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"Flat Plate Collector Solar Air Heater" Simulation and Analysis, Investigations in Flat Plate Collector (FPC): A Review

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Abstract - Solar thermal energy is one of the most abandoned sources of renewable energy available in the world. The scientific basis for the utilization of solar energy by man was acquired some years ago, but until recently, it was not considered technologically feasible to make use of it on a large scale. Already, small scale applications are at work and steadily gaining new market. A review of various research works and investigations based on simulation of thermal performance of FPC-type solar air heater has been conducted. Mathematical modelling and simulation techniques are found to be effective in studying the thermal performance of solar air heater. A good agreement is noticed in simulation and experimental results in some of the research works. A discussion is made at the end of the paper based on feasibility of applying simulation techniques.

Keywords— Solar air heater, Solar dryer, Thermal efficiency, Drying rate

I. INTRODUCTION

Solar Energy in current energy crisis is seen as a major alternative to the conventional energy sources. The solar energy is absorbed and converted into useful energy by two means viz. solar thermal technology and photovoltaic technology. Both the technologies are a matter of concern for the scientist as the cost of energy produced by this means is very high as compared to the conventional resources. The cost escalation is because of long process time, complexity of the process, unpredictability of availability of the energy, and high initial set up cost. It is very much required to focus on the design issues of solar energy systems, as it is an abundance source of energy and effective utilization of energy can greatly reduce the dependence on conventional energy systems.

In this paper, solar heating has been selected for analysis. Solar heating is found in building heating, food drying, water heating and in various agricultural applications. Various modelling and simulation investigations on solar thermal applications have been studied and analyzed in the context of feasibility of applying simulation. Modelling and simulation investigations carried out for predicting the performance of solar dryer is also presented. Finally, a discussion is made for performance evaluation and scope of further investigation and improvement.

II. BASICS OF FPC-TYPE SOLAR AIR HEATER

A conventional solar air heater is a flat-plate collector consists of an absorber plate with parallel transparent cover forming a passage through which the air to be heated flows. This passage is insulated at bottom as well as at all sides. Solar air heaters are made in variety of designs. A conventional solar air heater is shown in figure 1. This is used in inclined position and air in the passage absorbs heat from absorber plate as solar radiation passes through transparent cover. A continuous natural convection is thus set inside the solar air heater resulting is supply of heated air. Better thermal performance can be achieved by introducing forced convection.

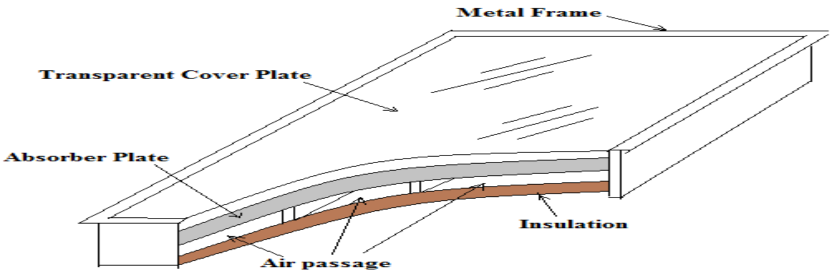


Figure 1:FPC-type solar air heater

In general, FPC-type solar air heaters can be classified under six categories as shown in figure 2 according to the type of absorber surface. (Courtesy: H. P. Garg , J. Prakash , S. P. Sukhatme and J. K. Nayak [1,2])

1. Simple Flat-Plate Collector: This is simplest and most commonly type of solar air heater. It is composed of one or two glazings over a flat plate backed by insulation. The path of air flow may be either above or below or both above and below the absorber plate.

2. Finned-Plate Collector: This is modified version of simple flat plate collector, where the heat transfer coefficient is increased by using fins on the plate absorber. The fins are located in air flow passage.

3. Corrugated –Plate Collector: This is another variation of the simple flat plate design, in which the absorber is corrugated either in rounded troughs or V-troughs. This increases the heat transfer area.

4. Matrix Type Collector: In this design an absorbing matrix is placed in the air flow path between the glazing and absorbing back plate. The matrix may be a wire mesh, or loosely packed porous material. This design offers a high heat transfer to volume ratio.

