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Flow Characteristics of Air in Square Channel Using Perforated Ribs

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Abstract: *The present experiment is conducted to study and analyse the effect of perforated ribs vortex generator having the aspect ratio (A.R) of 2, 3 and 5 on friction factor ratio of air flow through a square channel having the aspect ratio (A.R) of 1.0.The friction factor ratio and pressure drop characteristics in a square channel with different geometrical configurations of perforated ribs vortex generators are studied. Geometrical configurations in a square channel are symmetrically varied at different pitch to height ratio and at different aspect ratio of vortex generator. Perforated ribs vortex generators are inserted in a square channel. The experiment is repeated for different configurations of perforated ribs vortex generators and the results are reported for aspect ratio (A.R) of vortex generator 2,3,5 and pitch to height ratio (p/h) of 4, 8, 12, 16 for the corresponding Reynolds number (Re) ranges from 8000 to 24000.*
Keywords: *Square channel, perforated ribs, pressure drop, vortex generator, Aspect ratio, smooth duct, Friction factor ratio.*

I. Introduction

The process of improving the performance of heat transfer system is referred to as heat transfer enhancement. There are varieties of heat exchanger devices that are used to carry out these applications. Heat exchanger techniques are used in process industries, refrigerators, automobile radiators, air conditioning equipments, thermal power plants etc. Performance improvement in terms of improvement of heat transfer rate and reduction in the pressure drop becomes essential in such applications. In many such applications of heat exchanger, gas turbines and electronic equipment convective heat transfer plays a very important role. Many methods are available to increase heat transfer rate. Vortex generators are often used to increase thermal performance by manipulating flow field. This project presents experimental results of flow analysis of air inside a square channel. Square channels are mainly preferred to cool turbine blades effectively and also to achieve more compactness. There are large number of methods available to increase the heat transfer coefficient which may be classified as,

1.Active method: It requires external power such as twisted tapes, rough surfaces, extended surfaces, helical screw tape inserts, mechanical devices or surface vibration.

2. Passive method: This method does not require electric power such as electric or acoustic fields, mechanical devices or surface vibration instead it make use of special surface geometry. It is inexpensive compared to the other methods. In this method the inserts are placed in the direction of flow passage in order to increase heat transfer rate. It is more beneficial than active method since manufacturing of inserts is very simple and can be used in heat exchanger.

3. Compound method: Enhancement that uses more than one method is referred as compound method. This method includes both active and passive techniques to obtain heat transfer enhancement. The heat transfer enhancement by this method is greater than the heat enhancement produced by active method and passive method.

Here we are discussing about passive methods and are based on two stages one is by disturbing thermal boundary layer and the other one is by using bulk fluid mixing. The process of destruction as well as restarting of the boundary layer in the presence of roughness elements causes increase in heat transfer rate by producing a boundary layer which is thinner on an average than that of uninterrupted boundary layer. Vorticity in the flow can increase the heat transfer through bulk fluid mixing which reduces temperature gradients concentrating thermal gradient in the near wall region

II. Experimental Set-Up

The schematic representation of the experimental set up of 'Flow analysis of air in a square channel using perforated ribs' is as shown in the figure given below,

