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Experimental Investigation of Pressure Drop Characteristics in A Square Channel Using Detached Ribs as Vortex Generators

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Abstract: ***In recent day it is very necessary to find heat transfer characteristics of heat exchanger, heat exchanger as an important equipment widely used in day to day life, like in industry, home appliances, gas turbine, transportation, power production, in aircraft etc. the improvement of heat transfer performance of heat exchanger can done by using insertion of vortex generators in a square channel. The experimental study is conducted to examine the pressure drop characteristics in a square duct with different geometrical configuration of detached ribs, Detached Ribs as vortex generators are inserted 90˚ in a square duct having different aspect ratio (AR) of 2, 3, 5. The effect of width, pitch ratio (P/H) of inserting vortex generator, flow direction and aspect ratio of duct are examined for Reynolds numbers (Re) based on hydraulic diameter of square duct D_h, and it is in the range of 8000 to 24000. The results shows if pitch to height increases friction factor ratio decreases by 38.98% , if Reynolds number increases , 9.42% time friction factor ratio increases , if aspect ratio increases friction factor ratio decrease by 90.03%. The experiment is repeated for different AR of vortex generators 2,3,4,5, pitch ratio (P/h), width 15, 10, 6mm for different Re = 8000, 12000, 16000, 20000, 24000.***
Keywords: Square duct, detached ribs, pressure drop, vortex generator, Aspect ratio, Friction factor ratio

I. INTRODUCTION

Heat exchangers are used in almost all the industrial plants, transfer of hot fluid to cold and likewise , use of heat exchanger is there from olden days to till date and it will be continued, the principle is same from olden days to till today but there are changes in the use of techniques. and in future for better heat transfer enhancement and to improve pressure drop vortex generators as an obstacle in heat exchanger will be used. More industrial engineers and researchers focus on investigating the heat exchangers because of their wide use in industry, channel flow has got more importance in engineering industry because of their application, the channels may be rectangular, square, triangular, circular, non circular, trapezoid, and polygonal. In this paper, we are using square channel to achieve effective cooling and more compactness, detached ribs are used as vortex generators, the experimental result for detached ribs for different configurations are shown, the influence of pitch to height ratio, aspect ratio of vortex generator for different Reynolds number and pressure are discussed

K. yongsiri, p .Eeiamsa-ard, k. wongchare, S. eiamsa-ard (**2013**): In this paper researcher have taken the incline detached-ribs with different angle of attacks(θ) 0˚, 15˚, 30˚, 45˚, 60˚, 75˚, 105˚, 120˚, 135˚, 150˚, 165˚ with different Reynolds range from 4000 to 24000 for heat transfer, pressure loss, thermal performance and compare with the attached ribs of θ = 90˚. In CFD results at inclined ribs at θ = 60˚and 120˚ heat transfer, thermal performance factors are high than the other inclined ribs. In flow structure and temperature field for Reynolds number 4000, inclined detached ribs of angles 45˚, 60˚, 75˚, 90˚, 105˚, 120˚, 135˚ 150˚ create more recirculation zone after the ribs and also at the angles 0˚, 15˚, 30˚ and 165˚ we can't find recirculation zone, result include that medium angle of attack give better mixing of fluid. Amnart Boonloi (**2014**): Researcher use the 30˚ V-shaped baffles as the vortex generator placed on the double side of the thin with plate and without plate to perform heat transfer and thermal performance in a square duct, here 30˚V-shaped vortex generator are inserted diagonal to the square for different Reynolds number based on the hydraulic diameter square duct D_h, he find effect of the flow direction (V-Downstream and V-Upstream), pitch ratio, blockage ratio .G.V.Phadtare, Dr.A.A.Pawar, Dr.S.L.Brose, and S.V.channapattana (**2013**): They used vortex generator of preformatted aluminum plate with thickness 7mm and different dimensions of 3mm X 3mm, 5mm X 5mm, 7mm X 7mm, upstream and downstream for various Reynolds number between 45000 to 80000 with aspect ratio 1. Here they made test section with wooden

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they examined thermal and hydraulic action were investigate experimentally for the stationary square 180˚ degree bend change. In this experiment they find heat transfer co-efficient of the winglet vortex generator might have 108 times higher than the smooth tip. They examined that if with Reynolds number than Nusselt number also increases for both upstream and downstream. For heat transfer upstream shows good results than downstream for different shapes of vortex generator. Plate 7mm X 7mm vortex generator produces good heat transfer than the other two shapes of vortex generator. Yinxio zhan, Tae seon park (**2012**): In this experiment the study is to illustrate the effect of tilt angle of oblique plate for heat transfer and pressure drop for different Reynolds number Re = 200, 600, the tilt angle ranges from 50˚ - 130˚.This experiment is conducted on computational and shows that pressure drop and heat transfer heavily depends in tilt angle and Reynolds number. When the angle near the 90˚-100˚ the wall heat transfer is more. In this experiment the vortex generator is attached to the upper wall of channel through glue and studied by using finite volume method. In steady state the effect of tilt angle for pressure drop and heat transfer is not explicit, but when in unsteady state the tilt angle give affect noticeable on the heat transfer and pressure drop, when tilt angle α=90˚,100˚ it give better mixing of thermal and wall heat transfer

