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Experimental Investigation of Heat Transfer Enhancement from Circular Dimple with Different Winglet Vortex Generators in Square Channel

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ABSTRACT

Vortex generation is a new and innovative strategy of enhancing air-side heat transfer. Vortex generators such as wings and winglets can introduce vortices into the flow field causing heat transfer enhancement. Vortex can be divided into two categories based on the axes of these vortices: transverse vortices and longitudinal vortices. Longitudinal vortices are more efficient for heat transfer enhancement than transverse vortices. In this paper, experimental investigation is carried out to understand the influence of different winglets vortex generators such as delta, rectangular & Trapezoidal 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 is performed to calculate heat transfer characteristics by installing circular dimple and delta, rectangular & Trapezoidal winglets vortex generators on the flat plate. The horizontal pitch of circular dimple is constant by 18mm. Then All winglets are installed on the dimple plate with angle of attack Constant by 45º & Aspect ratio of delta, rectangular & Trapezoidal winglets vortex generators varies from 1, 1.5 & 2.The test results are compared with the flat plate results & The working fluid considered herein is air. From the experiment it is observed that the heat transfer enhances by using delta, rectangular & Trapezoidal winglet vortex generators. Best results are obtained for Reynolds number 20000 with 18mm pitch of circular dimple with rectangle winglet of aspect ratio 2having angle of attack of 45º as compared to delta & trapezoidal winglets. Enhancement ratio found to be 6.32 at 18mm pitch and α = 45º of rectangle winglet on the account of pressure drop across the test section & other aspect ratios 1 & 1.5 be same result.

Keywords: vortex generators, delta winglets, heat transfer enhancement.

I. INTRODUCTION

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 (Figure 1.1) 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' that is Λ=sb^2. The aspect ratio of vortex generator is an important criterion to compare the performance of the different shapes.

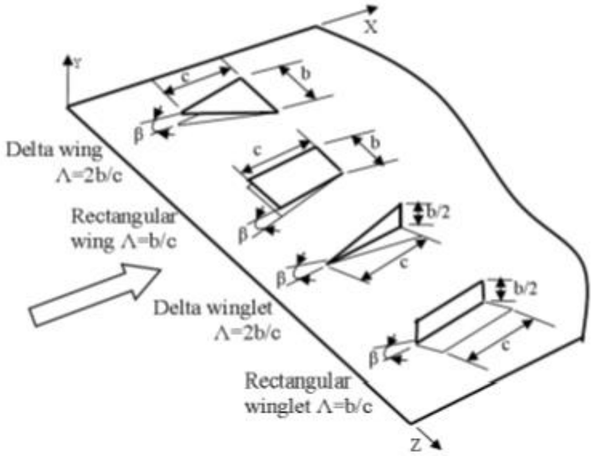
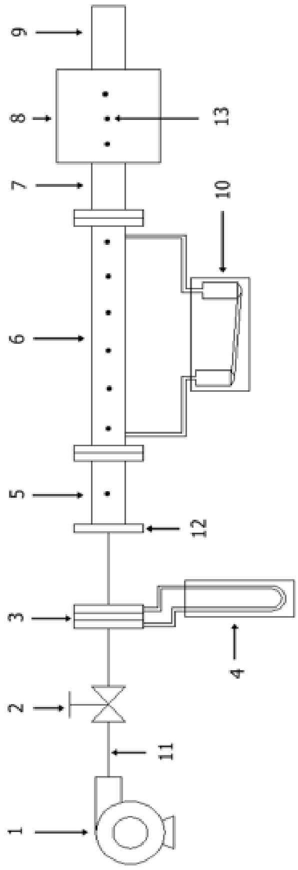


Figure1:Longitudinal vortex generators

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 1.2 shows a sketch of longitudinal vortices behind a delta winglet vortex generator placed in a laminar boundary layer on a flat plate. 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.