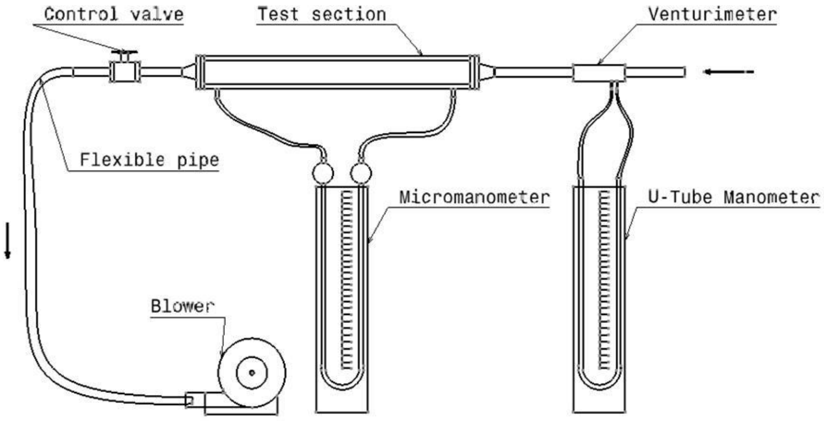

Fig 1. Experimental set-up

It consists of a square channel of size 900*30*30mm length, breadth and height of the square channel respectively. Two pressure taps are provided for the measurement of pressure across the test section. Variable speed blower having power of 6600watts is used. No load speed of the blower is 0-1600rpm.Air volume ratio is 3.5m^3/min and the weight of the blower is around 1.7kg.An U-tube manometer is used for the measuring differential pressure head across venturimeter. Differential manometer with a combination of water and benzyl alcohol (sp.gravity=1.046) as manometer fluids is connected to two pressure taps to measure the pressure drop across test section. A gate valve is used to regulate the air flow rate. Perforated ribs are glued on bottom surface of square channel with strong adhesives for roughening the channel.

III. Methodology

In this, the blower sucks the air. The air enters into the test section which is made up of acrylic sheet. The rate of air flow is controlled by using gate valve. Using venturimeter and U tube manometer, the air flow rate in the test section can be measured. When air flows in the test section, there is friction between the air and square channel surfaces. Thus pressure drop takes place. This pressure drop is measured by noting down the values of differential head of the benzyl alcohol in the micro differential manometer. By noting down the pressure drop values we can calculate the friction taking place in the duct. Then the perforated ribs are placed in main direction of flow passage in the test section. As air flows in the test section, the air collides with the vortex generators as a result of which pressure drop takes place which can be measured by micromanometer. Perforated ribs are used as vortex generators.

This procedure is repeated to obtain friction factor values for different configurations of the perforated ribs glued on the bottom surface of square channel for different Reynolds number, different aspect ratio and different pitch.

IV. Geometry And Computational Details

Axial pitch (p): The axial distance between the adjacent vortex generators is the axial pitch of the vortex generator configuration.

Vortex generator height (h): The distance between the perforated rib vortex generator top and bottom surface of the square channel upon which it is glued is the vortex generator height.

Vortex generator base (b): The base width dimension of the perforated rib vortex generator at which it is glued to the bottom surface is the vortex generator base.

Pitch to height ratio(p/h): It is ratio of the axial distance between two identical points of the adjacent vortex generators to the vortex generator height.

Aspect ratio (AR):The measure of the shape and size is known as aspect ratio of the vortex generator. The aspect ratio for perforated ribs vortex generator is given as AR=W/h.

Friction factor ratio(f/fs): The ratio of frictional factor of the rough duct to the frictional factor of smooth duct where, f-friction factor of square channel with vortex generator and fs-friction factor of square channel without vortex generator or smooth duct.

Reynolds number(Re): It is defined as the ratio of inertia force to viscous force., $Re=\rho v Dh/\mu$ Where v is velocity of air in duct, Dh hydraulic diameter, ρ - air density,µ - dynamic viscosity of air.

V. Data Reduction

Mass Flow Rate:

m= ρQ

ρ= air density

Reynolds Number:

Re= $\rho v D_h/\mu$

μ=absolute viscosity of air

v=Average velocity of air through the duct

Pressure Drop:

It is calculated by measuring pressure at the two pressure taps provided in test section which are connected to differential manometer. The equation is,

$$p_x - p_y = 2hg\rho_2[1 - \frac{\rho_1}{\rho_2}(1 - \frac{a}{A}) + \frac{\rho}{\rho_2}\frac{a}{A}]$$

Friction Factor Ratio(f/fs):

The friction factor ratio is determined in terms of pressure drop across test section,

$$\text{f/fs} = \frac{\Delta p}{[(4L/h)(\rho v^2/2)]}$$

Smooth Duct Friction Factor (ff) :

It is calculated by using the Blasius equation. Friction factor for fully developed turbulent flow,

$ff=0.046(Re)^{-0.2}$

VI. Results And Discussion

Fig 2 shows the graph obtained from plotting friction factor (ff) versus Reynolds number (Re) for a smooth square channel. Where 'fa' is the actual friction factor obtained from the experiment and 'ft' is the theoretical friction factor obtained from the Blasius correlation.

