Analysis of heat transfer and Fluid flow of rectangular tube using CFD

Pankaj k. Pal[*1] ,Rajwansh Pandit[#2], Ravi Vishwakarma[#3]
1Department of Mechanical Engineering, Rajiv Gandhi Prodyogiki Vishwavidyalaya, Bhopal, India
[1]yogeshlnct65@gmail.com
[3]santosh4mf@gmail.com
Ravikarma1165@gmail.com

Abstract: **The present investigation is concerned with evaluating heat transfer and friction characteristics of an artificial roughed solar duct using combination of rough surface on various relative roughness height and range of parameter studied are Reynolds number from 3000-14000. A computational analysis of heat transfer and flow characteristics with artificial roughness in the form of different types of ribs, heated wall of rectangular duct for turbulent flow has been carried out with k-e turbulence model is selected by comparing the predictions of different turbulence models with experimental results available in literature. This study evaluates, heat transfer and fluid flow behavior in a rectangular duct with square roughened ribs mounted on one of the principal wall (solar plate) by computational fluid dynamics software ANSYS (Fluent 6.3.26 Solver). In this study, The Reynolds-Averaged Navier–Stokes analysis is used as a numerical technique and the k-e model with near-wall treatment as a turbulent model. The results predicts a significant enhancement of heat transfer in comparison to that of for a smooth surface with different e/Dh. The performance evaluation in Terms of thermo hydraulic performance has been carried out for various value of Reynolds number for some selected artificial roughness geometries, in the absorber plate of solar air heater duct. Three roughness geometries as per the order of relative roughness height (e/Dh) 0.0471, 0.078, 0.083 are used to create turbulence, and a smooth plate to compare the result of roughened plates. The range of Reynolds number is 3000 to 14000, Relative Roughness height (e/Dh) .0471mm, .078mm, .083mm Rib and Heat flux 800 W /m^2. The Result has been compared with smooth duct under similar flow and boundary condition. The co-relation for heat transfer and friction factor developed by respective investigators has used to calculate the thermo hydraulic performance. It is found that artificial roughness on absorber surface effectively increases the thermo hydraulic performance and friction factor and efficiency in comparison to smooth surface.**

***Keywords*: Heat Transfer, Friction Factor, Reynolds Number, Roughness.**

I. INTRODUCTION

The prospect of fossil fuels finally running out has lead to an increased interest in renewable sources of energy such as solar, hydroelectric and wind. Such energy sources are useful and definitely needed for the future and to balance out our everyday needs for energy. There is a potential for them to make a big contribution to our energy needs and a great deal of time and money is currently being spent on developing renewable sources of energy.

Renewable energy sources are often thought of as being environmentally friendly because they can be used over and over again but there is a down side to all off this putting all sorts of contraptions all over the earth's surface could and will ruin valuable land scapes and scenery.

The Earth receives 174 peta watts (PW) of incoming solar radiation (insolation) at the upper atmosphere. Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. The spectrum of solar light at the Earth's surface is mostly spread across the visible and near-infrared ranges with a small part in the near-ultraviolet.

Earth's land surface, oceans and atmosphere absorb solar radiation, and this raises their temperature. Warm air containing evaporated water from the oceans rises, causing atmospheric circulation or convection. When the air reaches a high altitude, where the temperature is low, water vapor condenses into clouds, which rain onto the Earth's surface, completing the water cycle. The latent heat of water condensation amplifies convection, producing atmospheric phenomena such as wind, cyclones and anti-cyclones. Sunlight absorbed by the oceans and land masses keeps the surface at an average temperature of 14 °C. By photosynthesis green plants convert solar energy into chemical energy, which produces food, wood and the biomass from which fossil fuels are derived.

solar	3850000 EJ
wind	2250 EJ
Biomass	3000 EJ
Primary energy use(2005)	487 EJ
Electricity	56.7 EJ

