CFD Investigation on Heat Transfer Enhancement in Solar Duct with Slit Rib Roughness

Pankaj Parihar[1] Harbindra Singh[2] Avnish Kumar[3]
Uttaranchal University, Dehradun
pankajparihar2000@gmail.com

Abstract - In this present study, computational 2D studies are carried out to investigate the heat transfer enhancement and pressure drop characteristics in a rectangular duct by slit ribs. The ribs are oriented in one side of a wall and other wall of a duct is insulated. the fluid were taken air. The rib height to duct hydraulic diameter ratio is fixed at 0.0937; the rib pitch varies from 6 to 12 , and Reynolds number varies from 10,000 to 50,000. The geometry of problem have been made in ANSYS workbench

I. INTRODUCTION

Heat transfer enhancement is a part of energy which has been enhanced by different types of heat transfer techniques. Number of research work had been observed concerning the energy resources and their consumption. Energy is the most important part for industrial field and the methods which are used to produce and increase the energy and its efficiency are significant. So the main works for the scientists and engineers are to find out the simple and effective methods for enhance the energy. Day by day thousand of Researchers and Scientists are working on the techniques of heat transfer enhancement for saving the energy because of the increase demand of energy and consumption in the industrial development and population growth. Actually the heat transfer enhancement process is the conversion, utilization and recovery of energy, which involves a heat transfer characteristics, which is used to improve the thermal performance with the use of varies types of ribs and roughness surfaces.

A. Heat transfer enhancement

Heat transfer is a mechanism, which is responsible for energy transfer from one object to another when the two objectives have a temperature difference. Heat transfer also allows the rate at which energy is transferred across a surface due to temperature gradients at the surface and temperature difference between difference surfaces. The process of heat transfer is very essential in the heat exchanger applications and number of heat exchangers have been designed which are the applications of slit-ribs. Heat exchanger may be observed as equipment which transfers the energy from a hot fluid to a cold fluid, with maximum rate and minimum investment and running cost. Some common examples are steam generation and condensation in power and cogeneration plants, sensible heating and cooling of viscous media in thermal processing of chemical, pharmaceutical, agricultural products, refrigerant evaporation, condensation in air conditioning, refrigeration, gas flow heating in manufacturing, waste-heat recovery air, liquid cooling of engine and turbo machinery systems, cooling of electrical machines and electronic devices. So it has been proved that heat transfer applications are very useful to produce the energy. Now we need to improve the heat transfer applications, its thermal efficiency and design. The slit-rib may improve the heat transfer characteristics for heat transfer applications.

B. Heat transfer enhancement techniques

Heat transfer enhancement is very essential for its applications so what are the methods we are using to improve the thermal performance and heat transfer characteristics in the applications, these methods are known as techniques. The development of high performance thermal systems will improve the heat transfer. The study of improved heat transfer performance is referred to as heat transfer augmentation, enhancement, or intensification. A great deal of research has focused and worked on various enhancement techniques with help on rough surfaces, transverse or spiral ribs, transverse grooves, knurling, corrugated and spirally corrugated tubes, straight fins, and spiral and annular fins, Slit-ribs.

C. *Heat transfer through ribs*

In this study we will use the Passive techniques displaced enhancement devices (Inserts) Such as twisted tapes, wire coils, ribs, slit-ribs baffles, plates etc. To get the better heat transfer enhancement in rectangular duct using of ribs which is most frequently method is used now a day. Numbers of studies on heat transfer and flow characteristics have been observed the effect of rib design and parameters namely rib height, angle of attack, relative roughness pitch, rib arrangement and rib cross-section. However, the artificial roughness results in higher frictional losses leading to excessive power requirement for the fluid to flow through the duct.

