



MULTI OBJECTIVE SHAPE OPTIMIZATION OF INCLINED PROJECTED DELTA WINGLET PAIR IN RECTANGULAR CHANNEL

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ABSTRACT

In the field of heat exchangers, the role of the VG is the enhancement of the heat exchange process between the wall and the working fluid. The basic principle of VG is to induce secondary flow, particularly longitudinal vortices, which disturb or cut off the thermal boundary layer developed along the wall and remove the heat from the wall to the core of the flow by means of large-scale turbulence. In the present study, multi-objective shape optimization of VG in rectangular heat sink has been performed using Fast Non-Dominated Sorting Genetic Algorithm (NSGA-II) and Computational Fluid Dynamics (CFD). The maximum Nusselt number and the minimum friction factor is taken as objective functions in GA, which are considered as the function of four geometrical parameters. The output of GA provides the optimized results of VG which is further evaluated and compared with the results of original VG. The results of GA is obtained with the help of an add-in of Microsoft excel named SolveXL. Numerical simulations are conducted for the classical DWP and an innovative VG configuration named IPWP. The IPWP exhibits similar heat transfer rates than that of the DWP but with lower pressure drop penalty due to its special aerodynamic design. In this study, the shape of the previously designed IPWP is optimized to reduce its size as well as to increase the Nusselt number more as compared to friction factor which further affects the heat transfer rate and pressure drop.

The outcomes of Multi-objective optimization by Fast Non dominated Sorting Genetic Algorithm showed about 7.4% decrease in length of VG and 6.3 % decrease in height. On the basis of these optimized parameters, there is 23% increase in Nusselt number and 3% decrease in Friction factor is obtained. CFD simulation of optimized VG shows only 6.7 % error in Nusselt number and 3.9% error in Friction factor which shows the close agreement of CFD simulation to the values obtained through analytical Calculations. This shows that the methodology applied for CFD simulation is correct.

**Keyword:-CFD,CREO PARAMETRIC,NSGA,PLATE FIN H.E,VORTEX
GENERATOR,ANSYS12**



I.INTRODUCTION

HEAT EXCHANGER

A heat exchanger is a device which is used to transfer thermal energy between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact. Not only are heat exchangers often used in the process, power, petroleum, air-conditioning, refrigeration, cryogenic, heat recovery, alternative fuel, and manufacturing industries, they also serve as key components of many industrial products available in the market. The heat exchangers can be classified in several ways such as, according to the transfer process, number of fluids and heat transfer mechanism. Conventional heat exchangers are classified on the basis of construction type and flow arrangement. The other criteria used for the classification of heat exchangers are the type of process functions and fluids involved (gas-gas, gas-liquid, liquid-liquid, two phase gas etc.). The classification according to the surface compactness deals with one of the important class of heat exchangers named as compact heat exchangers. Heat transfer in laminar channel flow is distinct from the corresponding flat plate flow, at least with respect to two aspects. First, the channel has two walls and when vortex generator is attached to one wall; it affects the heat transfer on both the walls. Second, a favourable pressure gradient always persists in channel flows and it has a tendency to become fully developed in the downstream direction.

Fiebig et al [1] studied experimentally delta and rectangular wing and winglet vortex generators in a flat plate channel. The Reynolds number was assigned the values of 1360 and 2270 depending on the spacing between the plates. Aspect ratios of the wings and winglets were fixed at 1.25 and 1.0 respectively. Delta wing vortex generator enhanced the heat transfer by as high as 200% and overall Colburn factor was increased by 20 to 60 % at the Reynolds number 1360 by increasing the angle of attack from 10° to 50°.

Fiebig et al [2] further extended their work by considering the punched triangular and rectangular wings and winglets. Unsteady liquid crystal thermograph was used to get the heat transfer coefficient and the drag - a measure of flow losses - was measured by a balance. The flow visualization was done by laser light sheet. Local heat transfer enhancement of about 300% was achieved just one chord length behind the delta wing for an angle of attack of 30°. It was concluded that per unit vortex generator area, delta wings are most effective, closely followed by delta winglets and delta winglet pairs.

Fiebig et al [3] further extended the work with built-in rows of rectangular winglets. Eight different winglet arrangements resulted from the combination of inline or staggered, symmetric or parallel relative positioning, and attachment; either on one side or alternating both sides was thoroughly analyzed. Maximum average heat transfer enhancement was achieved for the in-line, symmetric winglet vortex generator configuration when attached alternatively to both the plates.

Biswas et al [4] analyzed laminar flow and heat transfer characteristics in a rectangular channel with built in delta wing and winglet pair.

Biswas et al [5] determined the flow structure developed by delta winglet vortex generator placed in a fully developed channel flow. Experiments were performed to corroborate the numerical predictions of the flow structure. Vorticity contours confirmed the formation of the main vortex, induced vortices, and the corner

vortex. A much higher value of (j/f) for an angle of attack of 15° was computed numerically as compared to those for 22.5° , 30° and 37.5° . Wu and Tao [11] numerically investigated the influence of various parameters i.e. the location of the winglet pair, space between the winglet pair, area and geometry of the vortex generator etc, on the heat transfer enhancement and flow resistance in a rectangular channel. They concluded that overall Nusselt number of the channel was found to decrease with increasing distance of the rectangular winglet pair from the inlet of the channel as well as with decreasing space between the pair. The location of the pair had no significant influence on the total pressure drop of the channel. With the area of the rectangular winglet pair fixed, increasing the length of the vortex generator resulted in an enhancement of heat transfer which was more pronounced as compared to that observed on increasing the height of the vortex generator.

