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Flow Analysis of Air in a Rectangular Channel Using Perforated Rectangular Rib

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Abstract In this particular work the flow analysis of air in a rectangular channel with perforated ribs were investigated. Calculations are made for rectangular channel. Pitch to height ratio (p/e) of 4,8,12 and 16 on friction factor ratio (f/fs). The fluid used in this experiment is air, Reynolds numbers (Re) varied from 8000,12000,16000,20000 and 24000 and its effect on friction factor ratio (f/fs) were observed. It is noted that by increasing the Reynolds number (Re) the Friction factor ratio (f/fs) increases. And aspect ratio (AR) varied to 1.6, 1.87, 2.25 and 2.28, its effect also noted. The effect of flow of air on friction factor ratio by varying the Aspect ratio (AR), Reynolds number (Re), and pitch to height ratio (p/e) were observed. And also the effect of perforated ribs, number of holes on ribs and its effect on friction factor ratio calculated.
Keywords - aspect ratio, perforated ribs, friction factor, pressure drop, micromanometer

I. INTRODUCTION

Most of the engineering industry that require heat addition or removal and a wide variety of heat exchange devices are used in these applications. The basic principle of the heat exchanger is to accomplish heat flow from hot fluid to cold fluid. This is achieved by the conductive or convective properties of the fluid and fluid state, which is done according to Newton‟s Law of Cooling. Then it becomes very important where improved heat transfer with reduction in pressure drop as a measure of Performance enhancement is required. High temperature gas turbines, heat exchangers and in several engineering applications heat transfer is the basic need. There are numerous techniques are there to increase the heat transfer. In this particular experiment we are using perforated rectangular ribs to manipulate the flow field and they can provide a beneficial effect on the thermal performance. Many researchers widely considered and conducted various experiments inner flow of air in various test sections like circular, non circular channels triangular, rectangular, polygonal, square, trapezoidal etc.

Rectangular channels are considered In order to get effective cooling of turbine blades and vanes. And this project offers experimental result of hydrodynamics of air inside the rectangular channel. To boost the heat transfer between energy shipping fluid and its surface ribs are used. Holes in the ribs make a reduced amount of resistance of blocks against the flow which results drop in friction factor on comparing with the solid one. The angles of Inclination of perforation do not make any noticeable effect on pressure drop. By increasing the diameter of the perforation improves both heat transfer and pressure drop over the channel. Generally friction factor increases with increase in Reynolds number for both solid and perforated ribs. The slot and hole perforation generally behaves the same.

There are various number of means for advancing heat transfer coefficients, which are classified as active, passive, and compound. Active methods involve outside power, such as acoustic or electric fields, surface vibration or mechanical devices while passive methods will not require any external power however make use of a best surface geometry. Compound method will make use of more than one method for continuous enhancement. Only passive techniques are deliberated here. The passive method of heat transfer enhancement is derived from two major techniques: by disturbing thermal boundary layer and using bulk fluid mixing. Blocking and restarting of the boundary layer in presence of roughness elements causes an augmentation in heat transfer by making a boundary layer that is thinner on average than the continuous boundary layer. The temperature gradient in the core flow concentrating thermal gradients at the wall region reduces because of Vortices which is caused by bulk fluid mixing which. Such mixing can be effected with the help of vortex generators, ribs, dimples, or surface bumps.

II. REVIEW

Maziyar Jalaal, Ahmad Khoshnevis, Faramarz Talati, Esmaeil Esmaeilzadeh [1] has done experiment on a three dimensional channel with a heater and examined the effect of comprehensive surface perforation on thermal growth. They calculated using two types of perforations those were hole and slot perforations. And they solved the equation using the software FLUENT 6.3 at the

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Reynolds number ranging from 6000 to 40000. They concluded as in all cases by using the perforation that is holes in the ribs heat transfer increased. And also by increasing the perforation angle by 45 the local heat transfer increases because more fresh reaches the fresh air. The heat transfer increases by increasing the perforation angle. But hole diameter in the rib is very significant constraint, by keeping the perforation area as kept before and changing the diameter of the holes will acts dissimilar since more air spreads across the perforation. The jets may have a collision in the downstream and the effect makes very high turbulence and more heat transfer coefficient.In comparison with solid cases, Perforation resists the blocks against the stream and the effect is reduction in the friction factor. The angle of Inclination of perforation will not make any considerable effect on pressure drop. Both heat transfer and pressure drop over the channel can be improved by increasing perforation diameter. in both solid and perforated ribs as the Reynolds number increases then Friction factor generally decreases. Slot and hole perforations generally behave the same. It may differ in, by using hole perforation, more overall thermal performance was achieved, and for spot cooling purposes slot perforations are considered.

