ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

HEAT TRANSFER ENHANCEMENT IN RECTANGULAR CHANNEL USING RECTANGLE WINGLET VORTEX GENERATOR

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DOI: 10.5281/zenodo.1173502

ABSTRACT

There are many applications in engineering industry that require heat addition or removal and a wide variety of heat exchange devices are used for different applications. Performance of improving coefficient of heat transfer becomes essential in all applications. Most of thermal devices like high temperature gas turbines, heat exchangers, electronic equipment, convective heat transfer plays a major role in most of the engineering applications. To attain higher coefficient of heat transfer, it is necessary that the surface of heat transfer flow is to be made turbulent.

However, energy for producing such turbulence must come from the blower or fan and the maximum turbulence leads to excessive power requirement to make the air flow through the duct. Therefore, maximum turbulence must be produced in the region which is very near to surface of heat transfer i.e. in the laminar sub-layer only and this is done by using vortex generators.

Vortex generator is responsible for creating the turbulence in the flow of fluid. The analysis is carried out to enhance the heat transfer coefficient with installing the rectangular winglet type of vortex generator in rectangular duct. These vortex generators are provided on bottom plate of the rectangular duct. These vortex generators cause stream wise longitudinal vortices in the test section which disrupt the growth of the thermal boundary layer and enhances heat transfer rate. Influence of geometrical parameter of rectangular winglet vortex generator such as winglet height, wings attack angle on heat transfer coefficient is studied. Air is taken as the working fluid; the flow regime is assumed to be laminar. By varying the above parameter, the heat transfer coefficient is calculated and by comparing all the result optimum height of rectangular winglet and attack angle is achieved

KEYWORDS: Turbulence, Vortex Generators, Winglet

I. INTRODUCTION

Increasing demands on the performance of heat exchangers used in power systems, automotive industry, electric circuit in electronic chip cooling, air conditioning and refrigerant applications, internal cooling of gas turbine blades and aerospace industry for reasons of compactness, manufacturing cost effectiveness and higher efficiency lead to use of heat transfer enhancement techniques. Heat transfer enhancement is usually required in heat exchangers. Various heat transfer enhancement techniques are used such as fins, ribs, dimpled surfaces, and protruding surfaces that generate vortices in a heat exchanger.

Heat sinks and heat exchangers are used in many applications today and the most common material used is aluminium because of its high thermal conductivity (205 W/m•K), low maintenance and production cost, and less weight. Copper is also used at times because of its very high conductivity (400 W/m•K), but it is not commonly used because it is heavy and costly. At times, diamond is also used for heat exchange enhancement since it has thermal conductivity of 2000 W/m•K; however, it is not commonly used unless called for because it is very expensive. Diamond is used in high powered integrated circuits. For higher performance, heat exchangers require more space and surface area, less weight and low cost. Hence, at times heat exchangers are made of aluminium and copper alloys because of their advantages. To improve performance, heat exchangers should have a large surface area, since the heat transfer takes place from the surface. In this study, aluminium is used as the material for the rectangular channel walls.

Different vortex methods for heat exchange enhancement:

There are three vortex methods to enhance heat transfer
1.Active vortex method
2.Passive vortex method
3.Compound vortex method

In fluid dynamics, a vortex is a region in a fluid in which the flow rotates around an axis line, which may be straight or curved. Vortices form in stirred fluids, and may be observed in phenomena such as smoke rings, whirlpools in the wake of boat, or the winds surrounding a tornado or dust devil.
Vortex generators:
Vortex generator is responsible for creating the turbulence in the flow of fluid. These vortex generators cause stream wise longitudinal or transverse vortices in the test section which disrupt the growth of the thermal boundary layer and enhances heat transfer rate.Vortex generators are most often used to delay flow separation. To accomplish this, they are often placed on the external surfaces of vehicles and wind turbine blades.

