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Experimental Investigation of Delta Wing Vortex Generators on a Flat Plate

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ABSTRACT

An experimental investigation is performed to study the effect of the delta wing vortex generator on a flat plate. In the current study, the flow structure and the heat transfer characteristics in a plate fin heat exchanger, having built in vortex generators have been analyzed. The vortex generators are in the form of delta wings. The vortex generators are mounted on surface with the help of a glue tape of aluminium. This study gives a performance data of a delta wings in a plate-fin heat exchangers. The heat transfer enhancement is observed with the use of vortex generators. Since, the vortex induced heat transfer enhancement depends strongly on shape and position of vortex generators, the subject of ongoing research is to find design strategies for device shape, angle of attack and placement optimization. Therefore, the task of presented work is to analyze the interaction between vortices and the thermal boundary layer, the impact of vortical flow structure on the heated wall and convective transfer of heat within the flow domain. Although various types of flow manipulating devices could be used for generating co- or counter rotating vortices, this consideration is restricted to delta wing vortex generators. The experiment is performed for delta wing vortex generators on Aluminium plate of 150mm x 150mm size and 10mm thick with angle of attack of 45^0, variation in velocities such as 2.5m/s to 4.5m/s and with inline and staggered positions of vortex generators. The results of all arrangements are compared with each other and optimum solution is identified. It is observed that at higher velocities, staggered arrangement of delta wings shows high values of heat transfer coefficient as compared to bare or inline arrangement.

Keywords— **Delta wings, Placement Optimization, Staggered arrangement, Vortical flow, Vortex Generators**

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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. A common method to enhance heat transfer is to apply Vortex Generators (VG) , such as ribs, wings and winglets. Vortex Generators are usually incorporated into a surface by means of embossing, stamping, punching or attachment process. They generate longitudinal vortices which serve the primary flow and increase the mixing of downstream regions. In addition, the vortex generators determine the secondary flow patterns.Thus, the heat transfer enhancement is associated with the secondary flow with relatively a low penalty of pressure drop[3]. When longitudinal vortex generators are placed near a heat transfer surface, they increase the heat transfer by transporting fluid from the wall into free stream and vice versa. The effectiveness of vortex generator in enhancing the heat transfer depends on the vortex strength generated per unit area of the vortex generator[4]. Heat sinks and heat exchangers are used in many applications today and the most common material used is aluminum because of its high thermal conductivity (205 W/m·K), low maintenance and production cost, and less weight.

In this study, aluminium is used as the material for the Delta wings. There are two different methods for heat exchange enhancement: active vortex method and passive vortex method. The active vortex method is used to actively control the secondary flow and pressure drop so as to meet the required heat transfer rates even at the cost of increased pumping power. There is little known use of this method in heat exchangers since the operating cost is very high. A few examples of active vortex method are the use of jets at different angles from the heat transfer surface into the boundary layer, and the generation of a secondary flow through acoustic excitation, and Electrohydrodynamics (EHD) which is the process of producing an electric field to create electric body force in the flow. Using longitudinal or latitudinal vortex generators for heat exchange enhancement is known as the passive vortex method. Delta wing, rectangular wing, delta winglet, rectangular winglet, trapezoidal delta wing, dimpled surfaces, ribs, and fins all are types of vortex generators[7]. This study focuses on air-side heat transfer enhancement using delta-wing vortex generators. The lift generated by the delta wing is accompanied by tip vortices that are carried longitudinally downstream by the main flow as shown in Figure 1[6]. These vortices interchange fluid near the plate with fluid from the freestream, and this bulk mixing (or boundary layer thinning) is the primary mechanism for heat transfer enhancement through vortex generation.

