INVESTIGATION OF HEAT TRANSFER BEHAVIOR OF A FINNED SOLAR AIR COLLECTOR USING FLUENT

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ABSTRACT

This study assesses the performance of solar air collector for space and process heating using computational fluid dynamic technique. Fluent software was employed to evaluate the impact of geometry, orientation and slope on the heat transfer process in the collector duct. The results of the analysis showed that presence of fins in the solar air collector results in larger heat transfer rates. Buoyancy effects are pronounced in larger slope angle of collector. Relatively high air temperature at the outlet of the collector can be achieved by using low flow velocity in the collector. It is suggested that collectors made of sheet metal can be used for low cost space heating purposes in the country.

1. INTRODUCTION

Abundant solar energy in the form of solar radiation can be utilized for replacing traditional fossil fuels for low temperature use. Pakistan is Sunbelt country with more than 300 sunny days in year. Solar energy can be used for space and process heating purposes. Winter season in a large part of Pakistan is sunny that offer us the opportunity to use this free energy source for space heating purposes. Figures 1 shows monthly mean sunshine hours for Karachi the while Figure 2 illustrates extraterrestrial, total and beam solar radiation for the first week of June for Karachi – it is obvious these graphs that abundant amount of solar energy available can be used for comfort and process heating.

A solar collector is a type of heat exchanger which converts solar radiation falling on its absorber surface into heat that is used to raise the temperature of a fluid (Duffie & Beckman, 1991). Due to its low cost and simple design and operation the most frequently used type of solar collectors is flat plat collector; it is none concentrating and has fixed south facing orientation. It consists of a black colored absorber plate, transparent cover for decreasing radiation and convection losses and side and back insulation for lessening. It is becoming increasingly common because of feasibility of its application in common life.

Higher fluid temperature at the collector outlet can be achieved by employing double glazing, selective absorber surface, high insulation and fins. Figure 3 shows efficiencies of black painted and selective coated air collectors. When air is the working fluid in the collector than sufficiently high temperature can be achieved by adopting above mentioned measure and increasing the residence time of air in the collector.

The low heat transfer properties of air necessitate a study of the factors which have an effect on the performance of air collector. The objective of this study is to ascertain two important issues regarding the use of air collector for gathering heat energy for space heating and process heating. Computation fluid dynamics (CFD) is a suitable technique to perform detailed fluid flow and heat transfer analysis of a solar air collector.

2. THERMAL ANALYSIS OF SOLAR AIR COLLECTOR

It has been observed that the heat transfer coefficient between the absorber plate and working fluid of solar air collector is generally low. It is attributed to two contributory factors; first, the formation of a very thin boundary layer at the absorber plate surface commonly known as viscous sub-layer (Chaube et al, 2006) and second, the low heat capacity of air (Lin et al, 2006). The predominant mechanism of heat transfer through the boundary layer is conduction, since the conductivity of air is very low hence it can be said that this boundary layer works as an impediment to heat transfer from the absorber plate to bulk air flow. To increase the heat transfer between absorber and air two variables can be improved i. e., heat transfer coefficient and heat transfer area (Goldstein & Sparrow, 1976). The convective heat transfer coefficient can be increased by providing artificial roughness on the heat transferring surface (Webb & Eckert, 1997) this technique tends to increase the heat transfer rate between absorber plate and air (Liou et al, 1993).

The other technique is to increase the heat transfer area which could result in an overall increase in heat transfer rate. One technique of increasing heat transfer area is to use fins below the absorber plate. Although the application of fins in a conventional solar air heater has been known to be an efficient method of enhancement of thermal efficiency of solar air heater and several experimental studies in this area have been carried out; literature search in this area revealed that few CFD studies have been done to investigate the effect of slope on the overall heat transfer in an inclined duct with staggered fins. In this work, an attempt is made to numerically predict effect of staggered fins, low flow velocity and solar collector slope angle on the heat transfer effects.

Following section gives a general brief overview of modeling procedure in Fluent computational fluid dynamics software.

3. MODELING PROCEDURE IN CFD

CFD modeling was originally developed for industrial application. Today it is used in research work, product development, and in almost all sphere of activity where a detailed picture of phenomena involving heat transfer and fluid flow, phase change etc is desired. Presently CFD techniques are increasingly used to model flow through solar collectors (Lee & Abdel-Moneim, 2001).