5. Overlapped Transparent Plate type Collector: This type of collector is composed of a staggered array of transparent plates which are partially blackened. The air flow paths are between the overlapped plates.

6. Transpiration Collector (Porous Bed Type): This is a variation of matrix type collector, in which the matrix material is closely packed and back absorber plate is eliminated. Mainly, the solar air heaters described above can be classified under two categories. In the first type of solar air heater, commonly known as non porous absorbers, the air does not flow through the absorber plate. In the second type of solar air heater, known as porous bed absorber, the air passes through absorbing material.

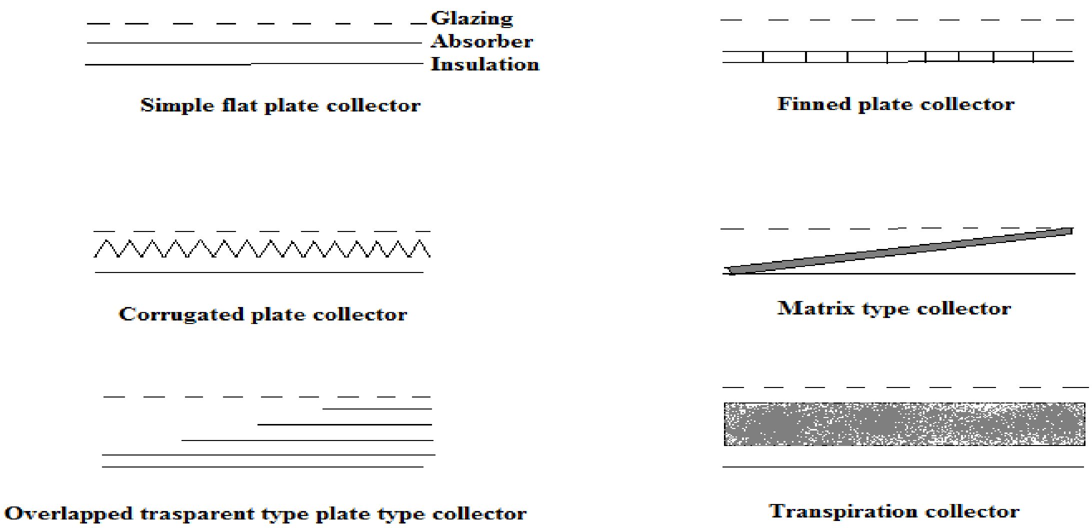


Figure 2. Types of Solar air heater based on absorber plate

According to air flow path through the heater, solar air heaters are classified in three categories. The arrangement is shown in figure 3(a), 3 (b), and 3(c). First arrangement is common in which air flows through the passage below the absorber plate. In second arrangement air is made to flow between transparent cover and absorber plate and in third design air flows between cover and the absorber plate, as well as through the passage below the absorber plate.

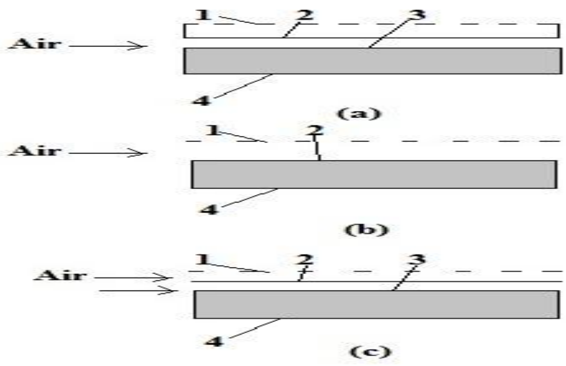


Figure 3. Types of Solar Air Heater based on air flow path (1. Transparent Cover, 2. Absorber Plate, 3. Bottom Plate, 4. Insulation)

III SIMULATION WORKS

Research works based on modelling and simulation side have been studied in order to visualize theoretical performance of solar thermal systems.