Table 1.1 Yearly Solar Fluxes & Human Consumption

The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 3,850,000 exajoules (EJ) per year. In 2002, this was more energy in one hour than the world used in one year. Photosynthesis captures approximately 3,000 EJ per year in biomass. The amount of solar energy reaching the surface of the planet is so vast that in one year it is about twice as much as will ever be obtained from all of the Earth's non-renewable resources of coal, oil, natural gas, and mined uranium combined. From the table of resources it would appear that solar, wind or biomass would be sufficient to supply all of our energy needs, however, the increased use of biomass has had a negative effect on global warming and dramatically increased food prices by diverting forests and crops into biofuel production. As intermittent resources, solar and wind raise other issues. Solar energy can be harnessed in different levels around the world. Depending on a geographical location the closer to the equator the more "potential" solar energy is available.

Solar energy:

The Sun is a source of enormous energy. It is a fusion reactor at a distance of about 150 ×106 km from the earth. The energy from the sun in the form of in the form radiation is called Solar Energy.Solar energy technology comprises of two distinct categories, viz., thermal conversion and photo conversion. Thermal conversion takes place through direct heating, ocean waves and currents, and wind. Photo-conversion includes photo-synthesis, photochemistry, photoelectro-chemistry, photo-galvanism and photo-voltaic. Solar radiation is collected and converted by natural collectors such as the atmosphere, the ocean and plant life, as well as by man –made collectors of much kind. There are a number of solar energy technology by which it can be harnessed.

Solar energy, radiant light and heat from the sun, has been harnessed by humans since ancient times using a range of ever-evolving technologies. Solar radiation, along with secondary solar-powered resources such as wind and wave power, hydroelectricity and biomass, account for most of the available renewable energy on earth. Only a minuscule fraction of the available solar energy is used. Solar powered electrical generation relies on heat engines and photovoltaics. Solar energy's uses are limited only by human ingenuity. A partial list of solar applications includes space heating and cooling through solar architecture, potable water via distillation and disinfection, daylighting, solar hot water, solar cooking, and high temperature process heat for industrial purposes. To harvest the solar energy, the most common way is to use solar panels. Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy. Active solar techniques include the use of photovoltaic panels and solar thermal collectors to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air.

II. LITERATURE REVIEWS

Bhagoria et al. [1] used wedge shaped transverse integral ribs in solar air heater rectangular duct. Maximum enhancement of heat transfer occurs at a wedge angle of about 10° while on either side of this wedge angle, Nusselt number decreases. The friction factor increases as the wedge angle increases. As compared to the smooth duct, the presence of ribs yields Nusselt number up to 2.4 times while the friction factor rises up to 5.3 times for the range of parameters investigated. The maximum heat transfer occurs for a relative roughness pitch of about 7.57.

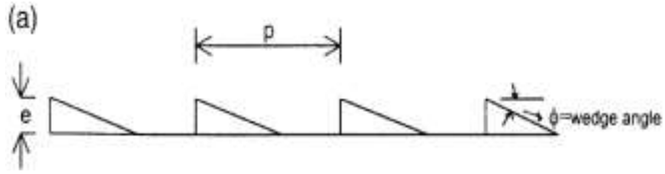


Fig.2.1 Rib geometries on Solar Plate.

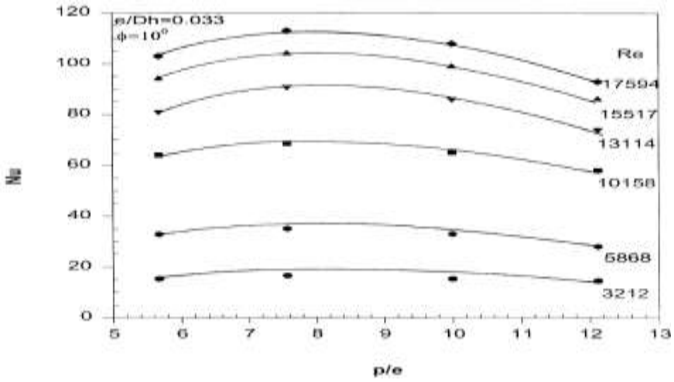


Fig.2.2 Nusselt number verses relative roughness pitch

Bhagoria and Sahu [2] have investigated the effect of 90° broken wire ribs on heat transfer coefficient of a solar air heater duct. A pitch of 20 mm gives the highest thermal efficiency of 83.5% for e = 1.5 mm and reported heat transfer coefficient of roughened duct improves 1.25–1.4 times compared to smooth duct under similar operating conditions at higher Reynolds number.

