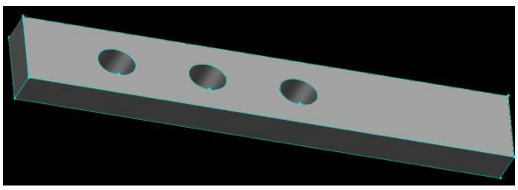


Figure 4. Heat Exchanger3D Model.

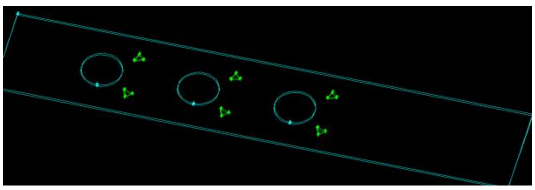


Figure 5. Test Section Geometry.

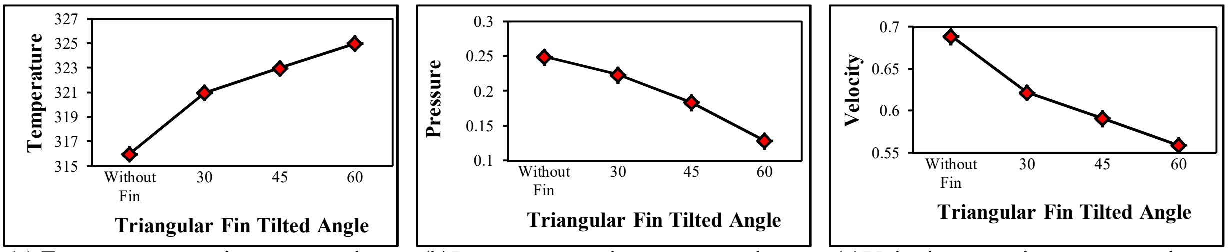
7. Results

To evaluate the proposed model, the system is numerically modelled and independency test is conducted using boundary conditions and governing equations before formal analysis. A rectangular shaped vortex generator is considered in the study with a base plate. The vortex generator is placed at three different angles. The system is placed with rectangular parallelepiped to find the flow conditions over base plate and vortex generator. The water is allowed to flow at different Reynolds number. At the outlet, the pressure is maintained at standard temperate and pressure. Finally, the base plate has constant heat flux to perform the numerical simulation.

A good quality mesh is used to capture the required information from CFD. At vortex generator, a better accuracy is maintained to determine the pressure, velocity and temperature. To maintain the grids to attain better solution, grid dependency test is performed. It is found that surface average Nusselt number and surface skin friction coefficient varies as the grid changes.

8. Comparative result

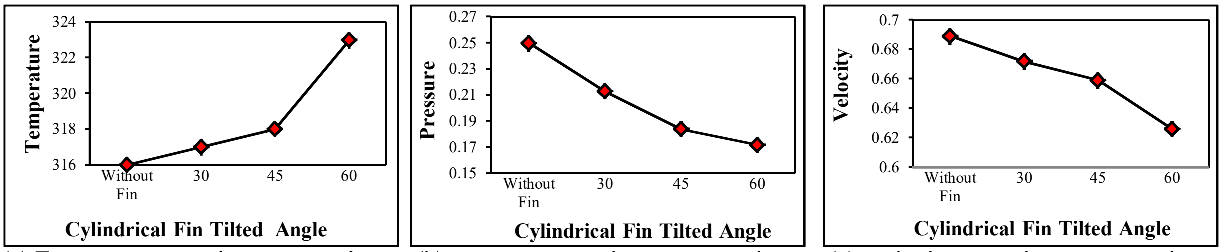
8.1. Tringale



(a) Temperature at various span angles (b)Pressure at various span angles (c)Velocity at various span angles

Figure 6. Cylindrical votex generator.

8.2 Cylindrical



(a) Temperature at various span angles (b) Pressure at various span angles (c) Velocity at various span angles

Figure 7. Cylindrical votex generator.

Temperature, Pressure and Velocity of triangular vortex generator at various span angles is shown in figure 6. Similarly, Temperature, Pressure and Velocity of cylindrical vortex generator at various span angles are shown in figure 7. The result shows that the temperature of vortex generator without fin in triangular shape is less than cylindrical shape. However, as the span angles increases, the triangular shaped vortex generator increases than cylindrical shaped. The pressure of both shapes are same without fin and the span angle with fin is lesser for triangular at 30º and it is same at 45º and further it is higher for cylindrical at 60º. Finally, the velocity of triangular without fin and cylindrical shapes are same. However, the pressure in cylindrical shaped fin vortex generator with fin increases as the span angle increases. The pressure with fin at varying angles is higher than triangular shaped vortex generator.

9. Conclusion

In this paper, the triangular and cylindrical vortex generator is simulated using CFD model under three span angles, which varies between α =30°, 45° and 60°. The entire system is tested with the Reynolds number ranging from 400 to 3000. The optimised heat transfer over three row tube with and without vortex generator is attained using the proposed design. Numerical simulation proves that proposed

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triangular model is better in its design that circular model. Here, the use of rectangular vortex generator improves the rate of heat transfer from plate to fluid. The utilisation of convex and concave modifications on trailing and leading surface of vortex generator improves the accuracy. The presence of high pressure at the walls alters the thickness resulting in decaying of vortex generator. Finally, it is seen that numerous convex profiles on trailing and leading faces leads to degradation in local skin friction. Hence, it is avoided in the present design and this is true in case of circular design than rectangular design.

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