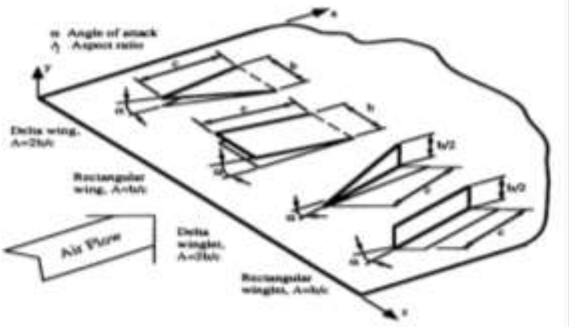

Figure 1.1 different types of vortex generators

II. LITERATURE REVIEW

J.M.WU and W.Q.Tao studied the CFD and experimental validation for Performance of heat exchanger with vortex generator channels. They conducted experimentation analysis on average heat transfer of top and bottom surfaces of a flat plate and a four plate with a pair of delta winglet longitudinal vortex generators punched directly from the plate at different attack angels of 15,30,45,60 respectively. They compared experimental and numerically obtained values in the paper. In their experimental procedure, the plate fixed horizontally in the centre of the tested channel is designed to stimulate the heat transfer in both the surfaces of a single plate piece of fin in a fin tube heat exchanger. Heat transfer rate in the test channels of five cases is numerically investigated. Experimental results show the average nusselt number on surfaces of plate increases with increase of attack angels. The computed velocity and temperature fields are analysed to understand the details of fin channel flow with longitudinal vortex generators. The experimental and numerical values reveal that transverse flow of air stream through the punched holes disturbs the air flow in lower channel, enhance the heat transfer on the under surface of fin.

Vitthal Chormale1, D.D. Palande conducted experimentation on Heat Transfer Enhancement in Tube in Tube Heat Exchanger Using Rectangular Wing Type Vortex Generator. which disrupt the growth of the thermal boundary layer and enhances heat transfer rate. In this experimentation, they used rectangular wing type vortex generator to enhance the rate of heat transfer. By varying the above parameter, the heat transfer coefficient is calculated and by comparing all the result optimum size of rectangular wing is achieved.

Aravind C. Angadi, V.V.Katti done the experimental validation over enhancement of Rate of heat transfer using vortex generator in air heater. They conducted the experiments to increase the rate of heat transfer by using external geometric structures which replaces the blowers and fans which requires additional power sources to run. To attain higher coefficient of heat transfer, it is necessary that the surface of heat transfer flow is

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

to be made turbulent. However, energy for producing such turbulence come from the blower or fan and the maximum turbulence leads to excessive power requirement to make the air flow through the duct. The experimentation shows that disturbance in the boundary layer can be achieved by making the height of the roughness element to be small as compared with the dimensions of duct. The roughness element height (e) and pitch (P) are the most important parameters to characterize the roughness shape and arrangement. All these parameters namely, angle of attack (β), relative roughness pitch (P/e), relative roughness height (e/D) are usually specified as dimensionless parameters.

Y.Xu.M.D.Islam , N.kharoua has done the experimentation analysis over numerical study of winglets vortex generator effect on thermal performance in a circular pipe .In this research ,heat transfer and wall friction in a pipe ,with vortex generator are numerically investigated. The effects of different attack angles and blockage ratios of VGs fitted inside smooth pipe are investigated. CFD simulations, with and without VGs insert, were conducted for an air flow with Reynolds numbers in the range 6000-33000 and for a constant heat flux on the pipe model surface. They inserted four VGs in a circular pattern on the inner surface of the pipe. The influence of attack angles (0°,15°,30°,45°), blockage ratios (0.1,0.2 and 0.3) on Nusselt number and friction coefficient are studied. The results indicate that the best set of parameters for thermal performance enhancement is attack angle =30° and blockage ratio=0.1.