Mohammed Q. Al-Oda, Abdullah H. AlEssa and [3] have numerically studied heat transfer incrimination from rectangular fin with triangular perforations. The heat dissipation rate from the solid rib is compared with the equivalent perforated fin. Thermal properties of fin and the effect of the perforated fin were calculated briefly. They found the next points. The perforated fin can resulted in heat transfer augment, for some data of triangular dimensions. The thermal conductivity and thickness of the fin are directly proportional to amount of augmentation. The amount of heat dissipation rate increases for perforated fins is a complicated function of the perforation geometry, the fin dimensions and the fin thermo physical properties. The perforation of fins decreases the expenditure of the fin material and at the same time enhances heat dissipation rates.

Ary Bachtiar Krishna Putra, Se Kyung Oh and Soo Whan Ahn [5] had done numerical investigation on the heat transfer characteristics and turbulent flow in rectangular duct using various types of baffles. They used four dissimilar types of baffles. They used the Reynolds number ranging from 23,000 to 57,000.The final outcome of the flow field found that, the flow pattern around various baffles completely changes which affect the distinctiveness of heat transfer. The perforation density of the baffle plate will strongly affect the friction factor characteristics and the heat transfer. Its depicted that three hole baffle has more heat transfer enhancement. The perforated baffle passage has less friction factor, comparatively solid-type

Zinat Rahman Arani, Afsanul Tanveer, Mohammad Mashud, Md. Ilias Inam and [6] experimented; a solid cylindrical fin with circular grooves and threads at their outside surface were examined. The temperature at the fin is changed such that the base temperature is maintained constant at steady state. The outcome of the observation denotes cylindrical fin with 3.5mm depth circular grooves loses the heat to the most. On comparing with the threaded cylindrical fin the grooved cylindrical fin loses 1.23 approx time"s greater heat per unit area and upon comparing with the solid pin fin at a lower pressure than atmospheric pressure. The grooved fin loses 2.17 times more heat per unit area. As pressure reduces, heat loss decreases.

III. EXPERIMENTAL SETUP

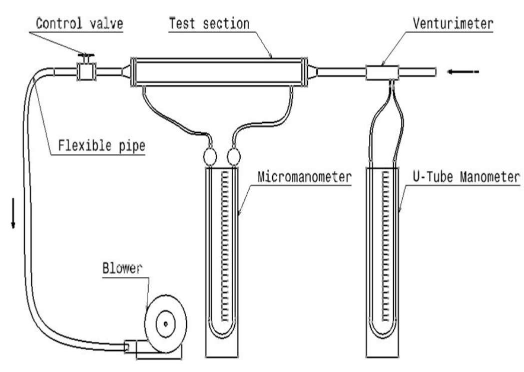

Fig.1 Experimental set-up

This setup is mainly consists of fallowing components.

Rectangular test channel

Venturimeter

Blower

Flow control (Gate) valve
U-tube Manometer and micro manometer
Connection pipes.

A. Rectangular Test Channel

The test section is the heart part of the experiment which is made by acrylic sheets. The Aspect ratio of duct is preferred to be 0.5. The test section includes top plate, bottom plate, flanges all these are fastened by nut and bolts. Two pressure taps are made to the bottom plate. So that test section is connected to the differential manometer in order to calculate the loss of pressure in test section after the use of perforated ribs.