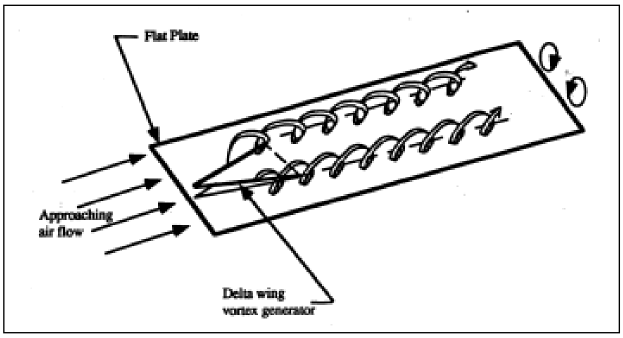


Fig. 1 A schematic representation of the longitudinal vortices generated by a delta wing. The lift of the delta wing leads to the creation of these tip vortices.[6]

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 (Figure 2) 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.*sb*2. The aspect ratio of vortex generator is an important criterion to compare the performance of the different shapes[5].

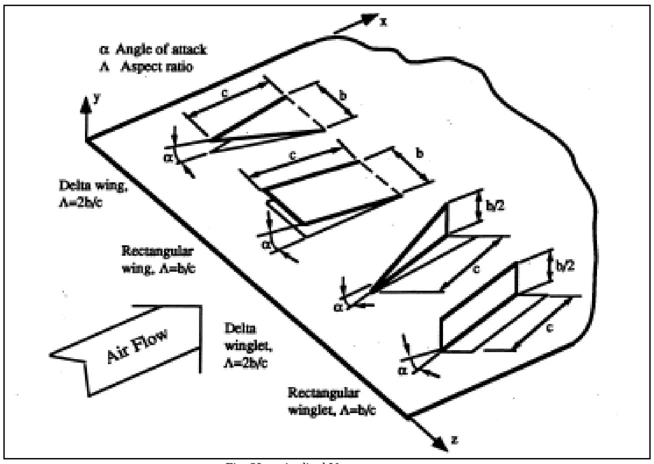
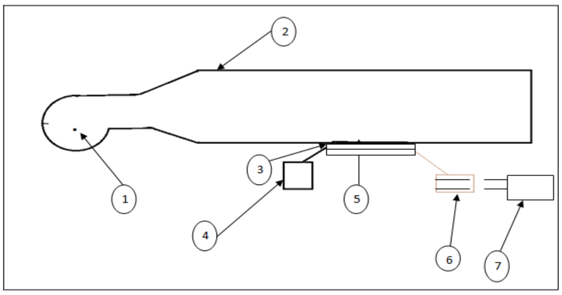


Fig. 2Longitudinal Vortex generators

Kai-Shing Yang *et al*.[1] conducted the experimental study to determine the airside performance of heat sinks having fin patterns of plate fin, interrupted fin geometry, dense vortex generator and loose vortex generator . Test results indicate that the heat transfer performance is strongly related to the arrangement of enhancements. The interrupted and dense vortex generator configurations normally contribute more pressure drop penalty than improvements of heat transfer. This is especially pronounced when operated at a lower frontal velocity. Actually the plain fin geometry outperforms most of the enhanced fin patterns such as of type fin patterns of plate fin and dense vortex generator at the fully developed region. This is because a close spacing prevents the formation of vortex, and the presence of interrupted surface may also suffer from the degradation by constriction of conduction path. The results suggest that the vortex generators operated at a higher frontal velocity is more beneficial than that of plain fin geometry. Wisam Abed Kattea[2] conducted the experimental study for heat transfer around heat exchanger using vortex generators (circular and square) in turbulent flow. In the experimental study, an apparatus was set up to measure the velocity and temperatures around the heat exchanger with constant heat flux using two shapes of vortex generators at a fixed point. There is an effect for the shapes of vortex generators on heat transfer, temperatures and velocity distribution. It was noticed that heat transfer is enhanced (36-56) % when Circular shapes of vortex generators are used and (39-51) % when Square shapes of vortex generators are used. Gupta A. *et al*.[6] conducted an experimental investigation to compare heat augmentation from plane and protruded rectangular fins to measure and calculate average heat transfer enhancement.During the study, it was observed that the heat transfer through the plane fin is lesser than protruded fin, as flow just pass over the surface and extract the heat from the fin. The heat transfer here also depends on the pitch, and density of the protrusion. One thing more the flow pattern also depends on the protrusion position whether protrusion is inline or staggered. The heat transfer from the fin is maximum for staggered dense protrusion as the flow pattern is disturbed considerably in this case. M.S. Aris*et al.*[8] conducted a study on an experimental investigation into the deployment of 3d, finned wing and shape memory alloy vortex generators in a forced air convection heat pipe fin stack. It was observed that, the fixed delta wings were found to provide heat transfer enhancements as high as 37% and a maximum increase in flow pressure loss of 15% compared to plain fin surfaces. M.C.Gentry*et al.*[9] developed a technique for assessing heat transfer enhancement of a vortex generator from flow visualization. The pressure drop penalty associated with these heat transfer enhancements was calculated using experimental data for delta wings. Vortex strength and vortex location relative to the boundary layer play very important roles in the heat transfer enhancement due to a vortex generator. The effects of vortex strength and vortex placement can be combined into a goodness factor that is useful in exploring the design of vortex generators.