II. EXTENDED SURFACE HEAT EXCHANGERS

Heat exchangers, on the basis of constructional details, can be classified into tubular, plate-type, extended surface and regenerative type heat exchangers. The tubular and plate-type exchangers are the primarily used surface heat exchangers with effectiveness below 60 % in most of the cases. The surface area density of these heat exchangers is usually less than $700\text{m}^2/\text{m}^3$. One of the most common methods to increase the surface area and compactness is to have extended surface (fins) with an appropriate fin density (fin frequency, fins/m) as per the requirement. These types of exchangers are termed as extended surface heat exchangers. The heat transfer coefficient 'h' on extended surfaces may be higher or lower than that of un-finned surfaces. The louvered fin s increase both the surface area and the heat transfer coefficient, while the internal fin s in a tube increase the tube surface area but may result in a slight reduction in heat transfer coefficient depending on the fin spacing. However, the overall thermal conductance increases due to the presence of extended surfaces.

Plate-fin and tube-fin heat exchangers are the two most common types of extended surface heat exchangers.

III. PLATE-FIN HEAT EXCHANGERS

This type of extended surface heat exchanger has corrugated fins mostly of triangular or rectangular cross-sections sandwiched between the parallel plates as shown in Figure 1

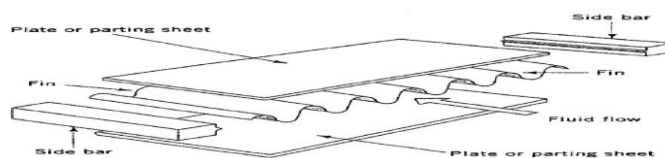


Figure I.1: Basic components of a plate–fin heat exchanger

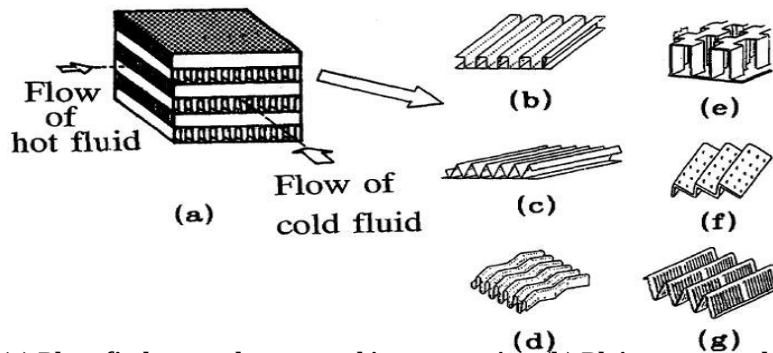


Figure 1.2: (a) Plate-fin heat exchanger and its geometries; (b) Plain rectangular fins; (c) Plain triangular fins; (d) Wavy fins; (e) Offset strip fins; (f) Perforated fins; (g) Louvered fins

The fins may also be incorporated in a flat tube with rounded corners. The parting sheet is usually replaced by a flat tube in the case of liquid or phase change fluid flows on the other side. Fins are die or roll formed and is attached to the plates by brazing, soldering, adhesive bonding, welding, mechanical fit, or extrusion. Plate-fins are categorized as: (1) plain i.e. uncut and straight fins, such as plain triangular and rectangular fins, (2) plain but wavy fins, and (3) interrupted fins such as offset strip, louvered fins, perforated fins etc. Figure 1.2 shows some of the most commonly used fins in parallel plate heat exchanger.

IV.VORTEX GENERATOR

One of the most important passive techniques to augment the heat transfer is the use of vortex generators. Transverse vortex generators produce vortices, whose axis is transverse to the main flow direction, whereas, the longitudinal vortex generators generate vortices whose axis is parallel to the main flow direction. It has been found that longitudinal vortex generators are more suitable than the transverse vortex generators when the heat transfer augmentation with pressure drop is an important consideration. The longitudinal vortices behind a slender aerodynamic object have been investigated for many years. Longitudinal vortices are found to persist for more than 100 protrusion heights downstream. A vortex generator is called a wing when its span is attached to the surface and is known as a winglet when its chord is attached to the surface. Longitudinal vortex generators may have any of the four basic shapes i.e. delta wing, rectangular wing, delta winglet and rectangular winglet. The aspect ratio ' Λ ' of a longitudinal vortex generator is the ratio of the square of the span ' b ' and the area of the vortex generator ' s ' i.e. b^2/s .