B. Venturimeter

The instrument that is used to measure the flow rate through pipes is called as Venturimeter. It works on the principle; the difference in the pressure is created by reducing the flow passage and calculating the pressure allows tofind the discharge through pipe. The area at the inlet section is more and it gradually decreases towards throat hence the velocity at the throat increases and the pressure reduces. The difference of pressure at that section is measured by connecting the U-tube manometer between the tsp provided at that section. By measuring the difference in the pressure allows to calculate the rate of flow.

C. Blower

Blower is a device used to suck the air with high flow rate. In this experiment the blower with the following specifications were used.

D. Flow Control (Gate) Valve

The Gate valves are mainly used when the fluid flow is straight and minimum restriction flow is required. This valve is used to govern the flow capacity of the fluid by rotating the gate. It allows the only amount of flow how much the gate is rotated. This is also called as “Sluice valve”

When the air flow from the Venturimeter is passed in a circular pipe directly to the test section, lots of turbulence created. A uniform air flow is needed in the test section for that a transition piece is used in the experiment. A transition piece is made in such a way that its inlet is circular and its outlet is rectangular, so that the air flow enters from circular inlet which distribute all over the transition piece which is connected to the test section. Hence the transition piece helps in the uniform flow in the test section.

E. U-tube Manometer And Micro Manometer

U-Tube manometer is used to calculate the difference in the pressure due to the fluid flow in a pipe. The area at the inlet of the Venturimeter is more than the its throat because off this difference in area the velocity increases and the pressure reduces. This can be calculated by U-Tube manometer by connecting its one end to inlet of the Venturimeter and the other to the throat. Below figure shows the U-tube manometer. The Micro manometer is also used to find the difference in pressure of flowing fluids. This Micro manometer consists of two bulbs and also consists of two liquids in two limb gauge columns. The water is used as gauge liquid of density 1000kg/m3, and Benzyl alcohol as manometric liquid with density 1046 kg/m3. The above said liquids have 18.7 times magnification of pressure head in comparing with normal U-Tube manometer. This pressure drop reduces the error in the pressure drop.

F. Connection Pipes

To connect the all above said components connecting pipes were used in this experiment. 0.8mm leveling pipes were used to connect the Venturimeter to U-tube manometer and pressure taps at test section to Micro manometer. To connect the Venturimeter, test section, gate valve to each other 1 inch PVC pipe used. And the blower is connected to gate valve using 1inch flexible pipe.

G. Methodology

The methodology of the experiment starts with sucking of air by the blower, the air enters the Venturimeter in that it passes through orifice where difference in the pressure takes place which is connected to the U-tube manometer by 0.8mm leveling pipe. The air flow rate is maintained as required by using gate valve. Further the air passes through the test section, the pressure drops here because of the friction between air and rectangular channel surface. This pressure drop is investigated by observing the difference in the head of the benzyl alcohol in Differential manometer. By this we can calculate the friction variation in the duct. The friction factor for various perforated ribs with different height and pitch length can be calculated by repeating the same procedure.

IV. COMPUTATIONAL DETAILS

These are the parameters which are used in this experiment can be defined as according to the Nalawade M K. (2006).

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

Vortex generator height (e): the normal distance between the above surface of the vortex generator (perforated rib) and the surface of the wall upon which it is attached or glued is the vortex generator height.

Vortex generator base (b): the span wise dimension of the vortex generator at which it is glued to the wall surface is the base or span of vortex generator.

The non-dimensional parameters are;

Vortex generator height to channel hydraulic diameter ratio (e/Dh): this is the ratio of the height of vortex generator above surface, measured above the surface upon which they are glued, to the channel hydraulic diameter.

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

Aspect ratio (ar): the non-dimensional parameter, which is a measure of the shape and size, is known as aspect ratio of the vortex generator.

Roughened wall width of the channel to the vortex generator base ratio (N): this is the ratio of the width of the surface upon which vortex generators are glued to the base width of the vortex generator. Since, this value exactly equals the number of span wise rows of the vortex generators it is an integer.

The dimensionless friction factor is defined as ff/ffr where ff is friction factor of rectangular duct with vortex generator and ffr is friction factor of rectangular duct without vortex generator or smooth duct

The Reynolds number is defined as Re=ρv*Dh/μ where v is velocity of air in duct dh is hydraulic diameter, ρ is density of air and μ is Dynamic viscosity of air.