A. study of fluid flow and heat transfer in a solar air heater was presented by S.V. Karmare, and A.N. Tikekar [3] using Computational Fluid Dynamics (CFD). The model of test cell was done in GAMBIT-2.2.30 and results have been simulated on FLUENT-6.2. Lower side of collector plate is made rough with metal ribs of circular, square and triangular cross-section, having 60° inclinations to the air flow. The grit rib elements are fixed on the surface in staggered manner to form defined grid. To validate CFD results, experimental investigations were carried out in the laboratory and it was found that experimental and CFD analysis results give the good agreement. The optimization of rib geometry and its angle of attack is also done. The square cross-section ribs with 58° angle of attack give maximum heat transfer. The percentage enhancement in the heat transfer for square plate over smooth surface is 30%. Figures 4 and 5 show the simulated results of temperature profile along height of the solar air heater and absorber surface respectively. As temperature gradient is intensive near absorber surface, an artificial roughness has been introduced to break it.

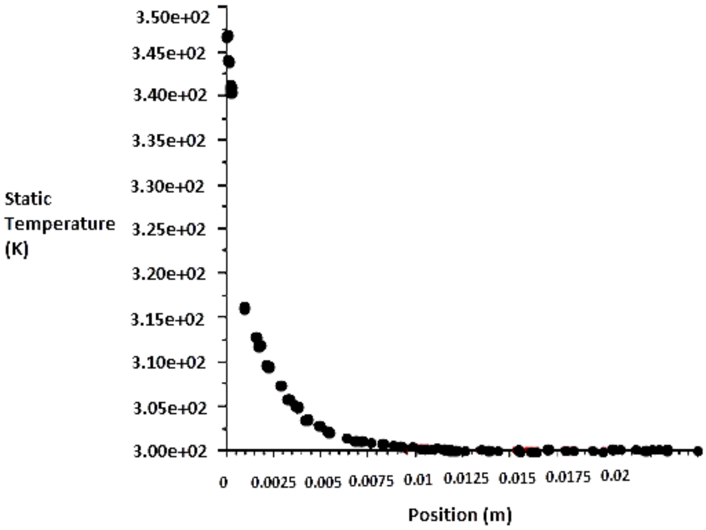


Figure 4. Temperature profile of air along the height of the duct

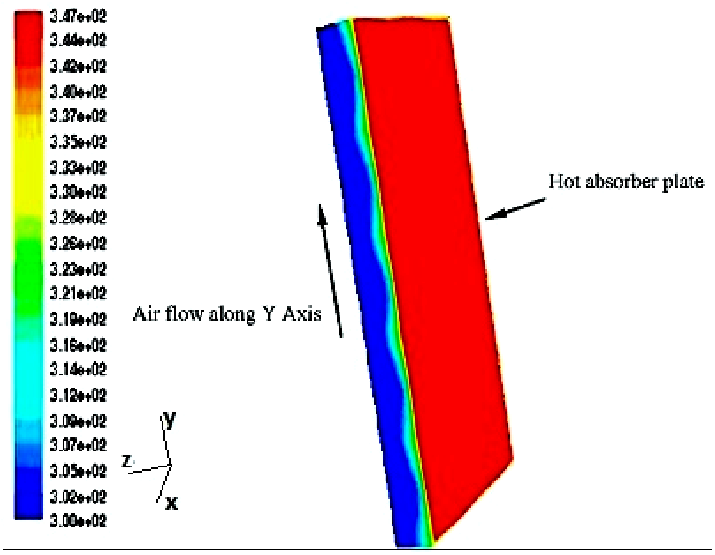


Figure 5. Contour of static temperature

B. Similar kind of investigation presented by P.W. Ingle et al [4] using computational fluid dynamics (CFD) tool to simulate the solar collector for better understanding the heat transfer capability. A three dimensional model of the collector (size 2000×1000×130mm3 with 4mm thick glass plate which is placed at around 126mm from the top side of the collector) with wavy structured absorber plate of 2000mm length, 1000mm wide and 2mm in thickness was modelled by ANSYS Workbench and the unstructured grid was created in ANSYS ICEM (Figure 6). Inlet of solar air collector is of circular cross section with diameter of 70mm. There are two outlets to the solar collector with circular cross section having diameter 60mm.