From the graph, actual friction factor fa agree well within range of ±7% and ±4% of the theoretical frictional factor 'ft' obtained from Blasius correlation

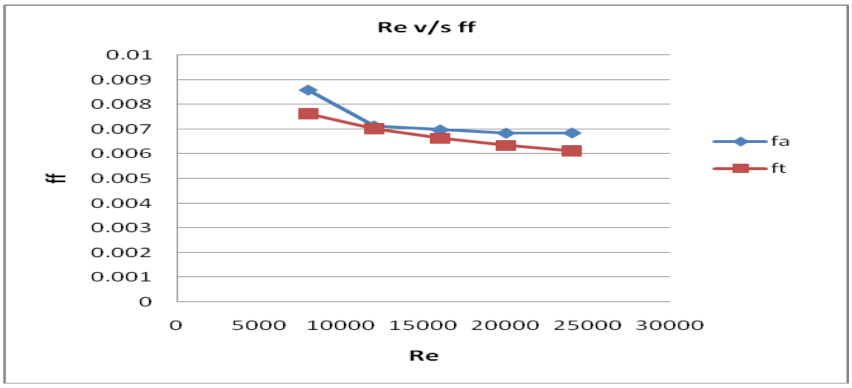

Fig 2.Result obtained from smooth Duct

Effect of Reynolds number *(p/e)* on Friction Factor Ratio *(f/fs)*

Figure 3 to 5 shows the effect of Reynolds number *(p/e)* on Friction Factor Ratio *(f/fs)*.It can be observed from graph that friction factor ratio increases as Reynolds number increases. The rate of vortex generation depends on the flow velocity in the square channel and the velocity of the fluid flow inside the square channel is directly proportional to Reynolds number. With increasing velocity, pressure drop increases automatically friction factor ratio increases. In fig 3,the friction factor ratio at Reynolds number 24000 is 35.52% greater than the friction factor ratio at Reynolds number 8000. Due to perforations laminar boundary layer gets disturbed as a consequence of which high turbulence is produced. Friction factor in perforated ribs is more than solid ribs due to turbulence and resistance against flow.

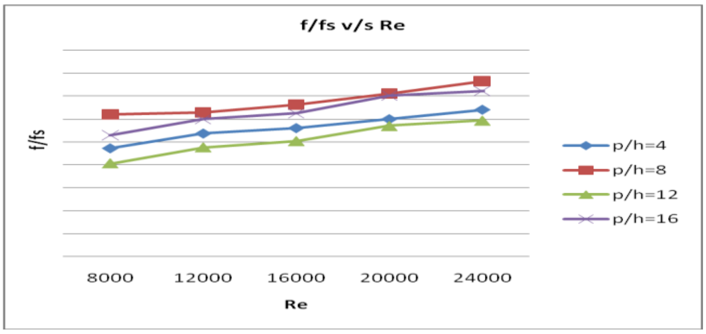

Fig 3.Variation of f/fs with Re (AR=5, h=6mm, Perforated ribs with 2mm dia. holes)

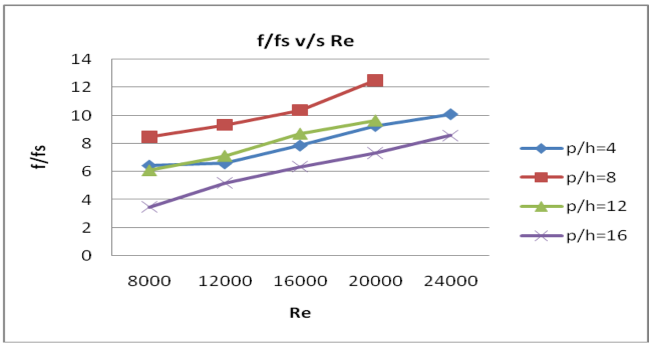

Fig 4. Variation of f/fs with Re (AR=3, h=10mm, Perforated ribs with 2mm dia. holes)

