Experimental investigation of heat transfer enhancement in a rectangular duct channel with and without delta wing vortex generator

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ABSTRACT— The Heat transfer enhancement on the walls of rectangular duct channel andthe Pressure drop across the duct can be studied by considering the effectof delta wing type of vortex generators.The effect of geometrical properties of vortex generator on the heat transfer enhancement will be reported. The various geometrical parameters of the vortex generator such as pitch, height, hydraulic diameter, aspect ratio will be varied to report the pressure drop and heat transfer in a duct at different angle of vortex generator positioning. The experimental results for the study of Nusselt number and friction factor will be estimated from the correlation proposed by Dittus-Boelter and Blasius equation which will describe the heat transfer enhancement in a prescribed duct, its effect and effect on the pressure drop across the duct.

Keywords— Heat transfer, Pressure drop, Delta wing type of vortex generator, Nusselt number, Friction factor.

I. INTRODUCTION

In many of industrial engineering applications several convective heat transfer methods are employed to improve the thermal performance of heat transfer devices such as treated surface, rough surface as well as incorporation of inserts like vortex generators, turbulence promoters etc. Therefore the heat transfer applications considering internal flow and mixed convection in a non-circular ducts and channels have been studied by many of researchers. For many of industrial applications it becomes more essential to improve the heat transfer coefficient and reducing pressure drop due limited source of operation such as in heat exchangers, high temperature gas turbine and electronic component.

For the enhancement of heat in a rectangular duct channel we are using passive method of heat enhancement technique, which is again classified in to longitudinal wise and transverse wise heat enhancement technique. Vortex generator is one of the method of insertion type which is found to enhancing the heat in a variety of industrial applications.

A vortex generator is considered as a passive flow control device which modifies the boundary layer fluid motion bringing momentum from the outer region into the inner region. The basic principle of vortex generator is to induce the secondary flow which will disturb the thermal boundary layer developed along the wall and removes heat from the wall of the ductdue to turbulence. The experiments were conducted to study the heat transfer and pressure drop in a rectangular duct channel by using the transverse type of delta wing vortex generator.The experimental study on the behavior of a unique longitudinal vortex generator embedded in a developing turbulent boundary layer with a zero pressure gradient (Shakaba, *et. al.,* 1985). At the punched longitudinal vortex generators in the form of winglets in staggered arrangements were used to observe the results of vortex formation, pressure distribution, velocity field, temperature fields, local heat transfer distribution in a heat exchanger and the global results for the oval tubes with two to four staggered winglets presented and compared (Y. Chen, *et. al.,* 2000).The comparison of fully developed heat transfer and friction factor characteristics has been made in the rectangular duct channel with roughened at five different shapes (S. W. Ahn, 2001). The implications of geometrical parameters of delta winglet vortex generators on heat transfer and pressure loss characteristics in a circular duct channel were evaluated (Yakut K., *et. al.,* 2005).

For the rectangular duct, the parameter examined were: flow velocity from 0.5 to 3.4 m/s, Reynolds number from 3000 to 20,000 and results were reported with and without mounting of the longitudinal vortex generators (Q. Wang, *et. al.,* 2007).The decaying swirl flow was produced by the insertion of vortex generators with propeller type of geometry and at three different positions of the vortex generator in the axial direction are examined (Betu Ayan Sarac, *et. al.,* 2007).

The heat transfer and pressure drop performance of a full-scale heat exchanger was studied before and after addition of wing type of vortex generators in two different configurations and also examined the winglet configurations at single vortex generator pair at the leading tube and three vortex generator array placed at alternate tubes (A. Joardar, *et. al.,* 2008). Theexperimental study of flow structure in horizontal equilateral triangular ducts having double rows of half delta wing type of vortex generators mounted on the duct (A. Akcayoglu, *et. al.,* 2010). This paper deals with heat transfer enhancement and pressure loss penalty inside a rectangular duct with a delta wing type of vortex generator.

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DESCRIPTION OF EXPERIMENTAL SETUP

Experiments will be performed as per the figure depicted in fig. 1. The experimental setup consists of a rectangular duct channel of hydraulic diameter of 300mm and length of 900mm and for measuring the pressure of test section through two pressure taps. Air blower provides air at the inlet of the duct passed through flow control valve and an orifice-meter. A simple U-tube manometer is used to measure the pressure heads across the duct channel.

