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Experimental Investigation of Heat Transfer Enhancement from Pin Fins with Delta Winglet Vortex Generators in Square Channel

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Abstract: Study has been carried out in a 50 mm × 50 mm test section to understand the influence of delta winglet vortex generators on heat transfer characteristics in a square channel. Reynolds number based on the hydraulic diameter is varied from 8000 to 20000. With constant heat flux, experiment was performed to calculate heat transfer characteristics by installing pin fins and delta winglet vortex generators on the flat plate. The horizontal pitch of pin fin is varied by 18 mm, 20 mm and 22 mm. Then delta winglets were installed on the finned plate with angle of attack varied from 30º, 45º and 60º. After test setup validation, experiment was conducted and test results were compared with the flat plate results. From experiment it is found that the heat transfers increases by using delta winglet vortex generators. Best results are obtained for Re 20000 with 18mm pin fin pitch having angle of attack of 45º, Enhancement ratio was found to be 3.77 on account of pressure drop across the test section. Thermo Hydraulic performance $(Nu/Nu_0)/\ (f/f_0)1/3$ were found 2.96. So from the experiment it is concluded that by using delta winglets, heat transfer enhances without severe penalties associated with the pressure drop.

Keywords: Generators, Heat transfer, Pressure

Nomenclature

$\dot{m}$	: Mass flow rate of air through test duct, kg/s
ΔP	: Pressure drop in test section, N/m^2
ΔT	: Temperature difference, ºC
A	: Cross sectional area of air duct, m^2
a_o	: Cross sectional area of orifice, m^2
C_D	: Coefficient of discharge of orifice
C_P	: Specific heat of air, J/kgK
D_h	: Hydraulic diameter of air duct, m
D	: Diameter of pin fins, m
f	: Average friction factor
f_0	: Friction factor of flat plate
S	: Horizontal Displacement of red gage fluid in manometer, m
g	: Gravitational acceleration, m/s^2
h	: Convective heat transfer coefficient, W/m^2K
hm	: Height of liquid column in manometer, m
H	: Height of duct, m
kair	: Thermal conductivity of air, W/mK

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L	: Length of test plate, m
P	: Pin fin pitch, mm
Q	: Convective heat transfer of air, W
T_{ae}	: Temperature of air at exit, ºC
T_{ai}	: Temperature of air at inlet, ºC
T_{bm}	: Bulk mean temperature of air, ºC
T_s	: Test surface temperature, ºC
V	: Average velocity of air, m/s
W	: Width of duct, m

I. INTRODUCTION

The enhancement in the performance of the heat exchangers have attracted many scientist form a long time as they are of great technical, ecological, and not the least, economical importance. The desire for improved heat exchanger performance has led to the various heat transfer augmentation techniques. The aim of these augmentation methods is to reduce the initial and operational cost of the heat exchanger. Initial cost can be reduced if the heat transfer augmentation allows a reduction in heat-exchanger volume or weight. Operating cost can be decreased if the augmentation allows the heat exchanger to meet their function with a lower pressure drop. Heat transfer inside flow passages can be enhanced by using passive surface modifications such as rib tabulators, delta winglet vortex generator, pin fins, protrusions and dimples. These heat transfer augmentation techniques have practical application for, biomedical devices combustion chamber liners and electronics cooling devices, internal cooling of turbine airfoils, food industries and heat exchangers. Recently, delta winglet vortex generators have drawn more attention because it shows significant enhancement in heat transfer with a lower penalty in the increased pressure drop. Force convection heat transfer in smooth and roughed ducts has been investigated by several researchers and large amount of useful data is available in the literature. The use of delta winglet vortex generators has attracted the attention of many scientists because of higher heat transfer rates associated with their use.

Number of researchers studied the passive heat transfer augmentation methods. Amin Ebrahimi et al. [1], evaluate the performance parameters in the laminar flow region with regard to the enhancement of heat transfer using winglet type vortex generators. The Effects of common flow up and common flow down pairs of vortices produced by longitudinal vortex generators with two different shapes of the winglets, a pair of rectangular winglet (RWP) and a pair of delta winglet (DWP), are studied at different Reynolds numbers. The common flow down configuration of delta winglet shows a better overall performance at Reynolds numbers lesser than 720 and common flow up configuration of delta winglet shows a better performance at Reynolds numbers greater than 720. MC Gentry et al. [2], experimentally developed and verified the flow visualization in case of heat transfer enhancement using delta winglet vortex generators. From the experiment it was found that Vortex strength and vortex location relative to the boundary layer play very important roles in the heat transfer enhancement due to a vortex generator [3-21]. Similar research works were carried out by SS Kore et al. [10], in his research the effect of Reynolds number and dimple depth on the heat transfer coefficient and friction factor had been studied. The present study is different from the existing investigations because here in this investigation pin fins are used to enhance the heat transfer from a plate along with the delta winglet vortex generators installed in a common flow up configuration. The experiment was performed for Reynolds number ranging from 8000 to 20000 with various angle of attack of delta winglets and pitch values of pin fins.

