

# CFD Simulation of Heat Transfer and Air Flow in Solar Air Heater

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**ABSTRACT:** Artificial roughness in the form of triangular protrusions on the absorber plate is an effective technique to enhance the rate of heat transfer to flowing fluid in the roughened duct of solar air heater. It is well known, that the heat transfer coefficient of a solar air heater duct can be increased by providing artificial roughness on the heated wall experiments are performed to collect heat transfer and friction data for forced convection flow of air in solar air heater rectangular duct. The Reynolds number of the air flow ranges from 10000 to 12000. The Nusselt number obtained is in the range of 50 to 110. The maximum Nusselt number is 42% higher than that of the smooth plate while the average value of the Nusselt number is 60% higher than that of the smooth plate. The apparatus is simulated in a virtual CFD environment to determine the temperature and velocity field to examine their distribution along the surface of the plate as well as the cross section of the duct

**KEYWORDS:** solar air heater, Nusselt number, Reynolds number, CFD

## I. INTRODUCTION

Forced convection heat transfer within the smooth and roughened ducts has been investigated by several investigators, and a large amount of useful information is available in literature. The use of artificial roughness on a surface is an effective technique to enhance heat transfer to fluid flowing in the duct. The applications of artificial roughness in the form of fine wires and ribs of different shapes have been recommended to enhance the heat transfer coefficient by several investigations. Heat transfer enhancement techniques have been employed to improve the performance of solar air heater which is the simplest and most commonly used device in solar energy applications, remaining low grade thermal energy, such as drying of agricultural produce, seasoning of wood, space heating, curing of industrial products. As the air flows through the duct of a solar air heater, a laminar sub layer is formed over the absorber surface that impedes the heat transfer to the flowing air. There by adversely affecting the thermal performance of the solar air heater. Use of artificial roughness to increase heat transfer coefficient has been studied using CFD. CFD based analysis for investigating heat transfer and friction characteristics of rib roughened rectangular air duct. In the present work, formation of triangular type protrusions on the surface of absorber plate has been considered to create artificial roughness. CFD based heat transfer and flow analysis of the chosen roughness element has been carried out by using flow simulation module available in solid works software. Nusselt number and friction factor correlations have been generated under present CFD based investigation. CFD is such type of numerical procedure, which helps in analyzing fluid flow and heat transfer related problems. During CFD based analysis, 2-D computational domain and grid were selected. Non uniform meshing is generated over the duct. Static pressure and air velocity were considered as inlet and outlet boundary conditions in order to have pressure drop in test section of the duct. As flow of air takes place within selected geometry, in order to carry out CFD analysis in two dimensional planes, some assumptions were made.

1. Flow is fully turbulent and steady
2. Thermal conductivity remains constant and do not change with temperature
3. Material of ribs and duct are homogeneous and isotropic

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In the present work, the aluminium plate materials are used as an absorber plates in the duct. The triangular protrusions are created over a method of CNC Milling machine.

## II. RELATED WORK

An artificial roughness is used as turbulence promoters on a surface. The surface roughness can be created by number of methods such as welding, fixing small ribs, fixing small diameter wires, machining and sand blasting, casting and forming. Many investigations on forced convective heat transfer in smooth and roughened ducts have been reported in literature. A create artificial roughness on the surface of absorber plate can be provided ribs, fixing small diameter wires, expanded metal mesh, wire mesh and dimple shape geometry has been reported by Hans et al. and BrizBhushan of different shapes to enhance the heat transfer co-efficient. Experimental investigations on heat transfer and friction in artificially roughened solar air heater duct have been reported by Gupta et al., Jaurker et al., Karwa, Karmare and Tikekar, Momin et. al., Prasad and Saini. Nusselt number and friction factor correlations have been developed by these investigators by using experimental data.

## III. EXPERIMENTAL SETUP

As shown in Fig.1. A rectangular duct with internal passage having dimensions 2400mm x 150mm x 15mm is made to allow the air flow through it. The flow system of the rectangular plywood duct is categorized as three sections i.e., entry, test and exit sections.