The analysis of a process in Fluent involves many steps in sequence to obtain the desired results. Figure 7.7 shows the steps needed to complete a Fluent analysis. Gambit is pre-processor software which facilitates the use of Fluent software. Its CAD interface facilities include

- Drawing two and three dimensional model,
- Defining their boundary conditions
- Generating the calculation mesh

The calculation mesh is exported to Fluent software which is mainly used as a calculation tool. These three steps are explained briefly in the following sections. Other details can be found by referring to Gambit help menu.

Gambit software is used for generating and analyzing grid. Boundary types can also be defined in Gambit; this task can also be defined in the Fluent preprocessor. Fluent can use unstructured as well as body fitted structured meshes with all types of mesh elements, such as triangular and quadrilateral elements in two dimensional, and tetrahedral, hexahedral, pyramid, and wedge elements in three dimensional analysis. This software is also capable of adapting all types of meshes during the solution. This allows one to refine the resolution in areas of significant gradients in order to prevent high numerical errors.

After the pre-processing part has been finished the simulation setup can be stored in a case file. This file includes information on the grid file, the boundary conditions and the physical as well as computational models of the run.

Fluent software can be employed to simulate airflow under the influence of various parameters such as air velocity, location and size of opening etc. however it is crucial to define the program settings correctly. Some relevant software settings are as follows:

3D, Single Precision
Segregated Solver
Implicit formulation
Steady state scheme
Boussinesq Model for modeling density
k-ε turbulence model
Thermo-physical properties

In the present case the specific heat, viscosity and thermal conductivity values of air were kept constant at T = 328 K.

After completing all the relevant settings Fluent starts to perform the calculation in an iterative manner until a sufficient tolerance, defined by the user, is achieved. This means that solution will converge after attaining that minimum error. The calculation time increases when a smaller error is defined.

The solution domain for the CFD analysis was adapted from the experimental details of solar air collector as described by Kurtabas & Emre, 2006. The collector absorber was a rectangular duct with length of 1960 mm, width 930 mm and height of 60 mm. The duct had 32 fins of 0.012 m^2 area each with a width of 200mm and height of 60 mm. In their experimental work Kurtbas et al placed fins in staggered fashion in the absorber duct. Because of the symmetrical nature of the solution domain a quarter portion of the collector was used for the domain to save computational time and power. Figure 4 illustrates the important functional part of the collector analyzed.

In the experimental details, the thickness of the heated plate was only 1 mm, which was very small in comparison to the surface area normal to the heat flow. Hence the Biot number was also very small, that means that the internal resistance could be neglected in comparison to convective resistance. This permitted a uniform heat flux of 400W/m^2 to be applied on absorber top surface, neglecting the conduction resistance within the plate. A 3-D analysis of heat transfer and air flow through the quarter portion of the solar air collector duct, inclined at 24º and 45º, with parallel fins, insulated bottom side was done on Fluent 6.2 CFD software. Figure 5 shows the meshing in quarter portion of the air collector absorber region to save on computation time and memory.

4. RESULTS AND DISCUSSION – FLUENT

The CFD analysis was carried out on a solar air collector for two slope angles of 45º and 24º in light of the optimal solar gain for Karachi latitude 24º. A closer inspection of the physics of heating by an inclined overlaying surface revealed that, under free convection conditions, increase in slope angle promotes heat transfer. A horizontal plate is the worst case scenario, while vertical plate is the best case

Figure 6 shows the contours of velocity magnitude for 45ºcollector inclination, the buoyancy effects are apparent as the lateral velocity is low. Since solar radiation is falls from the sky heating was carried out from a surface overlaying the absorber. Top heating of absorber results into inefficient heating of air. Hot air due to its low density clings to under side of the top surface while relatively cool air because of high density stays in the lower regions. This stratification effect is clearly shown in 45º and 24º slope angles of the absorber in Figures 7.

Effects of bouncy are not totally absent but play a part in the heat transfer process along with the forced convection effects this can be noted in Figure 8 for 24º slope. The reason for this type of flow behavior is the higher buoyancy induced flow at steeper angle. It is apparent that the sweep action of the bulk flow velocity is unable to dislodge the dead regions or diminish their size.