II. EXPERIMENTAL SETUP

The experimental model is as shown in fig .1 the test section consists of square duct with dimension 30mm x 30mm x 900 mm. This test section is made up of Acrylic sheet having thickness 8mm, and two pressure taps were fitted for measurement of pressure drop across the test section, to this pressure taps micro manometer is connected through the transparent and flexible pipe, Venturimeter and test section are connected through PVC pipe of diameter 30mm, in Venturimeter two pressure taps are connected to U-tube manometer through transparent and flexible pipe. Inside the test section detached ribs as vortex generator are fixed on to bottom surface with adhesive. The distance between two pressure taps is 850 mm and between the pressure taps the vortex generators are fixed, gate valve is connected through PVC pipe to test section and then gate valve to blower is connected by flexible pipe of diameter 32 mm

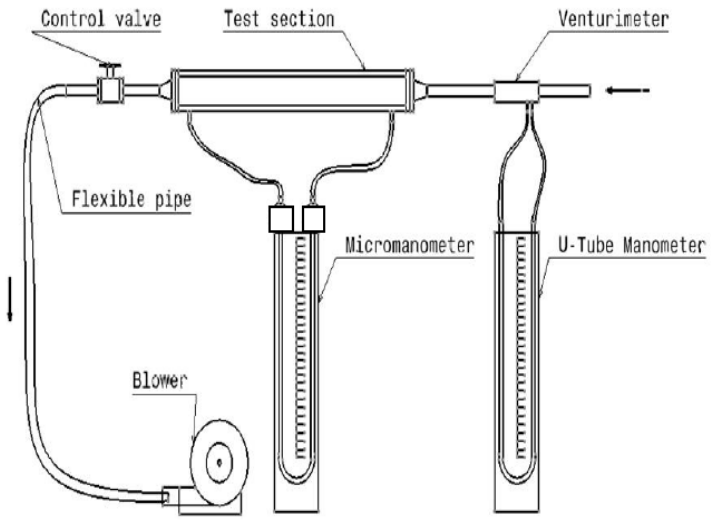


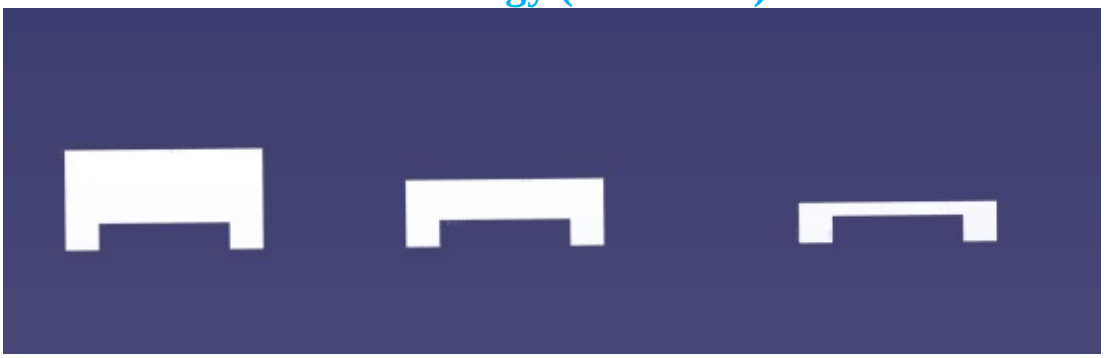
Fig. 1: Experimental setup

In this experiment blower sucks air through atmosphere and that air enter the Venturimeter, when air passes through Venturimeter there will be pressure difference in U-tube manometer and then air passes through the test section causing pressure drop in micro manometer, in this test section pressure drop occur due to friction, surface area and air passing into Venturimeter and test section is controlled by gate valve, we fix the Reynolds number by controlling air through gate valve, the readings in U-tube manometer and then in the micrometer are noted down. Same procedure is continued for different Reynolds number for different geometrical configuration of vortex generator and the readings are noted down in micro manometer.