Fig. 1. Photographic view of experimental setup

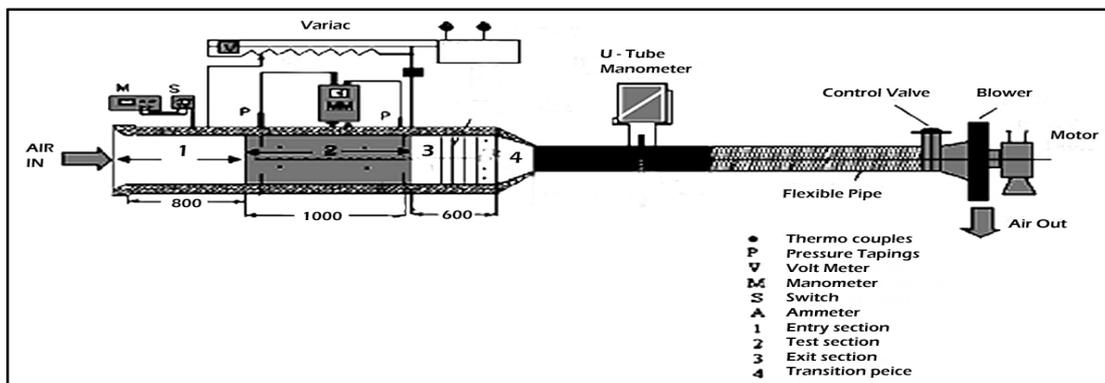


Fig.2. Line diagram of experimental setup

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An aluminium absorber plate emits the heat which it has absorbed from the electric heater provided over it, through radiation to the flowing air by the process of forced convection. A transition at the exit of the duct connects the rectangular cross-section to circular cross section of the G.I. Pipe. An orifice meter is also provided over the pipe for flow measurement. A by-pass valve is connected to the G.I. Pipe through a T-joint to regulate the air flow. A centrifugal blower is the main source of pressure inside the duct that pulls the air from atmosphere through the apparatus by creating suction in the duct. The process can be visualized from the fig.2.

### ALUMINIUM ABSORBER PLATES

Four Aluminium Absorber plates of surface dimension 1000mm X 150mm and thickness of 6mm are same for all plates.



Fig.3. Smooth Aluminium Absorber Plate



Fig.4. Aluminium Absorber Plate with 30° apex angle

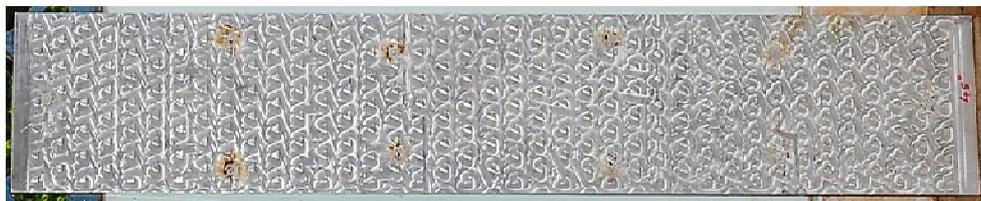


Fig.5. Aluminium Absorber Plate with 45° apex angle



Fig.6. Aluminium Absorber Plate with 60° apex angle

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## IV. EXPERIMENTATION

The setup is checked for proper operation. At the beginning the blower is then switched on and joints have been checked for leakage. The absorber plate is placed on the test section and the heater is placed above the absorber plate. The duct is then fully covered with thick glass wool insulation. The electric heater is connected to the variac. Copper-constantan thermocouples are used to measure the temperature of absorber plate and the air. Flow of air is controlled with the help of control valve. Initially the control valve is closed and switch on the heater. The plate is allowed to get heated and the blower is switch on the temperature of the plate and air are maintained to assume steady state. Under steady state conditions the test runs to collect relevant heat transfer data. Later the absorber plate is replaced by another absorber plate with protrusions of different configurations and the experimentation is repeated.

