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CFD SIMULATION OF HEAT TRANSFER THROUGH A ABSORBER PLATE OF SOLAR AIR HEATER WITH ARTIFICIAL ROUGHNESS

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Abstract - Solar energy is abundantly available and its use in various applications has always been of great interest among the common man, designer, engineer and researchers. One of the applications among several is in heating of air. Hot air is of use in domestic and industrial purposes. The efficiency of any solar air heater can be understood as the ability of the solar air heater to transfer the heat from the absorber plate where the solar radiations are absorbed to the air flowing over this. Since the heat transfer is affected by the surface of the absorber plate, study of surface conditions becomes essential for improving the efficiency of the heater. Many researchers have done several studies for the improvement of the heat transfer from the absorber plate to the air. In this paper, the authors have simulated the heat transfer from an absorber plate in which artificial roughness elements are provided. The simulation results show that the heat transfer is improving because of the turbulence development near the surface of the absorber plate. The temperature and velocity contours have been presented in this paper. Temperature, velocity, heat transfer coefficient and Nusselt number plots for the absorber plate are also shown.

Keywords – Artificial Roughness, Absorber Plate, CFD, Heat Transfer, Solar Heater

I. INTRODUCTION

Solar air heaters are used for the heating of air which can be applied in domestic and commercial applications. Since the fossil fuels are limited and their usage adversely affects our environment, usage of solar energy in our day to day applications is gaining importance among the policy makers, individuals, designers, engineers and researchers. The solar air heaters as shown in fig. 1 consist of an absorber plate where the incident solar radiations are absorbed according to the condition and design of absorber plate. Many researchers have done several studies on the heat transfer from the absorber plate.

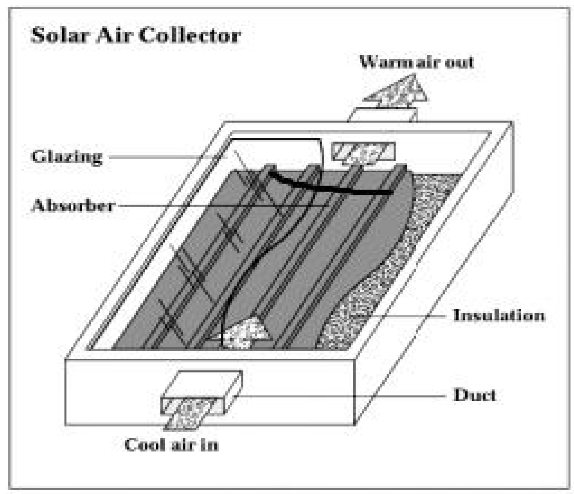

Figure 1: Air Flat Plate Collector

It has been a great challenge for the researchers to improve the efficiency of the absorber plate to transfer heat from the surface of the plate to the air flowing over it. Many scientists have worked upon the surface roughness and resulted that if the surface is artificially roughened by providing artificial roughness elements over it, the heat transfer can be improved. The smooth surface are not able to transfer hear efficiently. Further research has been taken place in the design of absorber plate with different shape an, size and orientation of the roughness elements.

In modern research work application of those research tools is becoming popular which are cost effective and which consumes less time of study and analysis without affecting the quality and accuracy of results. Computational Fluid Dynamics is one of the fluid flow and heat transfer analysis technique gaining rapid interest among researchers due to its capability of time saving and accuracy in results within the acceptable limits.

The CFD has procedure of working in most of the common engineering analyses as shown below.

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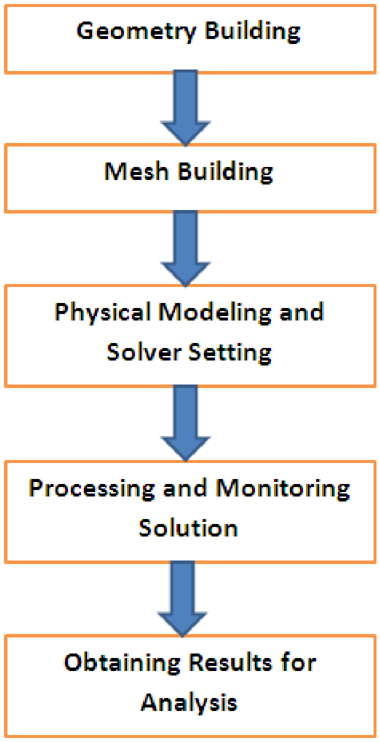
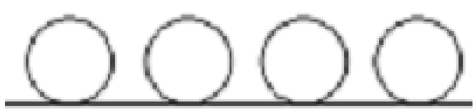


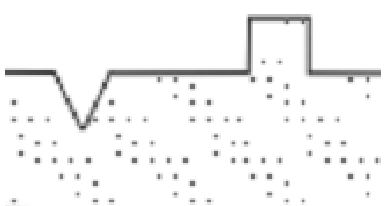
Figure 2: Steps in CFD

II. ARTIFICIAL ROUGHNESS ON ABSORBER PLATE

Artificial roughness is the provision of roughness elements over the absorber plate of some particular shape and size and ina particular arrangement. There are various types of roughness elements upon which researchers have studied for the heat transfer analysis. Some of the roughness elements are V shaped, Square shaped, wire rib etc as shown in fig. 3.