III. SIMULATION OF RECTANGULAR CHANNEL WITH RECTANGULAR WINGLET TYPE VORTEX GENERATOR:

In this section, a complete description of the numerical simulation is provided. Geometric modelling, computational grid, and setup for this model are discussed. The flow is laminar and the velocity of the flow is calculated as,

$$Re=\rho vd/\mu \qquad \text{----equ.3.1}$$

where, Re = Reynolds number, (dimensionless)
ρ = density of the fluid, (kg/m3)
V = mean velocity of fluid flow, (m/s)
d = characteristic length or hydraulic diameter, (m)
μ = dynamic viscosity of the fluid, (kg / (m•s))

In this case, since the flow is through a rectangular channel, the hydraulic diameter is taken as

d=4*(area of rectangular cross section)/(perimeterof rectangular cross section)

$$d=4*B*H/2(B+H \qquad \text{-----equ.3.2}$$

d = 64mm or 0.064m

where B = breadth of rectangular cross section
H = height of rectangular cross section

Nusselt number is the ratio of convective heat transfer coefficient to the conductive heat transfer coefficient. It is a dimensionless number. Nusselt Number is close to one when the magnitude of convection and conduction are similar and it is found in a laminar flow. For fully developed internal laminar flow, the Nusselt number is a constant value. The values depend on the hydraulic diameter.

$$Nu=hd/k \qquad \text{----equ.3.3}$$

where, h = heat transfer coefficient, (W / (m2•K))
d = hydraulic diameter, (m)
K = thermal conductivity, (W / (m•K))

The average surface Nusselt number is the surface integral of Nusselt number over a givensurface and is denoted as ¯Nu

The heat transfer coefficient is used to calculate the convective heat transfer.

$$h=Q/((A*\Delta T)) \qquad \text{----equ.3.4}$$

where, Q = heat transfer capacity, (W)
A = heat transfer surface area, (m2)
ΔT = log mean temperature difference, (K)

The log mean temperature difference (LMTD) is the logarithmic average between the hot and cold streams at inlet and outlet of the heat exchanger. Larger LMTD signifies higher heat transfer.

$$\Delta T = ((T_W - T_{IN}) - (T_W - T_{OUT}))/\ln\left(\frac{T_W - T_{IN}}{T_W - T_{OUT}}\right) \qquad \text{----equ.3.5}$$

ISSN: 2277-9655
Impact Factor: 5.164
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where, Tw = wall temperature, (K)

Tin = temperature at inlet, (K)

Tout = temperature at outlet, (K)

Geometric model:

The rectangular channel has a cross-section of 0.16 x 0.04 m; the length is 0.5.Rectangular winglet type vortex generators are installed at distance of 0.22 m from the inlet section of Rectangular channel. The stream wise coordinate of the LVG's from the end of the rectangular winglet. The Length of the winglet is 0.06 m and thickness is 0.002 m. the height of the winglet is varied (5mm,10mm,20mm,30mm,40mm). The flow in the channel is laminar. Shown in Figure 4-1 is the isometric view of the channel along with the inlet and outlet section.

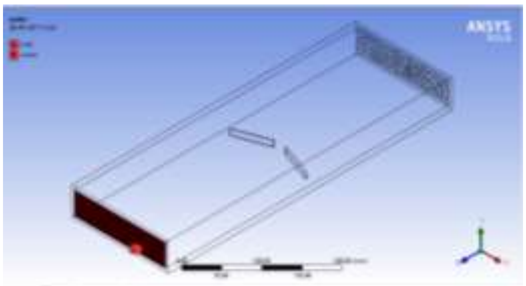

Figure 3.1 Isometric view of the entire channel showing the inlet section and outlet section

Rectangular winglet:

Rectangular winglet is shown iv figure 4.2. The dimensions of winglet are thickness is 0.002m, length is 0.06m and winglet pair is 0.02m apart from each other. Winglet is placed at 0.22mm from the inlet of the section

