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THREE DIMENSIONAL NUMERICAL ANALYSIS OF HEAT TRANSFER BY FORCED CONVECTION THROUGH HEAT SINK WITH RECTANGULAR RIBS

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Abstract— Numerical simulation of heat transfer in the rectangular fin type of heat sink has been made under various operating conditions. Commercially available software package Ansys Fluent is used for the purpose. The methodology is validated by analyzing the flow through rectangular channel with heat transfer. The computed result is compared with the standard available data and it is concluded that 'k-ω' turbulence model gives best element in case of turbulence flow. In the present study the methodology has been validated by CFD then it is used to analyse the heat transfer characteristics of plate fins with rectangular ribs. Analysis have been made for various dimensions and spacing of the ribs. It is observed that the introduction ribs enhance the heat transfer capabilities. They effect of flow velocities on Nusselt number at various rib length(0.2mm,0.3mm,0.4mm, and 0.5mm) as well as diagonal pitches(1.25mm,1.5mm,1.75mm, and 2mm) have been quantitevely analyzed. The analysis shown that rib length 0.5mm and diagonal pitch 1.25mm gives the highest enhancement in the heat transfer. The provisional of ribs also result in increases in the pressure drop through the passage. Hence it is necessary to optimize both heat transfer co-efficient and pressure drop simultaneously.

Keywords—CFD, Rectangular ribs, pressure drop, Nusselt number, Friction factor**.**

I. INTRODUCTION

The rapid developments in the electronic technology and electrical appliances has resulted an increase in the heat flux while at the same time there is a need to keep the component sizes small. The effective increase in the component temperature has necessitated the improved design of the cooling systems so that the temperature can be maintained within the liable limits. Hence there is a need to design of the heat sinks which are used for cooling purposes in such devices

II. LITERATURE SURVEY

Gui-Lian Wang, and Da-Wei Yang **[1],** proposed numerically and experimentally investigated the heat transfer and performance of heat sinks with variously-shaped micro-ribs, *i.e.*, rectangular, triangular and semicircular ribs. Thermal performance of air cooling through mini channel heat sink with various configurations in order to increase the rate of heat transfer to air stream, by increasing its channel's base temperature.

Experimentation was studied by 'Sandeep Jaiswal and Dr. K. R. Aharwal **[2].**proposed three-dimensional CFD simulations are carried out to investigate heat transfer and fluid flow characteristics of artificially roughened duct using Ansys- Fluent. Fluid flow and heat transfer of different roughness configurations are simulated and results compared using turbulent flow model (k-ω, with SST*)*, with steady-state solvers to calculate pressure drop, flow, and temperature fields. Rectangular duct has an aspect ratio of 5, while the domain length for numerical analysis is kept 450 mm long. The bottom wall of the duct is roughened by two different geometries of discrete ribs. Reasonable difference is found between the heat transfer simulation data for different roughness configurations.

Fifi N.M. Elwekeel and Antar M.M. Abdala **[3],**proposed by numerical studies are carried out to investigate the heat transfer in rectangular duct roughened by square and trapezoidal shaped ribs on one wall using different fluids. The coolant fluids such as air, steam, air/mist and steam/mist were investigated. The computational results show that the shear stress transport (SST) turbulence model is selected by comparing the predictions of different turbulence models with experimental results. Both heat transfer and pressure drop increases with different velocity.

Experimentation was studied by Seri Lee **[4],** have observed optimizing the thermal performance of bidirectional Heat sinks in a partially confined configuration. Sample calculations are carried out, and parametric plots are provided, illustrating the effect of various design parameters on the performance of a heat sink.

Ravishankar Prasad Maurya and Ankesh Kumar Pataskar **[5],** have observed that the pressure drop is proportional to width and inversely proportional to length of the grooved type rib. Investigations are on the thermal resistance of groove shape rib and also on performance of heat sink with variable rib attached along with uniform rib.

L. Arulmurugan, M. Ilangkumaran and, K. Vishnu Prakash **[6],** was proposed by experimentally investigation on thermal performance and effect of PCM based heat sink with different ribs. Modern portable electronic devices have seen component heat load increasing, while the space available for heat dissipation has decreased. This requires the thermal management system to be optimized to attain the high performance heat sink. The results of an experimental investigation of the performance of pin fin heat sinks filled with phase change materials for thermal management of electronic device.

III. CFD METHODOLOGY

Methodology is nothing but the step by step course of action with which a CFD code works. A proper methodology is essential for any practical problem to be solved. Computational fluid dynamics (CFD) is a computer-based simulation method for analyzing fluid flow with heat transfer. It will be advantageous to use CFD, since large amount of results can be produced at virtually no added expense. Parametric studies to optimize equipment are very inexpensive with CFD when compared to experiment. Numerical analysis of fluid flow and heat transfer problems will require proper methodology to solve the governing equations of motion subject to appropriate boundary conditions .In the present study ANSYS FLUENT 14 software is used for analysis. It uses finite volume method to solve the equations and it is very essential to ensure that the flow domain is descretized properly. The governing equations like conservation of mass, Navier-Strokes equations and energy equations have to be solved simultaneously. In addition, if the flow is turbulent proper choice of the turbulence model is very crucial. Thus any methodology needs to be validated by using a standard problem.