V. DATA REDUCTION

Flow rate through Orifice-meter

$$Q_{th} = C_d \frac{A_0 A_1}{\sqrt{A_0^{\,2} - A_1^{\,2}}} \sqrt{2g[\frac{\rho_w}{\rho_{air}} - 1]H} \qquad \text{Eq. (3.1)}$$

A_i= Area of pipe
A_o=Area of orifice
C_d=co-efficient of discharge

The Reynolds number based on the channel hydraulic diameter is given by

Reynolds number: $Re = \rho v D_h/\mu$ Eq. (3.2)

μ=absolute viscosity of air Pa s
v=Average velocity of air through the duct

Flow rate of Mass: $m' = \rho_a Q$ Eq. (3.3)

ρ_a = density of air

A differential manometer connected to pressure taps measures the decrease in pressure across the test duct. The measurement of pressure drop was done at the atmospheric temperature condition (i.e., tests without heating). In a fully developed duct flow using equation 3.4 according to Dr. D.S.Kumar (2008) .

$$P1-P2=2hg\rho_m \{1-\rho_{a}/\rho_m (1-a/A)+\rho_{w}/\rho_{m*a/A}\}$$ Eq. (3.4)

The friction factor was determined in terms of pressure drop across the test duct and the mass velocity of air using equation 3.5

$$ff = \frac{\Delta p}{[(4L/h)(\rho v^2/2)]}$$ Eq. (3.5)

The friction factor of the present study was normalized by the friction factor for fully developed turbulent flow in smooth duct ($10^4 <$ Re $< 10^6$) proposed by Blasius as.

$$fft = 0.046\,\mathrm{Re}^{-0.2}$$ Eq. (3.6)

VI. RESULTS AND DISCUSSION

A. Effects of Perforated Ribs

1) Effect Of Reynolds Number (Re) On Friction Factor Ratio (f/fs): From fig.2 it is noted that by increasing the Reynolds number (Re) the Friction factor ratio (f/fs) increases. As increase in the Reynolds number (Re) increases velocity of the flow inside the rectangular channel they are directly proportional to each other. The perforation in the ribs provides the more surface area which results in the enhancement in the pressure drop which in turn increases the friction factor ratio (f/fs). The Reynolds number is varied from 8000 to 24000. From graph it is clearly noted that friction factor ratio (f/fs) at 8000 is less than that at the 24000 at height 8mm and aspect ratio (AR) of 2.8, pitch to height ratio (p/e) of 4.

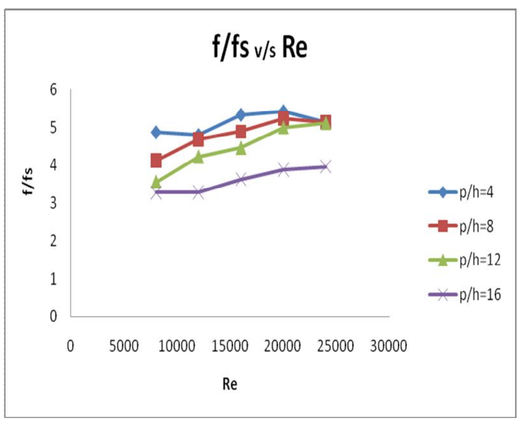

Fig.2. variation of f/fs with Re (AR=2.8, h=8mm)

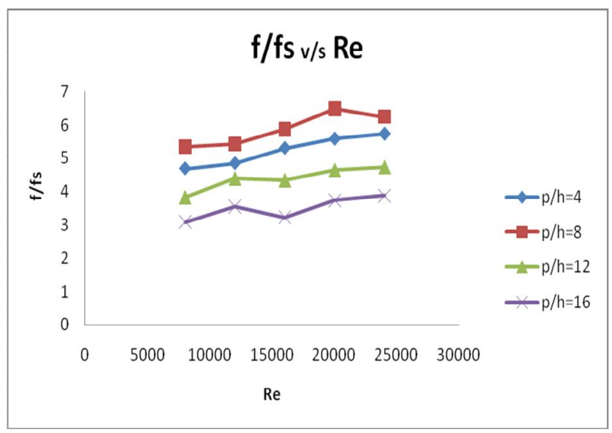

Fig.3. variation of f/fs with Re (AR=2.25, h=10mm)