A. Detached Ribs as Vortex Generator

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W=29.5mm, B=15mm W=29.5mm, B=10mm W=29.5mm, B=6mm

Fig. 2: Different heights of detached ribs

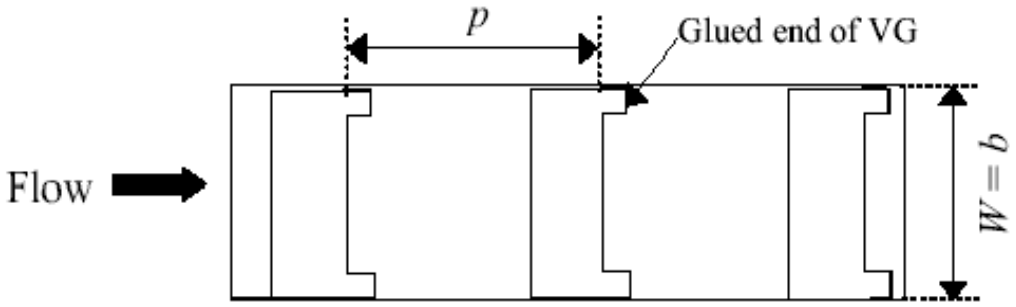


Fig. 3: Arrangement of detached ribs

III. DATA COLLECTION AND ANALYSIS

In the present work

Height of Gap for detachment of ribs from base = 4mm.

Actual discharge (Q_{act}) is calculated: $Q_{act} = V/t$ m^3/s

Theoretical discharge (Q_{th}) is given by the formula; $Q_{th} = \frac{a_1 \times a_2 \times \sqrt{2gH}}{\sqrt{(a_1^2 - a_2^2)}}$ m^3/s the

coefficient of discharge is give by the formula: $C_d = Q_{act}/Q_{th}$

Reynolds number is given by the formula: $Re = \frac{V \times \rho_w \times d_1}{\mu}$

$v = \frac{Qact}{a_1}$ m^3/s

ρ_w = density of water = 1000 Kg/m^3

μ = dynamic viscosity of water 8.9×10^{-4} Ns/m^2

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A micro manometer is connected across the square duct in order to measure the pressure drop in duct. The pressure is given by

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

Actual frictional factor based on pressure drop across the duct is given by

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

According to Blasius the friction factor in smooth channel (10^4<Re<10^6) for turbulent flow is given by;

$$ff_t = 0.046Re^{-0.2} \quad (3)$$

IV. RESULT AND DISCUSSION

A. Variation Of Pitch-To-Height (p/h) With Friction Factor Ratio (f/fs)

Fig.4 to 6 shows variation of pitch on friction factor ratio (f/fs) with different Reynolds number for detached ribs having different Aspect ratio AR = 2, 3, 5 and different width h = 6, 10, 15 mm in square channel .If pitch-to-height (p/h) increases than friction factor ratio (f/fs) will decrease as shown in fig 4 to 6 . If small pitch-to-height (p/h) gives smaller axial distance, it means distance between vortex generator are very small for this reason when air pass it get obstruction in the channel for this reason we get high friction factor ratio and high pressure drop, due to high friction factor ratio there will be increasing in mixing of flow and also increase in pressure drop. When height of vortex generator increases friction factor ratio value also increases and increase in pressure drop in fig 6. In fig 4 we compare higher friction factor ratio for pitch-to-height 16 and 4, we found that higher value pitch to height at (p/h) 16 is 42.42% time less than the friction factor ratio (f/fs) at lower value pitch to height at (p/h) 4 for Reynolds number 24000. In fig 5 we take pitch to height ratio 8 and 16 for Reynolds number 24000, because for p/h = 4 friction factor ratio is out of range for Reynolds number 24000, higher value pitch to height at (p/h) 16 is 40.40% less than the lower value pitch to height at (p/h) 8.In fig 6 we take pitch-to-height ratio12 and 16 for Reynolds number 16000, because for Reynolds number24000 and 20000 and also for pitch-to-height4and 8 is out of range, higher value pitch to height at (p/h) 16 is 34.12% less than the lower value pitch to height at (p/h) 12.