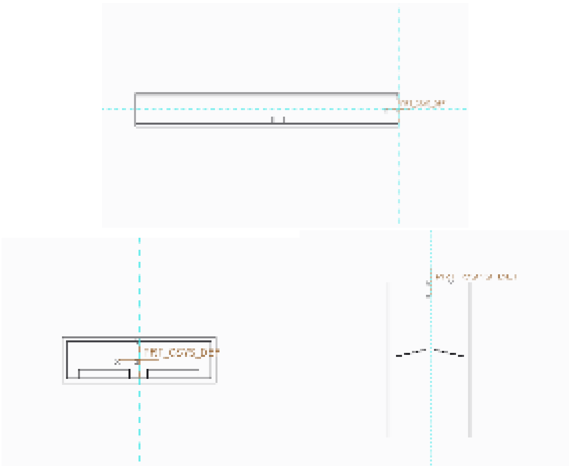

Fig.3.2Rectangular Winglet

Grid Generation

In this study ANSYS Workbench was used as a meshing tool. Figure 3.3 shows the grid formation in meshing.

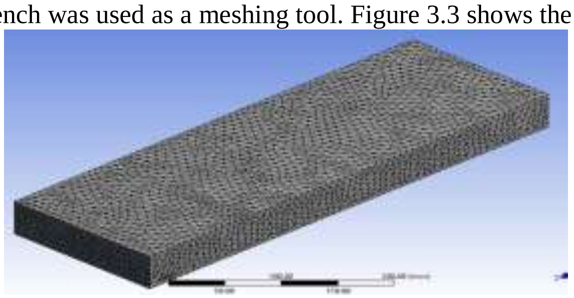

Figure 3.3 Mesh layout

FLUENT Setup:

FLUENT 15.0 was used for CFD analysis in this study. Importing the mesh files created in ANSYS Workbench, the model is setup to allow energy equation in a viscous laminar model. The fluid in this study is air with a constant density of 1.225 kg/m³, dynamic viscosity of 1.7894e-5 kg/m·s, the constant pressure specific heat is

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1006.43 J/m·K, and thermal conductivity is 0.0242 W/m·K. The operating condition on the interior of the channel is fluid while the before mentioned boundary conditions are applied on the rectangular channel including the inlet and outlet channel.

Boundary conditions:

The boundary conditions for the inside the channel are prescribed as follows

The inlet has been given an inlet temperature of 300 K and the velocity given at the inlet is 0.05 m/s .

Outlet At the we set the pressure outlet for the tube outlet boundary condition and stream wise gradient of temperature is set to zero as the outlet velocity is not known a priori but needs to be iterated from the neighbouring computational cells. This pressure is assumed to be in atmospheric pressure in outlet flow.

The wall is in stationary state and no slip is applied to shear condition. And a heat flux of 1000 W/m2 is applied.

IV. RESULTS AND DISCUSSION

The numerical simulations are carried out for a rectangular channel with rectangular winglet vortex generator with different attack angles and winglet height. Variation of outlet temperatures of rectangular channel with different attack angles and winglets height is tabulated below.

S.NO	ATTACK ANGLE(degrees)	WINGLET HEIGHT(mm)				
		5	10	20	30	40
1	30	880.15	904.10	891.71	885.47	887.92
2	45	883.24	905.64	895.40	885.30	893.92
3	60	885.42	907.27	899.12	886.63	894.28
4	70	887.42	908.01	902.34	895.06	904.62
5	75	885.32	906.79	900.46	885.79	893.85

