

Experimental Investigation of Trapezoidal Duct using Delta Wing Vortex Generators

#¹Gokul N Wakchaure, #²Prof. Shivanand S Talwar

#¹²³Department of Mechanical Engg, Jayawantrao Sawant college of Engineering, Savitribai Phule Pune University, Pune, India.

ABSTRACT— This paper deals with experimental study of heattransfer and flowcharacteristics of air flowing through trapezoidal duct. The duct is roughened with delta wing vortex generators. Three casesviz. delta wing VGs making angle 30° , 45° , 60° with base surface of ductare considered for the present project work.Experiments to be performed for each case to estimate Nusselt number, pressure drop & friction factor as a measure of heat transfer and flow characteristics. Also above parameters are to be evaluated for smooth duct and comparison of different cases with & without VGs is proposed. For the validation purpose, The Nusselt number and friction factor which are obtained from the smooth trapezoidal duct are to be compared with the correlations of Dittus-Boelter, Gnielinski; Blasius and Petukhov for turbulent flow in ducts.

Keywords— Delta wing VG, Convective heat transfer, Nusselt Number, Friction Factor, Pressure drop

I. INTRODUCTION

Various applications in engineering domain needs heat addition or extraction. These application uses no. of devices to exchange the heat. Performance of these devices is judged by improvement in heat transfer coefficient and reduction in pressure drop. Some heat transfer improvement technique increases the rate of transfer of heat, along with pressure drop. This subsequently raises the pumping cost. Thus any device which helps to improve augmentation should be optimized in between the merits of the increased heat transfer coefficient and the higher cost involved because of the increased friction. (VadirajKatti et al., 2013)

HT Enhancement techniques are of two types i.e. passive and active methods. Active techniques need external supply of power to maintain the enhancement mechanism. Passive techniques does not need any such power input. Using surface modifications or geometrical alterations to flow channel, they alter the existing flow behaviour and promote higher values heat transfer coefficients. (Warren M. Rohsenow et al)

Vortex Generators:

A vortex or turbulence generator is an aerodynamic device, it consist of a small vane that is attached to an aerofoil, and are positioned obliquely so that they have an angle of attack with respect to the local airflow so as to create tip vortex. The basic principle of (VG) is to create secondary flow, which disturbs or cuts the thermal boundary layer developed along the surface of wall and by doing so it removes the heat energy from the wall and gives it to the core of the flow by creation of turbulence. Different types like rectangular and triangular wings VG and winglets VG have been studied for flow characteristics and heat transfer improvement by several researchers, which are shown in Fig. 1. Most researches have focused their attention on wings and winglets which could be punched easily or can be mounted easily on the channel walls and could effectively generate longitudinal vortices. (S.A. Wani et al, 2015)

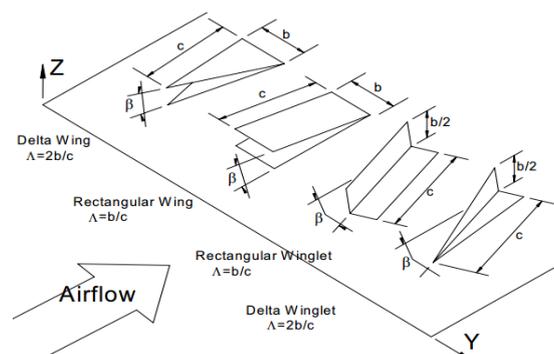


Fig.1.1: Basic forms of vortex generators

Turbulence promoting devices like delta wing or delta winglet VGs are used to interrupt the flow field and they can greatly improve the thermal performance of system. (Manohar S. Sohal, 2005)