## V. RESULTS AND DISCUSSION

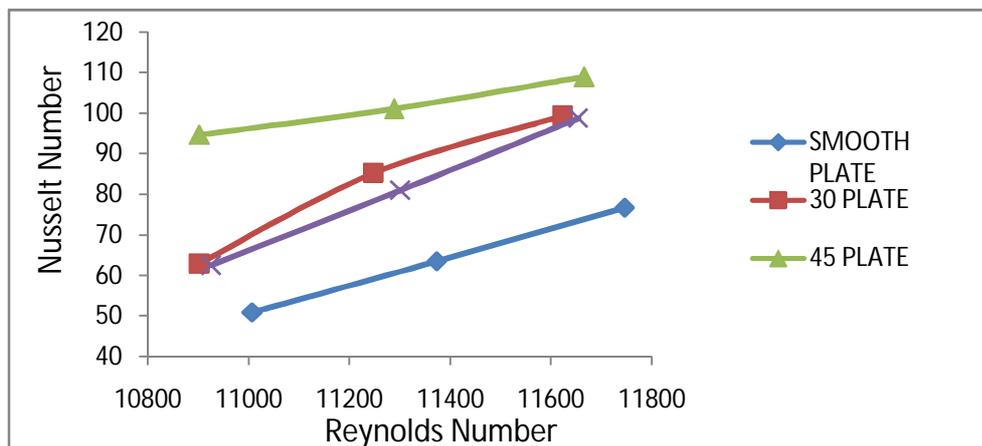


Fig: 7. Friction factor vs. Reynolds number

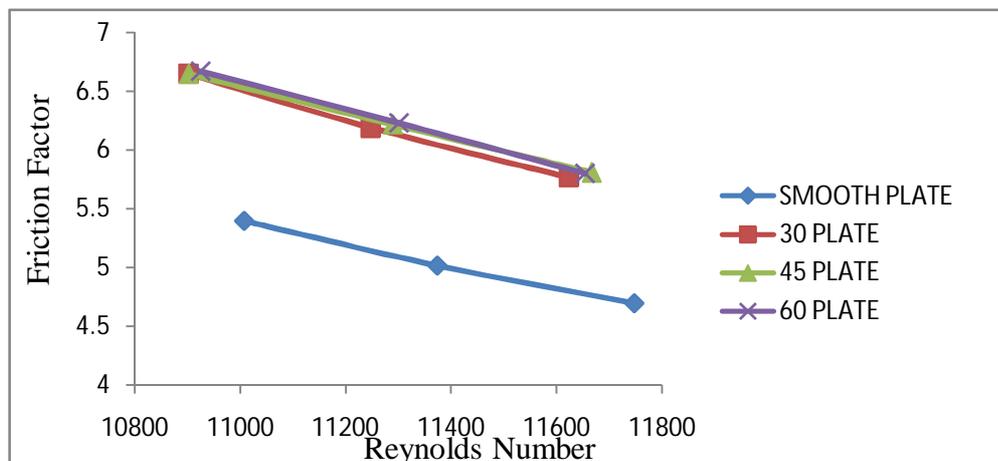


Fig: 8. Friction factor vs. Reynolds number

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Fig.7.shows itt can be observed that the Nu increases with increase in the Re.The Nu values of the roughened plates are higher than that of the smooth plate.The Nu is maximum for the 45<sup>0</sup> apex angle plate.

Fig.8.shows the friction factor decrees with increase in Reynolds number. The friction factor values of the roughened plate are higher than that of the smooth plate. The friction factor values for all the roughened plates are almost same.

## VI. COMPUTATIONAL FLUID DYNAMIC SIMULATION

The CFD simulations provides a clear 2-D image of the velocity and temperature distribution of the air layers by which one can simply judge the effect of provided protrusions and their performance from those pictures. The temperature and velocity graphic scenes let us easily find out the temperature and velocity of air at any point inside the test section.

### Utility of CFD

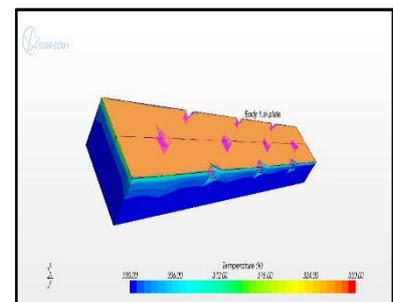
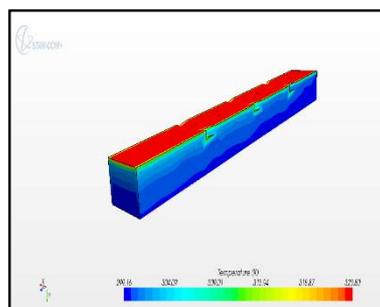
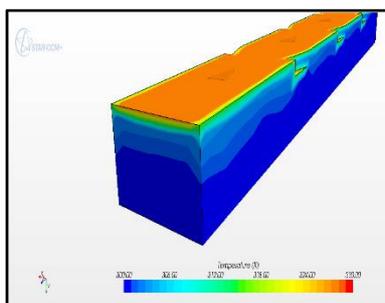
Whatever results have been obtained, CFD analysis provides us an opportunity to visualize and explain how the shape, size and configuration of the triangular protrusions affected the performance of the apparatus. For this purpose, a virtual apparatus, environment and experimental conditions were generated in STAR CCM+software that are used to carry out the CFD analysis for this experiment.

### Modeling

First, the model of the apparatus is designed in the module of STAR-CCM+ called feature-based parametric solid modeller, 3D-CAD. The geometry created with 3D-CAD is stored as 3D-CAD models, which can be subsequently converted to geometry parts for integration with the meshing and simulation process. Models are created by carrying out a series of operations called features such as sketching, extruding and cutting and the chronological overview of these features is displayed in the feature tree. 3D-CAD models are visualized in a 3D-CAD View scene.