A. SOLUTION DOMAIN AND BOUNDARY CONDITIONS

Study involves the numerical analysis of forced flow of cooling air through rectangular channels with rectangular ribs. The dimensions of the rectangular channel are chosen such that they represent the region of flow between two successive ribs in a typical heat sink. Flow of air through the plane channels is simulated with 4 inlet velocities (6.m/s 8m/s, 10m/s and12m/s) and initial computations are made for the channel without any ribs. Subsequently, different configurations of rectangular ribs are incorporated into the flow domain. The flow is assumed to be three dimensional, turbulent, incompressible and steady so that heat transfers through buoyancy and radiation effects are not considered. The details regarding the software and solution methodology are given in reference and hence are not repeated here.

1. Geometry

For the flow through micro channel without ribs Initial model has been done through CFD software by giving the constant base length of the as 500mm, width as 5mm and height 5mm as shown in the Fig 1 dimensions with geometrical parameters are of values taken from the suitable reference and Domain used for 3D analysis with rectangular ribs is shown in Fig 2

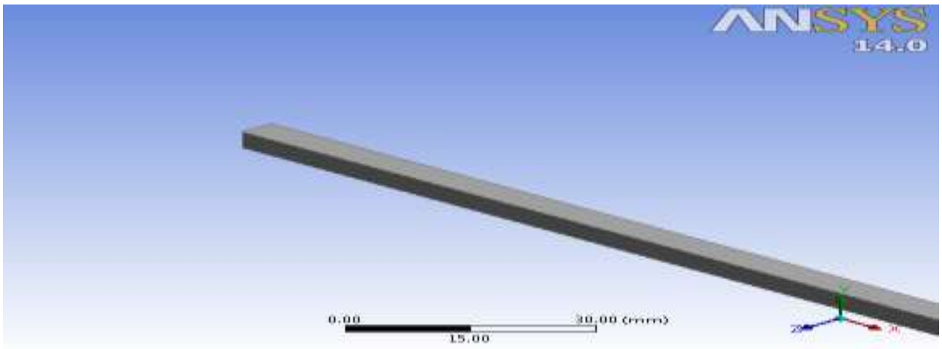


Fig 1: Computational domain used for micro channel without rectangular ribs

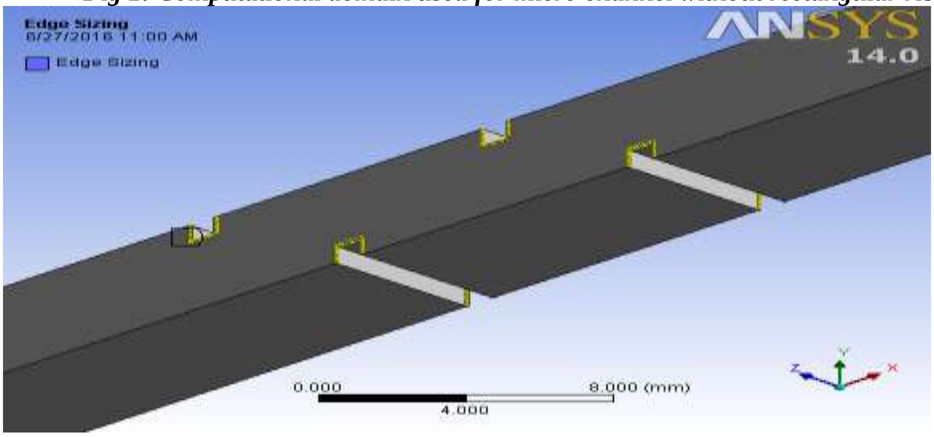


Fig 2: Computational domain used for the 3D analysis of heat transfer with rectangular ribs

Table 1 represents the geometrical parameters of rectangular ribs with various width of rib and various diagonal pitches so that for each set of individuals, velocity will be varied in such a way that model is made to run for 4 different velocities.

Table 1: Geometrical parameters of the rectangular ribs for 3D heat transfer analysis

Velocity (m/s)	**Rib length(mm)**	**Diagonal pitches(mm)**			
6	0.2	1.25	1.5	1.75	2
8	0.3	1.25	1.5	1.75	2
10	0.4	1.25	1.5	1.75	2
12	0.5	1.25	1.5	1.75	2

2. Meshing

After the selection of an appropriate model, next step is by concentrating on meshing number of elements will be taking into consideration for mesh convergence test so that after the optimization of results the values of all the edges are selected refinements, sizing and inflations mapped facing are kept constant for further simulations with various parameters.