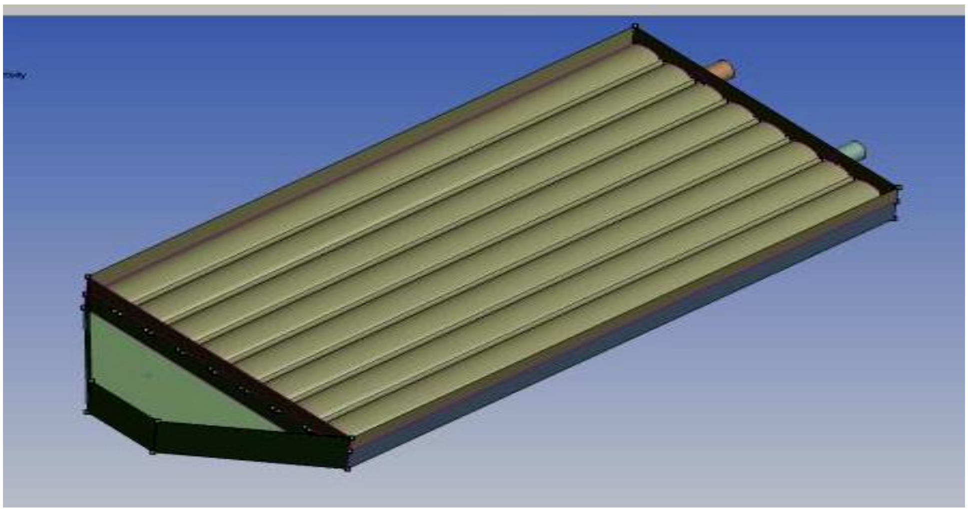


Figure 6. Model of solar air collector visualizing the absorber plate

The results were obtained by using ANSYS FLUENT software (figure 7 and 8). The objective of this work is to compare theoretically and experimentally work done by using computational fluid dynamics (CFD) tool with respect to flow and temperature distribution inside the solar collector. The outlet temperature of air is compared with experimental results and there is a good agreement in between them. In simulation, air velocity is found maximum at inlet while air temperature was found maximum near outlet.