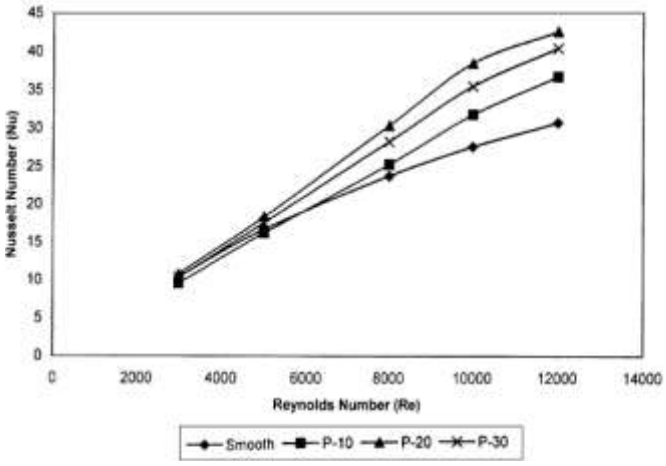


Fig. 2.3 Variation for Nusselt number (Nu) with Reynolds number (Re).

It is found that the maximum thermal efficiency of roughened solar air heater to of the order of (51–83.5%). At low Reynolds number (below 5000) a smooth duct gives better heat transfer than the artificial roughened duct. Maximum enhancement of heat transfer coefficient occurs at pitch of about 20 mm. Nusselt number increases sharply at low Reynolds number and this becomes constant or increases very slightly at high Reynolds number..

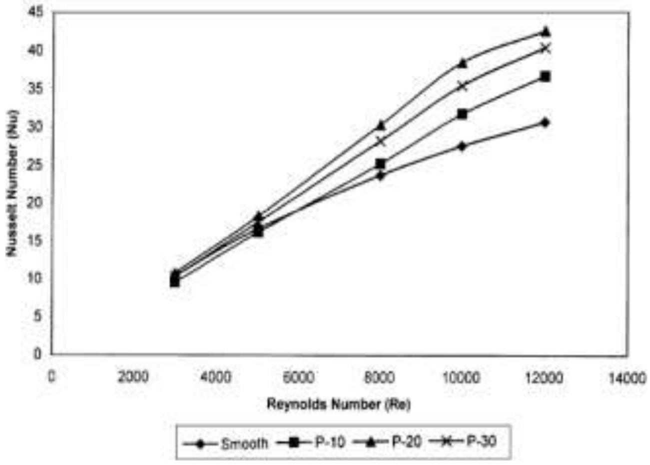


Fig. 2.4 Variation for Nusselt number (Nu) with Reynolds number (Re).

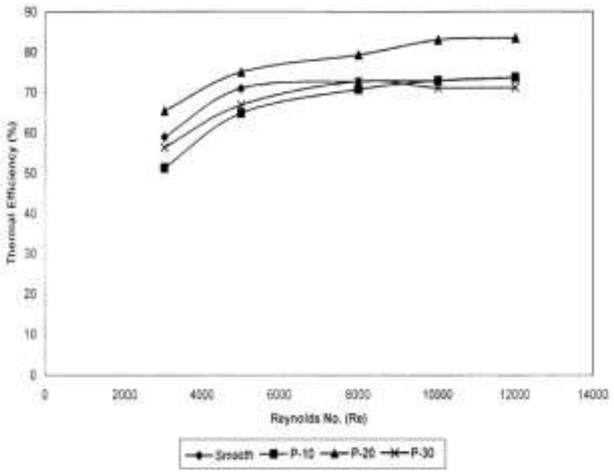


Fig. 2.5 Variation of thermal efficiency (%) Reynolds number (Re).