II. METHODOLOGY

In the present work, numerical simulation has been carried out to investigate the effect of slit- rib. The working fluid is air flowing through a constant heat flux rectangular duct with the slit-ribs, the bottom surface of the duct contains constant heat flux while the top surface is insulated. Analysis type 2-Dimensional CFD study of fluid flow and heat transfer enhance characteristics in a rectangular duct with slit-ribs of variation in angle in flow direction. Application of the CFD to analyze a fluid problem requires the following steps. All CFD codes contain three main elements:

1. A pre-processor, which is used to input the problem geometry, generate the grid, an define the flow parameter and the boundary conditions.
2. A flow solver, which is used to solve the governing equations of the flow subject to the conditions provided.
3. A post-processor, which is used to massage the data and show the results in graphical and easy to read format.

Computational model of the project heat transfer enhancement in rectangular duct flow over slit-ribs has been developed and analysis has been carried out on commercial software ANSYS WORKBENCH (FLUENT 14.0). ANSYS FLUENT solves the equations of CFD (continuity, momentum and energy) of fluid flow by means of a finite volume method (FVM).

A. Range of parameters

The computational analysis by Jenn-Jiang Hwang, And Tong-Miin Liou [10] conducted of heat transfer and flow characteristics with artificial roughness in the form of slit-ribs, uniform heat wall of rectangular duct of 1200mm length for turbulent flow with Reynolds number range (10,000 to 50,000) and p/e (7 to 12) has been carried out with k-e turbulence model is selected by computational fluid dynamics software (Fluent 14.0 Solver).

B. Geometric model

For a constant property fluid flowing with constant cross section area the velocity profile becomes independent on the stream-wise flow at some distance from the inlet. The air will flow into the rectangular duct length and repeats itself in a periodic manner within each rib interval. Since the analysis is two dimensional (2-D), the duct width (w) has no direct influence in the investigation. But the mass flow rate (m) is calculated only on the basis of hydraulic diameter(D_h) and hence the rectangular duct width is taken into consideration. The mass flow rate increases as the rectangular duct width increases. This mass flow rate affects the velocity of the flow. Since there is a change in the velocity, the heat transfer coefficient may increase or decrease finally affecting the heat transfer performance. The configurations considered here consist of two-dimensional rectangular duct with slit-ribs are created on the bottom surface of rectangular duct and ribs are made all along the length of the duct.Rectangular duct flow is geometrically simple. It is a rectangle on the X-Y plane, enclosed by the inlet, outlet and wall boundaries. The flow under consideration is expected to attain a fully-developed flow condition. Air enters the rectangular duct at an inlet temperature, T_in of 300K. The rectangular duct is 1200mm long and the cross-sectional area of the rectangular duct is 40mm × 160mm for Y-Z plane (40 mm in height and 160 mm in width) and has an aspect-ratio of 4:1. The hydraulic diameter (D_h) of the duct is 64mm. the upper wall of the channel is thermally insulated and the lower wall is heated with a constant heat flux of 1000w/m^2. There are some basic dimensionless geometrical parameters that are used to characterize roughness:

- Relative roughness pitch (p/e): it is defined as the ratio of distance between two consecutive ribs (p) and height of the rib (e).
- Relative roughness height (e/D): Relative roughness height (e/D) is the ratio of rib height (e) to equivalent diameter of the duct (D).
- Angle of attack: Angle of attack is inclination of rib with direction of air flow in duct.
- Aspect ratio: It is the ratio of duct width to duct height. This factor also plays a very crucial role in investigating thermo-hydraulic performance.

The slit-ribs as roughness elements have been integrated at the bottom surface of the rectangular duct. Aluminium slit-ribs are used in this study for their high thermal conductivity and machinability. The height (e) of the ribs is 6mm. The relative roughness pitch, (P/e) varies from 7 to 12, the relative roughness height, (e/D) is 0.09375, the relative roughness angle varies 65°, 70°, 75°, 80°, 85° and the blockage ratio is (e/H) defined as the ratio of rib height to rectangular duct width 0.0375 as shown in fig.3.1. The Reynolds number based on hydraulic diameter (D_h) is fixed at Re = 10000-50000. Prandtl number is set to 0.707.