II. EXPERIMENTATION

Flow Domain of Acrylic sheet of 5mm thickness and dimensions of 2100mm x 150mm x 100mm is used as a base material for the duct. The sheet is given a rectangular cross section of dimensions 150 mm x 100 mm. A square slot is cut with the help of a snip tool at the bottom of the duct. The slot is made to insert the plates and heater assembly in the duct. Area of the slot provided is 150mm x 150mm. A diffuser section of MS sheet is used which provides passage of air from the blower to the duct. An aluminium plate of industrial grade of 150mm x 150mm x 10 mm is used as a test specimen. Delta wings are manufactured with the help of aluminium sheet of 0.6mm thickness. Thermocouples of type Pt-100 Simplex are used alongwithdatalogger with 16 channels. Vane type anemometer with 0-30m/s range is used to measure the air velocity. Wattmeter of range 0-750W is used to indicate the input power. Electric plate heater with Nichrom coil is used to heat the aluminium plate. The dimmer-stat with a range of 0-260V is used to control the output voltage applied to the plate heater.



1-Blower, 2-Acrylic duct, 3-Test specimen, 4-Temperature indicator,
5-Heater, 6-Wattmeter, 7-Dimmerstat

Fig. 3Experimental Set Up

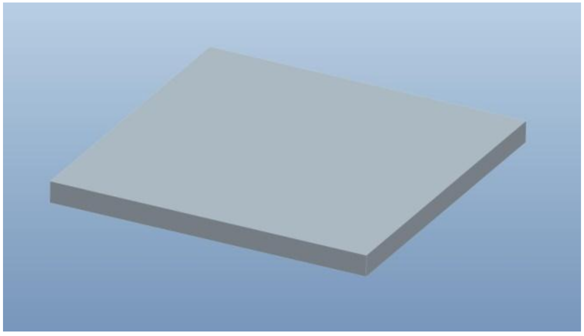


Fig. 4 Bare Plate

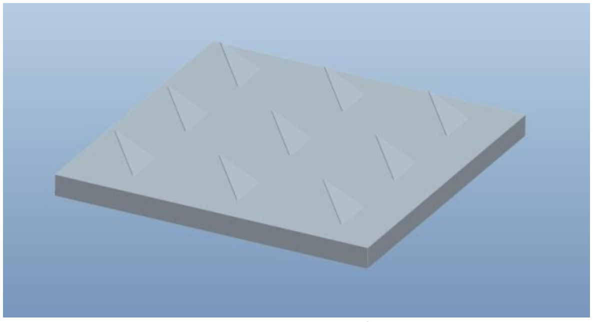


Fig. 5 Inline Arrangement of Delta Wings

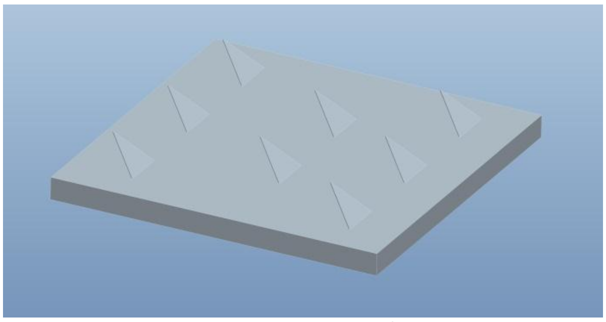


Fig. 6 Staggered Arrangement of Delta Wings

Figure 3 shows the experimental set up with all instruments and figure 4,figure5 and figure 6 describes the CAD models for bare, Inline and staggered arrangements of delta wings.

In the first stage, the experimentation is carried out for optimum angle of attack for delta wings using different angles such as 30^0,45^0,60^0,75^0,90^0 etc. The angle of attack which provides optimum solution for heat transfer coefficient is considered for further study. In the second stage, using optimum angle of attack and with different variable parameters such as velocity, input power etc., an optimum solution is found out with different delta wings arrangements such as Inline and Staggered and result are compared with the bare plate.

III.CALCULATIONS

A. To find Reynolds number