Mapped facing of mesh will be given at the inlet and at edges of walls; mainly sizing are given to the edges of the walls of the rectangular ribs thereby accurate results will be expected with finer meshes. The 3D quadrilateral elements are used for meshing. The number of elements used defends on each case analyzed and in the range 3 to 7*103.

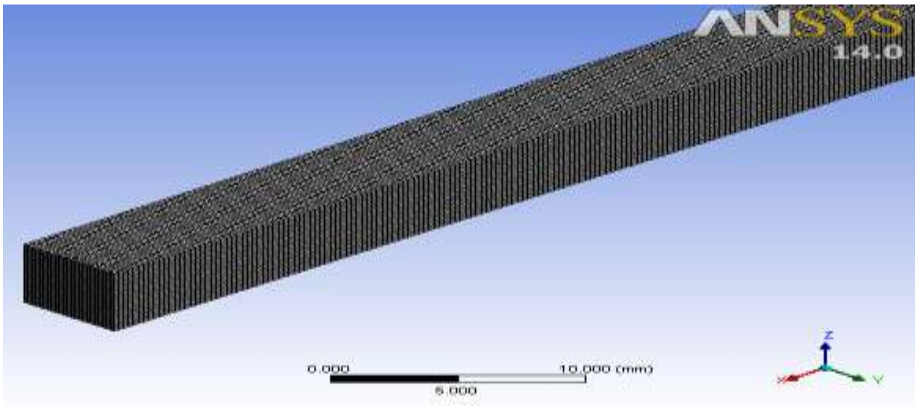


Fig 3: Unstructured mesh for 3D analysis of heat transfer without rectangular ribs

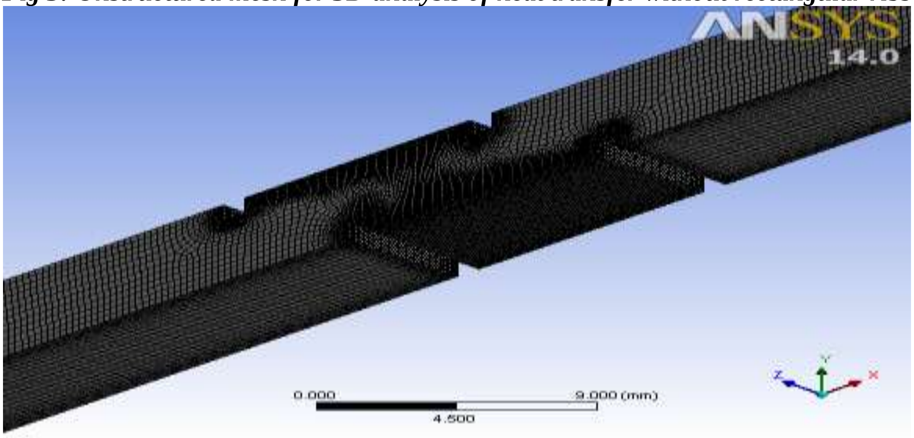


Fig 4: Unstructured mesh for 3d analysis of heat transfer with rectangular ribs

3. Boundary conditions

Model is made to import through Fluent after doing mesh convergence test (Grid independent Test). Simulation is made to run with following boundary conditions by giving the temperature of fluid medium as 298^{o} K, and constant wall temperature will be given for all the walls of 333^{o} K.

Table 2 gives the boundary conditions for micro channel without rectangular ribs.

Table 2: Boundary conditions used for 3D heat transfer analysis of micro channel without rectangular ribs

Boundary	Conditions
Inlet	Velocity (m/s) and temperature inlet (° k)
outlet	Pressure outlet
Side wall 1	Constant wall temperature (° k)
Side wall 2	Constant wall temperature (° k)
Bottom wall	Constant wall temperature (°k)
Top wall	adiabatic

Table 3: Boundary conditions used for 3D heat transfer analysis of micro channel with rectangular ribs

Boundary	Conditions
inlet	Velocity (m/s) and Temperature inlet(° k)
outlet	Pressure outlet
Side wall1	Constant wall temperature (° k)
Side wall2	Constant wall temperature (° k)
Top wall	adiabatic
Bottom wall	Constant wall temperature (° k)

Ribs	Constant wall temperature (° k)

The fluid is chosen the air for all analysis and the properties of the fluid assumed are given in table 4

Table 4: Properties of the fluid medium (Air) used in the analysis

Fluid Properties	**Values**
Specific heat of air(Cp)	1006.43 j/kg-k
Thermal conductivity of air (K)	0.0242 w/m-k
Viscosity (μ)	1.7894 X 10^-5 kg/m-s
Density of air (ρ)	1.225 kg/m3

IV. RESULTS AND DISCUSSION

Study involves the numerical analysis of forced flow of cooling air through rectangular channels with and without a rectangular rib fins. Flow of air through the channel without rib fins is simulated initially and subsequently further studies are carried out with insertion of an rectangular rib fins in order to study the effect of the following parameters on heat transfer and pressure drop across the channel.