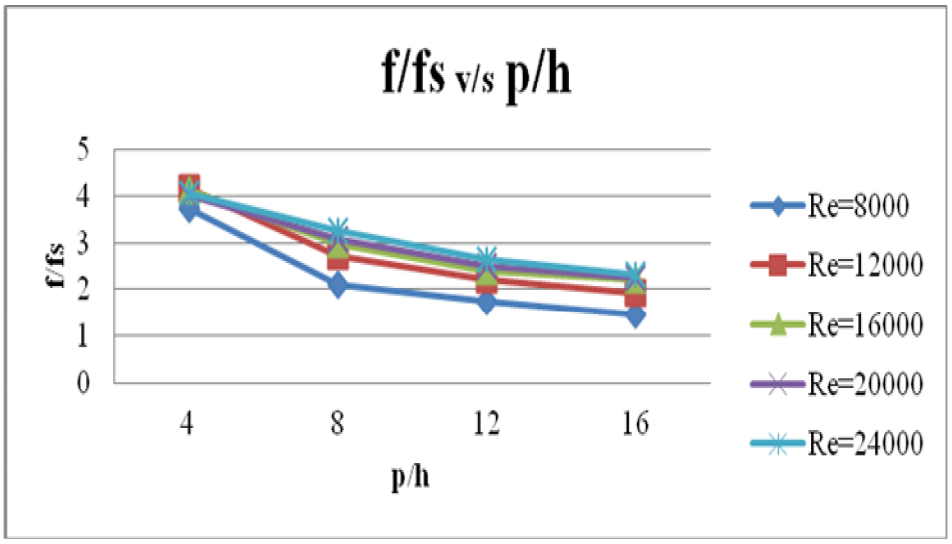


Fig. 4: variation of f/fs with p/h (AR=2, h=6mm), Detachment=4mm

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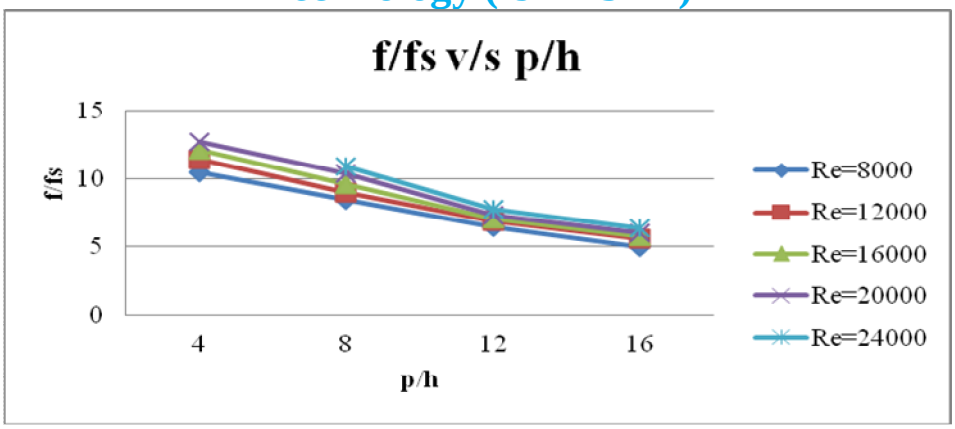


Fig. 5 : Variation of f/fs with p/h (AR=3, h=10mm), Detachment=4mm

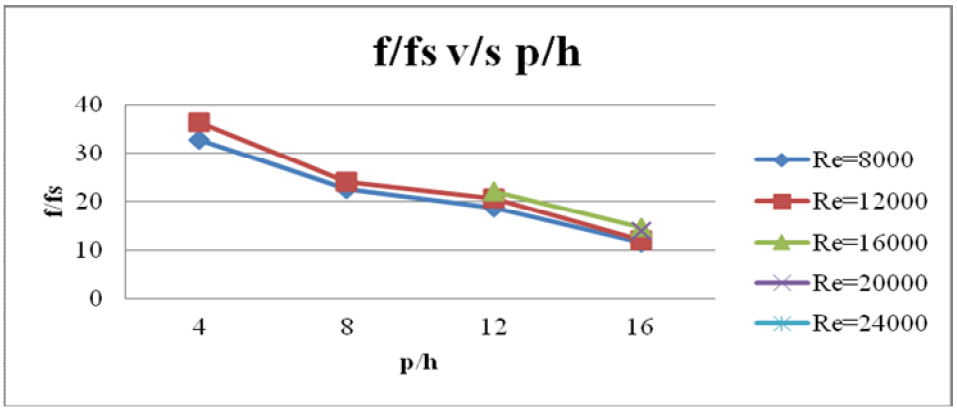


Fig 6: Variation of f/fs with p/h (AR=5, h=15mm), Detachment=4mm

B. Variation Of Reynolds Number (Re) With Friction Factor Ratio (f/fs)

Fig.7 to 9 shows the variation of Reynolds number (Re) with friction factor for pitch to height (p/h) for detached ribs having different aspect ratio (AR) 2, 3, 5 in square channel. Comparing all the graphs from fig 7 to 9 we can see only small friction factor ratio variation from all graphs. If Reynolds number increases friction factor ratio also increases, if fluid velocity increases than Reynolds number (Re) also increases and automatically friction factor ratio also increases.