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Vortex Generators

One of the most important passive techniques to enhance the heat transfer is the use of vortex generator. Here in this project we have used delta winglet vortex generator. For delta winglet vortex generator, two vortices are produced as the obstructed fluid passes over the wing from both the side edges (Fig. 1). 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 (Fig. 2). The horseshoe vortex is formed at the junction of the tube and fin, and the delta winglets passively generate longitudinal vortices.

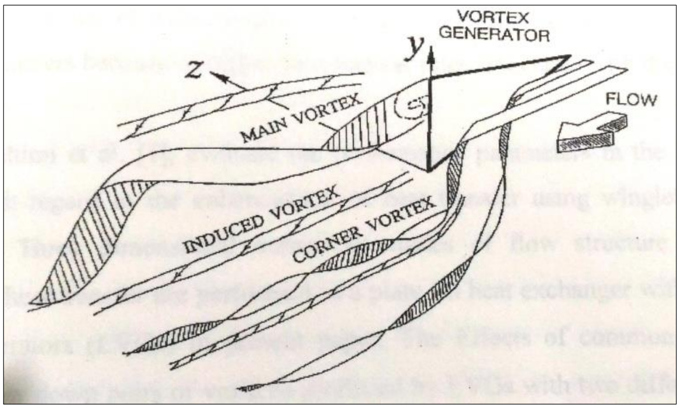

Fig. 1. Vortex system behind a delta winglet [1].

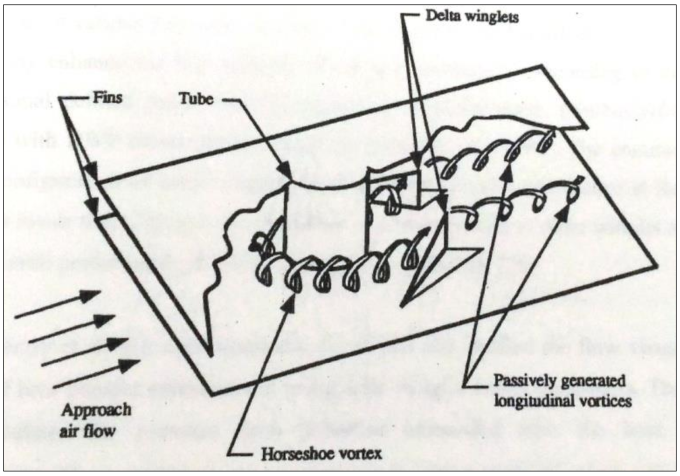

Fig. 2. Horseshoe and longitudinal vortex system [2].

II. EXPERIMENTAL INVESTIGATION

Experimental Setup

The experimental setup for this investigation consist of orifice meter for flow measurement, flow control valve, centrifugal blower, an entrance section, the main test section and then plenum (mixing section) with exit section for the air. The duct is of size 1050 mm × 50 mm × 50 mm and is constructed from epoxy resin material of 10 mm thickness. The main test section is of the length 700 mm. The entry and exit section length are 250 mm and 100 mm respectively. The exit section of 100 mm is used after the test section in order to reduce the end effects and to get uniform

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temperature across the duct. A 250 mm epoxy resin square section provides hydro-dynamically fully developed flow at the entrance of test section. To provide uniform heat flux, electric heater of size 700 mm × 50 mm is used. The heater is installed at the bottom side of the test section to provide uniform heating of the test plate. The bottom side of heater is covered with epoxy resin sheet of thickness 10mm and having length 700 mm to reduce the heat loss from the bottom side of the heater. The test section is insulated from all sides with ceramic wool having thermal conductivity 0.11 W/mK of thickness 30 mm. The mass flow rate of air is calculated by an orifice meter and to control flow of air Gate valve is provided. For temperature measurement calibrated 10 K type Cr/Al thermocouples are used. The pressure drop across the test section is measured by an inclined manometer having red gauge fluid with specific gravity 0.81.

Experimental Procedure

The test section is assembled and checked for air leakages. The blower was switched on so that air can flow through the duct. A constant heat flux is applied to the test surface through electrical heater. The average test surface to bulk mean air temperature difference and the net heat flux was determined over a test section. At each value of flow rate and the related heat flux, the system was allowed to attain a steady state and then only the temperature data were recorded. Once the steady state reached, the pressure drop was measured.