- Length of rib
- Diagonal pitch of rib
- Velocity

A. Heat Transfer into rectangular channel without ribs

Analyses of flow and heat transfer through a rectangular channel without rib fins have been made at 4 different velocities in the range 6 m/s to 12m/s.It is observed that both Nu Number and pressure drop increase with increase in velocities.

Table 5: Computed values of Nu and Δp for rectangular channel without rib

Velocity (m/s)	Δp(pa)	Nu
6	9.9347	4.41
8	15.0729	5.68
10	21.213	6.89
12	28.236	8.05

B. Effect of velocity on Nu and Δp in the presence of the rectangular rib

Simulations have been made for various_combination_of air velocity. Width of rib and diagonal pitch of rectangular ribs, the results are analyzed to identify the effects of each parameter.

1. Effect of rib length on heat transfer and pressure valve

Figures 5.2(a) and 5.2(b) show the effect of pitch length on heat transfer rate and pressure drop for pitch 1.25. As obvious, both heat transfer and pressure drop increased with increase in the inlet velocity of air. Configuration with 0.5mm and0.4mm of pitch length resulted with highest Nu number throughout the range of inlet velocities considered in this work. Configurations with 0.2mm, 0.3mm and 0.4mm exhibited similar trends in the increase of Nu with the velocity at inlet. In contrast to that, configuration with the 0.5mm of diagonal pitch showed lesser slope of variation in Nusselt number at the higher inlet velocities.

In general, for a considerable range of inlet velocities, it can be observed that configurations with narrowly placed ribs exhibited lesser heat transfer and configurations with broadly placed ribs exhibited higher heat transfer.

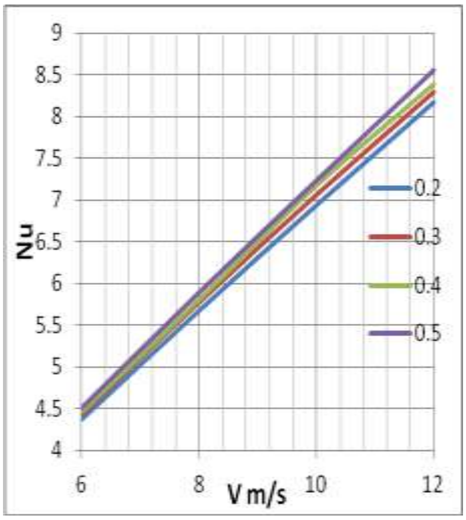


Fig 5.2 (a): Nu v/s V plot for rib pitch=1.25

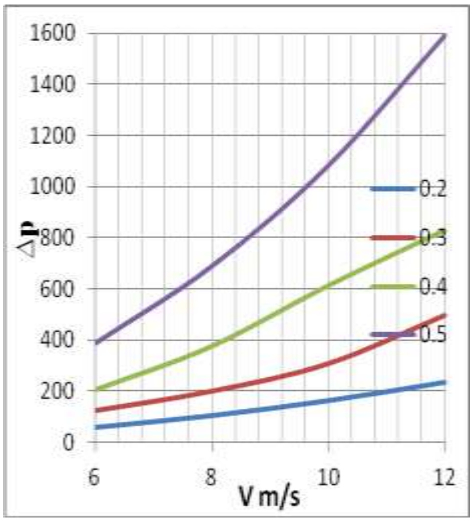


Fig 5.2 (b):Δp v/s V plot for rib pitch

It is observed from fig 5.2(b), that pressure drop with 0.5mm of pitch length shows highest pressure drop throughout the range of velocity considered. Configuration with pitch length 0.3mm, and 0.4mm showed similar variation of pressure drop with the inlet velocity in contrast to this, pitch length 0.2mm shows lesser slope in the increase of pressure with inlet velocity. Configuration with 9mm of longitudinal pitch showed highest pressure drop throughout the range of velocities considered. Configurations with longitudinal pitch 9mm, 13mm and 17mm showed similar trend in variation of pressure with the inlet velocity. In contrast to this, configuration with 21mm of longitudinal pitch showed lesser slope in the increase of pressure with inlet velocity at higher inlet velocities. In general, for the considerable range of inlet velocity, configuration with narrowly placed fins exhibited higher pressure drops and configurations with broadly spaced fins exhibited lesser pressure drop.

2. Effect of diagonal pitches on heat transfer and pressure valve.

Fig 5.6(a) and fig 5.6(b) shows the effect of different diagonal pitches on heat transfer rate and pressure drop for rib length0.2. Both heat transfer and pressure drop increased with the increase of different velocity of air configuration with the diagonal pitches 1.25 resulted with highest Nusselt number for the range of inlet velocities considered in this work. The diagonal pitches 1.5 and 1.75mm almost giving similar trend so that all the configuration are following similar trends to increase Nu with the inlet velocity .the configuration of diagonal pitch 2mm showed lesser heat transfer with different inlet velocity.