II. LITERATURE REVIEW

Sujoy Kumar Saha (2010) in the research work focused on experimentation to study HT and the pressure drop or flow characteristics in square ducts. Duct was having internal axial corrugations combined with twisted-tape inserts. Working Fluid was air with turbulent flow. Heat duty improvement upto 55% and pumping power reduction upto 47% was observed by using combined geometry. The effect of delta wing VG on the wall of square duct and pressure drop, combined effects of geometrical parameters of VG on friction factor are observed for the Reynolds number which is based on duct hydraulic diameter. Through this experimental study decrease in friction factor (FF) ratio with increase in pitch to height ratio, increase in FF ratio with increase in ratio of VG height to hydraulic diameter of duct, with increase in aspect ratio and increase in Reynolds number was observed. (Vadiraj Katti et al., 2013) Pongjet Promvong et al. (2012) carried out experimental research on turbulent flow. Characteristics of heat transfer in a square duct were studied. Duct was fitted with diagonally placed finned tape with fins making angle of 30° . Friction factor and HT improvement with smaller fin pitch spacing was observed during the study.

The experiments were also conducted to study above parameters in a narrow rectangular channel placed horizontal with longitudinal vortex generators. The working medium or fluid was water. The result shows that LVG greatly improves the rate of heat transfer by 10 – 45%, when they are mounted on the two sides of duct than mounted on one side (Qiuwang Wang et al., 2007). Numerical investigation was conducted to study the effects of common flow up pair produced by VG in the rectangular channel flow. Fluid flow characteristics and heat transfer properties were studied. The values of thermal boundary layers, skin friction and heat transfer properties were observed much closer to the experimental values of other researchers (J.S. Yang et al., 2008). Modified LVG which were mounted in rectangular channel was used for experimental study of Flow and heat transfer characteristics. A modified LVG which is obtained by cutting off the four corners of edges of rectangular wing. The study indicates that modified wing pair shows better results than pair of rectangular wing VG (Chunhua Min et al.). The influences of various parameters of LVG in a rectangular duct were studied. Average Nusselt no. value and the flow loss increases with the increase in area of LVG. With fixed area, when we increase the length winglet pair, it results in more heat transfer. With the same LVG area, delta winglet VG pair is more effective (J.M. Wu et al., 2008).

The influence of VG on a friction for fully developed flow of in a triangular duct is studied. Results are indicating the rise in friction factor by 43.5% when attack angle was changed from 30° to 50° for triple pair case (Hamdi E. A. Zangana, 2008). Numerical study of forced convection HT in a triangular channel ribbed with longitudinal winglet VG was carried out. Turbulent air flow with constant rate of heat flux was considered. Significant effect of rib and the VGs on the smooth wall channel along with higher values of Nusselt no. and friction factor is observed (Amit Garg et al. 2014). Experimental study of structure of flow with two rows of half delta-wing VG was carried out. Duct with Equilateral triangular shape was considered for the study (Azize Akcayoglu, 2011). Atole Santosh (2014) in his research work experimentally studied the HT enhancement in a triangular shaped duct with rectangular wing.

Numerical results for natural convection HT were reported in the partially divided cavities of trapezoidal shape. The effects of Prandtl no., baffle height, Rayleigh number, and location of baffle on heat transfer are studied. The study reveals a reduction in heat transfer rate due to the presence of baffles and with its rate was generally increasing with the rise in baffle height (M. Darwish). An enlarged model of trapezoidal duct was built up in the nearby region the leading-edge in the blade. The effects of the impinging jets, swirl, cross and effusion flow are investigated experimentally. A result reveals that small jets effectively impinge target wall while the large jets contribute to induce and impel a strong anticlockwise vortex (LIU Haiyong, 2011)

The above literature review shows Numbers of experiments has been conducted in order to study the influence of various enhancement techniques on HT and flow characteristics of fluid flowing through ducts. Many of this study concentrate on mixed convection, internal flow in non-circular channels and ducts such as square, polygonal, rectangular, triangular and trapezoidal.

A small or much less quantity of experimental work has also been conducted using trapezoidal channel using baffles and impingement jets. In much of the studies carried out, LVG's & Delta wing VGs have given better performance in terms of HT enhancement. Review also shows that very less or no work has been done to analyze the flow in trapezoidal duct using any kind of vortex generators.