II. EXPERMENTAL SET UP

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



Part No	Part Description
1	Air Blower
2	Flow Control Valve
3	Orifice Plate
4	U Tube Manometer
5	Entry Section
6	Test Section
7	Exit Section
8	Plenum Chamber
9	Outlet Pipe
10	Inclined U Tube Manometer
11	Piping
12	Flange
13	Thermocouples

Figure 2:Experimental set up

To provide uniform heat flux, electric heater of size 700mm X 50mm is fabricated from a galvanized Iron sheet of thickness 0.5mm of 250 volts electric supply with 800 watt rating. 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 700mm to reduce the heat loss from the bottom side of the heater. The heat input to the heater is controlled by the use of dimmer stat having range 0 to 230 volts. The voltage and current across the heater is measured by digital voltmeter. The total test section along with the entrance and exit section is covered with ceramic wool having thermal conductivity 0.11 W/mK of thickness 30mm to avoid any heat losses to the surrounding from the test section.

III.EXPERIMENTAL PROCEDURE

Initially all the necessary units were assembled at their respective places. Blower was switched on and the test section along with entire setup was checked for air leakages. Then a constant heat flux was applied to the test plate. By using flow control valve, air flow was controlled and then measurements were taken after the test section reaches to steady state. Steady state condition is assumed to be reached when temperature at a point does not change for about 20 minutes. After starting from cold it took around 50 to 60 minutes to gain the steady state of the system. For different Reynolds numbers data was recorded after reaching the steady state. During experimentation following parameters were measured,

- Pressure difference across the orifice meter
- Temperature of the heated surface and air temperature at inlet and outlet of the test section
- Pressure drop across the test plate

IV. RESULT AND DISCUSSION

A. Effect of Circular Dimple with winglet vortex generators on Nu

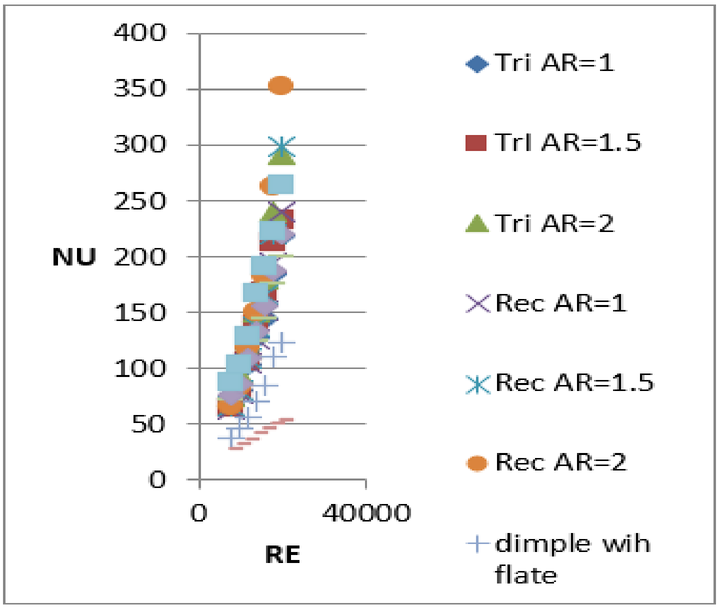


Figure 3:Variation of Nu as a function of Re

From Fig.3 it is clear that the value of Nusselt number decreases as the aspect ratio decreases. The reason behind this decrement in the heat transfer is the number of dimple available for heat transfer. In case of 18mm pitch, there are 37 numbers of circular dimple that can be drilled on the flat plate of 700mm length. So, as the number of aspect ratio decreases the Nusselt number also decreases due to reduced net effective surface area of heat transfer.