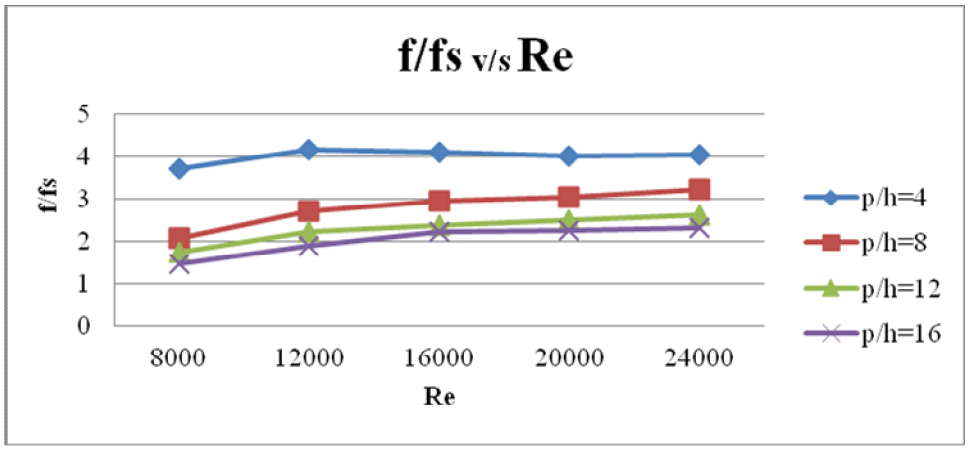


Fig 7: Variation of f/fs with Re (AR=2, h=6mm), Detachment=4mm

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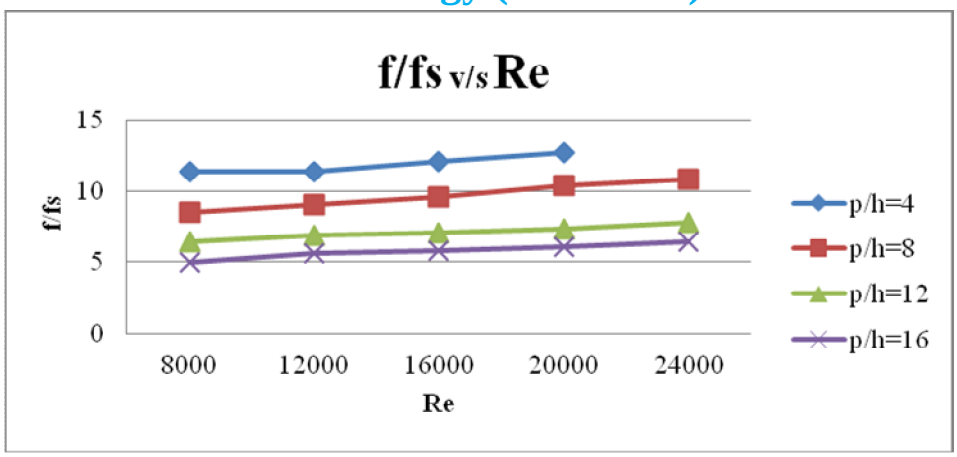


Fig 8: Variation of f/fs with Re (AR=3, h=10mm), Detachment=4mm

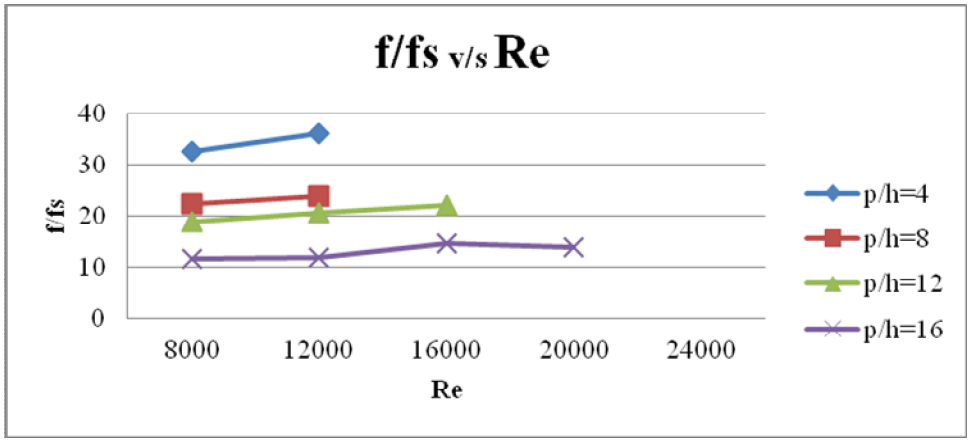


Fig 9: Variation of f/fs with Re (AR=5, h=15mm), Detachment=4mm

In fig 7 friction factor ratio for Reynolds number 24000is 8.20% time more than the friction factor ratio for Reynolds number8000 for pitch to height (p/h) 4. In fig 8 graph friction factor ratio for Re 20000 is 10.3% time more than the friction factor for Re 8000, here we taken Re 20000 instead of 24000 because for Re 24000 friction factor ratio will be out of range. In fig 9 graph friction factor ratio for Re 12000 is 9.76% more than the friction factor ratio Re 8000 for (p/h) 4, her we taking 12000 instead of 24000, 20000 and16000 because for Reynolds number 24000 to 16000 friction factor ratio will be out of range, because if height increase friction factor ratio increase, the vortex generator top face is flat surface not a tip due to flat surface fiction factor will be more friction factor than tip surface.