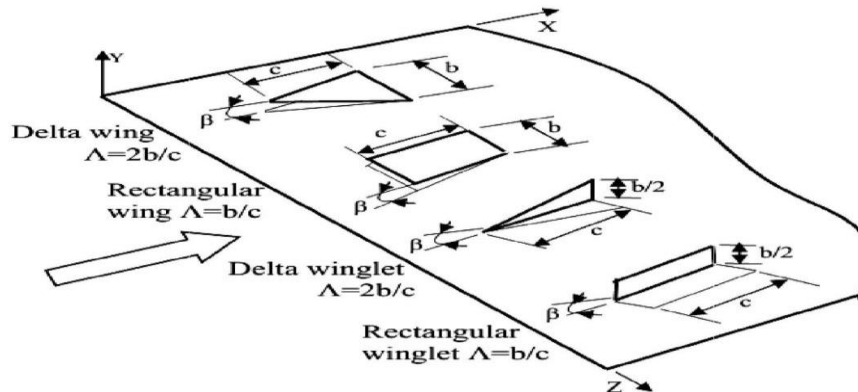


Figure II.1: Longitudinal vortex generators

In case of winglet, single vortex is generated by the fluid which passes over the winglet; however, for the wing vortex generator, two vortices are produced as the obstructed fluid passes over the wing from both the side edges. Figure 1.5 shows a sketch of longitudinal vortices behind a delta winglet vortex generator placed in a laminar boundary layer on a flat plate (Torii et al. [1994]). The flow separation at the leading edge of the winglet generates a main vortex and the corner vortex is formed by the deformation of near-wall vortex lines at the pressure side of the winglet. Sometimes an induced vortex is also observed rotating opposite to the main and corner vortex. The winglet vortex generators may also be arranged forming Λ and V shaped pairs. When the direction of the secondary flow between two counter rotating vortices is away from the wall, the vortices are called common flow-up and when the direction is towards the wall, they are called common flow-down.

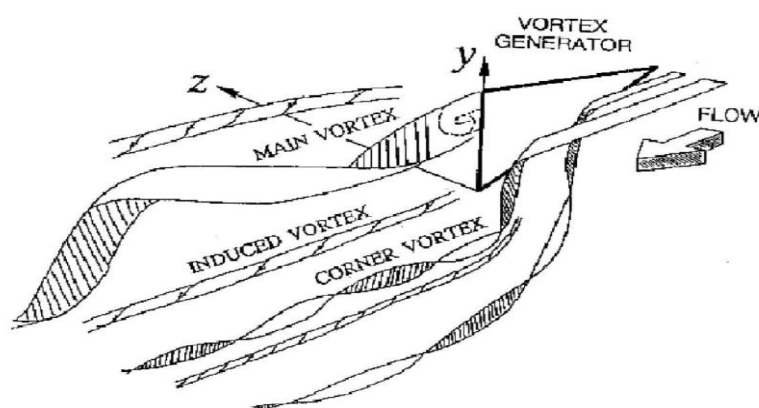


Figure II.2: Vortex systems behind a delta winglet

V.GEOMETRIC MODELING

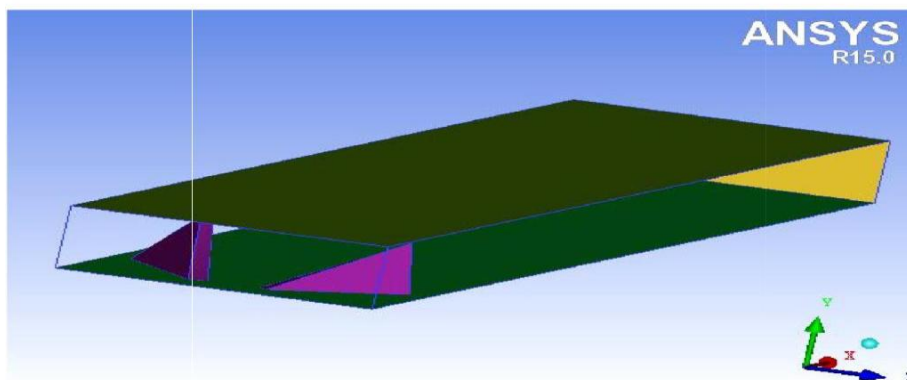
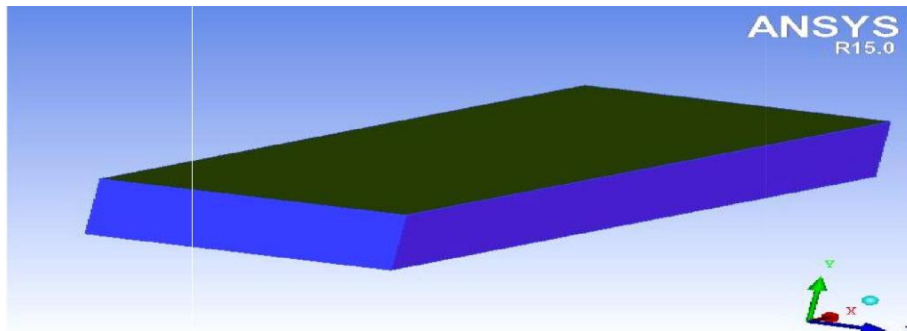


