CFD Analysis on Enhancement of Heat Transfer in Solar Air Heater by using Artificial Roughness on Absorber Plate

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Abstract—Solar energy is available in nature at free of cost and may fulfill. Our requirements if it could be utilized with the help of devices developed for the specific requirement. The solar air heaters are used for heating of air by the absorbed solar radiations. The heat transfer from the collector surface to the air increases in case it is provided with roughened surface. It is found in the literature that several types of surface roughness are suitable for use in solar air heater for improved heat transfer rate. The present work comprises CFD analysis of artificially roughened surface with triangular and square shaped ribs alternatively placed over the absorber surface. The heat transfer rate for this arrangement is evaluated for the solar air heater with assumed solar radiations. Computational Fluid Dynamics is widely being used in the analysis of the flow problems and the same tool has been used in this research work for the development of methodology for analysis of the artificially roughened surface with two different shape ribs alternatively arranged. The simulation results are obtained in the form of contours and plots by solving the problem using turbulent k-ε model. Temperature and velocity contours have been shown to represent the temperature and velocity distribution in the flow regions. The results so obtained demonstrate that this arrangement is a better option for the improved performance of the solar air heater as compared to the arrangement of artificial roughness element available in the base paper. The work also provides the procedure and methodology in the systematic manner to numerical simulate the heat transfer analysis providing guidance for further such analysis with acceptable accuracy.

Keywords: Heat Transfer, CFD, Artificial Roughness

I. Introduction

Energy plays key role for economic and social development of the nation also. Demand for energy has been rising rapidly with growing population, transportation and industrialization of any country or nation. Due to the continuous use of fossil fuels in most of activities of society or industry, not only the energy starvation is felt at global level but another serious problem of environment degradation all around has also been resulted in last several years. The rapid depletion of conventional energy sources has necessitated the finding of alternative energy sources to meet the energy demand. Among the available alternatives, non- conventional energy source of solar energy is an important an alternative which can be thought of long range promise towards meeting the continually increasing demand for energy. Solar energy is available freely, omnipresent and an indigenous source of energy providing a clean and pollution free atmosphere.

II. Solar air heater

Solar air heaters have been made in variety of designs. In some the absorber surface beneath the glazing, includes overlapped, spaced, clear and black glass plates, single smooth metal sheets, flow through stacked screen or mesh, corrugated metal plates, finned metal sheets and others. In other air passing beneath the plate or underlying air passage reduces downward heat loss and one or two covers of glass or transparent plastic provide resistance to upward convection and radiate losses. The various methods of solar energy utilization can be broadly classified and is shown in fig.

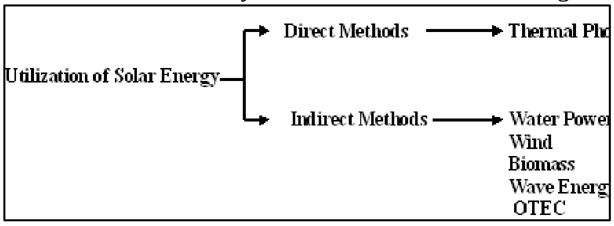


Fig. 1: Classification of Solar energy utilization

III. Artificial roughness

Thermo hydraulic performance of a solar air heater can be improved by providing artificial roughness on the absorber plate. The artificial roughness has been used extensively for the enhancement of forced convective heat transfer, which further requires flow at the heat-transferring surface to be turbulent. However, energy for creating such turbulence has to come from the fan or blower and the excessive power is required to flow air through the duct. Therefore, it is desirable that the turbulence must be created only in the region very close to the heat transferring surface, so that the power requirement may be lessened.

The researchers are working on analysis of solar air heaters [1] have made an attempt has to carry out CFD based analysis using FLUENT 6.2 to fluid flow and heat transfer characteristics of solar air heater having roughened duct provided with artificial roughness. CFD based performance analysis of solar air heater duct provided with artificial roughness in the form of square type protrusion shape geometry has been reported [2]. Effect of square type protrusions on heat transfer and friction has been investigated for Reynolds number range of 4000-20000 and relative roughness pitch of 38.8-61.1 at fixed relative roughness height of 0.016. The study evaluates heat transfer and fluid flow behavior in a rectangular duct with inverted *U*- type turbulator roughened ribs mounted on one of the principal wall (solar plate) by computational fluid dynamics software (Fluent 6.3.26 Solver) [3]. In this study CFD software has been used to perform a numerical simulation for enhance turbulent heat transfer. In this study, the Reynolds-Averaged Navier– Stokes analysis is used as a numerical technique and the k-ε turbulent model with near-wall treatment as a turbulent model.