Table.5.1Variation of outlet temperature with attack angle

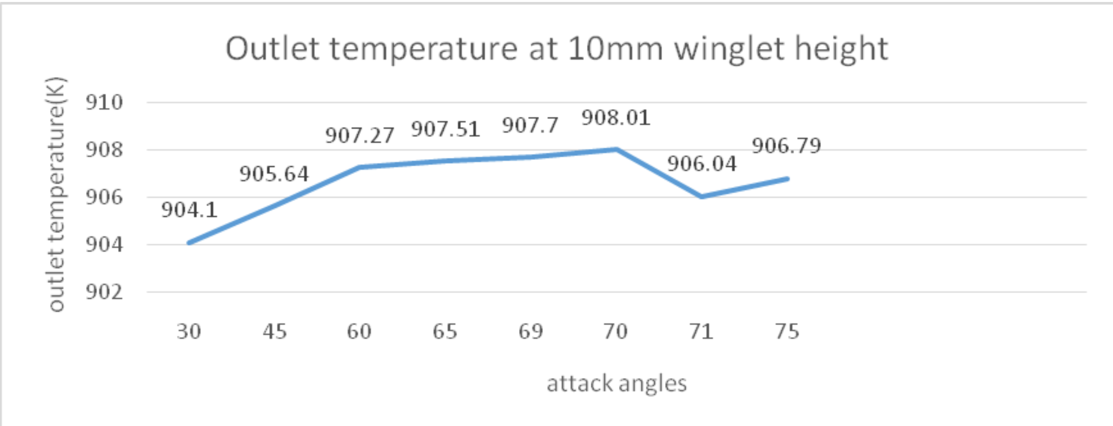

Fig.4.1.Variation of Outlet temperatures with attack angles at 10mm winglet height.

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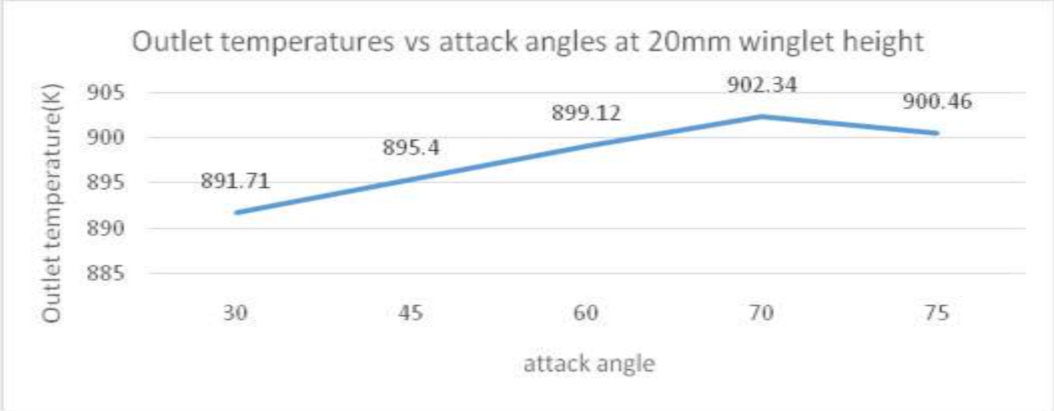

Fig.4.2Variation of outlet temperatures with attack angles at 20mm winglet height

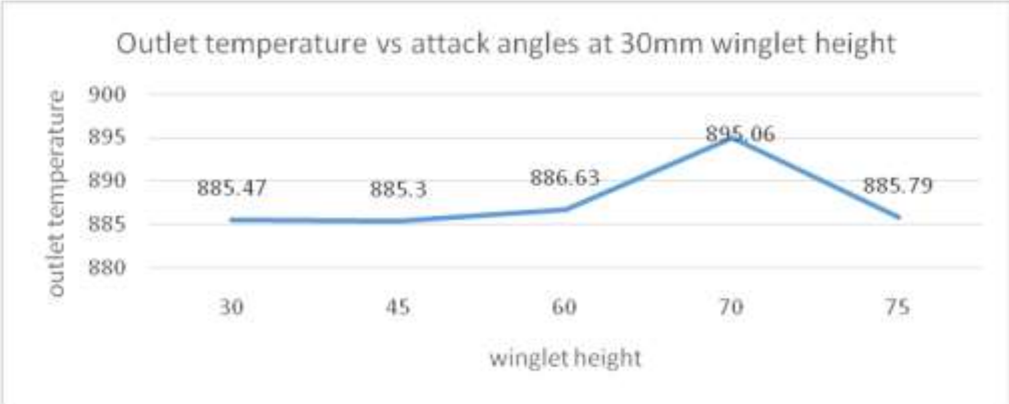

Fig.4.3Variation of outlet temperatures with Attack angles at 30mm Winglet height