C. Variation Of Aspect Ratio (Ar) With Friction Factor Ratio (f/fs)

Fig 10 to 13 shows the variation of friction factor ratio and aspect ratio (AR) for detached ribs with Reynolds number 8000 to 24000 and height h = 6,10,15 mm. If aspect ratio (AR) increase friction factor ratio (f/fs) decreases, AR=2 has higher value than the remaining AR 3 and 5, because of the height of vortex generator, so when height increases friction factor ratio value also increases, vortex generator top plate is not a tip surface it has flat surface, for flat surface there will be better mixing of air flow in square channel.

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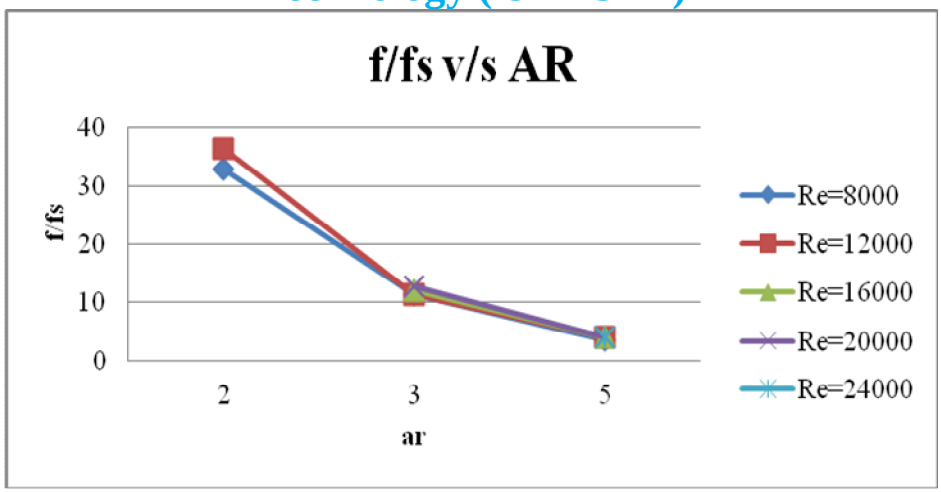