B. Effect of winglet vortex generators on Nu/Nu0.

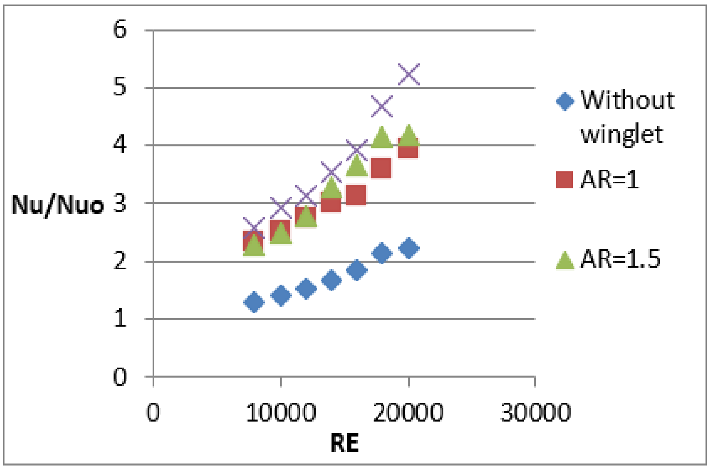


Figure 4:Enhancement ratio versus Reynolds number for Triangle

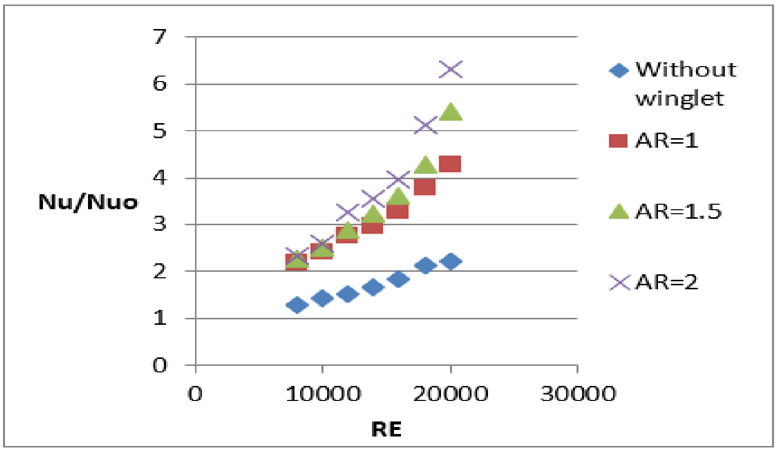


Figure 5:Enhancement ratio versus Reynolds number for Rectangle

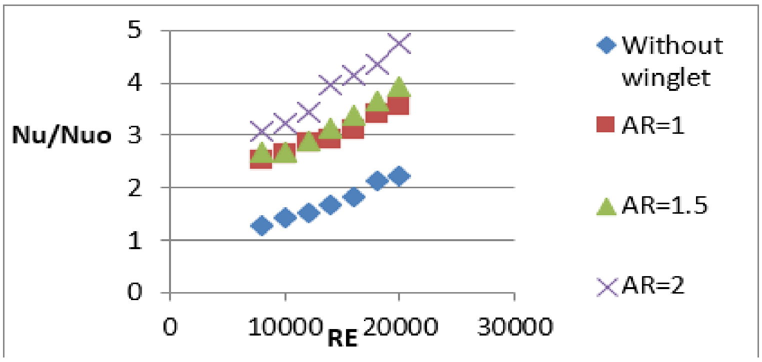


Figure 6:Enhancement ratio versus Reynolds number for Trapezoid

The ratio of heat transfer on plate surface having circular dimple and Triangular, Rectangular, and Trapezoidal vortex generators to the flat plate has been introduced as heat transfer enhancement ratio (Nu /Nu0). Fig 4 to 6 shows the enhancement ratio as a function of Reynolds number. It is seen that aspect ratio of Triangular, Rectangular, and Trapezoidal winglet vortex generators shows increasing trend for increased Reynolds number. Enhancement ratio for aspect ratio 1 is in the range of 2.19 to 4.39, for aspect ratio 1.5 is in the range of 2.28 to 5.4 and for aspect ratio 2 is in the range of 2.34 to 6.32. So it is clear that the heat transfer enhancement is more in case of aspect ratio 2 in Rectangular winglet .