Figure III.1: Geometry of Heat exchanger with original dimensions of VG

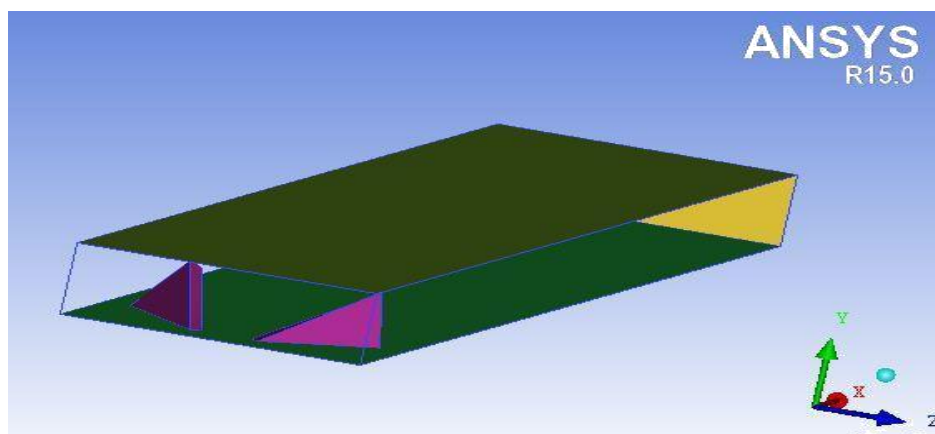


Figure III.2: Geometry of Heat exchanger with optimized dimensions of VG

Table III.1: Geometrical parameters of Original VG

Parameters	Values
Length (l)	0.054 m
Height (h)	0.0446 m
Shape inclination (θ)	30° , 45° 60° , 90°
Attack angle (β)	30° , 45° , 60° , 90°

Table III.2: Geometrical parameters of Optimized VG

Parameters	Values
Length (l)	0.0506 m
Height (h)	0.04153 m
Shape inclination (θ)	34°
Attack angle (β)	43°

VI.MESHING AND SIMULATION

The three-dimensional models are then discretized in ANSYS ICEM CFD. In order to capture both the thermal and velocity boundary layers the entire models are discretized using tetrahedral/mixed shaped mesh elements which are accurate and involve less computational effort. ANSYS ICEM CFD provides advanced geometry acquisition, mesh generation, and mesh optimization tools to meet the requirement for integrated mesh generation for sophisticated analyses. The ANSYS ICEM CFD Tetramesher takes full advantage of object-oriented unstructured meshing technology.