The rectangular duct is roughened by using delta wing type of vortex generators placed in a series and at different angle of attack. The duct of 900mm in length is surrounded by the heater for heating of duct and air moving inside of duct. The vortex generators are stickled on the bottom surface of the duct channel. These delta wing type of vortex generators are made up of 0.5mm thick stainless sheet and placed at different angle of attack on the bottom surface of the duct.

The high velocity air from the blower is supplied to duct through flow control valve and orifice meter where the pressure is given to rise. As air is leaving the orifice meter it enters in to the rectangular duct surrounded by heating element and gets heated. The variation in the temperature inside the duct is measured by the fourteen thermocouples placed on the duct surface.

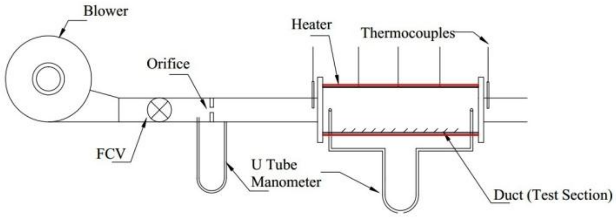
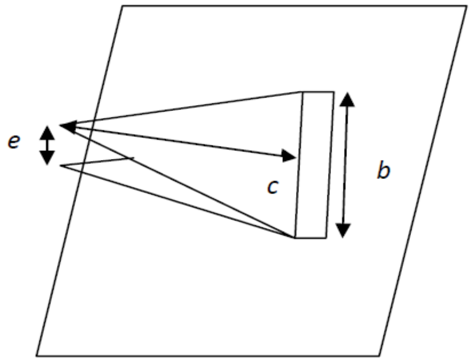


Fig.1 Experimental Set-up

GEOMETRY OF VORTEX GENERATOR

For analyzing the flow characteristics and its effect on the heat transfer the delta wing type of vortex generator is mounted on the bottom surface of the duct having L, H and W along with the aspect ratio given by W/H. The parameter of vortex generator effecting the friction factor is shown in fig.2 (Nalawade M. K., 2006).



Delta wing vortex generator

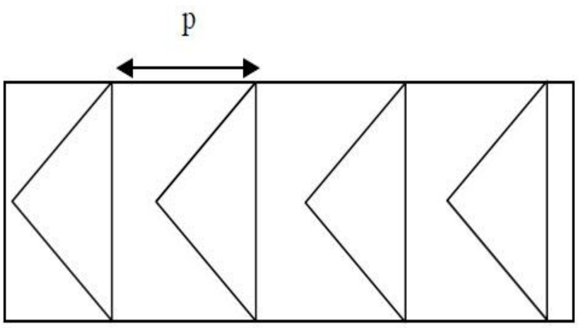


Fig.2 Geometry of delta wing vortex generator

Axial pitch (P): The axial distance between adjacent vortex generators is known as pitch of the vortex generator.

Vortex generator height (e): The distance between the tip of vortex generator to the surface of the wall where vortex generator is mounted.

Chord length(c): The distance of tip of vortex generator to the base of the vortex generator is known as chord length.

Vortex generator base (b): The surface of vortex generator stickled on the wall surface of the duct is called as vortex generator base.

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DATA REDUCTION

For investigating the heat transfer and flow friction behaviors in a rectangular duct with the implication of insertion of a delta wing type of vortex generators we requires experimental calculations such as, average heat transfer coefficients are evaluated from the local measured temperatures and heat inputs. As heat is uniformly supplied to the air and the temperature difference of wall surface and fluid i.e. air (T_s–T_b), average heat transfer coefficient will be calculated from the measured data as:

$$Q_{air} = Q_{conv} = m\, C_p\, (T_o - T_i) = VI$$

where,

T_i – inlet temperatures of air
T_o – outlet temperatures of air
V – Voltage supplied to the heater
I – Current supplied to the heater

Heat flux is calculated as,

$$q = \frac{Q_{air}}{\text{Surface Area}}$$

The experimentation was done at constant heat supply and the calculations are performed to obtain the results. A sample observation table is shown below showing the parameters need to be observed during experimentation.