C. Effect of winglet vortex generators on f

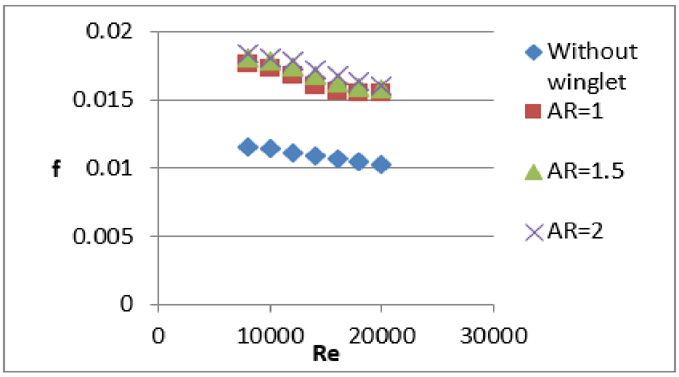


Figure7:Friction factor versus Reynolds number for Triangle

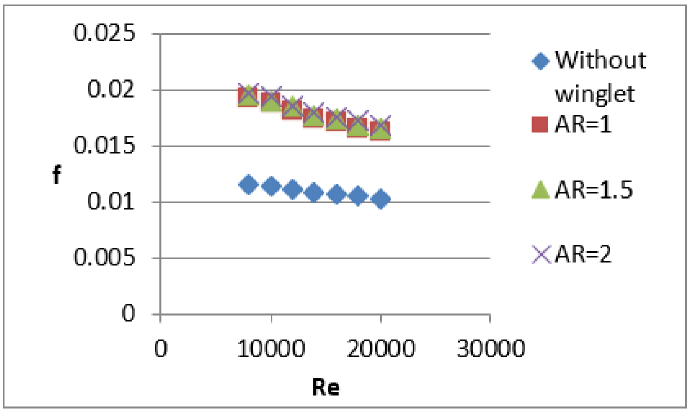


Figure8:Friction factor versus Reynolds number forRectangle

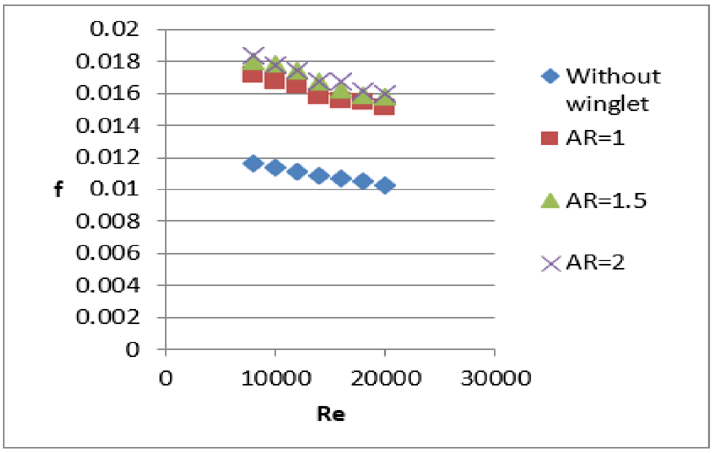


Figure9:Friction factor versus Reynolds number forTrapezoid

Fig. 7 to 9 shows the effect of Reynolds number and Aspect ratio of the Triangular, Rectangular, and Trapezoidal winglets on friction factor in the range of Reynolds number 8000 to 20000. It is seen that the value of friction factor decreases with increasing Reynolds number in all cases. The friction factor is maximum at Rectangular winglets having aspect ratio 2. Friction factor shows decrement with increasing Reynolds number and vice versa. This is due to less vortex shedding and reattachment point on the Triangular, Rectangular, and Trapezoidal winglets.

It is also observed that as aspect ratio decreases, friction factor goes on reducing. Maximum value of friction factor (0.01975) is found at Reynolds number 8000 with aspect ratio 2 in case of Rectangular at α = 45º.