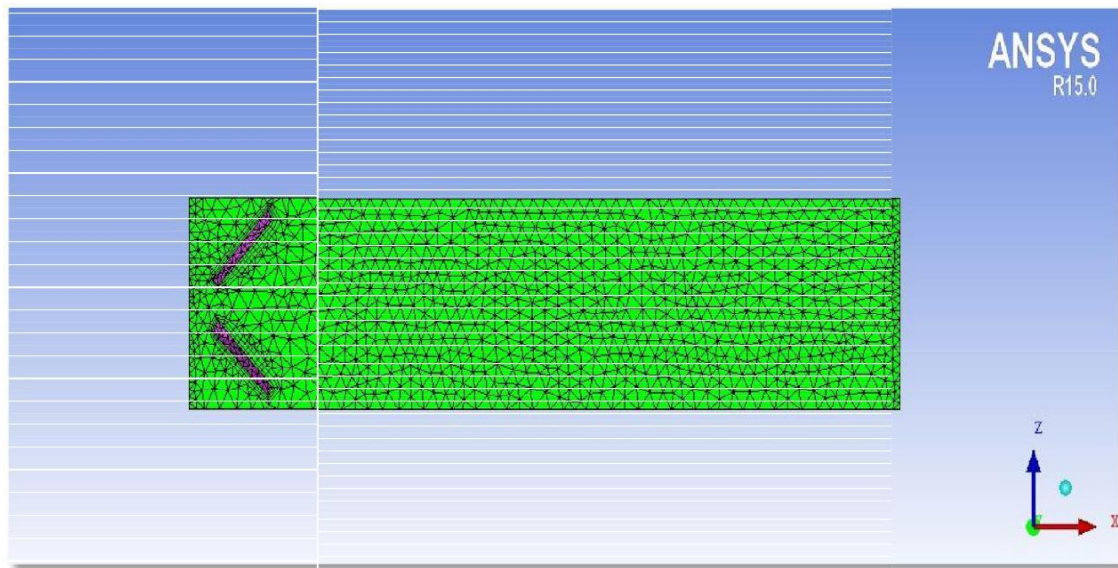


Figure IV.1: Meshing of Heat Sink with Original VG

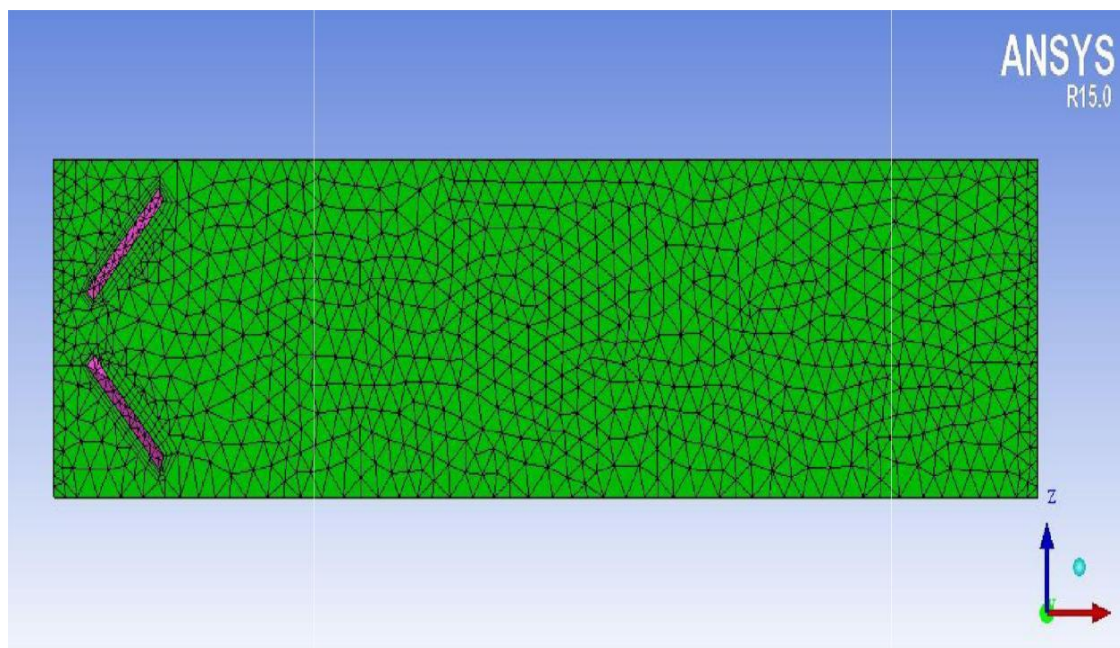


Figure IV.2: Meshing of Heat Sink with Optimized VG

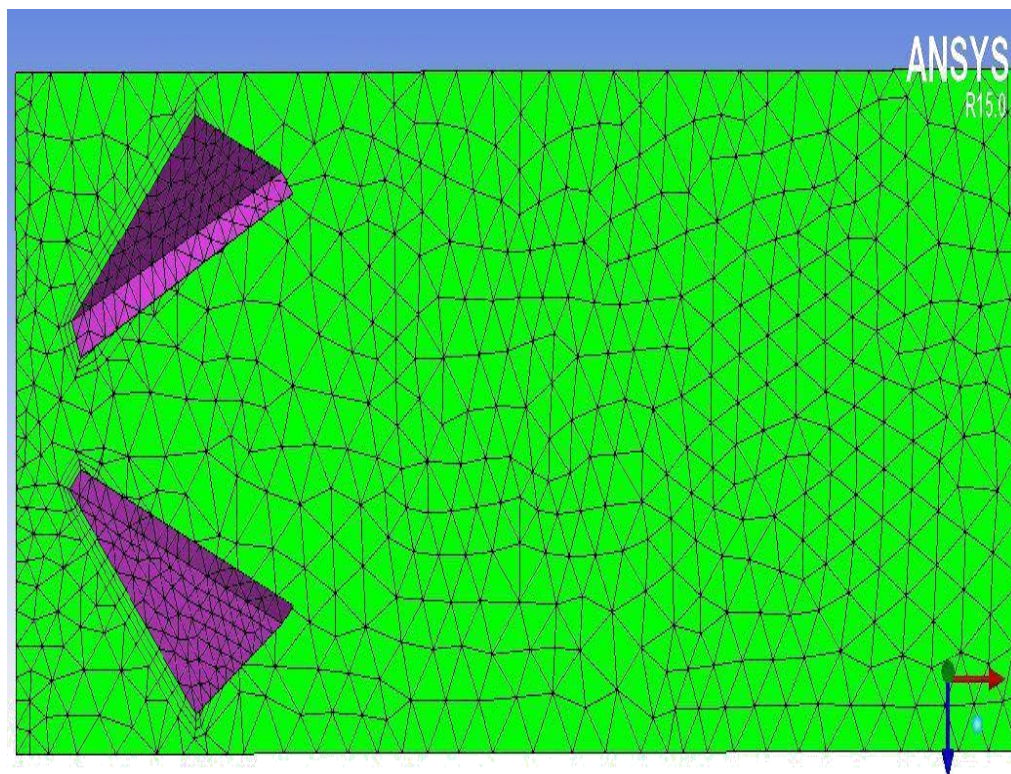


Figure IV.3: Magnified view of Meshing of Heat Sink with Optimized VG

VII.RESULTS AND DISCUSSION

For Heat Exchanger with Original dimensions

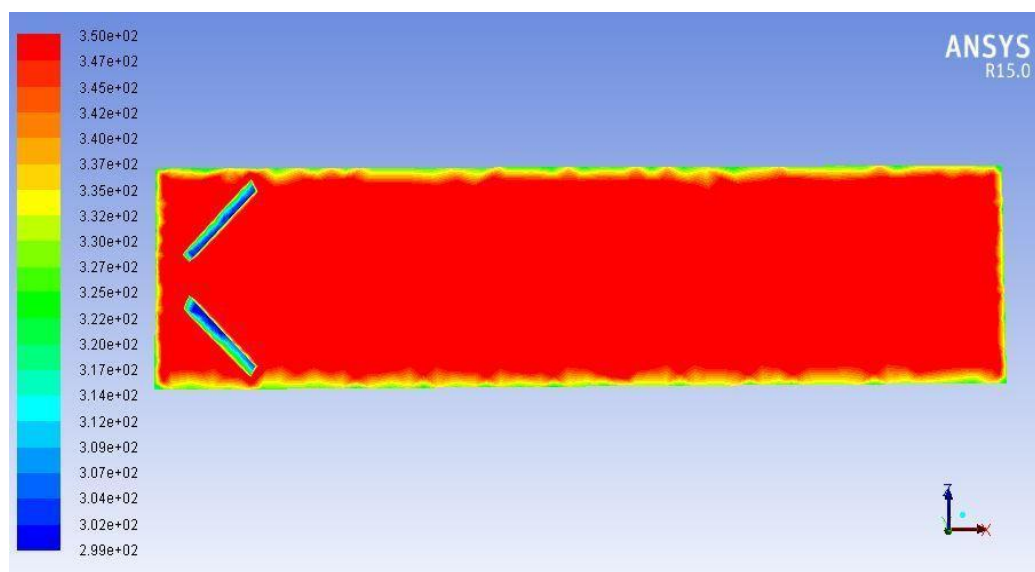


Figure V.1: Contours of temperature of heat sink with VG

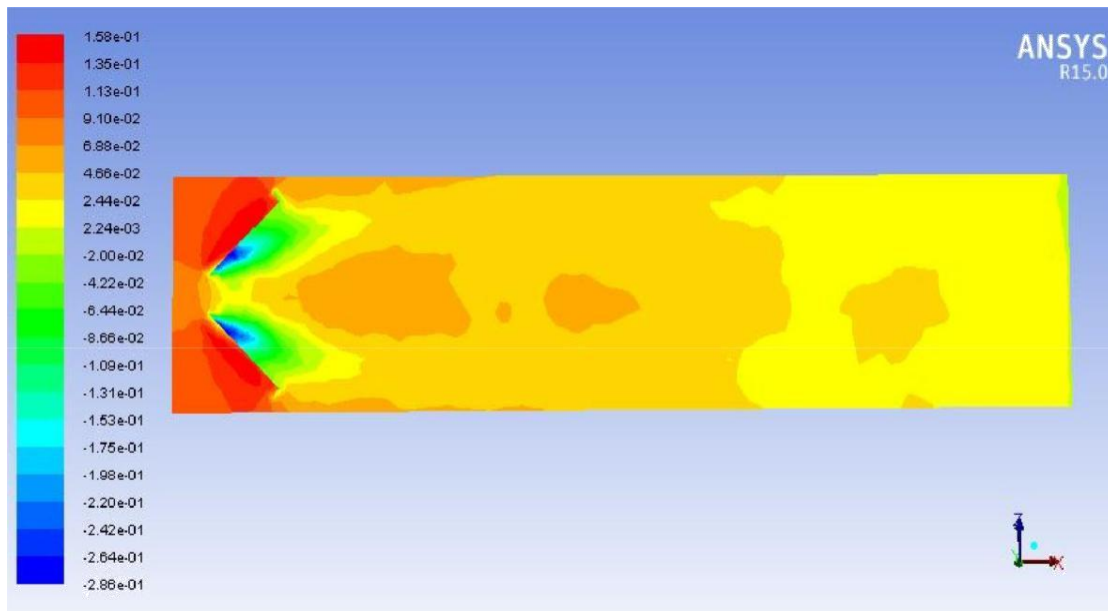