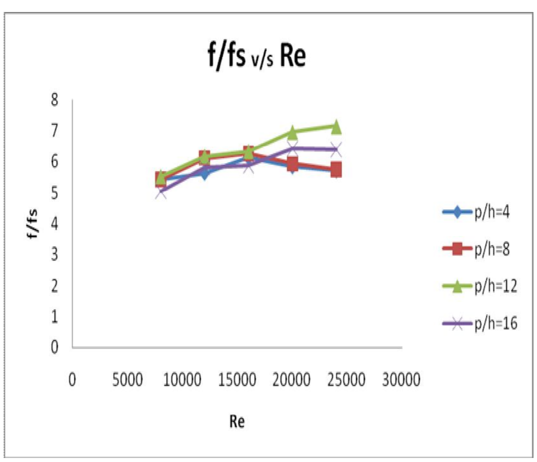

Fig.4. Variation of f/fs with Re (AR=1.87, h=12mm)

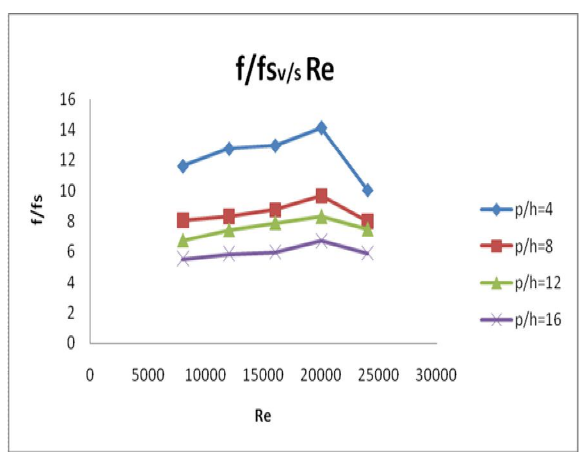

Fig.5. Variation of f/fs with Re (AR=1.6, h=14mm)

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2) Effect Of Pitch To Height Ratio (p/e) On Friction Factor Ratio (f/fs): The friction factor ratio (f/fs) reduces by increasing the pitch to height ratio (p/e) for various Reynolds numbers. The obstruction created by smaller pitch length in the test section i.e. the distance between the two ribs is smaller which increases the overall mixing of the flow results in the enhancement in the pressure drop. The overall mixing of the flow is directly proportional to pressure drop. As the number of holes increases in the ribs then more surface area is provided which results in the decrease in the pressure drop and hence the friction factor ratio (f/fs). Hence the friction factor ratio (f/fs) decreases by increasing the pressure drop. The friction factor ratio (f/fs) at p/e=4 is 15% higher than at p/e=16.

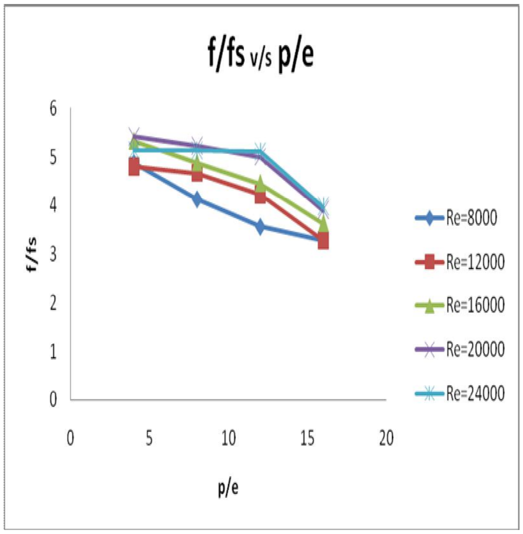

Fig.6. variation of f/fs with p/e (AR=2.8, h=8mm)