The meandering path lines of the air elements are clearly shown in Figure 8 as air being heated from top side passes along and through the gaps between fins. Left side shows the orderly entrance to side of collector. Longer streak lines imply longer residence time which results in air attaining a higher temperature in the collector at lower velocity.

Temperature contours on the mid plane (created virtually to view results) of the heater 30mm from the top are shown in Figure 9. Rising plumes of air indicate that buoyancy effects are present, collector slope 24º

5. CONCLUSIONS

The CFD analysis of air collector showed that regions around and between the fins promoted heat transfer from the absorber plate to air. The results showed a dependence of buoyant flow on low flow velocity, a necessity for achieving longer residence time, and slope of collector. It was also demonstrated that at low flow velocity inclination of solar absorber affected the temperature and velocity profile with buoyancy playing a part in determining the flow pattern and the heat transfer rate.

The presence of staggered fins in the absorber resulted in the larger heat transfer rates. Fins also helped in increasing the residence time of air consequently increasing air temperature gain. Existence of fins also supported to the mixing of air masses at different temperature thus increasing the thermal energy yield.

If such finned solar air collectors made of sheet metal with single glazing and proper insulation are employed on a large scale nationwide for space heating purposes than a substantial saving in fuel such natural gas, LPG and wood can be achieved. This will result in a lower environmental damage and improved indoor air quality of home in winter in Northern areas of Pakistan.

6. REFERENCES

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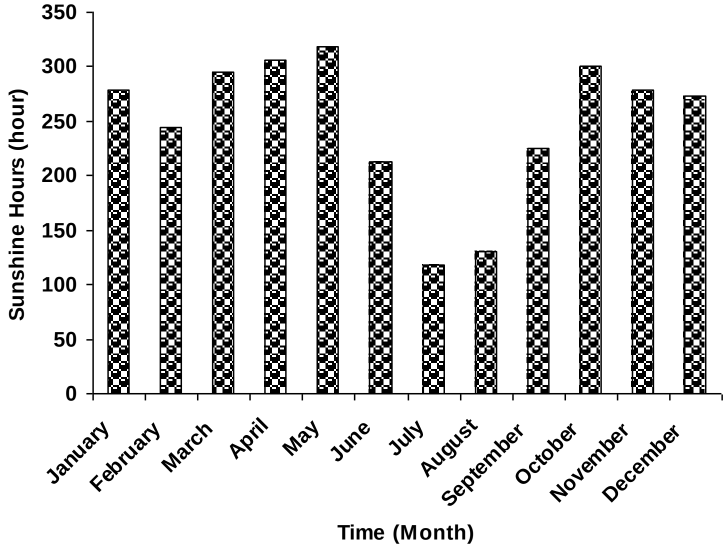

Fig 1. Monthly mean sunshine hours for Karachi

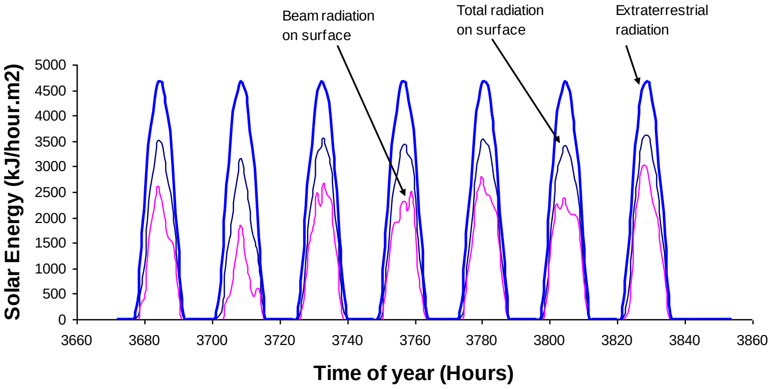

Fig 2. Extraterrestrial, total and beam solar radiation for the first week of June for Karachi