Wire rib



Transverse rib grooved

Figure 3 - Roughness geometries

III. CFD ANALYSIS

For the purpose of this dissertation work, a 3D model of solar air heater absorber plate as shown in figure 3.4 is developed using GAMBIT software. The absorber plate is provided with artificial roughness with square and triangular elements alternatively arranged over whole of the test length. The size of the solar air heater for this CFD work is taken as 200mmx20mmx850mm long. The inlet and exit sections are of the size 200mmx20mm. The inlet length of the absorber plate where the plate is smooth is taken as 180mm while exit length of the plate is taken as 91 mm. The total length of the test plate with ribs is 554mm. The height of the rib element is 2mm. The pitch of the ribs is taken as 24mm.

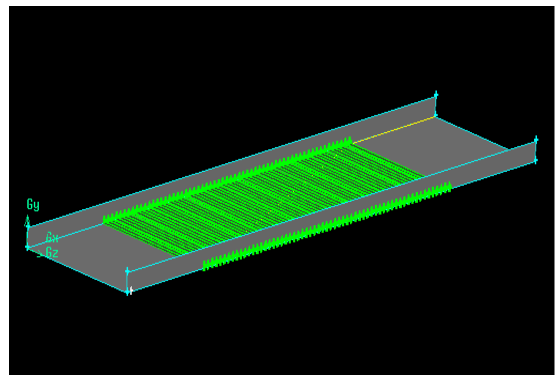


Figure 4-: Model of Solar Air Heater absorber plate with artificial roughness

(a) Boundary Conditions

For the solution of the heat transfer problem with artificial roughness on the solar absorber plate, the boundary conditions on the 2D geometry were set as per the FLUENT boundary conditions and for the viscous flow using k-Ɛ turbulent model for the flow. The boundary conditions are shown in table 1.

Table 2.1: Boundary conditions

Boundary	Type
Inlet	Velocity Inlet
Exit	Pressure outlet
Absorber plate	Wall
Insulation	Wall

(b) Governing Equations

The Transport Equations for K-Epsilon model are for k and epsilon as under

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$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial t}(\rho k u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+P_k+P_b-\rho\epsilon-Y_k+S_k$$

$$\frac{\partial}{\partial t}(\rho\epsilon)+\frac{\partial}{\partial t}(\rho\epsilon u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial\epsilon}{\partial x_j}\right]+C_{1\epsilon}\frac{\epsilon}{k}(P_k+C_{3\epsilon}P_b)-C_{2\epsilon}\rho\frac{\epsilon^2}{k}++S_\epsilon$$

Standard variant of k-epsilon model has been used for the present dissertation work the other variants useful for the regions of turbulent and high Reynolds number are RNG k-epsilon model and the Realizable k-epsilon model.

IV. SIMULATION RESULTS

The numerical simulation for the heat transfer from the roughened surface used in a solar air heater has been performed. FLUENT software was used for the CFD analysis. A 2D model of the absorber plate with artificial roughness of triangular and square shaped rib was modeled in GAMBIT software.

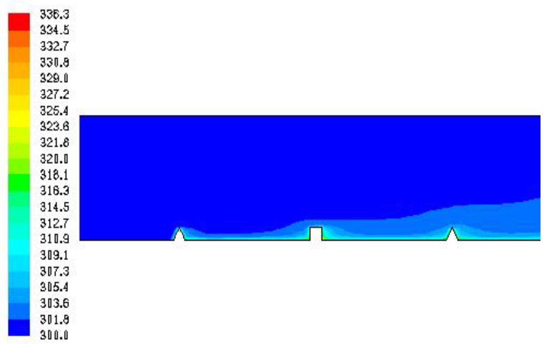


Figure 5: Temperature contours (K)