The thermal performance of solar air has been carried out with k-ε turbulence model is heater is generally poor due to low heat transfer selected by comparing the predictions of different coefficient between the absorber plate and air flowing in turbulence models with experimental results available the duct. In order to improve the thermal performance with the help of computational artificial roughness is provided on the underside of absorber plate due to which turbulence is created in the used for simulation [4]. Fluid flow (FLUENT) module has heat transfer zone and ultimately performance of solar been used in present work. Fluid flow (FLUENT) air heater improves considerably. The research predicts the outlet temperature, velocity, in a rectangular duct in an application of solar air heater having triangular rib roughness on the surface of the absorber of solar air heater.

IV. NUMERICAL RESULTS

In order to provide the useful results a 2-dimensional solution domain used for CFD analysis has been generated as shown in fig. 2. The solution domain is a horizontal duct with triangular transverse wire rib roughness on the absorber plate at the underside of the top of the duct while other sides are considered as smooth surfaces.

Fig. 2: Schematic of two-dimensionalSolution domain

The various ranges of geometric and operating parameters are given below in table 1. After studying the performance of different selected models with the experimental results, the SST K-ε model has been found to yield closer to the experimental results as compared to other models and used in this research work.

Operating Parameters	Range
Uniform heat flux 'I'	1000 w/m^2
Reynolds number 'Re'	4000,8000,12000
Prandtl number 'Pr'	0.7441
Relative roughness pitch 'P/e'	10, 12 and 14
Relative roughness height 'e/D'	0.03 Constant
Duct aspect ratio'W/H'	5

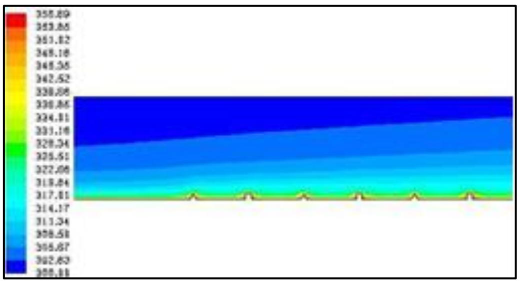
Table1: Range of Operating Parameters

V. TEMPERATURE AND VELOCITY CONTOURS

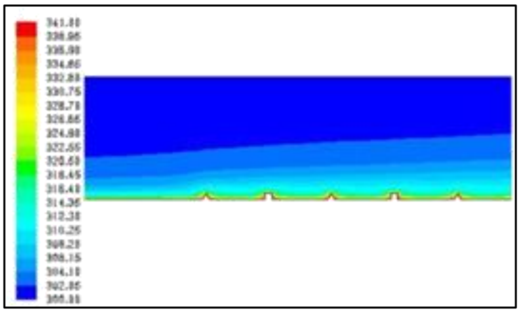
The results obtained in the form of temperature and velocity contours are shown in Figure 3&4 (a) – (c) for Case 1, Figure 4&5 (a) – (c) for Case 2 and Figure 5&6 (a) – (c) for Case 3,

Case	p/e	Re
I	10	4000-12000
II	12	4000-12000
III	14	4000-12000

Table 2 : Cases



(a)