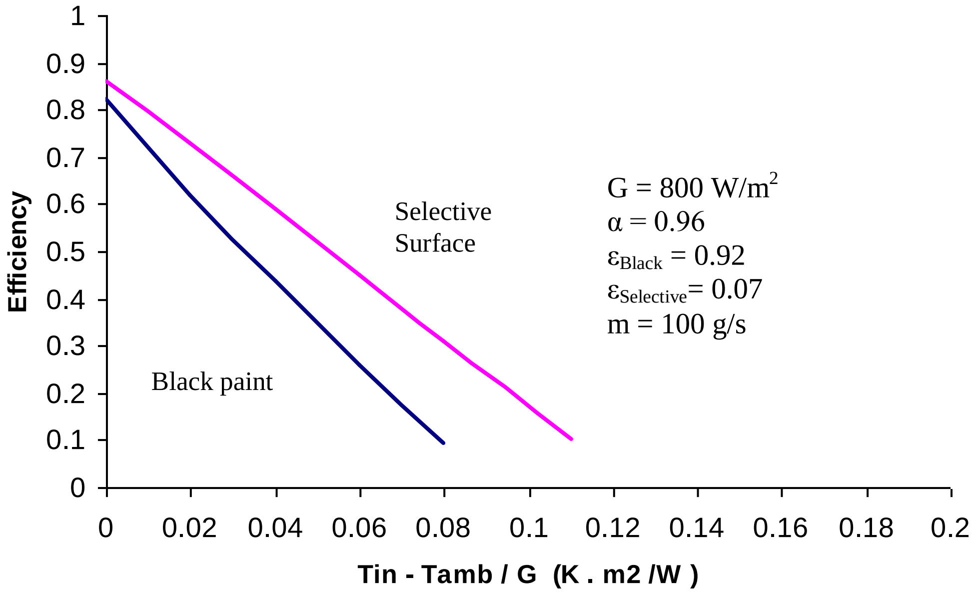

Fig 3. Efficiencies of black painted and selective coating absorber air collectors [2]

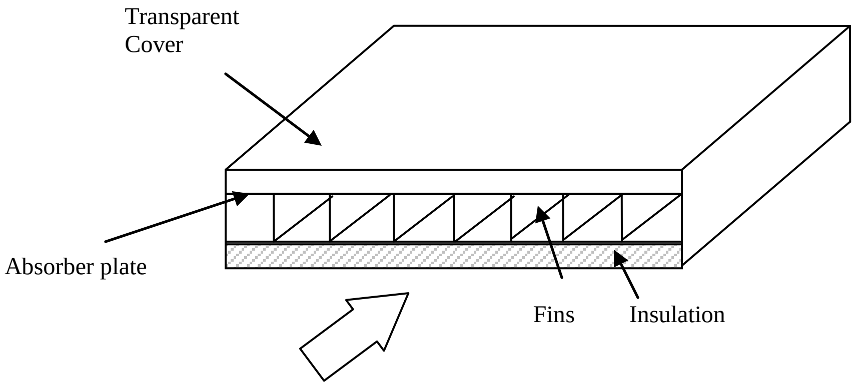

Fig 4. Solar air collector absorber plate and fins

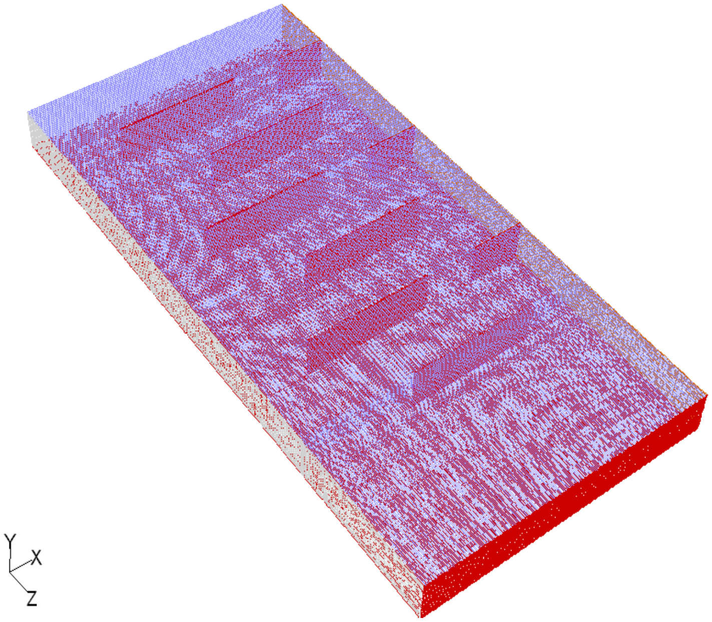

Fig 5. Meshing in quarter portion of the air collector absorber region to save on computation time and memory