C. Boundary conditions

The boundary condition is limited for the rectangular duct. The boundary conditions define fluid flow behaviour and its variation from entrance to exit part and the boundary conditions are very essential and beneficial in numerical simulation. In this numerical simulation the rectangular duct is enclosed by the inlet, outlet and wall boundaries. No-slip conditions for velocity in solid surfaces are assumed and the turbulence kinetic energy is set to zero on all solid walls and velocity is define by Reynolds number. The top wall boundary condition is selected as insulated and bottom wall is assumed as constant heat flux of 1000 W/m^2.

D. Mesh Generation

The meshing of the geometry has been performed using ANSYS FLUENT 14.0 CFD software. Surface meshes are generated in Fig 3.3. The quality of mesh plays a major part in the numerical computation. The mesh quality parameters are orthogonal and aspect ratio. A two-dimensional non-uniform mesh with very fine mesh size is used according to geometry used. In order to examine the turbulent flow and heat transfer critically in source-rib region, so a fine mesh has been created near to the walls. The domain is meshed with the use of size functions. The size functions controls the size of the mesh element edges and the maximum edge element length. The update of the mesh is handled automatically by ANSYS WORKBENCH at each time step based on the new positions of the boundaries.

III. RESULT AND DISCUSSION

In the present investigation of the project heat transfer enhancement in two dimensional rectangular duct flows over slit-ribs has been completed using ANSYS WORKBENCH 14.0. The heat transfer enhancement and friction characteristics of the rectangular duct with or without slit-ribs are discussed with the help of heat transfer, Nusselt number and friction factor. The numerical analysis data is presented in terms of contour-vector plots (fig.4.3-4.13) of fluid flow characteristics such as turbulent intensity (fig. 4.29), turbulent kinetic energy(fig. 4.27.), and velocity distribution around the slit-rib. Comparison has been made between smooth duct and Dittus-Boelter correlation in fig. 4.1. The results of Nusselt number and friction factor for rectangular duct without slit-rib have been compared with the Dittus-Boelter Correlation under similar operating conditions to explain the heat transfer enhancement and friction factor on basis of slit-ribs as artificial roughness. The plot has been shown in fig. 4.2. A uniform air velocity has been taken at the inlet of rectangular duct and at the outlet-pressure situation is taken. In the present work, a numerical investigation has been done to study the heat transfer and flow friction characteristics of a rectangular duct having slit-ribs of height 6mm as artificial roughness have been planted at constant heat flux 1000w/m^2 bottom surface named as source of the rectangular duct. All the results, plots, graphs and tables are presented for two-dimensional geometry as shown in the figures (4.1 - 4.29.). In the present work coupled algorithm has been used as scheme of pressure-velocity coupling. The transport equations have been solved finite volume method in the steady state condition and are solved using the commercial software ANSYS FLUENT 14.0 CFD and second order upwind scheme has been chosen for transport equations.The figure 4.1 shows variation in Nusselt number with respect to Reynolds number in the range of 10,000-50,000 and the results between the smooth duct and dittous-boelter equation correlation. The maximum Nusselt numbers are 116.0533 and 119.0500723 for respectively smooth duct and dittous-boelter equation correlation. It is observed that both results show the deviations between 3% - 6%.

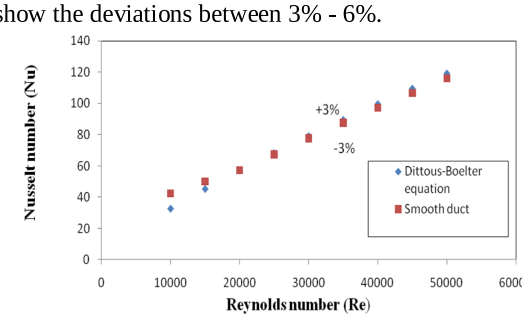

Fig.4.1. Variation of Nusselt number versus position at different Reynolds number for smooth duct.