Figure V.2: Contours of pressure of heat sink with VG

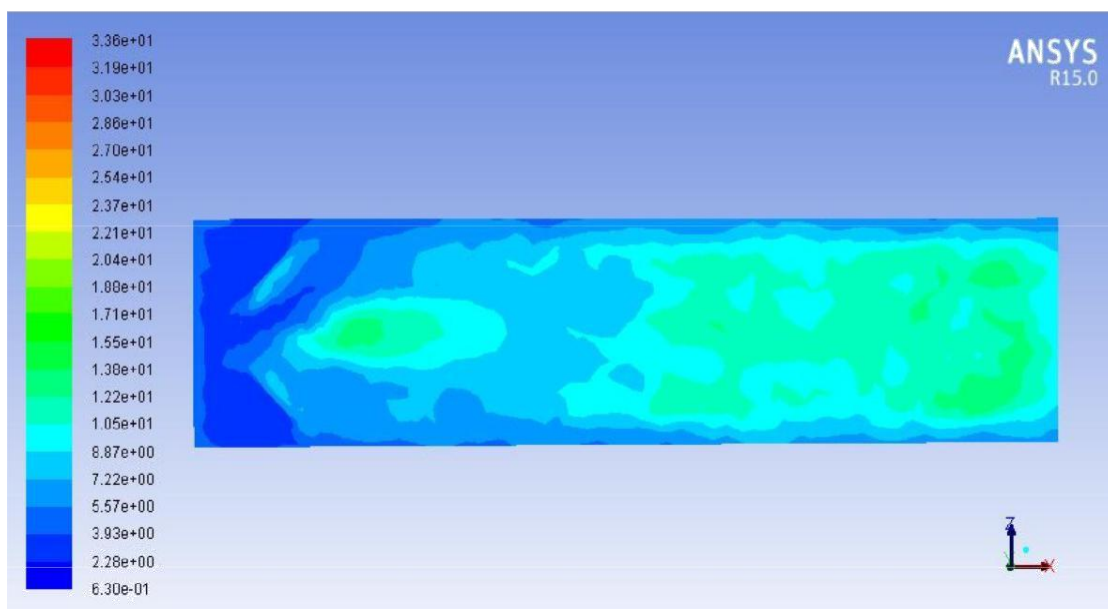


Figure V.3: Contours of turbulent intensity of heat sink with VG

From above contours (Figure V.1 to Figure V.3) of static temperature and static pressure, it can be seen that air side inlet temperature is 300 K whereas air side outlet temperature is around 307 K which shows that the increase in temperature is by 7 K. Also, Pressure of tube side fluid drops from 0.26 Pa to 0.206 Pa.