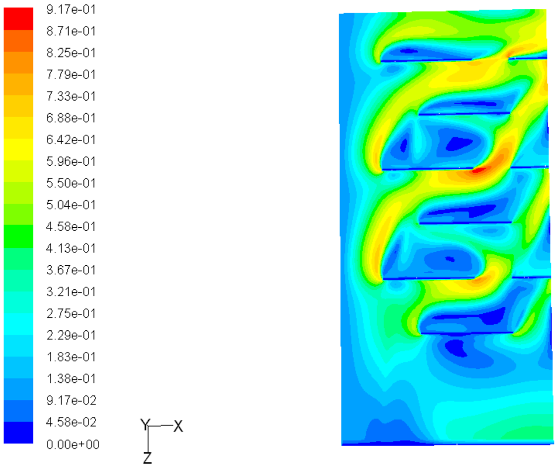

Fig 6. Contours of velocity magnitude. The buoyancy effects are apparent as the lateral velocity is low

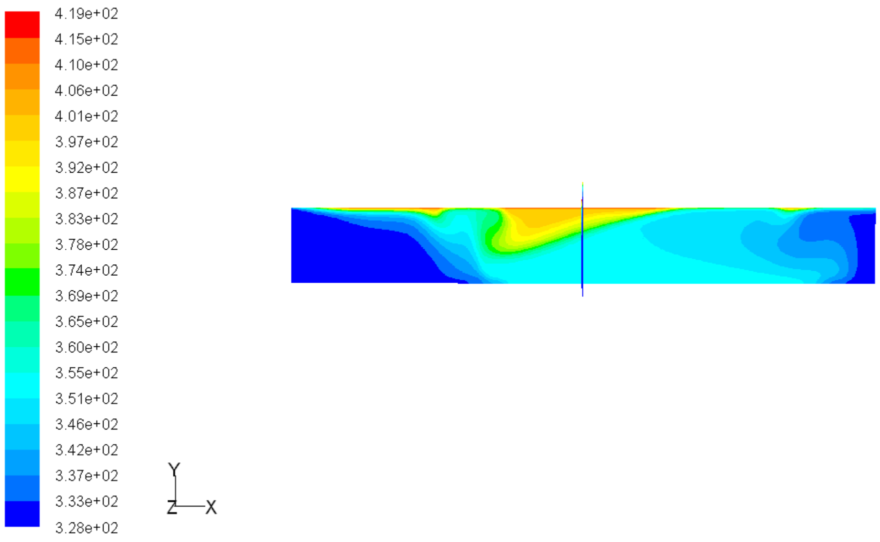

Fig 7. Contours of temperature for 45º slope of collector, the air in contact with the underside of the absorber plate

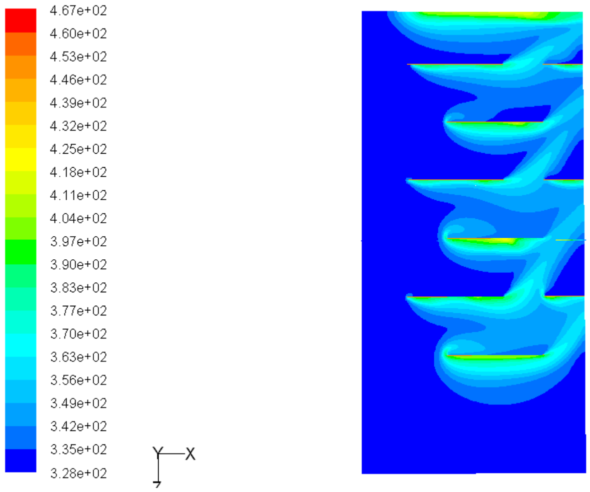

Fig 9 Temperature contours on the mid plane (created virtually to view results) of the heater 30mm from the top. Rising plumes of air indicate that buoyancy effects are present, collector slope 24º