Saini and Saini [3] investigate solar air heater having artificial roughness in the form of arc-shape parallel wire. The effect of system parameters such as relative roughness height (e/d) and arc angle (a/90) have been studied on Nusselt number (Nu) and friction factor (f) with Reynolds number (Re) varied from 2000 to 17000. The maximum enhancement in Nusselt number has been obtained as 3.80 times corresponding the relative arc angle (a/90) of 0.3333 at relative roughness height of 0.0422. However, the increment in friction factor corresponding to these parameters has been observed 1.75 times only.

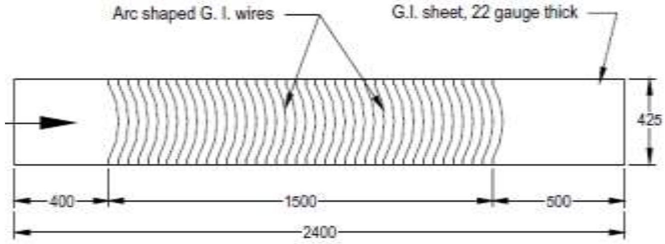


Fig. 2.5 Absorber plate.

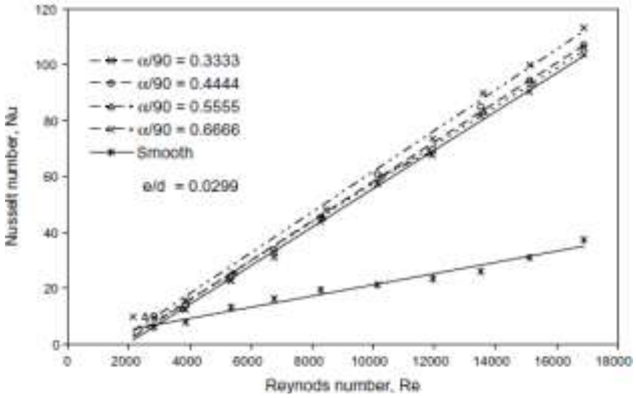


Fig. 2.7 Variation of Nusselt number with Reynolds factor with number for different values of a/90 number for different values of a/90.

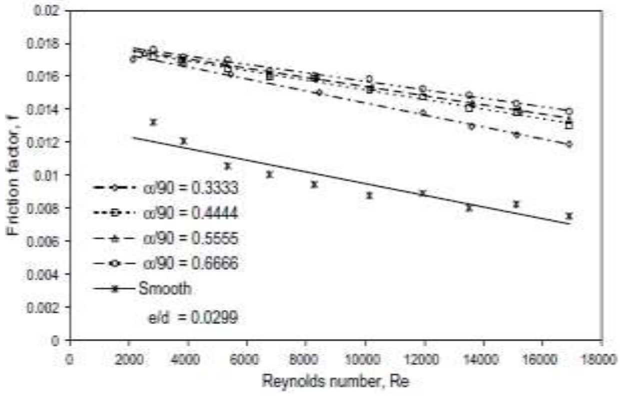


Fig. 2.8 Variation of friction Reynolds.

III. THEORY OF COMPUTATIONAL FLUID DYNAMICS

Computational fluid dynamics (CFD) is one of the branches of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. Computers are used to perform the millions of calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions. Even with high-speed supercomputers only approximate solutions can be achieved in many cases. CFD - a computational technology that enables us to study the dynamics of things that flow.

Methodology of CFD Analysis

The objectives of this study are to develop:

1. Analytical models that can be used to predict fluid flow and heat transfer in solar air heater duct for different ribs geometry.
2. Heat transfer enhancement analysis for different ribs configuration have been studied and optimized the best rib either will be Square, Rectangular, Chamfered, Triangular or Wedge shaped .
3. Fluid flow and friction analysis for above configurations of ribs for less pumping power requirement.

To accomplish these objectives, the work is divided into the four tasks which can be described as follows:

Task 1:
Conduct an extensive literature survey of heat transfer enhancement by ribs inserts in solar air heater duct by different researchers.