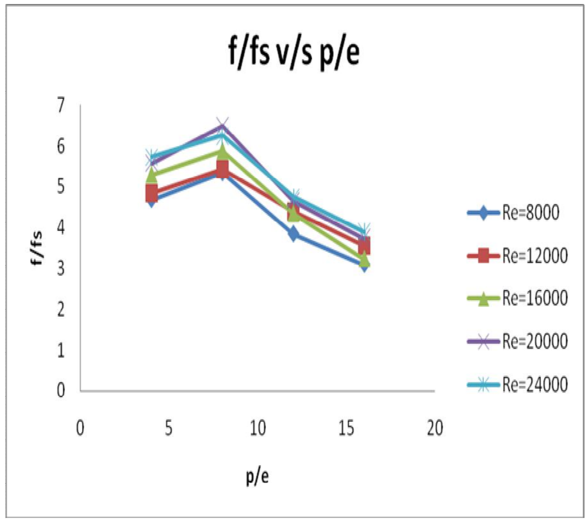

Fig.7. variation of f/fs with p/e (AR=2.25, h=10mm)

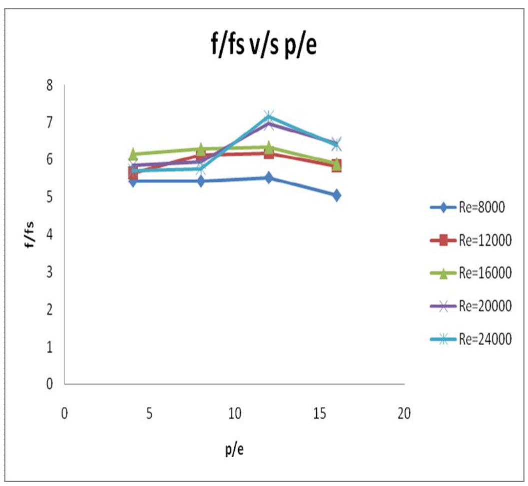

Fig.8. variation of f/fs with p/e (AR=1.87, h=12mm)

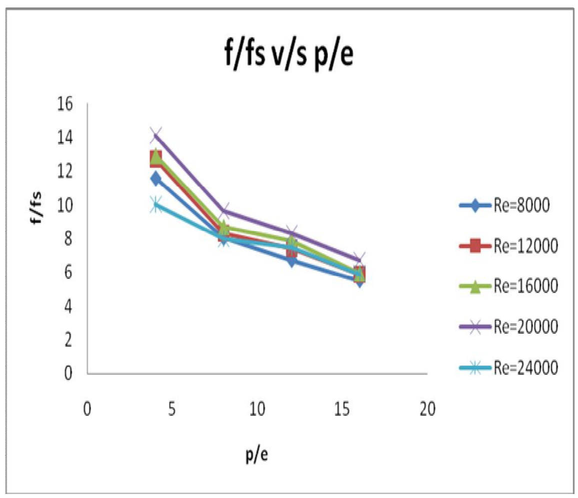

Fig.9. variation of f/fs with p/e (AR=1.6, h=14mm)

3) Effect Of Vortex Generator Aspect Ratio (AR) On Friction Factor Ratio (f/fs): From graph it is clearly observed that by increasing the Aspect ratio (AR), friction factor ratio (f/fs) decreases. This is because it is strongly related to the height of the ribs, as the aspect ratio increases height of the ribs decreases and as the height decreases the number of holes also decreases hence pressure drop reduces this can be recognized by the obstruction in the flow which is by reverse flow due to the presence of perforated ribs in the test section. Also the pitch length decreases these results in the fewer blockages to the flow which decreases the formation of vortices in the rectangular test section. Hence pressure drop reduces which ultimately results the decrease in the friction factor ratio (f/fs).