D. Effect of circular Dimple with Triangular, Rectangular, and Trapezoidal winglets winglet vortex generators on on f/fo

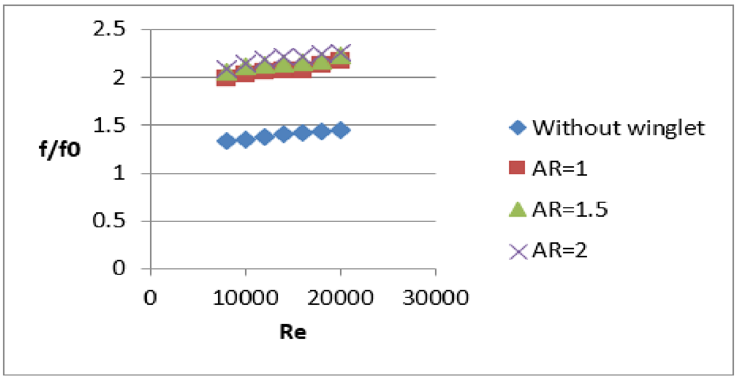


Figure20:f/fo versus Reynolds number for Triangular

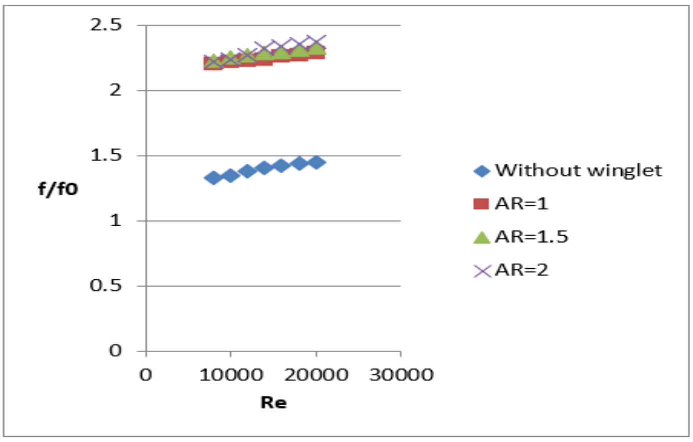


Figure31:f/fo versus Reynolds number for Rectangular

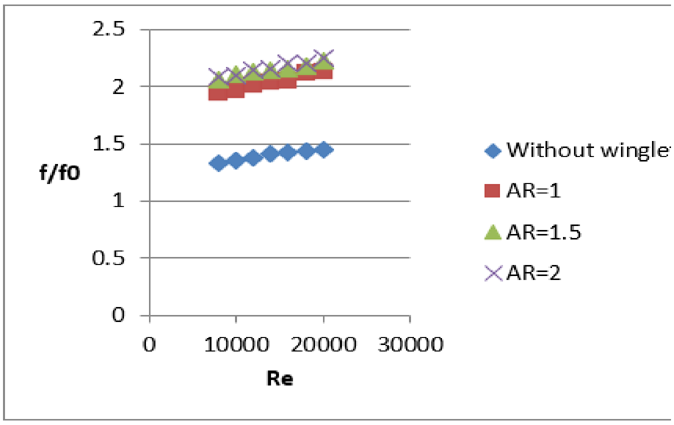


Figure42:f/fo versus Reynolds number for Trapezoidal

Fig. 10,11 & 12 shows the variation of Normalized friction factor ratio (f/fo) as a function of Reynolds number. The increased amount of fluid flow shows increasing nature of the friction factor. For all arrangements of the circular Dimple and Triangular, Rectangular, and Trapezoidal winglets vortex generators the friction factor increases with increase in the Reynolds number of the flow.