Description of Experimental Set-Up

The schematic diagram of arrangement made for experimental work is given in Figure 1. It consists of a blower fitted with the test section which is connected to the blower delivery side. Flow control valve is installed after the blower which controls the air flow rate through the test section. Orifice is fitted after the blower to measure volume flow rate of air through the pipe. Test Section of duct is surrounded by heater to heat the air. The test region is a trapezoidal duct. Two pressure taps are installed for the pressure measurement across the test section of duct. U-tube manometer measures the difference in pressure head across the orifice meter and across the test section. The delta wing VGs are mounted on bottom surface of trapezoidal duct. Three

thermocouples are attached to each wall of the duct to measure the surface temperature, one at the inlet of duct for inlet air temperature&one at the outlet of duct for outlet air temperature.

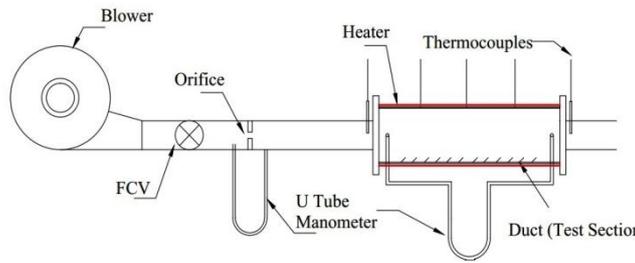


Fig: Schematic diagram of experimental Setup

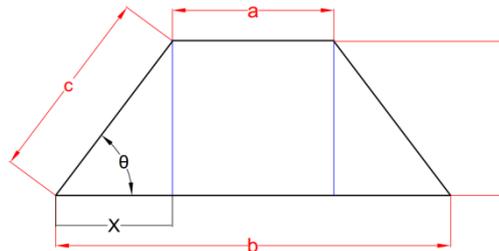


Fig: Cross section of trapezoidal duct

Specifications of set up:

- 1 Inner diameter of pipe = (d_o) = 0.06m.
- 2 Length of test section = L =0.9m.
- 3 Capacity of blower = 0.56h.p.
- 4 Diameter of orifice (d) =0.03m.
- 5 Range of Ammeter = 0 to 5 amp.
- 6 Range of Voltmeter= 0-270V ac.
- 7 U-tube manometer = 0-300 mm of WC
- 8 Calibratedthermocouple(K type)= -270⁰C to 1350 ⁰C)
- 9 Nichrome wire (resistivity=1.5 x 10⁻⁶Ωm) heater wound around test section.

Data reduction

The main aim of the present work is to investigate the heat transfer and flow friction behaviors in a trapezoidal duct with delta wing VGs. Heat is being added uniformly to air and for the temp.difference of wall surface and fluid i.e. air (T_s-T_b), average coefficient of heat transfer will be calculated from the measured data byusing the following equations:

$$Q_{air} = Q_{conv} = m C_p(T_o-T_i) = VI \tag{1}$$

where, T_o and T_i are the inlet and outlet temp. of air

V& I= Voltage& Current supplied to the heater.

Heat flux is calculated as, $q = \frac{Q_{air}}{\text{Surface Area}}$ (2)

A sample observation table is shown below to understand the parameters need to be observed during experimentation.

Table 1 Sample observation table

Sr No.	Temperatures °C					Manometer Diff.	
	T ₁	T ₂	T ₁₃	T ₁₄	h _w	H _w

where,
 T₂ to T₁₃ are the surface temperatures and
 T₁ and T₁₄ are the ambient temperatures of air at inlet and outlet.

h_w and H_w is U-tube manometer difference in mm across the orifice and duct.

$$\text{Avg. Surface Temp.}, T_s = (T_2 + T_3 + \dots + T_{13}) / 12 \quad (3)$$

$$\text{Avg. Temp of air}, T_b = (T_1 + T_{14}) / 2 \quad (4)$$

From table of properties for air the parameters like density, Kinematic viscosity, thermal conductivity (k), specific heat, Prandtl number (Pr) can be taken.

Manometer difference = water head = h_w

$$\text{Air head}, h_a = h_w \left(\frac{\rho_w}{\rho_a} \right) \quad (5)$$

where, ρ_w = Density of water = 1000 kg/m³.