Task 2:
Develop analytical model for different ribs configuration like Square, Rectangular, Chamfered, Triangular and Wedge shape in solar air heater duct.

Task 3:
Conduct analysis of above ribs configuration on fluid flow and heat transfer using FLUENT 6.3.26 as CFD analyzing CODE.

Task 4:
Compare the above configurations and optimize the best rib shape in terms of heat transfer and fluid flow.

IV. SOLUTION DOMAIN AND METHODOLY

4.1 METHDOLOGY

Problem Solving Steps are

Once you have determined the important features of the problem you want to solve, you will follow the basic procedural steps shown below.

1. Create the model geometry and grid.
2. Start the appropriate solver for 2D or 3D modeling.
3. Import the grid.
4. Check the grid.
5. Select the solver formulation.
6. Choose the basic equations to be solved: laminar or turbulent (or Inviscid), chemical species or reaction, heat transfer models, etc. Identify additional models needed: fans, heat exchangers, porous media, etc.
7. Specify material properties.
8. Specify the boundary conditions.
9. Adjust the solution control parameters.
10. Initialize the flow field.
11. Calculate a solution.
12. Examine the results.
13. Save the results.
14. If necessary, refine the grid or consider revisions to the numerical or physical model.

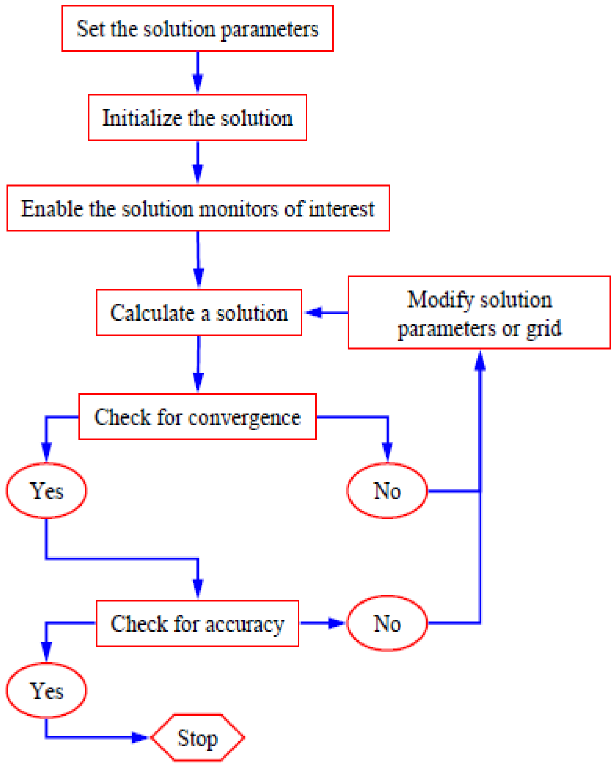


Fig. 4.1 Working steps in ANSYS and Fluent Solver

4.2Methodology having a followings step

1. Problem Specification
2.Create Geometry in ANSYS
3.Mesh Geometry in ANSYS
4. Specify Boundary Types in ANSYS
5. Set Up Problem in FLUENT
6. Solve!
7. Results

4.1 Problem Specification-
Problem specification is done in previous chapter-4.

4.2 Create Geometry in ANSYS-

Starts ANSYS & Select Solver for Specify that the mesh to be created is for use with FLUENT 5/6. In creating the geometry for flow field we must consider what is necessary for our model to approximate real flow. A boundary layer grows along the plate, which must satisfy the no slip condition.

The flow velocity at the plate must be zero. Although the y-velocity is significantly smaller in magnitude than the x-velocity, it can affect the solution significantly if not taken into consideration when creating the geometry of the flow field. First of all create rectangle of dimension 500X20 mm2. Inlet length for fully developed flow is 150mm according to requirement of total length, solar plate and outlet length are 150mm, 500mm and 75mm respectively. Place roughness at specific angle on solar plate away from the entry length in rectangle section according to pitch and roughness height which is shown in table 5.1.Same procedure is used creating remaining geometry in Gambit for various "p/e" from 5 to 20 and 'e/Dh'=0.03986.