The Reynolds number represents the ratio of the importance of inertial effects in the flow to viscous effects in the flow. For a pipe or a duct the characteristic length is the hydraulic diameter.

The Reynolds Number for a duct or pipe can be expressed as-

$Re = \rho\, u\, d_h / \mu$

$= u\, d_h / \nu$

where

d_h = hydraulic diameter (m)

u = Flow Velocity

ρ and μ are the fluid properties.

Reynolds Number,

$Re = (1.164 \times 0.5 \times 0.12) / (1.872 \times 10^{-5}) = 3730.78$

As Reynolds no. is 3730.78, it is a transition(close to turbulent)flow.

B. To find Entry length for duct

The hydrodynamic entry length is usually taken to be the distance from the tube entrance where the wall shear stress reaches within about 2 percent of fully developed value[10]. For Re= 20, the hydrodynamic entry length is about the size of a diameter, but increases linearly with velocity. In the limiting case of Re= 2300, the hydrodynamic entry length is 115D.

In turbulent flow, the intense mixing during random fluctuations usually overshadows the effects of molecular diffusion, and therefore the hydrodynamic and thermal entry lengths are of about the same size and independent of Prandtl number[10]. The entry length is much shorter in turbulent flow, as expected, and its dependence on the Reynolds number is weaker.

In this case,

Entrance length E_L

E_L= le/d

Where, le= Length of fully developed velocity profile,m

d= duct diameter,m.

E_L= 0.06 Re ……………………………(For Laminar flow)

E_L= 4.4 (Re)1/6 ………………………...(For Turbulent flow)

As Reynolds no. is 3730.78(near to Turbulent conditions), we can use equation of Turbulent flow.

E_L= 4.4 (Re)1/6

= 4.4 (3730.78)1/6

= 17.328

E_L= le/d= 17.328

Hence, le= 2.079m

C. To find heat transfer coefficient

Heat transfer coefficient (h) is found by using the equation-

$Q = h\, A\, \Delta T$

IV.RESULT & DISCUSSION

a In the first stage of experimentation, the study has been conducted to identify the optimum angle of attack which can be applied for the further experimentation. It is observed that, (Figure 7) at 45^0 angle of attack, the value of heat transfer coefficient is more as compared to other values. Hence, 45^0angle of attack is the optimum solution and this angle of attack for delta wings is considered for further study.