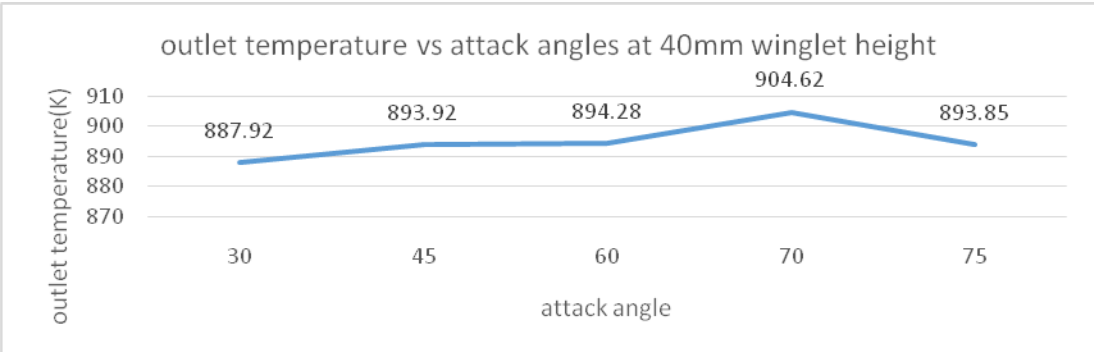

Fig.4.4Variation of Outlet temperature with Attack angle at 40mm Winglet height

From the above graphs, at constant winglet height heat transfer rate increases with increase in attack angle upto 70 and then decreases. Heat transfer rate is maximum at 70 attack angle at various Winglet heights as shown in above graphs.

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Temperature contours:

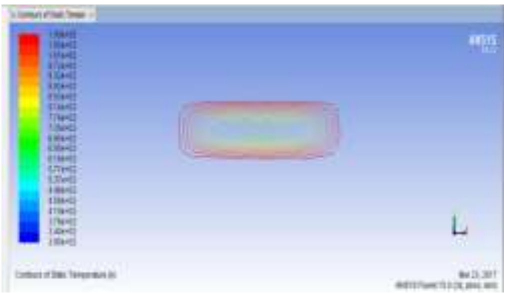

Figure 4.5 Temperature contour at outlet at 70° attack angle and 10mm height

Pressure contours :

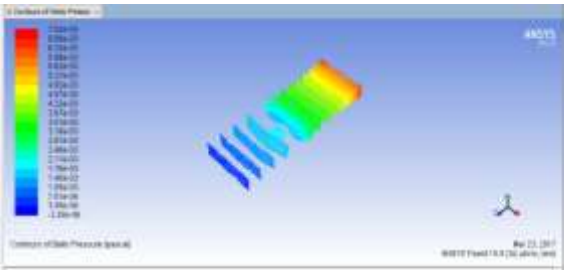

Figure 4.6 Pressure contour at 70° attack angle and 10mm winglet height

Velocity contours :

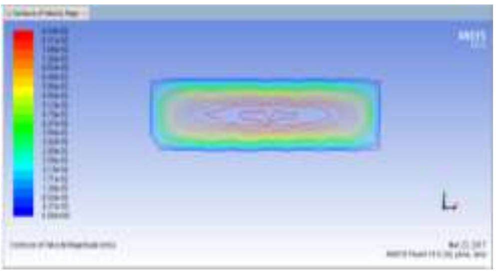

Figure 4.7 Velocity contour of outlet at 70° attack angle and 10mm winglet height.

V. CONCLUSION

In this study, influence of rectangular winglet type longitudinal vortex generator on the heat transfer in rectangular channel is numerically studied and compared on the basis of average surface Nusselt number by varying the geometrical parameters of the rectangular winglet type vortex generator such as attack angle and winglet height. The following was concluded after this study.

- Heat transfer performances of rectangular winglet vortex generators have been found best as compared to smooth duct for the same flow condition.
- The Enhancement of heat transfer for all the relative height and any arrangement of rectangular winglet is because of increased turbulence.
- Optimum attack angle and winglet height of rectangular winglet type vortex generators is 70° and 10mm respectively for maximum heat transfer rate in rectangular channel.

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