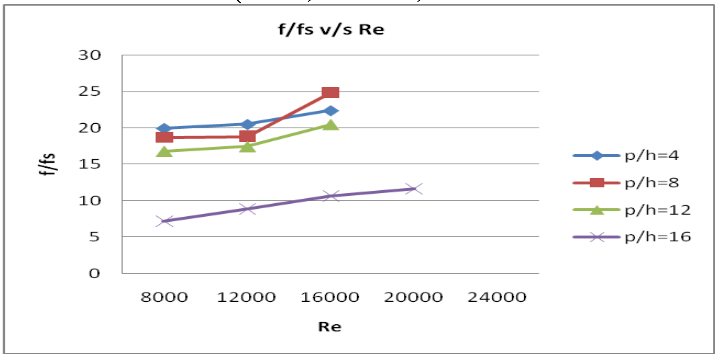

Fig 5. Variation of f/fs with Re (AR=2, h=15mm, Perforated ribs with 2mm dia. holes)

Effect of Pitch to Height Ratio *(p/e)* on Friction Factor Ratio *(f/fs)*

Figures 6 to 8 shows the effect of pitch to height ratio on friction factor ratio (*f/fs)* for different Reynolds number with ribs having aspect ratios *AR*=2,3 and 5.The axial distance between the two perforated ribs vortex generators plays an important role here. If the axial pitch of the perforated rib is small than the flow gets disturbed by the next perforated rib vortex generator resulting into high pressure drop. If the distance between the two adjacent perforated ribs vortex generator is high then pressure drop decreases and as a result of which friction factor ratio also decreases. Here the number of holes is 3 and all the 3 holes are of 2mm diameter. In fig 6 we can observe that friction factor ratio increases upto (p/h)=8 and then it gradually decreases upto (p/h)=12 and then again it starts (p/h)=16.This fluctuation is mainly due to the breakdown of vortices in the test section.If the axial pitch is small then flow gets disturbed by next perforated rib vortex generator resulting in breakdown of vortices.For the rest of the flow pattern is nearly the same.The flow collides the ribs and enters the perforations and leaves the ribs from the other side.

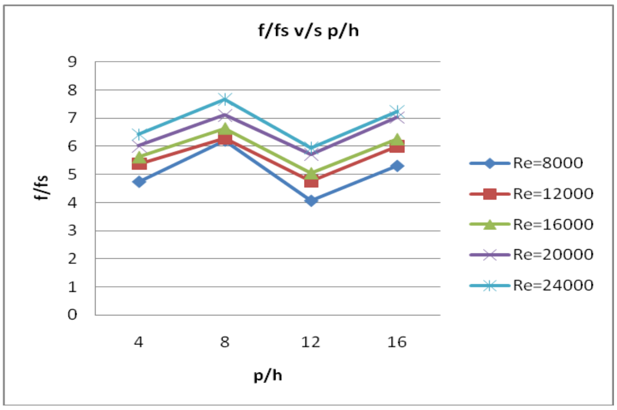

Fig 6. Variation of f/fs v/s p/h (AR=5, h=6mm, Perforated ribs with 2mm dia. holes)

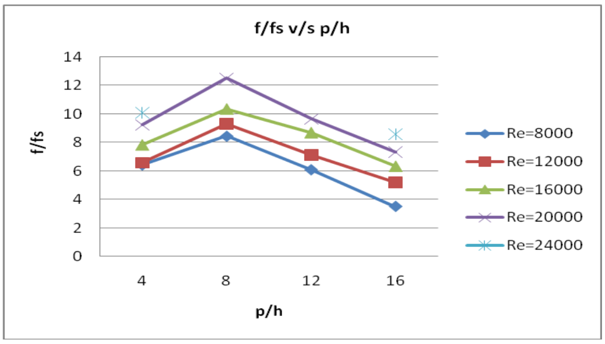

Fig 7. Variation of f/fs v/s p/h (AR=3, h=10mm, Perforated ribs with 2mm dia. holes)