Table 1 Sample observation table

Sr. No.	Temperature°C					Manometer Difference	
						Orifice	Across the duct
	T_1	T_2	…	T_{13}	T_{14}	h_w	H_w

Where,
1. T_2 to T_{13} are the surface temperatures
2. T_1 and T_{14} are the ambient air temperatures at inlet and outlet of duct.
3. h_w and H_w is U-tube manometer difference in mm.
4. Avg. Surface Temp.,

$$T_s = (T_2 + T_3 + \ldots\ldots + T_{13})/12$$

5. Avg. Temp of air,

$$T_b = (T_1 + T_{14})/2$$

From table of properties of air required parameters can be taken.

6. Manometer difference =water head =hw
7. Air head, $h_a = h_w \left(\frac{\rho_w}{\rho_a}\right)$

where,
ρ_w= Density of water = 1000 kg/m^3

Flow rate of air through Orifice-meter,

$$Q_a = C_d \frac{A_0 A_1}{\sqrt{A_0^2 - A_1^2}} \sqrt{2g\left[\frac{\rho_w}{\rho_{air}} - 1\right]H}$$

where,
A_1 = Area of pipe
A_o = Area of orifice
C_d = Co-efficient of discharge

Mass flow rate, $\dot{m} = Q_a \times \rho_a$
Velocity of air, $V = Q_a / A$

where,
A= cross sectional area of pipe.

Heat carried out, Q = $\dot{m}$*Cp*(T14-T1)

$$h = \frac{Q}{A\,(T_s - T_b)}$$

where,
h = heat transfer coefficient.
T_s = surface temperature

The Reynolds number based on duct hydraulic diameter is,

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$$Re = \frac{VDh}{\upsilon}$$

where,
V= velocity of the fluid.
D_h= Hydraulic Diameter of Duct
ν = Kinematic viscosity of the fluid.

For the internal flow if Reynolds number (Re) exceeds by 4000 then the flow is turbulent. Once the type of flow is decided then the Nusselt number can be calculated. The theoretical Nusselt number can be calculated (i.e. without considering friction) and then calculated by considering friction which will be experimental Nusselt number,

$$Nu_{th} = 0.023*(Re)\ 0.8*(Pr)0.4$$

This equation is called Dittus-Boelter equation.

$$f_s = (1.82 \log_{10}Re^{-1.64})^{-2}$$

This equation is used to find friction factor called as Petukhov equation for smooth surface.
where,
f_s= Friction factor for smooth tube.
Re= Reynolds number.
The actual pressure drop & friction factor is calculated with the help of tapping at both the ends of test pipe connected to U-tube manometer.

The friction factor is calculated from the formula given below:

$$f = \frac{\Delta P}{\frac{L}{D} * \frac{\rho_a V^2}{2}}$$

where,
ΔP= pressure difference at both ends of test pipe.
L= length of test section.

The experimental Nusselt number is calculated as:

$$Nu = hD/k$$

Where,
h = heat transfer coefficient
k = thermal conductivity of fluid
D = diameter of test section i.e. Hydro. diameter

The thermal performance enhancement factor, defined as the ratio of the heat transfer coefficient of a duct with VG, h to that of a smooth duct, h_o, at an equal pumping power is given by:

$$TEF = \eta = \frac{(Nu/Nuo)}{(f|fo)^{1/3}}$$

By using above methodology for the calculation of heat transfer and pressure drop will be carried out for determining the heat transfer enhancement for the defined duct channel(Sompol Skullong, 2012).

The friction factor for the fully developed turbulent flow in smooth duct ($10^4 < Re < 10^6$) is given by Blasius equation as,

$$fft = 0.046Re^{-0.2}$$

RESULTS AND DISCUSSIONS

1Performance evaluation

The experimental results on heat transfer and friction factor in a rectangular duct are first of all obtained for the Nusselt number and friction factor, by using Dittus-Boelter and Blasius equation. Meanwhile the heat loss, Reynold's number, heat transfer coefficient is calculated for different angle of attack of vortex generator.