It is observed that from the fig 5.6(b) that pressure drop, configuration 1.25mm of diagonal pitch show the highest pressure drop throughout the range of different velocity considered. Configurations with diagonal pitch 1.5 and 1.75mm are giving similar trend in variation of pressure with the inlet velocity. In contrast to this; diagonal pitch 2mm of showed lesser slope in the increase of pressure with inlet velocity at all the different velocities

For Rib length 0.3 both heat transfer and pressure drop characteristics in which diagonal pitch 1.25mm is giving maximum rate of heat transfer and highest pressure drops is obtained by pitch of 2mm at its maximum velocity inlets. Configurations with diagonal pitch 1.5 and 1.75mm are giving similar trend in variation of pressure with the inlet velocity. In contrast to this; diagonal pitch 2mm of showed lesser slope in the increase of pressure with inlet velocity at all the different velocities.

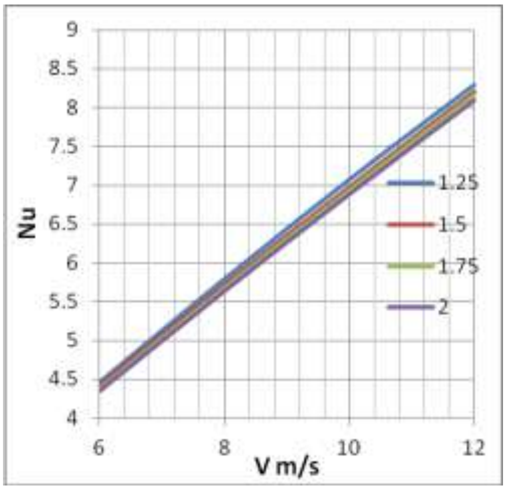


Fig 5.6(a): Nu v/s V plot for rib length

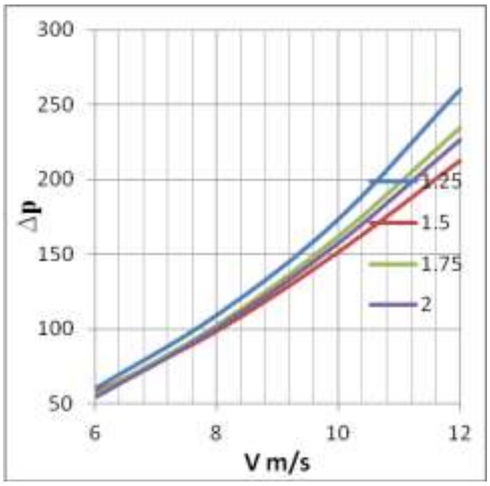


Fig 5.6(b):Δp v/s V plot for rib length

C. Effect of provision of rib on the heat transfer rate and pressure valve.

1. Comparison of no rib for all diagonal pitches

Fig 5.10(a) and 5.10(b) shows the effect of all diagonal pitches for different rib length and no rib on both heat transfer and pressure drop characteristics. In all diagonal pitches it is observed that rib length 0.5 is giving maximum rate of heat transfer with maximum amount of pressure drop. The effect of diagonal pitches will be compared at no rib. For rib length 0.2 and no rib gives less heat transfer rate and pressure drop will be compared with all diagonal pitches. In this pitches no rib gives the lesser heat transfer rate and pressure drop for comparing the all diagonal pitches.