E. Variation of Performance Parameter with Reynolds number

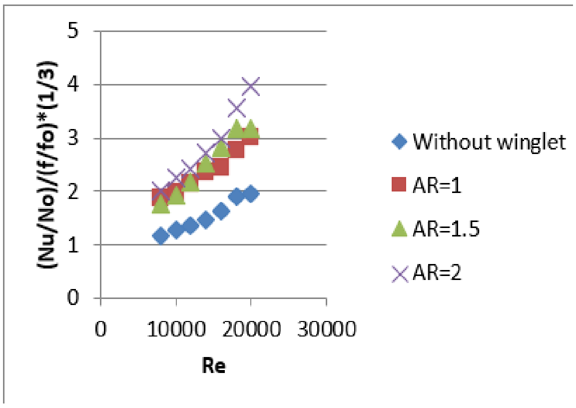


Figure53:Variation of Performance Parameter with Reynolds number for Triangle

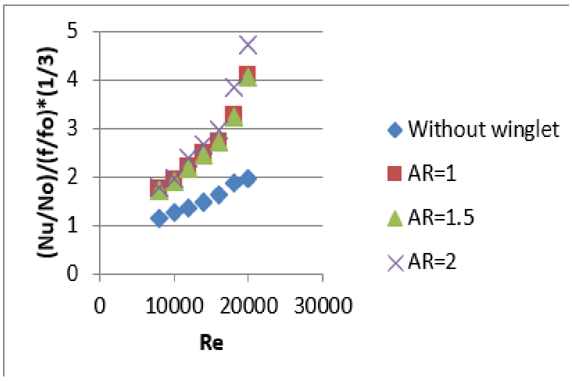


Figure64:Variation of Performance Parameter with Reynolds number for Rectangle.

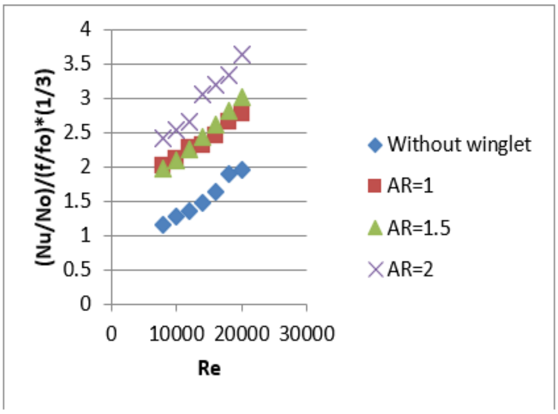


Figure75:Variation of Performance Parameter with Reynolds number for Trapezoid.

Thermal performance shows in Fig. 13,14 & 15 it is seen that in comparison all 3 cases Dimple with Triangular, Rectangular, and Trapezoidal winglets having aspect ratio 2 in case rectangular winglet of is giving the best thermo hydraulic performance of 4.74 for the studied range of Reynolds Number.

V. CONCLUSION

An experimental investigation of turbulent flow of air in a square channel over Circular Dimple and delta , rectangular, trapezoidal winglets vortex generators at uniform flux, with one extended surface wall and other three smooth insulated walls is carried out. The effect of Reynolds number, Constant horizontal pitch and Constant angle of attacks & Different Aspect Ratios (1, 1.5, &2) of delta, rectangular, trapezoidal winglets vortex generators on heat transfer coefficient and friction factor has been studied. Results have been compared with those of smooth duct under similar flow conditions to determine enhancement in heat transfer coefficient and friction factor.

Following conclusion have been drawn from the test results,

- It is found that the heat transfer rate is more for dimpled surfaced plate when compared with plane plates.
- From the experiment it is concluded that Friction factor reduces with increase in Reynolds number. This is due to suppression of secondary vortices at higher flow rates.
- From the experiment it is observed that the heat transfer enhances by using delta, rectangular & Trapezoidal winglet vortex generators.
- Best results are obtained for Reynolds number 20000 with 18mm pitch of circular dimple with rectangle winglet of aspect ratio 2 having angle of attack of 45º as compared to delta & trapezoidal winglets. Enhancement ratio found to be 6.32 at 18mm pitch and α = 45º of rectangle winglet on the account of pressure drop across the test section & other aspect ratios 1 & 1.5 be same result.
- 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, rectangular, trapezoidal winglets vortex generators.

VI. FUTURE SCOPE

Rectangular winglet shows better enhancement as compared to delta,trapezoidal winglets flat surface. In present studies it is seen that increasing values of Aspect ratio of winglet gives better heat enhancement but on the account of increasing pressure drop. Rectangular winglets also show best results in case of heat transfer augmentation with negligible increase in the pressure drop. So following are the recommendations for future work,

- The investigation can be done using different angle of attack of winglets.
- The investigation can be done using different horizontal pitch of winglets.
- Investigation can be done by changing the size of the Circular Dimple.
- shapes of dimple cavity like triangular, leaf shape, tear drop shape etc. can be used.
- Investigation by analytical method can be done.
- Numerical analysis using Ansys and Fluent software can be done.
- Application of this type of technique in case of IC engines and heat exchangers of power plants can be studied.

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