In 3D-CAD, each region is treated as a part and has its own properties and features. A function is assigned to it so as to serve in the simulation environment. In this case the wooden walls on the three sides of the duct are treated as a single part which is adiabatic and does not allow any thermal interaction with the surroundings. The top surface of the duct is assigned to be the absorber plate which has protrusions into the duct cross section through which the air flows. A geometry part represents an object or collection of objects that can be used as the input geometry for the meshing tools. In the current simulation each extruded body act as a separate component as such each triangular protrusion over the surface of the absorber plate and the absorber plate alone act as different components which are united into a single region. The three wall of the rectangular wooden duct act as individual bodies also united to form a single region.The surface applied for the current model enables the body to be recognized by some features like colour, structure, size, material etc. A surface is the interface to interact with the environment. The surface is responsible for the capability of the body to interact with the surrounding environment. The interaction might lead to heat transfer, momentum transfer or of any other kind.

### TEMPERATURE (SCALAR) SCENES OF 30<sup>0</sup>,45<sup>0</sup>& 60<sup>0</sup> PLATE

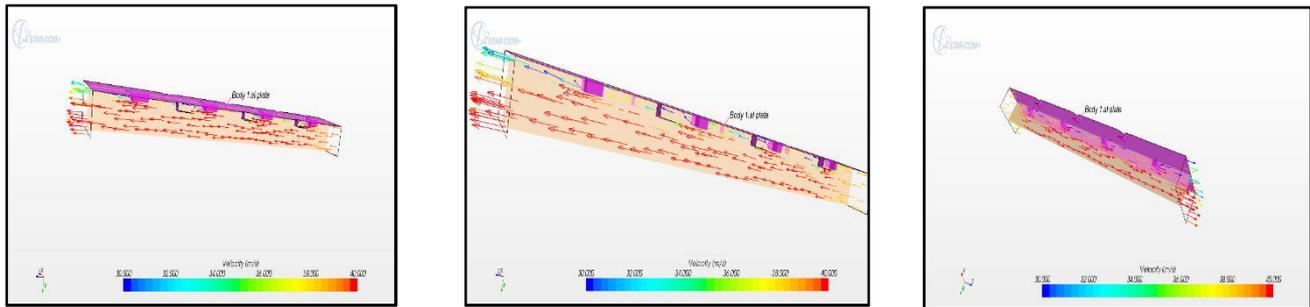


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## VELOCITY (VECTOR) SCENES OF 30<sup>0</sup>,45<sup>0</sup>& 60<sup>0</sup> PLATE



It is possible to use the experimental results of this work for computational fluid dynamics simulation. CFD study makes the work simple and helps in studying the effect of change in any parameter used for design of triangular protrusions without physical models.

Along with experiment, the apparatus is simulated in a virtual CFD environment to determine the temperature and velocity field to examine their distribution along the surface of the plate as well as the cross section of the duct. This may help in understanding the effect of providing protrusions in effecting the Heat transfer at the flow of air. It is observed the above figures the temperature and velocity fields are maximum at 45<sup>0</sup> apex angle plate

## VII. CONCLUSIONS

An experimental investigation is done on a solar air heater with simulated conditions in the laboratory. In this experiment, triangular protrusions have been used as roughness elements on aluminium absorber plates to better heat transfer enhancement of a solar air heater duct.

- It is observed that the Nusselt number value increases with increase in Reynolds number. It can be noticed that maximum Nusselt number values are obtained for the plate with 45<sup>0</sup> apex angle protrusions at all possible values of Reynolds number.
- The maximum Nusselt number is 42% higher than that of the smooth plate while the average value of the Nusselt number is 60% higher than that of the smooth plate.
- It is observed that the friction factor value decreases with increase in Reynolds number. The value of the friction factor is observed to be almost the same for all the plates with different roughness elements used. But the friction factor value of the absorber plates with roughness elements is higher than the corresponding values of the smooth plate.
- The maximum value of friction factor for the roughened absorber plate is  $6.7 \times 10^{-3}$  which is obtained for the 45<sup>0</sup> plate while the corresponding friction factor value of the smooth absorber plate is  $5.4 \times 10^{-3}$ .
- Along with experiment, the apparatus is simulated in a virtual CFD environment to determine the temperature and velocity field to examine their distribution along the surface of the plate as well as the cross section of the duct. This may help in understanding the effect of providing protrusions in effecting the heat transfer at the flow of air.

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