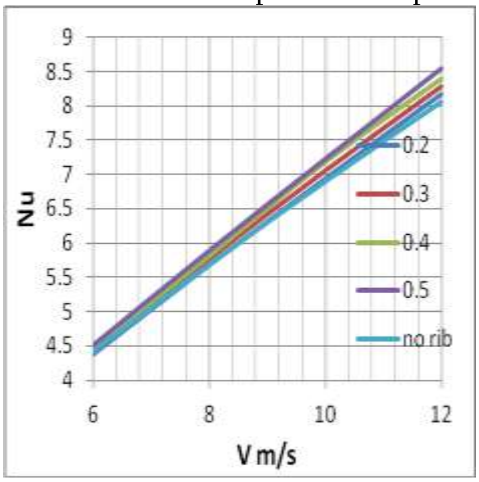


Fig 5.10(a): Nu v/s V plot all pitches

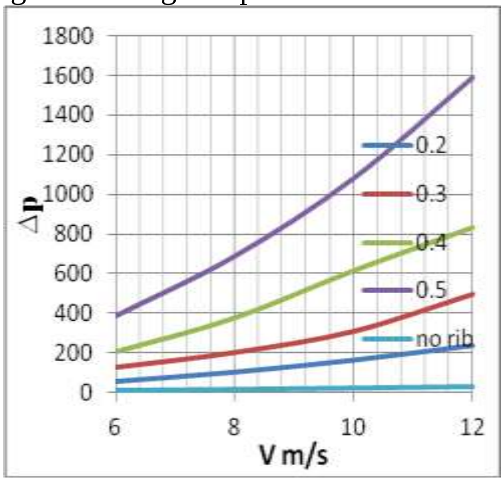


Fig 5.10(b): Δp v/s V plot for all pitches

2. Comparison of no rib for all different rib length

For Rib length 0.2 and 0.3

Fig 5.11(a) and 5.11(b) shows the effect of rib length 0.2 and 0.3 for different diagonal pitches and no rib on both heat transfer and pressure drop characteristics. In rib length 0.2 and 0.3 it is observed pitch 1.25 is giving maximum rate of heat transfer with maximum amount of pressure drop. The effect of rib length will be compared at no rib. Configurations with no rib exhibited similar trends in the increase of Nu and lesser pressure drop with all the different velocities. In contrast to that, For 2 pitches gives less heat transfer rate and will be compared with rib length 0.2 and 0.3. In this pitches no rib gives the better maximum heat transfer rate and lesser pressure drop for comparing the rib length 0.2 and 0.3.

For Rib length 0.4 and 0.5

Fig 5.12(a) and 5.12(b) shows the effect of rib length 0.4and 0.5 for different diagonal pitches and no rib on both heat transfer and pressure drop characteristics. In rib length 0.4 and 0.5 it is observed pitch 1.25 is giving maximum rate of heat transfer with maximum amount of pressure drop.

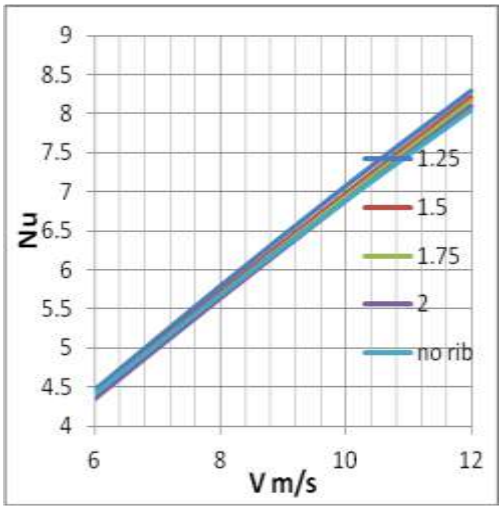


Fig 5.11 (a): Nu v/s V plots for rib length 0.2 &0.3

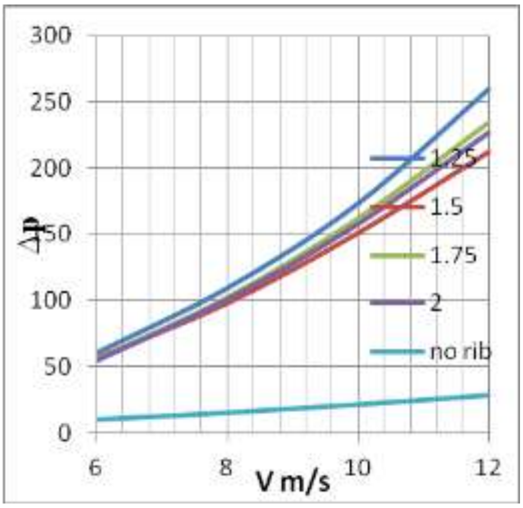


Fig 5.11(b): Δp v/s V plots for rib length 0.2 &0.3.

The effect of rib length will be compared at no rib. Configurations with 1.5mm, 1.75mm, and 2 mm exhibited similar trends in the increase of Nu and pressure drop with all the different velocities. In contrast to that, for effect of no rib gives less heat transfer rate and pressure drop will be compared with rib length 0.4 and 0.5. In this pitches no rib gives the better maximum heat transfer rate and lesser pressure drop for comparing the rib length 0.4 and 0.5.