Fig 10: Variation of f/fs with AR (p=4mm), Detachment=4mm

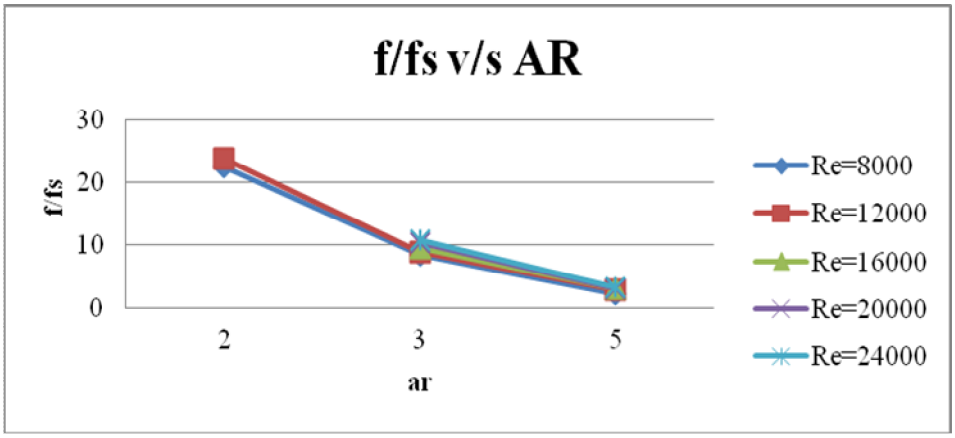


Fig.11: Variation of f/fs with AR (p=8mm), Detachment=4mm

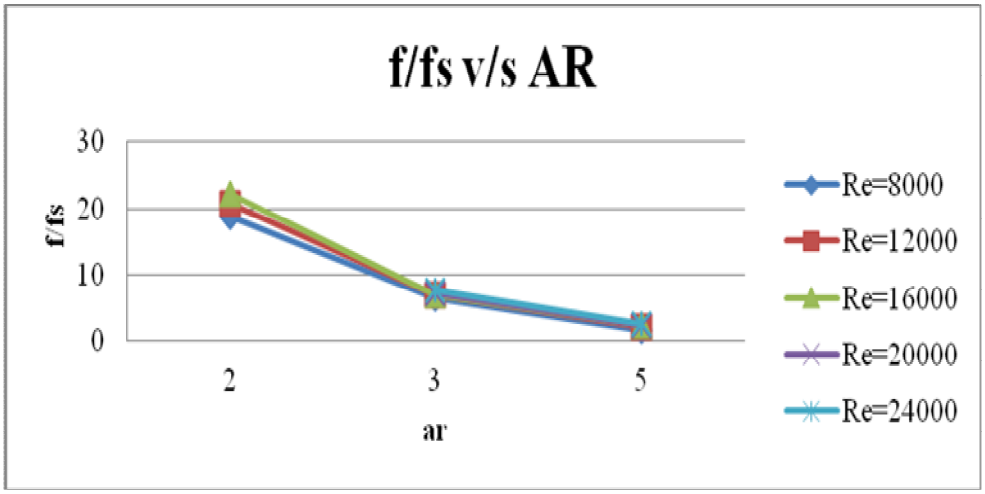


Fig 12: Variation of f/fs on AR (p = 12mm), Detachment=4mm

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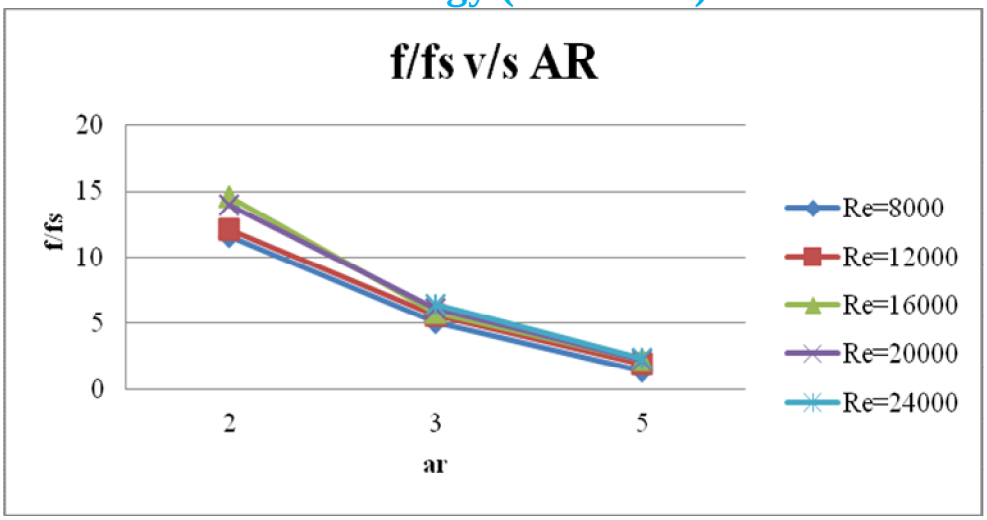


Fig 13: Variation of f/fs on AR (p=16mm), Detachment=4mm

In fig 10 Friction factor ratio (f/fs) for aspect ratio (AR) 5 is 88.64% is lower than friction factor ratio (f/fs) for aspect ratio (AR) 2, for Re = 24000, 20000, 16000 the friction factor will be out of range, because when height of vortex generator increase friction factor ratio will high value for that reason Re = 24000 for that reason Re = 24000 is only for AR = 5 there will be high obstruction automatically friction factor ratio value increases. In fig 11 Friction factor ratio (f/fs) for aspect ratio (AR) 5 is 90.75% lower than the friction factor ratio for aspect ratio (AR) 2 for 8000 Reynolds number (Re), here for AR 2 , Re = 24000, 20000, 16000 friction factor ratio will be out of range , compare to fig 5.8 the friction factor is lower than the fig 5.9 due to decreases in pitch, if pitch decreases friction factor also decrease because there will less blockage for that reason there will less mixing of air flow this results less pressure drop . In fig 12 Friction factor ratio for aspect ratio (AR) 5 is 90.72% lower than friction factor for aspect ratio (AR) 2 for Reynolds number (Re) 8000 and for AR = 2 Re = 20000 and 24000 will be out of range due to increase of pitch there will less friction factor, because of less blockage in channel and less pressure is take place hence friction factor decrease. In fig 13 Friction factor ratio for aspect ratio(AR) 5 is 87.37% for friction factor ratio for aspect ratio (AR) 2 for Reynolds number 8000 and for AR = 2, Re = 24000 will be out of range, comparing from graphs 5.8, 5.9 and 5.10 friction factor value is continuously decreases because pitch value increase , if distance between two adjacent vortex generator is more than there will be less disturbance or less friction in the channel and there will less mixing of air flow due to this there will be less pressure drop.