TABLE I

α / h	0^0	30^0	45^0	60^0	75^0	90^0
h w/m^2K	52.55	69.33	92.94	79.54	72.38	67.28

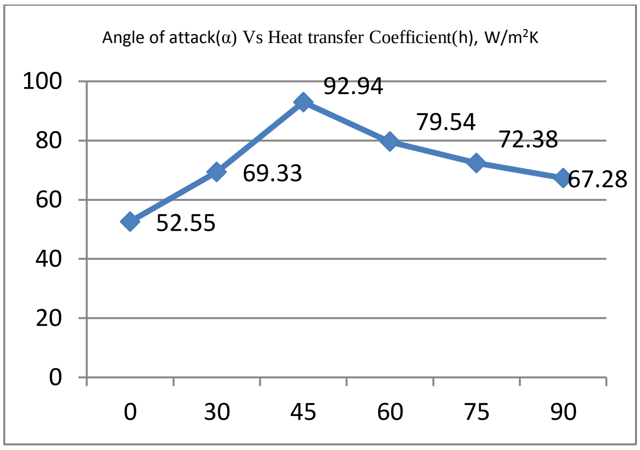


Fig. 7Graph for h Vs α

In the second stage of experimentation, the study has been conducted with 45^0angle of attack of delta wings with inline and staggered arrangement and it is compared with the results obtained for bare plate.

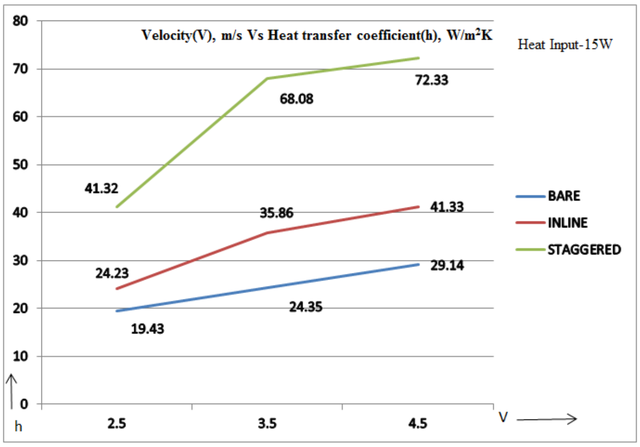


Fig. 8 Graph for Velocity Vs heat transfer Coefficient (for Q=15W)

The experiment is conducted with different velocities such as 2.5m/s, 3.5m/s and 4.5m/s and with 2 sets of power input (15W and 30W). Figure 8 describes that, for 15W heat input and for different sets of velocities, staggered arrangement of delta wings shows maximum value of h as compared to inline arrangement and bare plate.

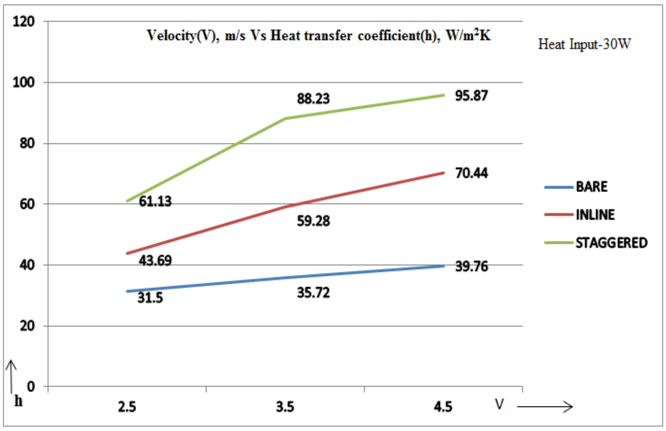


Fig. 9 Graph for Velocity Vs heat transfer Coefficient (for Q=30W)

Figure 9 describes that, for 30W heat input and for different sets of velocities, staggered arrangement of delta wings shows the heat transfer coefficient value $95.87 W/m^2K$, which is maximum as compared to previous values of inline arrangement and bare plate.

Hence, from both the results, we found that with higher velocities, the staggered arrangement of delta wings shows optimum solution for heat transfer coefficient. Hence. staggered arrangement shows 30%-40% rise in heat transfer augmentation as compared to bare plate.

V.CONCLUSION

The important findings of the experimental investigations are as follows-

1. The entire experiment on the apparatus was performed successfully and heat transfer coefficients of delta wing plate for different sets of attack angle were evaluated.