The figure 4.2 shows the comparison of Nusselt number between the duct with different relative roughness slit-ribs pitch p/e=7, p/e=8, p/e=9, p/e=10, p/e=11, p/e=12, and smooth duct at the Reynolds number 10000, 15000, 20000, 25000, 30000, 35000, 40000, 45000, 50000. In fig.4.2 we have been observed that the Nusselt number was increased with relative roughness pitch (p/e) increasing and maximum Nusselt number was observed at p/e = 12 and Nusselt number in smooth duct is lowest because no disruption in smooth duct.

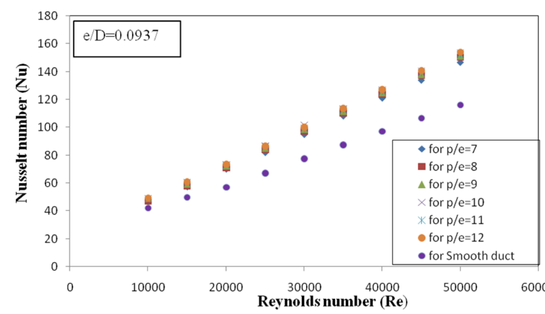

Fig.4.2. Comparison of Nusselt number for smooth duct with respect to the numerical investigation.

A. Pathlines and reattachment lines

Figure 4.14 shows the reattachments point which is created by pathlines.it is created by the trapped air between the two slit- ribs. when the distance between the slit-ribs is too small that flow reaches the next slit-rib without reattaching the surface.increasing in pitch creates the reattachment region in this case nusselt increases.

B. Effect on Nusselt number

Shows the variation on the results of Nusselt number with Reynolds number at angle of attack at 65° for different relative roughness pitch p/e = 7, 8, 9, 10, 11, 12. The maximum Nusselt number was obtained at relative roughness pitch p/e = 12.The heat transfer rate increases with the rise of Reynolds number (10000 - 50000) for all relative pitch roughness pitch ratios.

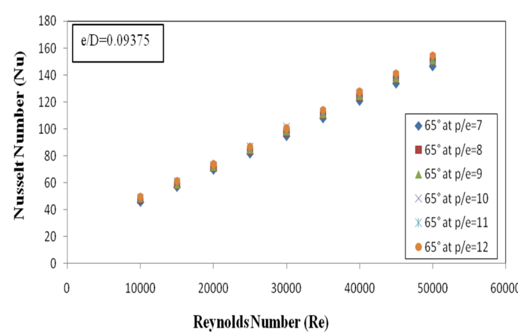

Fig.4.3. Variation of Nusselt number with Reynolds number (10000 - 50000) for different pitch roughness (p/e = 7, 8, 9, 10, 11, 12) at 65°.

C. Effect on friction factor

Figure 4.20 shows the relation between the variation of friction factor with Reynolds number at 85° for different relative roughness pitch p/e = 7, 8, 9, 10, 11, 12. The friction factor decreases with the rise of Reynolds number (10000 - 50000) for all relative roughness pitch ratios. The friction factor is minimum at p/e = 9.

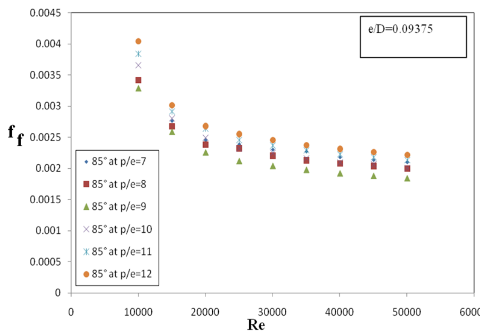

Fig.4.3. Variation of friction factor with Reynolds number (10000 - 50000) for different relative pitch roughness (p/e = 7, 8, 9, 10, 11, 12) at 85°.

IV. CONCLUSION

The present work deals the two-dimensional (CFD) analysis has been carried out to study the heat transfer, fluid flow behaviour and the friction characteristics in a rectangular duct with slit-ribs.the slit-ribs are placed on bottom of the rectangular duct through which air is drawn to find out the effects of geometrical parameters. The effect of Reynolds number (10000-50000), relative roughness pitch (p/e=7-12), and relative roughness angle α on the heat transfer and friction factor have been studied and which are discussed with the help of Nusselt number and friction factor as plots. In the work the k-e model has been taken to simulate turbulent flow in the rectangular duct.