Air Flow rate through Orifice-meter

$$\text{VFR} = C_d \frac{A_o A_1}{\sqrt{A_o^2 - A_1^2}} \sqrt{2g \left[\frac{\rho_w}{\rho_{air}} - 1 \right] H} \quad (6)$$

where, VFR = Volume flowrate of air,

A_1 = Area of pipe,

A_o = Area of orifice

C_d = Co-efficient of discharge

$$\text{Mass flow rate}, \dot{m} = \text{VFR} \times \rho_a \quad (7)$$

$$\text{Velocity of air}, V = \text{VFR} / A \quad \text{where, } A = \text{c/s area}$$

$$\text{Heat carried out}, Q = \dot{m} * C_p * (T_{14} - T_1) \quad (8)$$

$$h = \frac{Q}{A (T_s - T_b)} \quad (9)$$

where, h = heat transfer coefficient.

The Reynolds number which is based on hydraulic diameter of duct is,

$$\text{Re} = \frac{VD_h}{\nu} \quad (10)$$

where, V = velocity of the fluid

D_h = Hyd. Dia. of Duct

ν = Kinematic viscosity of the fluid.

The experimental Nusselt number is:

$$\text{Nu} = hD/k \quad (11)$$

where,

h = heat transfer coefficient

k = thermal conductivity of fluid

D = diameter of test section i.e. Hyd diameter

The actual pressure drop & friction factor is calculated from the formula given below:

$$f = \frac{\Delta P}{\frac{L}{D} \times \frac{\rho_a V^2}{2}} \quad (12)$$

Where, L = length of test section.

ΔP = pressure difference at both ends of test section.

As per the methodology discussed above the experimental calculations are to be carried out for the duct with and without VG. (Paramveer Patil et al., 2015, PongjetPromvonge, 2012)

Results & discussion

1. Validation of the smooth duct

The experimental results of HT and friction characteristics of flow in the smooth wall trapezoidal duct can be validated in terms of Nusselt no. and friction factor. The Nusselt no. and friction factor obtained which are obtained from the present smooth trapezoidal duct are to be compared with various correlations i.e. Dittus-Boelter, Gnielinski; Blasius and Petukhov equation for turbulent flow in ducts. For internal flows, if Reynolds number exceeds by 4000 then the flow is turbulent. After the flow is decided then the theoretical Nusselt number can be calculated (i.e. without considering friction) for smooth duct as,

$$Nu_s = 0.023 \times (Re)^{0.8} \times (Pr)^{0.4}$$

This equation is called Dittus-Boelter equation.

$$f_s = (0.79 \ln Re - 1.64)^{-2}$$

This equation is used to find friction factor called as Petukhov equation for smooth surface

Correlation of Blasius,

$$f = 0.316 Re^{-0.25} \quad \text{for } 3000 \leq Re \leq 20,000$$

Correlation of Gnielinski

$$\frac{(f/8)(Re-1000)Pr}{1+12.7(f/8)^{1/2}(Pr^{2/3}-1)} \quad \text{for } 3000 < Re < 5 \times 10^6$$

The thermal performance enhancement factor, TEF, defined as the ratio of the heat transfer coefficient of a duct with VG, h to that of a smooth duct, h_s , at an equal pumping power is given by following relation. (Pongjet Promvong, 2012)

$$TEF = \eta = \frac{(Nu/Nu_s)}{(f/f_s)^{1/3}}$$

III. CONCLUSION

A literature review shows that, lot of research work has been carried out HT Enhancement in the duct using vortex generator. Majority of the previous work focuses on rectangular, square, triangular and circular duct. A very less work has been carried out on trapezoidal duct using vortex generator.

In our proposed work, we are going to carry out an experimentation to investigate HT and flow characteristics inside the trapezoidal duct by the insertion of delta wing VG. The Manufacturing of Experimental set up is completed and experimentation work has been undertaken. For the study, differently positioned delta wing VG with variation in the parameter such as pitch to height ratio will be used to create turbulence within the trapezoidal duct. For clearly defining of heat transfer enhancement in a trapezoidal duct channel with and without vortex generator the results of friction factor and Nusselt number will be used.

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