2. It is observed from the first stage of experimental results that the heat transfer coefficient is enhanced with 45^0angle of attack for delta wings. This can be attributed to the fact that in delta wing plate, the relative strength of the vortices and turbulence effects increase by a substantial amount thereby increasing the heat transfer rate from the heated plate to the air blown over it.

3.Thus, in the second stage of experimentation, it is found that with 45^0angle of attack for delta wings with staggered arrangement, we get 30%-40% rise in heat transfer coefficient value as compared to inline arrangement and bare plate.

The performance of the heat exchangers can be improved by mounting protrusions on the surfaces. The surface geometries, which are popular in different industrial applications, which are wavy fins, off-strip fins, perforated and louvered fins. Somewhat different concept for the reduction of thermal resistance and enhancement in heat transfer is the use of longitudinal vortex generators in the form of winglet.

REFERENCES

[1] Kai-Shing Yang, Shu-Lin Li, IngYoun Chen, Robert Hu, Chi-ChuanWang,"An Experimental Investigation of Air Cooling Thermal Module Using Various Enhancements at Low Reynolds Number Region", International Journal of Heat and Mass Transfer, Elsevier Ltd., Vol.2, pp. 5675-5681, Sept.2010.

[2] Wisam Abed Kattea, "An Experimental Study on the Effect of Shape and Location of Vortex Generators Ahead of a Heat Exchanger", Al-Khwarizmi Engineering Journal, Vol.8, No.2, pp. 12-29, Jan.2012.

[3] K. Thirumalai Kannan, B. Senthil Kumar, "Heat Transfer and Fluid Flow Analysis in Plate-Fin and Tube Heat Exchangers with Different Shaped Vortex Generators", International Journal of soft computing and Engineering (IJSCE), Vol.2, Issue-1, pp.357-361, March 2011.

[4] Amit Garg, Sunil Dhingra, "Numerical Simulation for Heat Transfer Enhancement in a Triangular Ribbed Channel with Winglet Vortex Generators", International Journal of Engineering research and General Science, Vol.2, Issue 4, pp.549-561, July 2014.

[5] GulshanSachdeva, "Computation of Heat Transfer Augmentation in a Plate-Fin Heat Exchanger using Rectangular / Delta Wing", PhD thesis, National Institute of Technology, Kurukshetra, India, March 2010.

[6] Anirudh Gupta, PramodBhatt,"An Experimental Investigation of Compact heat Augmentation From Plane and Protruded Rectangular Fins", IOSR Journal of Engineering (IOSRJEN), Vol.2, Issue 9, pp. 17-25, Sept. 2012.

[7] Ninad C. Maniar, "Heat Transfer Enhancement in a Rectangular Channel Using Vortex Generator in a Laminar Flow", Master Thesis, The University of Texas, Arlington, December 2012.

[8] M.S. Aris, R. McGlen, I. Owen, C.J. Sutcliffe,"An Experimental Investigation Into the Deployment of 3-D, Finned Wing and Shape Memory Alloy Vortex generators in a Forced Air Convection Heat Pipe Fin Stack", Applied Thermal Engineering Journal, 11th March 2011, pp. 2230-2240.M. Wegmuller, J. P. von der Weid, P. Oberson, and N. Gisin, "High resolution fiber distributed measurements with coherent OFDR," in Proc. ECOC'00, paper 11.3.4, p. 109, May 2000.

[9] M.C. Gentry, A.M. Jacobi,"Heat Transfer Enhancement on a Flat Plate Using Delta-Wing Vortex generators", Air Conditioning & Refrigeration Center Project Report, University of Illinois, Urbana, July 1995.

[10] Yunus A. Cengel, Afshin J. Ghajar, "Heat & Mass Transfer", Tata Mc Graw Hill Publication, 4th Edition, 2011.

[11] P. K. Nag," Heat & Mass Transfer", Tata Mc Graw Hill Publication, 3rd Edition, 2011.