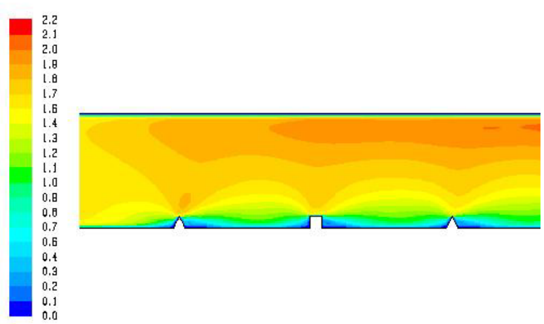
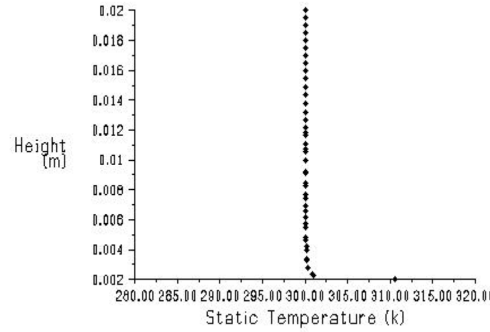
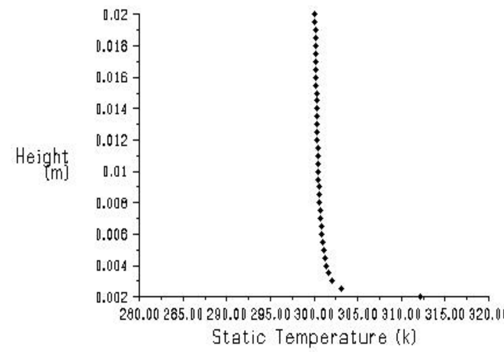


Figure 6: Velocity contours (m/s)

Temperature variation in vertical direction from the absorber plate to the complete height of the flow channel has been obtained in the form of the temperature plot. Temperatures plots at the triangular shaped rib and square shaped ribs are plotted as shown in the figure 7 (a) and (b).



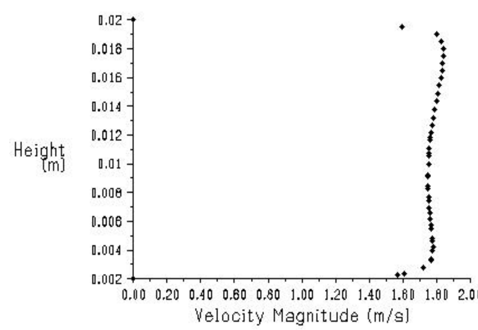
(a) Temperature at triangular rib



(b) Temperature at square rib

Figure 7: Temperature plots

Vertical velocity variation in the flow channel of the heater with absorber plate has been obtained in the form of the temperature plot. Velocity plots at the triangular shaped rib and square shaped ribs are plotted as shown in the figure 8 (a) and (b).



(a) Velocity at triangular rib

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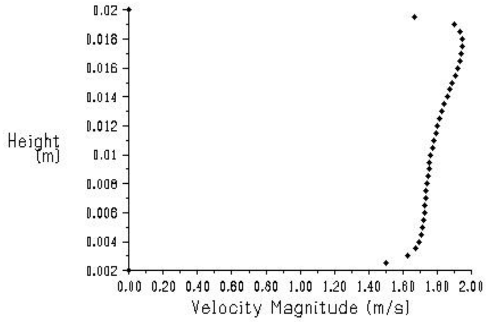

(b) Velocity at square rib

Figure 8: Velocity plots

The numerical simulation results for the heat transfer coefficient along the length of the absorber plate have also been obtained and the same are shown in the figure 9.

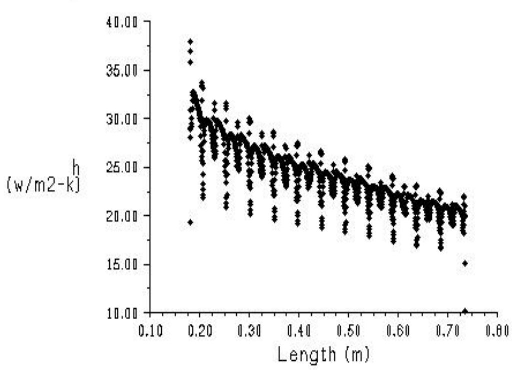

Figure 9: Heat transfer Coeff.

The numerical simulation results for the Nusselt Number along the length of the absorber plate have also been obtained and the same are shown in the figure 10.

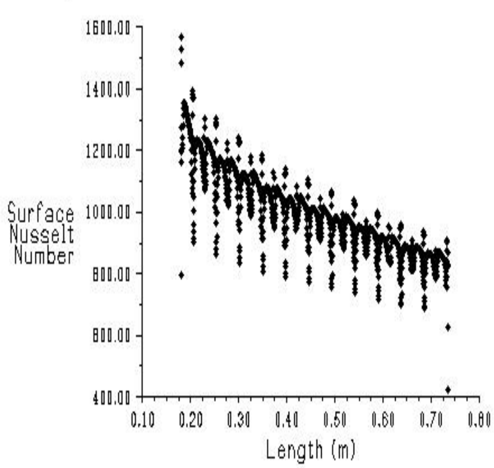

Figure 10: Nusselt Number

V. CONCLUSION

The results clearly show that the laminar sub layer at the absorber plate surface has been broken due to the artificial roughness provided over the absorber plate. The turbulent occurring at the laminar sub layer region improving the heat transfer and the Nusselt number is increasing showing the better performance of the solar air heater. The increase in the value of friction coefficient over the absorber plate surface due to the artificial roughness results in increase in the friction which will lead to the requirement of more power of the blower in the air heater to make the flow of air from the inlet to the exit section.

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