For Heat Exchanger with Optimized VG

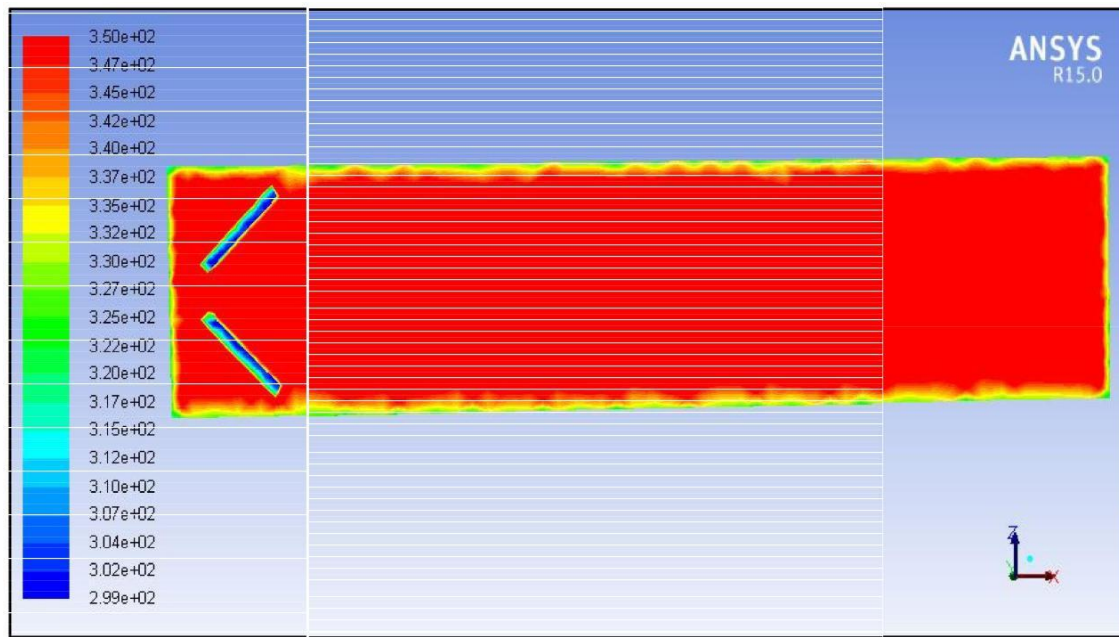


Figure V.4: Contours of temperature of bottom wall with VG

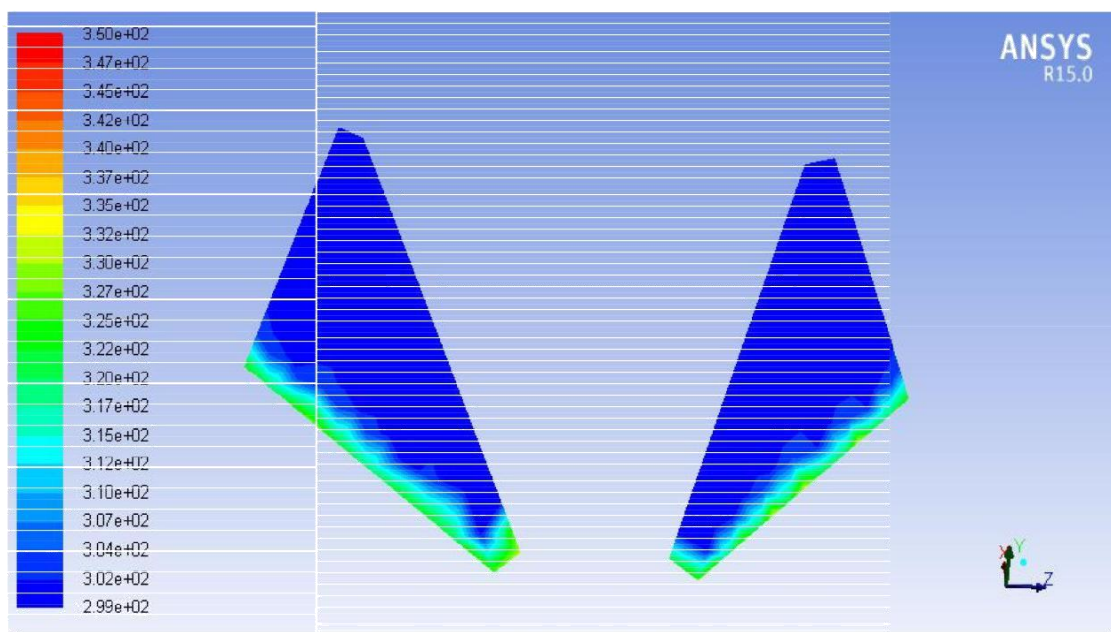


Figure V.5: Contours of temperature of IPWP VG

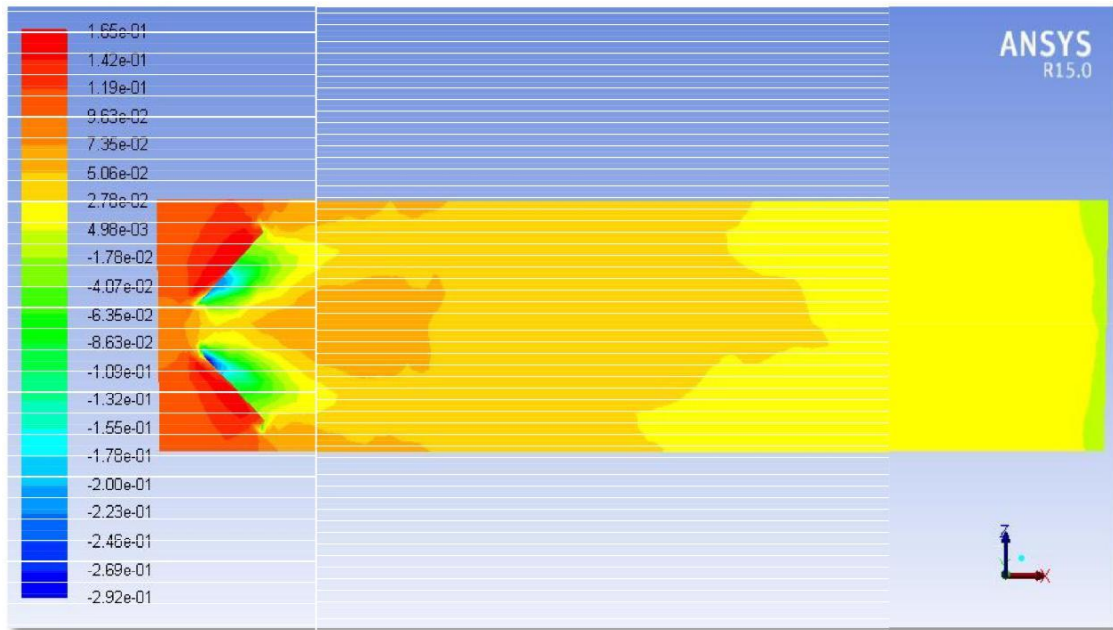
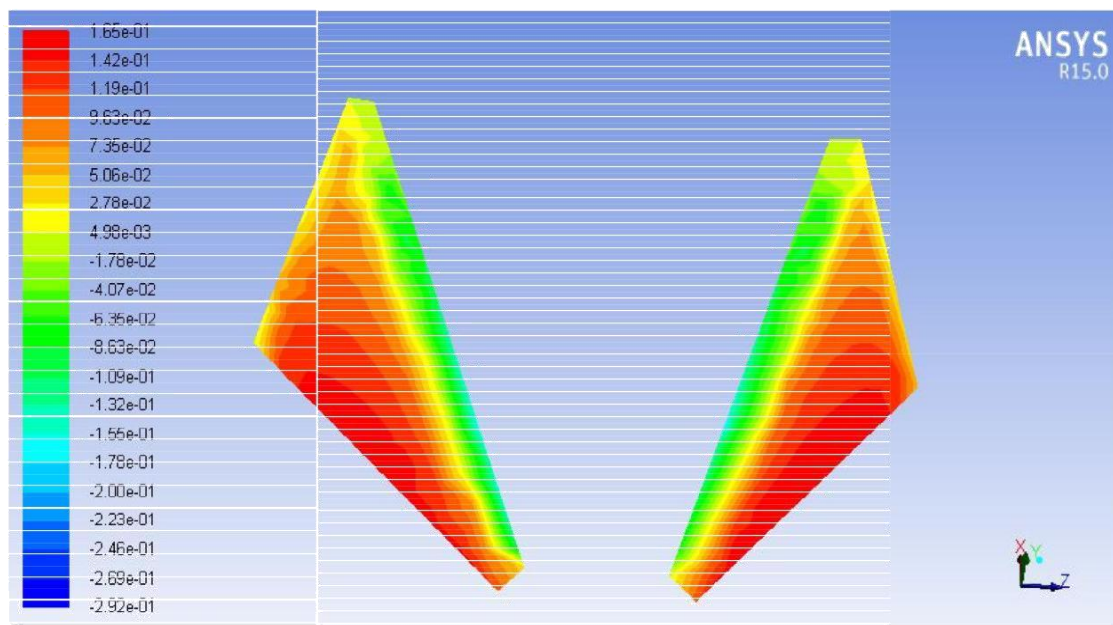


Figure V.6: Contours of pressure of bottom wall with VG



FigureV.7: Contours of pressure of IPWP VG.

From above contours (Figure V.4 to FigureV.7) of static temperature and static pressure, it can be seen that air side inlet temperature is 300 K whereas air side outlet temperature is around 337 K which shows that the increase in temperature is by 37 K. Also, Pressure of tube side fluid drops from 0.142 Pa to 0.00498 Pa.

VIII.CONCLUSION

An IPWP vortex generator is optimized using Multi-objective optimization technique. For optimization of parameters of VG, a rectangular heat sink is taken as case study. Two flat plate fins of the heat sink are chosen to reduce the complexity in the calculation and to reduce the time of calculation. IPWP VG is punched on one of the plate fins which is considered as plates of a rectangular channel. The design parameters (decision variables) are Length of VG, Height of VG, Shape inclination, Attack angle.

In the present optimization process, the Nusselt number and friction factor are considered as objective functions. A generalized procedure has been developed to carry out the optimization to find the maximum Nusselt number and the minimum friction factor of the heat exchanger.

From the Multi-objective optimization technique, it is found that:

- Multi-objective genetic algorithm yields a wide range of optimal solutions, which allows the user to select the best solution in order to meet project requirements.
- 7.4% decrease in length of VG and 6.3 % decrease in height of VG are obtained from NSGA-II results. On the basis of these optimized parameters, there is 23% increase in Nusselt number and 3% decrease in pressure drop is obtained

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