4.3 Mesh Geometry in ANSYS

Now create a mesh on the rectangular face with .1 and .2 and .3 interval size according to roughness height 2mm and interval size of .2 in the vertical direction and horizontal direction. We'll first mesh the edges and then the face. The desired grid spacing is specified through the edge mesh. In creating this mesh, it is desirable to have more cells near the plate because we want to resolve the turbulent boundary layer, which is very thin compared to the height of the flow field.

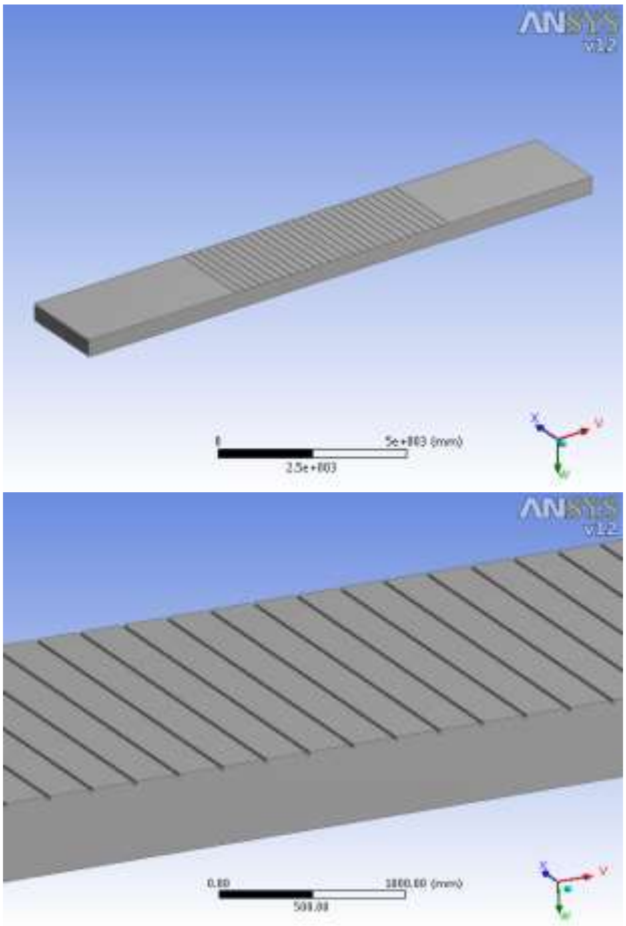
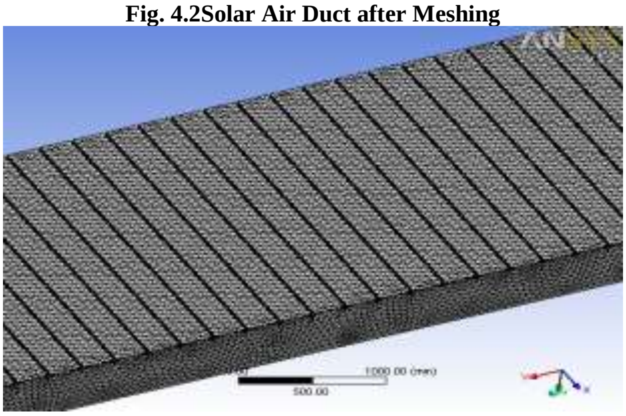