During experiment following parameters were measured:

i) Pressure difference in the orifice meter.

ii) Temperature of the test plate and temperatures of air at inlet and outlet of the test section.

iii) And the Pressure drop across the test section.

Data Reduction

Steady state temperature values of the plate and air in the channel, at various locations for a given heat flux and mass flow rate of air, was used to determine the values of performance parameters (Fig. 3).

Fig. 3. Pin fins with Delta winglet vortex generators

The mass flow rate of air is determined from the pressure drop across the orifice meter, using a following relation:

$$\dot{m} = Cd \times a_0 \times \frac{\rho_{air} \times \sqrt{2gH_a}}{\sqrt{1-\beta^4}} \qquad (1)$$

The useful heat gain of the air is calculated as:

$$Q = m\ Cp\ (Tae - Tai) \qquad (2)$$

The heat transfer coefficient for the test section is:

$$h = \frac{Q}{A_s \times (T_s - T_{bm})} \qquad (3)$$

The Nusselt number as,

$$Nu = \frac{h \times D_h}{K_{air}} \qquad (4)$$

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The friction factor was determined from measured vales of pressure drop across the test section using:

$$f = \frac{\Delta P \times D_h}{2 \times \rho_{air} \times L \times V_{air}^2} \qquad (5)$$

The thermal and physical properties of air used in the calculation of heat transfer and friction parameter were taken from standard data books which corresponding to mean bulk air temperature of air. The relative humidity of air was found in the range of 20 to 30% and hence the variation due to humidity was neglected during the experimentation and calculations.

III. Results And Discussion

Validation of Experimental Set Up

The main basic purpose of validity test is to serve as a basis of comparison of results of friction factor and heat transfer from the correlations available in literature review. Before actual experimentation starts, flat plate test experimentation is done. The experimental result of Nusselt number is validated with the Nusselt number obtained from the standard Dittus Boelter correlation. The Nusselt number by Dittus Boelter equation is given by:

Nu = 0.023 Re0.8Pr0.4 (104 ≤ Re ≤1.24 × 105) (6)

And the friction factor for flat plate is given by modified Blasius correlation as,

f_0 = 0.085 Re-0.25 (7)

The deviation of experimental Nusselt number is in the range of 1.37% to 9.70% for Reynolds number 8000 to 20000. Friction factor is measured by using inclined tube manometer. Inclined tube manometer is used to measure small pressure differences with high accuracy. It is clear that as Reynolds number increases the Friction factor goes on decreasing. The results of actual test shows similarity with the friction factor obtained from the modified Blasius correlation.

Effect of Pin Fins with Delta Winglet Vortex Generators on Nu

The flow structure for channel with delta winglet is analyzed with angle of attack 30°, 45° and 60° for different pin fin pitch values of 18 mm, 20 mm and 22 mm. The incoming fluid strikes the delta winglets and flowing through the both edges of the winglet. It creates the secondary vortices in the channel. These vortices enhance the heat transfer rates. It is clear that the value of Nusselt number and hence the net rate of heat transfer increases as the Reynolds number of flow increases. It is because when Reynolds number of flow increase, the turbulence in the flow increases and hence more number of fluid particles comes in contact with the plate surface for exchanging the heat. Nusselt number decreases as the pitch between the pin fins increases. The reason behind this decrement in the heat transfer is the number of pin fins available for heat transfer. In case of 18 mm pitch, there are 39 numbers of pin fins that can be installed on the flat plate of 700 mm length. Now in case of 20 mm pitch value, there are 35 numbers of pin fins that can be installed on the plate. That means there are 4 less number of pin fins than with the 18mm pitch. So, as the number of pin fins decreases the Nusselt number also decreases due to reduced net effective surface area of heat transfer.

It is clear from experiment that the heat transfer is maximum at an angle of attack of 45º. For 30º and 60º the heat transfers rates are lower as compared to the heat transfer rates obtain at angle of attack 45º. If we compare the results of heat augmentation with respect to the angle of attack of the delta winglets then it can be seen that the Nusselt number increases as the angle of attack increases from 30º to 45º in all 3 cases. It is because when the angle of attack increases the strength of vortex generators also increases.

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That's why we are getting increased rates of heat transfer from 30º to 45º. Now from 45º to 60º winglet angles, the Nusselt number shows some decrement. The reason behind this decrement is the orientation and the geometry of the delta winglets at 60º angle of attack. In case of 30º and 45º angle of attack, the primary flow is directed towards the pin fin hence more turbulence is created in the channel. When we are using angle of attack 60º for the delta winglets, the main primary flow is diverted away from the pin fins. Hence here less amount of turbulence is there as compared to other two cases. Hence the rate of heat transfer decreases in this case.