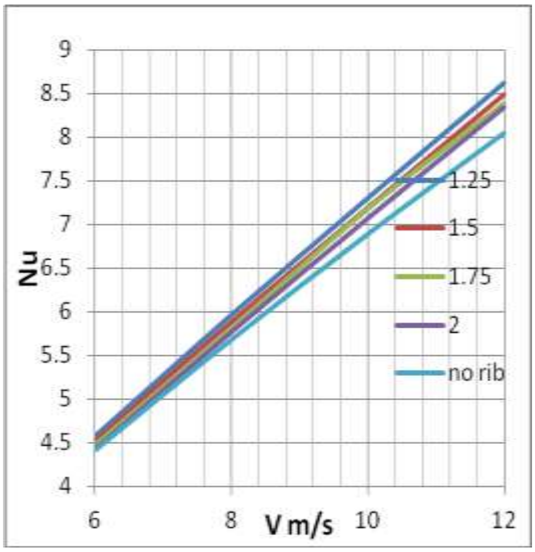


Fig 5.12(a): Nu v/s V plots for rib length 0.4 &0.5

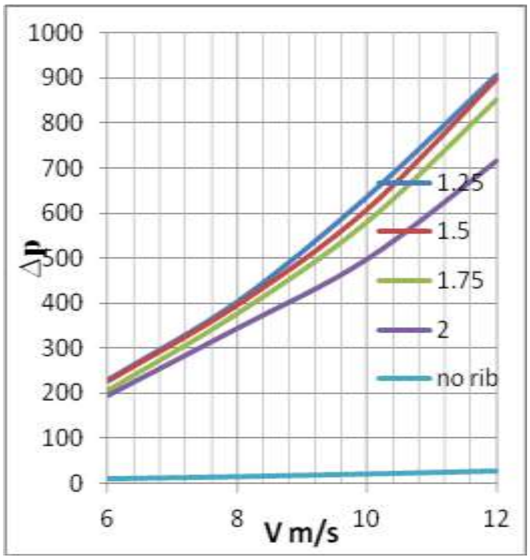
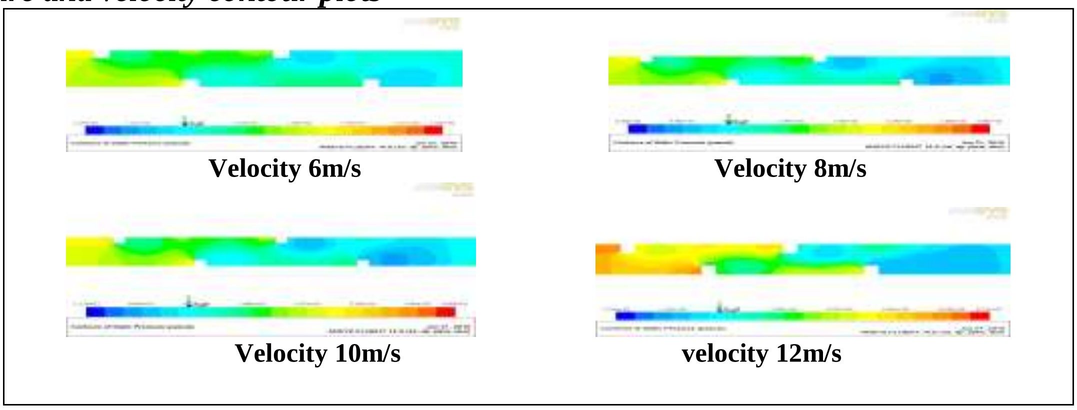
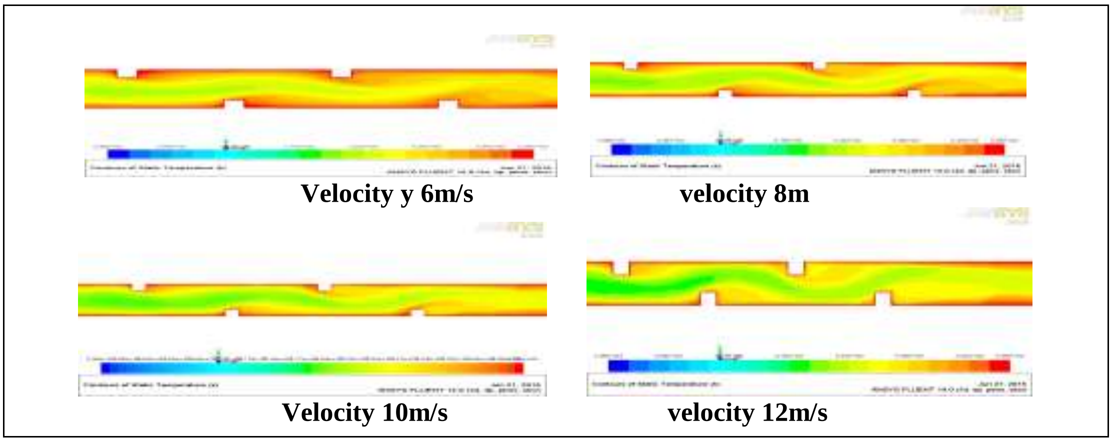