V. CONCLUSIONS

The following conclusions can be drawn from this work:

If pitch to height increase then friction factor ratio decrease, if pitch to height increase then friction factor ratio decrease by 38.98%, because if pitch distance between two vortex generators increase their will be less friction or disturbance in the duct.

If Reynolds number increase friction factor ratio also increase because there will be better air mixing flow because of vortex generators, when Reynolds number is low, low velocity of fluid will have low air mixing, when Reynolds number increases, 9.42% time friction factor ratio also increase.

If height of vortex generator increases then friction factor ratio also increases, because it is depended upon dimension of duct and if height of vortex generator is half of duct then there will be greater friction factor ratio and if height of vortex generator is (1/3) rd of duct then there will be lesser friction factor ratio.

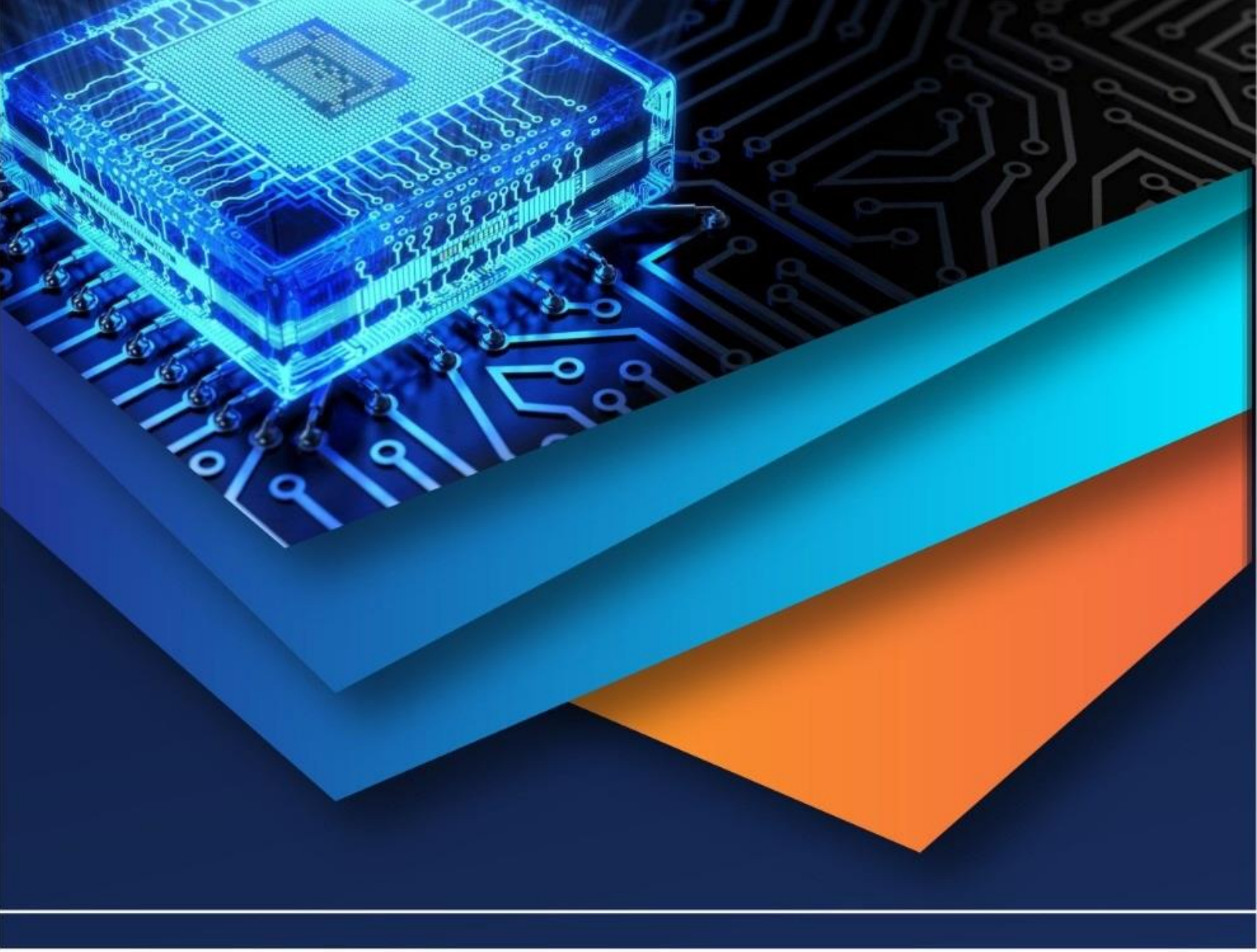
If aspect ratio (AR) increases friction factor ratio decreases, when aspect ratio increase then friction factor ratio decreases by 90.03%, because of the height of vortex generator and also the angle of attack, which is placed at 90^{0}.

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