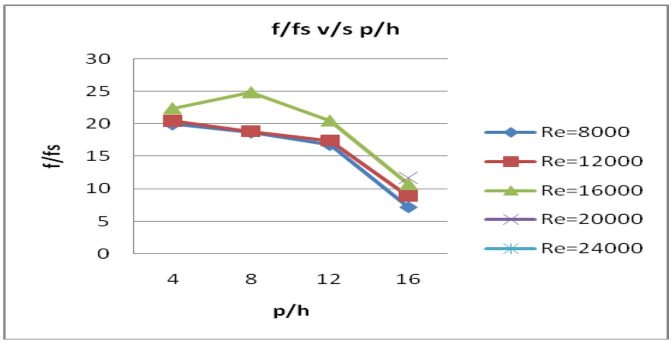

Fig 8. Variation of f/fs with p/h (AR=2, h=15mm, Perforated ribs with 2mm dia. holes)

Effect of Vortex Generator Aspect Ratio (*ar*) on Friction Factor Ratio (*f/fs*)

Figures 9 to 12 shows the variation of friction factor ratio with change in aspect ratio of perforated ribs vortex generator for different Reynolds numbers. Friction factor ratio increases with aspect ratio upto optimum value of p/h ratio. The size of the vortex generator plays an important role in generating vortices. When aspect ratio is less the height of vortex generator is high, hence vortices generated overlaps one over the other due to lesser axial pitch and hence laminar boundary layer gets disturbed because of which high turbulence is produced which causes blockage of air as a result of which pressure drop increases and hence friction factor ratio (f/fs) also increases.

If aspect ratio increases then height of vortex generator decreases thus the size of the vortex generator decreases hence blockage of the flow is very less compared to the vortex generator having lower aspect ratio. Therefore friction factor ratio decreases dramatically as height decreases due to less deflection and less bulk flow blockage. This can be noticed from graph friction factor ratio at aspect ratio 3 to aspect ratio 5.

From the above graph, friction factor ratio increases upto aspect ratio 3 and then it decreases steeply upto the aspect ratio value of 5.Friction factor ratio (f/fs) at aspect ratio 5 is 33.34% lower than that of the (f/fs) value at aspect ratio of 2 for corresponding (p/h) value of 16 at the Reynolds number of 8000.

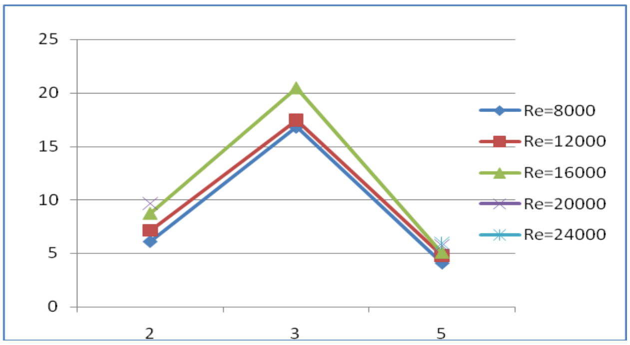

Fig 9.Variation of f/fs with AR (p=4mm, Perforated ribs with 2mm dia. holes)

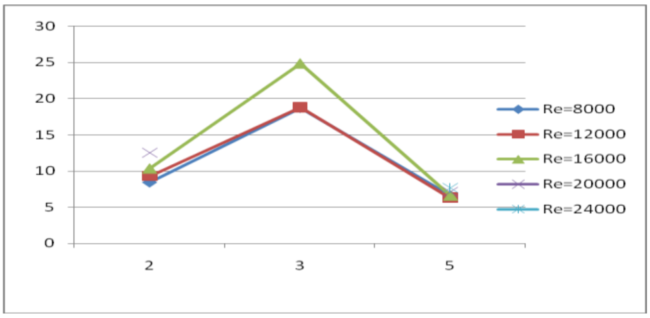

Fig 10: Variation of f/fs with AR (p=8mm, Perforated ribs with 2mm dia. holes)