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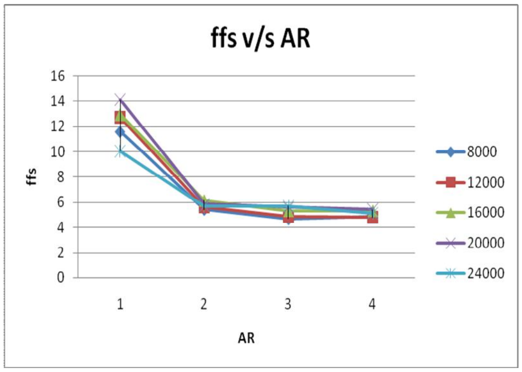

Fig.10. variation of f/fs with AR (p/e=4)

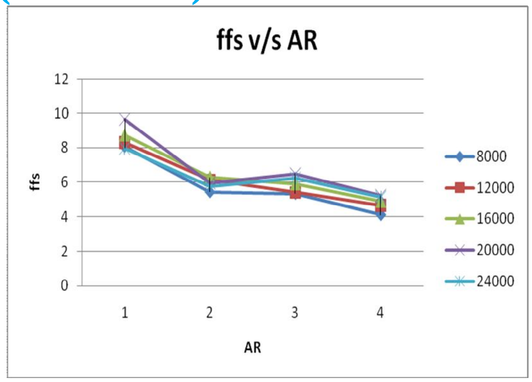

Fig.11. variation of f/fs with AR (p/e=8)

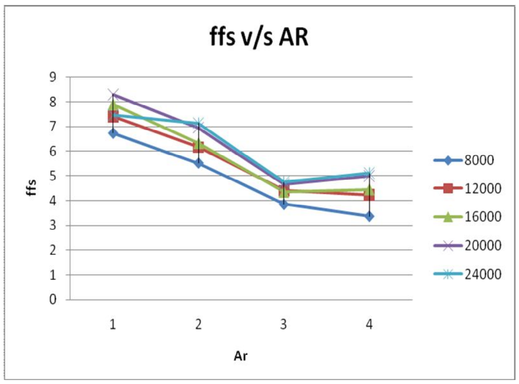

Fig.12. variation of f/fs with AR (p/e=12)

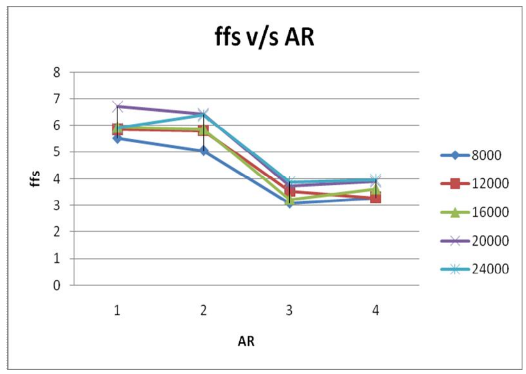

Fig.13. Variation of f/fs with AR (p/e=16)

VII. CONCLUSION

In this experiment conducted in rectangular channel with perforated ribs to attain pressure loss/ friction factor. The results obtained during the experiment concluded as:

The effect of Pitch to height ratio (*p/e*) on friction factor ratio in rectangular channel with perforated ribs obtained. With different aspect ratios, different heights of the ribs and various pitch lengths can be done. And upon comparing all the results it is concluded that; friction factor ratio (f/fs) decreases upon increasing the Pitch to height ratio (*p/e*). Friction factor ratio (f/fs) at p/e=4 is 86% and at p/e=16 is 51% hence it decreases around 34%.

The effect of Reynolds number (Re) on the friction factor ratio (f/fs) was also examined and discloses that increase in the Reynolds number (Re) increases the friction factor ratio (f/fs). As increase in the Reynolds number (Re) increases velocity of the flow inside the rectangular channel they are directly proportional to each other. The perforation in the ribs provides the more surface area which results in the enhancement in the pressure drop which in turn increases the friction factor ratio (f/fs). Friction factor ratio (f/fs) at Re=8000 is 75% and at Re=24000 is 87% hence it is increased by approximately 12%.
The effect of smooth channel also examined and concludes that by increasing the Reynolds number (Re) decreases the friction factor ratio (f/fs). But by using the perforated ribs the results conclude that increase in the Reynolds number (Re) increases the friction factor ratio (f/fs). As above point 2 said.
The friction factor ratio (f/fs) decreases as Aspect ratio increases. Friction factor ratio (f/fs) at AR=1.6 is 31.6% and at AR=2.8 is 82.7% hence friction factor ratio (f/fs) decreases by approximately 50%.

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