The Nusselt number ratio i.e. Nu/Nu_0, defined as ratio of implication of insertion Nusselt number to the Nusselt number of smooth rectangular duct.

The isothermal friction factor i.e. f/f_0,defined as implication of insertion friction factor to the friction factor of smooth rectangular duct. Finally, the graph of heat transfer coefficient v/s Nusselt number, Reynold's number v/s friction factorwere plot to determine the thermal performance enhancement within duct at different angle of attack of Vortex Generator.

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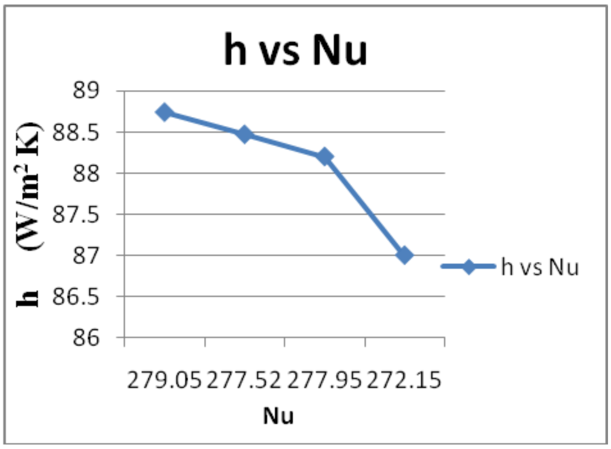
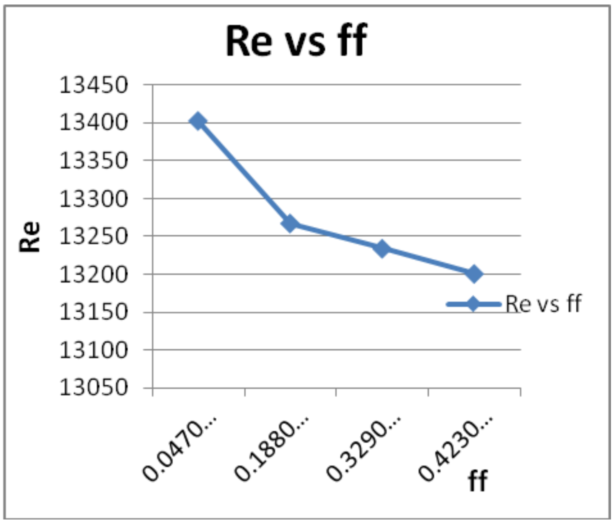
1.1 Graph of heat transfer coefficient v/s Nusselt number:

Graph – 1: h v/s Nu



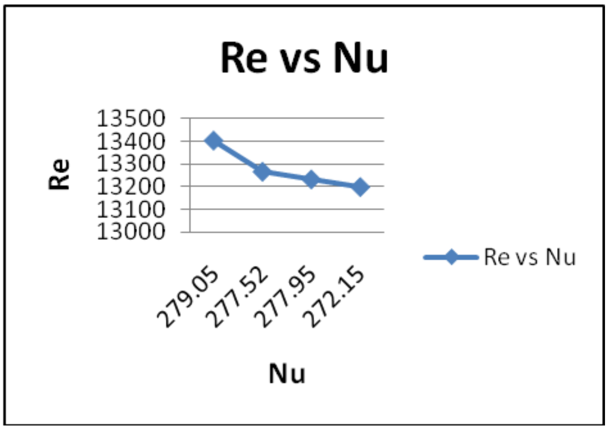
1.2 Graph of Reynold's number v/s friction factor:

Graph – 2: Re v/s ff



1.3 Graph of heat transfer coefficient v/s Nusselt number:

Graph – 3: Re v/s Nu



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II. CONCLUSION

An experimental study wasperformedto determine the airflow friction inside the rectangular duct, heat transfer coefficient and enhancement in heat from the duct by, the implication of insertions like transverse type of delta wing vortex generator at different angle of attack. From the results of friction factor and Nusselt number we can clearly describe the heat transfer enhancement in a rectangular duct channel with and without vortex generator. Atdifferent angle of attack of vortex generator the Nusselt number, Reynold’s number, heat transfer coefficient and friction factor variation was seen where it is best suited at an angle of 30̊ of vortex generator.

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