On the basis of present study, the following conclusions can be drawn:

- The heat transfer increases and friction factor decreases with the increasing in the value of Reynolds number.
- The Nusselt number increases with the rib spacing (p/e) increases.
- From the result it has been observed that the Nusselt number increases with the decreasing in the value of roughness angle.
- The highest Nusselt number is obtained at roughness angle α= 65°, Reynolds number Re=50000 and pitch ratio p/e=12 which has been discussed in plots.
- The lowest friction factor is obtained at the value of roughness angle is 85° and Re=50000.

V. REFERENCES

[1] Andallib Tariq, P.K. Panigrahi, K. Muralidhar, "Flow and heat transfer in the wake of a surface-mounted rib with a slit", Experiments in Fluids 37 701–719, (2004).

[2] Amit Garg, Sunil Dhingra., "Numerical simulation for heat transfer enchancement in a triangular ribbed channel with winglet vortex generators". International Journal of Engineering Research and General Science Volume 2 ISSN 2091-2730, (2014).

[3] Abhilash Kumar, R. Saravana, Sathiya Prabhahar, "Numerical investigation of heat transfer characteristics in a square duct with internal ribs", IJIRSET, Volume 3, Special Issue 1, (2014).

[4] Thianpong, T.Chompookham, S.Skullong, P.Promvonge, "Thermal characterization of turbulent flow in a channel with isosceles triangular ribs", International Communications in heat and mass transfer 36,712-717, (2009).

[5] Esmaeilzadeh, A. Alamgholilou, H. Mirzaie, A. Khoshnevis., "Numerical investigation of heat transfer enhancement of rectangular ribs with constant heat flux located in the floor of a 3d duct flow". Proceedings of the 12th Asian Congress of Fluid Mechanics (2008).

[6] Giovanni Tanda, Diego Cavallero, "Heat transfer coefficient measurements in ribbed channels using Liquid Crystal Thermography", The 10th International Symposium on Flow Visualization F0038, (2002).

[7] J. C. Han & Park J. S., "Developing heat transfer in rectangular channels with rib turbulators". Int. J. Heat Mass Transfer, Vol. 31, No. 1, pp. 183-195, (1988).

[8] J. C. Han, L. R. Glicksman and W. M. Rohsenow, An Investigation of Heat Transfer and Friction for Rib-Roughened Surfaces. International Journal Heat Mass Transfer, 1978. Vol. 21: p. 1143-1156.

[9] J. C. Han, Heat Transfer and friction characteristics in rectangular channels with rib turbulators. Journal of Heat Transfer, 1988. Vol. 110: p. 321 - 328.

[10] Jenn-Jiang Hwanga,And Tong-Miin Liou, "Heat transfer and friction in a low-aspect-ratio rectangular channel with staggered slit-ribbed walls", International Journal of Rotating Machinery, Vol. 4, No. 4, pp. 283-291, (1998).

[11] Jie Cui, Virendra C. Patel, Ching-Long Lin, "Large-Eddy simulation of turbulent flow in a channel with rib roughness", International Journal Of Heat And Fluid Flow 24, 372–388 (2003).

Avnish Kumar received M.Tech. Degree from U.P.T.U Lucknow and pursuing PhD in Mechanical Engineering from Uttarankhand Technical University, Dehradun. He is working as an Assistant professor in Uttaranchal University, Dehradun. His research interests include Heat transfer and solar Energy

Pankaj Parihar received his B.Tech degree in Mechanical Engineering and M.Tech in Thermal Engineering. He is working as an Assistant professor in Uttaranchal University, Dehradun. His research interests include Heat transfer and Solar energy.

Harbindra Singh received his M.Tech degree in Thermal Engineering from Uttaranchal University, Dehradun. His research interests include Heat transfer.