Effect of Pin Fins with Delta Winglet Vortex Generators on Nu/Nu_0

The ratio of heat transfer on plate surface having pin fins and delta winglet vortex generators to the flat plate has been introduced as heat transfer enhancement ratio (Nu/Nu_0). It is seen that 45º angle of attack of delta winglet vortex generators shows increasing trend for increased Reynolds number. Enhancement ratio for 30º angle of attack is in the range of 2.33 to 3.26, for 45º angle of attack is in the range of 2.59 to 3.77 and for 60º angle of attack is in the range of 2.29 to 3.04. So it is clear that the heat transfer enhancement is more in case of 45º of angle of attack.

Effect of Pin Fins with Delta Winglet Vortex Generators on f/f_0

Nusselt number and friction factor depends up on both flow and geometrical parameters of the test surface. It is also observed that as number of pin fins reduces with increase in pitch, friction factor goes on reducing. Maximum value of friction factor (0.0203) is found at Reynolds number 8000 with P = 18 mm and α = 60º. The increased amount of fluid flow shows increasing nature of the friction factor. For all arrangements of the pin fin and delta winglet vortex generators the friction factor increases with increase in the Reynolds number of the flow.

Effect of Pin Fins and Delta Winglets on Thermo Hydraulic Performance

Thermal performance for the internal flow over pin fins and winglet geometry gets improved as the flow rate is increased. At higher Reynolds number, thermal performance is also more, this is due to more expenditure required to propel air through the duct. It is seen that in comparison with flat plate, Pin fin with delta winglets having pin fin pitch 18 mm and angle of attack 45º is giving the best thermo hydraulic performance of 2.96 for the studied range of Reynolds Number (Figs. 4-6).

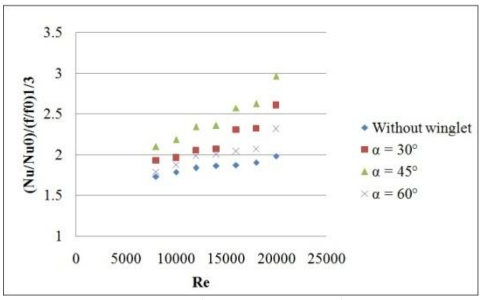

Fig. 4. Thermal performance vs Re for P 18 mm.

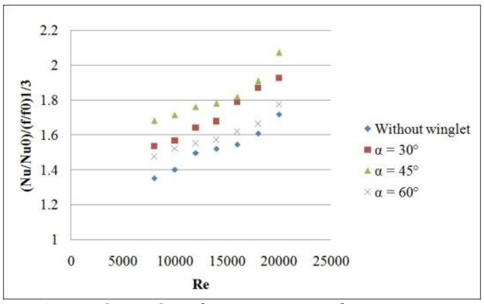

Fig. 5. Thermal performance vs Re for P 20 mm.

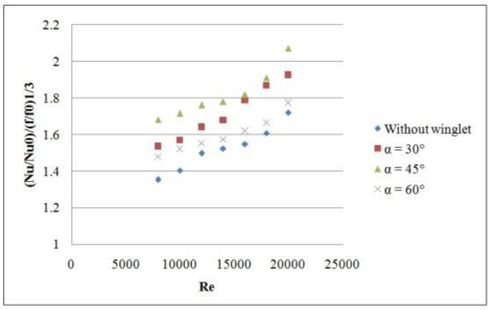

Fig. 6. Thermal performance vs. Re for P 22 mm.

IV. CONCLUSION

An experimental study of the flow of air in a square channel with pin fins and delta winglet vortex generators, subjected to uniformity of heat flux boundary condition has been performed. Investigation have been done in two stages first with installation of only pin fins with different horizontal pitch (18 mm, 20 mm and 22 mm) and then delta winglets were installed on the plate in various angle of attacks (30º, 45º and 60º). Following conclusion have been drawn from the test results:

1. From the experiment it is concluded that with decreasing the horizontal pitch of Pin fin the heat transfer rates increases.
2. Friction factor reduces with increase in Reynolds number. This is due to suppression of secondary vortices at higher flow rates.
3. In case of delta winglet vortex generators, the heat transfer enhances but on the account of increases in the pressure drop. For Pin fin of 18mm pitch the friction factor ratio varies from 1.67 to 2.25.
4. It is observe that the heat transfer augmentation is maximum for 18 mm pin fin pitch with 45º angle of attack of delta winglet vortex generators. The maximum value of enhancement ratio is 3.77 with friction factor ratio of 2.06.

From the experiment it is found that the heat transfer rates and the pressure drop across the test section depends upon both geometry of the extended surfaces and the orientation of the delta winglet vortex generators.

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