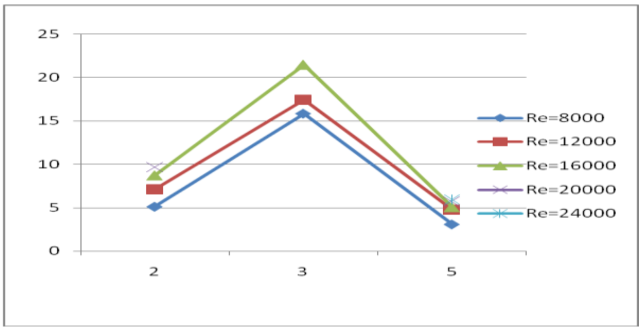

Fig 11. Variation of f/fs with AR (p = 12mm, Perforated ribs with 2mm dia. holes)

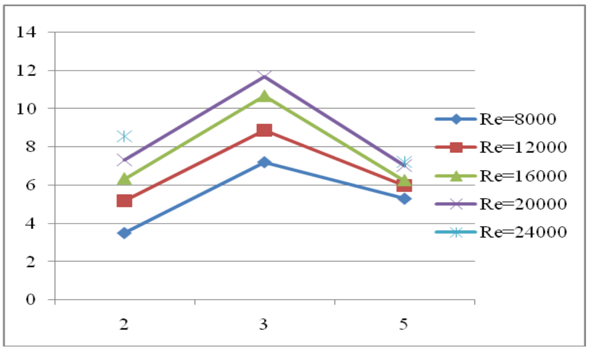

Fig 12. Variation of f/fs with AR (p=16mm, Perforated ribs with 2mm dia. holes)

VII. Conclusions

1.The friction factor ratio decreases with increase in Reynolds number in case of smooth channel but from the graphs it is observed that square duct having perforated ribs vortex generators the friction factor ratio increases as Reynolds number increases because in these ducts better mixing of air takes place and the vortex generator blocks maximum amount of air in ducts at higher Reynolds number.

For Aspect Ratio =5,h=6mm :The friction factor ratio at Reynolds number 24000 is 35.52% greater than the friction factor ratio at Reynolds number 8000.

2. It is observed from the results that for a flow in square channel that friction factor ratio decreases with increase in pitch to height ratio.AR=5, h=15mm:friction factor ratio at (p/h) = 16 is 45.61% lower than that of the friction factor ratio (f/fs) at (p/h) = 4.
3. For Aspect Ratio =5 and h=6mm friction factor ratio increases upto (p/h)=8 and then it gradually decreases upto (p/h)=12 and then again it starts increasing upto (p/h)=16. This fluctuation is mainly due to the breakdown of vortices in the test section.
4.From the graph friction factor v/s aspect ratio friction factor ratio increases upto aspect ratio 3 and then it decreases steeply upto the aspect ratio value of 5.
5.For 4 holes the highest value of friction factor ratio is at p/h=8 and it is of value 12.52 and for 8 holes the highest value of friction factor ratio is at p/h=8 and it is of value 24.86.

VIII. Nomenclature

A	=	Area (m^2)
A_1	=	Area at inlet (m^2)
A_2	=	Area at throat (m^2)
Q	=	Flow rate of air (m^3/s)
Cd	=	Co-efficient of discharge
g	=	Acceleration due gravity (m/s^2)
h	=	Height of perforated rib
L	=	Channel length (mm)
p	=	Pitch to height ratio
Re	=	Reynolds number
t	=	thickness (mm)
V	=	Velocity (m/s)
υ	=	Kinematic viscosity
W	=	Channel width (mm)
ρ	=	Density (Kg/m^3)
ff	=	Friction factor ratio between channels.
α	=	Angle of attack
AR	=	Aspect ratio
f/fs	=	Friction factor ratio
P	=	Pressure

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