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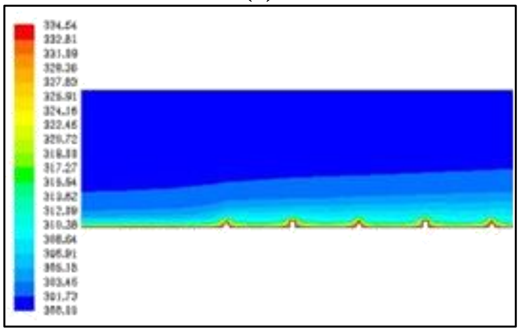
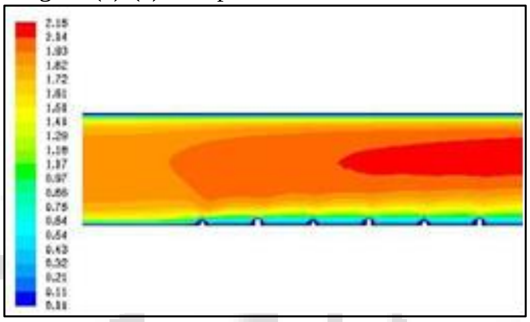
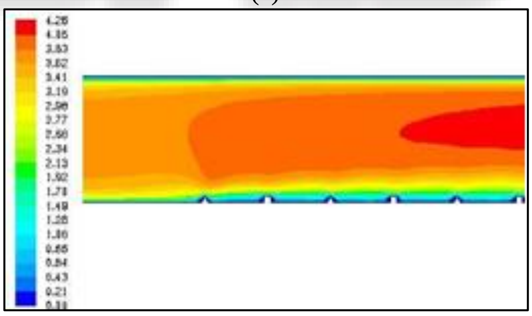


(c)

Fig. 3: (a)-(c):Temperature contours for case 1



(a)



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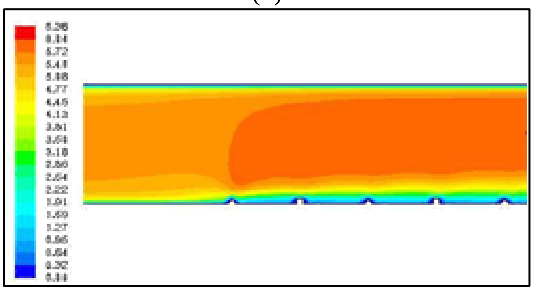
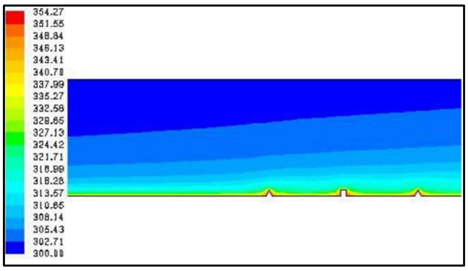
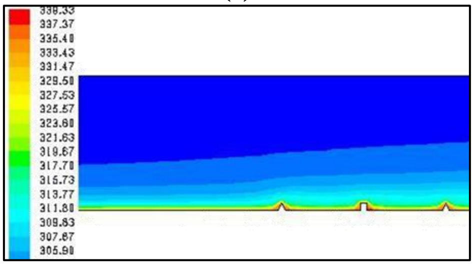


(c)

Fig. 4: (a) – (c)velocity contours for Case 1.



(a)



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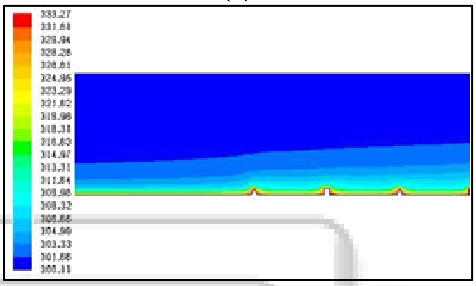
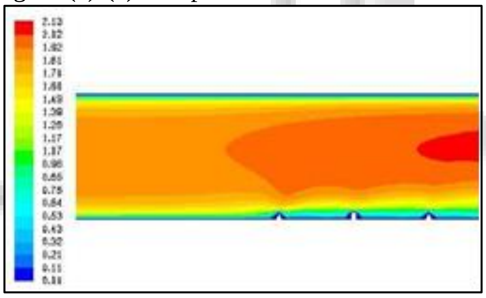
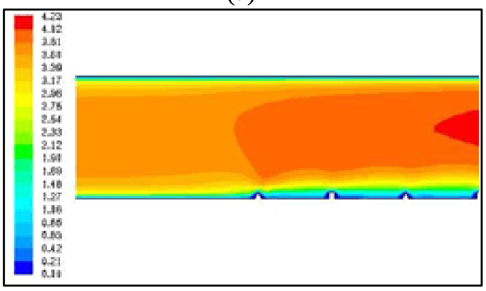


(c)

Fig. 5: (a)-(c) Temperature contours for case 1I



(a)