Fig. 4.2Solar Air Duct after Meshing



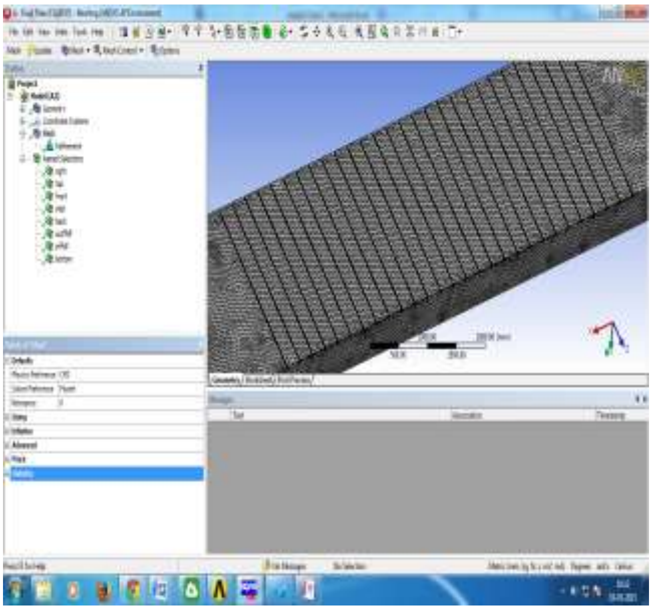


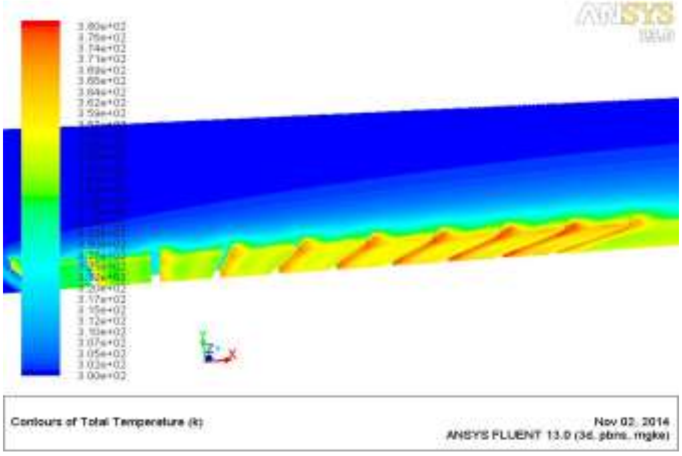
Fig. 4.3 Geometry of Solar Air Heater with square ribs in Gambit Window

V. RESULT AND DISCUSSION

Flow over Three-dimensional ribs

Fig 4.1 shows the velocity vectors for the different shape of ribs inserted in a solar air heater duct. The recirculation zones are clearly identified and the flow is seen to reattach before the following in all cases. Of the four cases, the flow over the triangular ribs appears to be the most complex; since the rib face is perpendicular to the flow direction, sizable primary and secondary recirculation regions form near the front and rear corners at the rib bottom. The size of the recirculation zone, however, is largest for the chamfered rib and smallest for the semicircular ribs. 2. Heat Transfer in Roughened Duct.

The flow and heat transfer characteristics get affected in the flow direction due to rib provided in the form of artificial roughness. In the vicinity of the rib the values of Nusselt number has been found to be low. The reason may be that heat transfer takes place around the rib due to conduction only. The values of Nusselt number have been observed to attain very high value upstream and downstream of the rib. Nusselt number starts decreasing as the flow approaches the rib and near rib region it drops down to lower value. However, as the flow past the rib in the downstream, the Nusselt number increases. The increase in Nusselt is attributed to the variation in flow parameters downstream of the rib. The presence of rib along the flow direction creates vortices just downstream of the rib and the fluid also separates from the wall. Separation of flow decreases heat transfer whereas vortices make fluid to mix thus increasing heat transfer. Downstream of the rib in its vicinity, vortices effect will be predominant than flow separation effect, thus values of Nusselt number increases in this region As Reynolds number increases, Nusselt number also increases in inter-rib regions.



CFD results have critically analyzed the flow separation and reattachment to explain other related phenomenon such as increase in Nusselt number for different roughness parameters.