Fig 5.12(b): Δp v/s V plots for rib length 0.4 &0.5

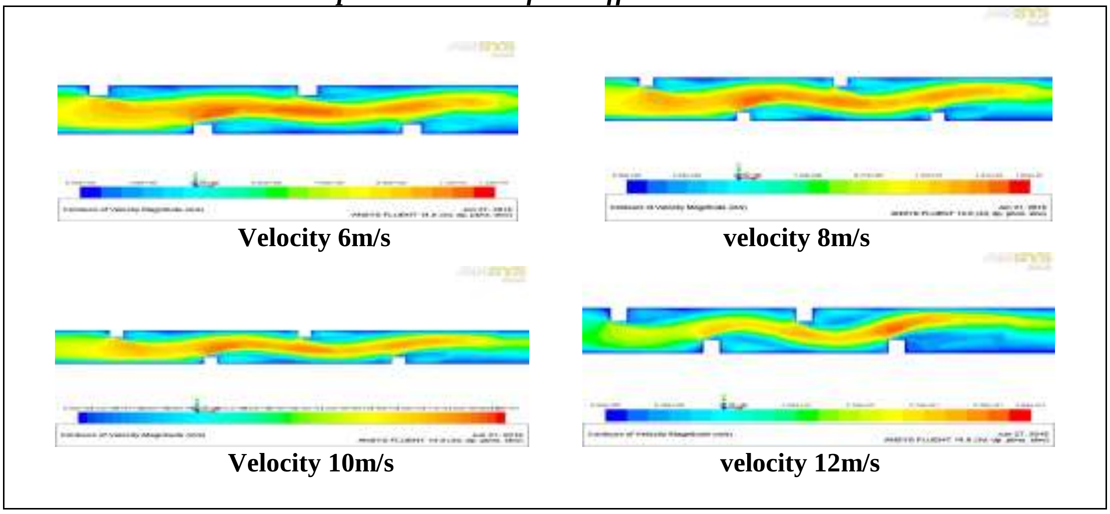
D.Pressure and velocity contour plots



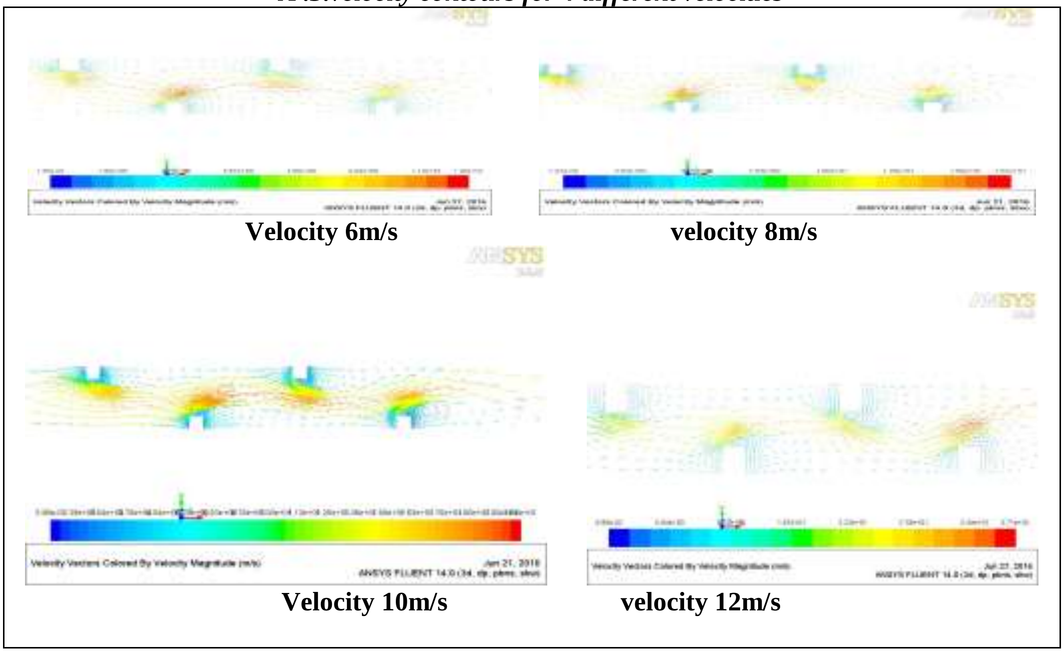
A.1 Pressure contour for 4 different velocities



A.2.Temperture contours for 4 different velocities



A .3.velocity contours for 4 different velocities



A .4.velocity vector for 4 different velocities

V. CONCLUSION

Flow of air through the micro channels with and without ribs is simulated and conclusions drawn from the different cases are as follows:

- From the analysis, it is observed that rate of heat transfer and pressure drops will be higher with the insertion of ribs on comparison with those of simple channels without the ribs.

- For all the length of rib, pitch 1.25mm and pitch 1.5mm resulted in higher rate of heat transfer with relatively increase in the pressure drop.
- With all the diagonal pitches considered, length of rib 0.5 showed maximum rate of heat transfer with maximum pressure drop throughout the entire range of input velocities considered.
- Length of rib 0.3 and 0.4 exhibited nearly similar trends in the increase of Nu with the increase of their velocities.
- Configurations with staggered ribs resulted in higher heat transfer rates and pressure drops. Higher velocities near the wall and higher turbulence induced mixing in staggered arrangement contribute towards better convective conditions and higher pressure drop in comparison with the inline arrangements.
- Among all the diagonal pitches considered in staggered arrangements of ribs, configuration with 1.25mm of diagonal pitch resulted with maximum rate of heat transfer and maximum pressure drop.

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