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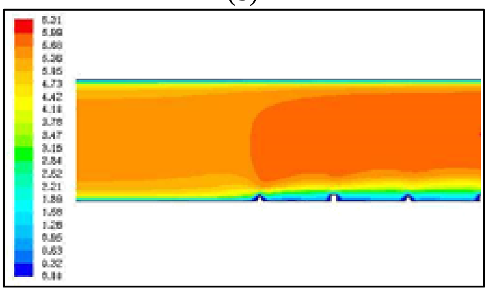
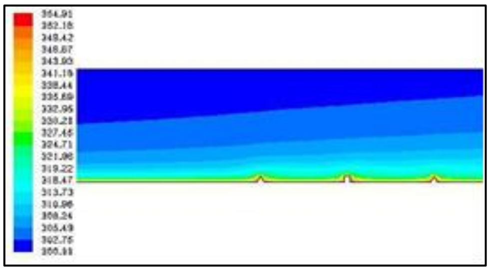
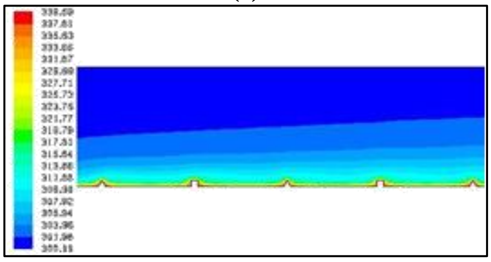


(c)

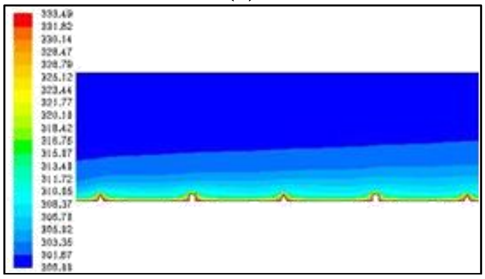
Fig. 6: (a)-(c) velocity contours for case II



(a)

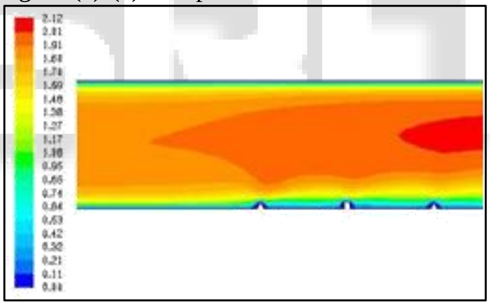


(b)

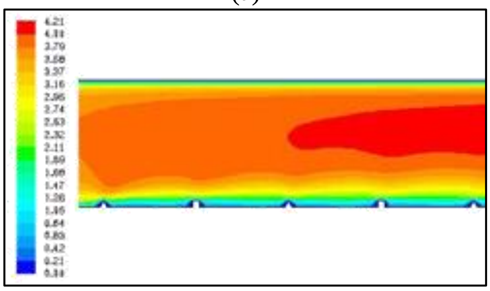


(c)

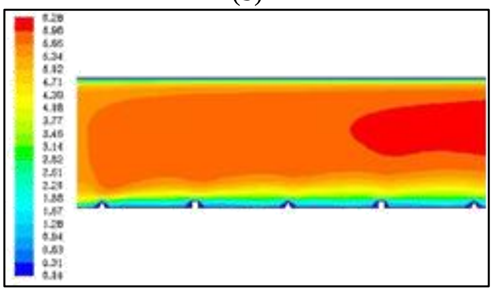
Fig. 7: (a)-(c) Temperture contours for case III



(a)



(b)



(c)

Fig. 8: (a)-(c) velocity contours for case III

VI. Conclusion

For the effective utilisation of the solar air heater, the performance of the system needs to be improved. It is found that the thermo-physical performance of the solar heater is greatly affected by the heat transfer from the absorber plate to the air. It is also available in the literature that the surface improvement with the means of artificial roughness improves the heat transfer rate by increasing the turbulence. Several geometry and orientations of the roughness elements have been studied by the researchers over a long time. The authors have also studied a case in which the geometry in the form of square and triangle shape elements alternatively arranged over the surface of the absorber plate. The study shows that the heat transfer rate is improving as compared to the triangle shaped geometry alone. The results obtained from the CFD analysis are presented to show the temperature and velocity distribution in the heat transfer region.

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