Friction factor and heat transfer coefficient determined from the computational data on a smooth duct were compare with those obtained from the Modified Blasius equation for friction factor.

$$f_s = 0.085(Re)-0.025 \ldots\ldots\ldots\ldots \quad (4.1)$$

Fig. 4.1 shows the comparison of the computational and predicted Values of friction factor. It is found that the smooth plate data agree reasonably well with the values predicted by correlation (4.1)

The values of friction factor predicted by Eq. (4.1) have also been plotted in Fig. (4.1) and the deviation between the predicted and experimental result in this case is within ± 10 %

Fig. 4.2 shows the comparison of the computational and predicted Values of Nusselt Number. It is found that the smooth plate data agree reasonably well with the values predicted by correlation (3.2)

$$Nu_s=0.024Re^{0.8}Pr^{0.4} \quad \ldots\ldots\ldots\ldots(4.2)$$

The values of Nusselt no predicted by Eq. (4.2) have also been plotted in Fig. (4.2) and the deviation between the predicted and computational result in this case is within ± 10%. It is also seen from the fig. (4.2) that Nusselt Number increase with Reynolds Number.

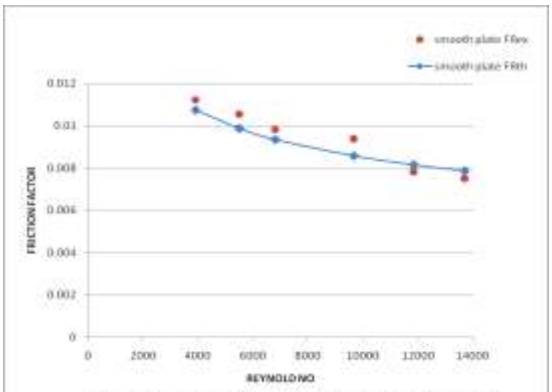


Fig 4.1 Comparision b/w Reynold no. Vs Friction Factr for smooth plate

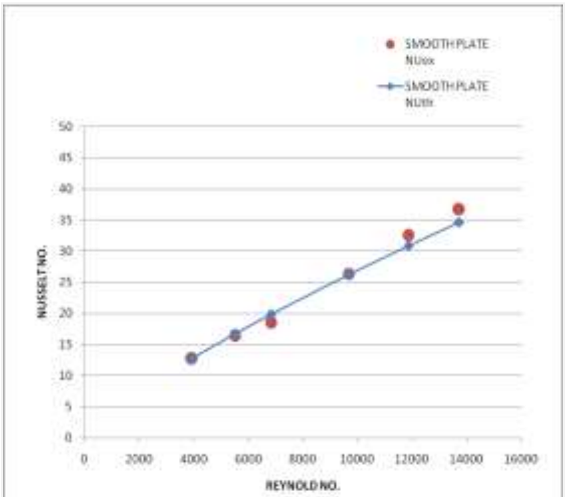


Fig 4.2 Comparision b/w Reynold no. Vs Nusselt no. for smooth plate

VI. CONCLUSION

Analysis In the view of present analysis the following conclusions are drawn:

(1) In the entire range of Reynolds number, it is found that the Nusselt number increases, attains a maximum Value for relative roughness height (e/Dh=0.083) plate and decreases with decreasing Roughness geometry.

(2) It is observed that the 3D analysis model itself yields results, which are closer to the experimental ones.

(3) On increasing the roughness on the plate the friction factor also increase.

(4) The value of the Friction factor reduces sharply at low Reynolds number, and then decrease very slightly in comparison to low Reynolds number.

(5) The computational values of the thermo hydraulic performance of the four Roughened absorber plate has been compared with smooth plate. The plate having relative roughness height (e/Dh=0.083) gives the maximum thermo hydraulic performance. But also it is seen that increase in relative roughness height beyond (e/Dh=0.078) results in marginal increase of thermo hydraulic performance.

(6) Efficiency increases as Reynold no increses .Highest Efficiency occur for plate relative roughness height (e/Dh=0.083) .As we decreses relative roughness height Efficiency also reduces. But also it is seen that increase in relative roughness height beyond (e/Dh=0.078) results in marginal increase of Efficiency.

(7) Because of artificial roughness Nusselt number is increasing but simultaneously it will also increasing friction factor. So performance of solar air heater duct can be provided on the basis of thermo hydraulic performance which incorporates both the thermal as well as hydraulic considerations.

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