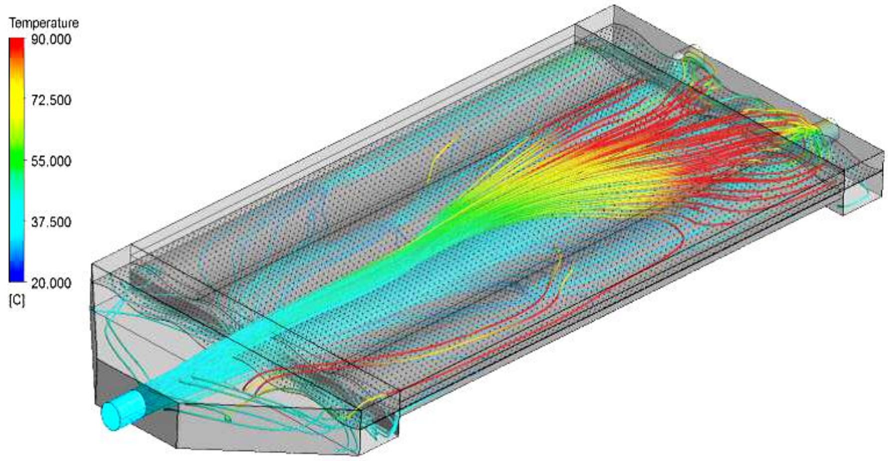


Figure 7. Streamlines for temperature distribution at 9am of the day

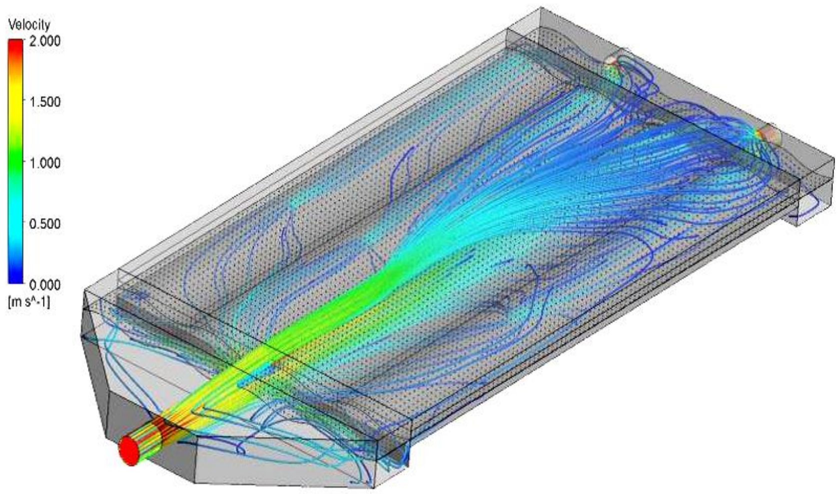
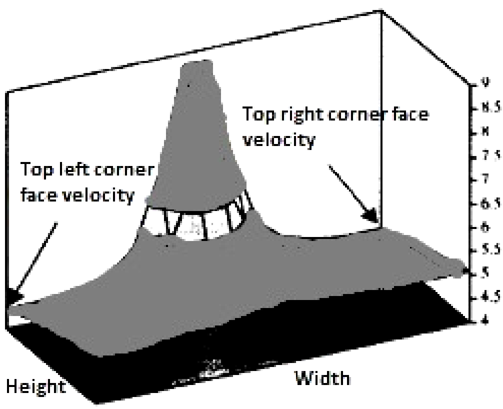
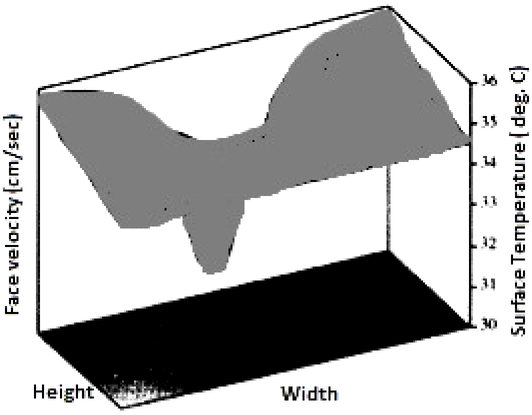


Figure 8. Streamlines for velocity distribution at time 9am of day

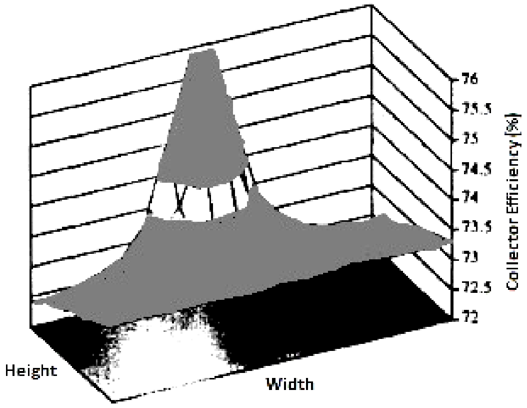
C. Dymond and C. Kutscher [5] developed mathematical model to determine thermal performance of unglazed, transpired solar collector. Pipe network methods were used to develop a set of simultaneous equations. Results are in the form of three absorber profiles. The first profile is the flow distribution of the air entering the absorber surface (Figure 9 a), the second profile is the temperature distribution of the collector surface (Figure 9 b), and the third profile is of the local collector efficiencies (Figure 9 c).



(a)



(b)



(c)

Figure 9 (a): Flow distribution of air (b): Temperature distribution of collector surface (c): Efficiency profile for unglazed and transpired solar collector

A mathematical model of a single pass, double duct solar air heater was developed by F.K. Forson et al [6]. The model provides a design tool capable of predicting: incident solar radiation, heat transfer coefficients, mean air flow rates, mean air temperature and relative humidity at the exit. Results from the simulation are presented and compared with experimental ones obtained on a full scale air heater and a small scale laboratory one. Reasonable agreement between the predicted and measured values is demonstrated. Predicted results from a parametric study are also presented. It is shown that significant improvement in the heater performance can be obtained with an appropriate choice of the collector parameters and the top to bottom channel depth ratio of the two ducts. The air mass flow rate is shown to be the dominant factor in determining the overall efficiency of the heater.

IV DISCUSSION

Process simulation has become an accepted tool for the performance, design, and optimization of thermal processes. Solving the mathematical models representing solar heating process units and systems is one of the most tedious and repetitive problems. Nested iterative procedures are usually needed to solve these models. To tackle these problems, several researchers have developed different methods, techniques, and computer programs for the simulation of very wide variety of solar heating process units and systems. It is evident that simulation is a very important tool for performance, design, and optimization of solar heating systems. These systems which are governed by the principles of heat transfer, thermodynamics, fluid mechanics, and mass transfer, arise in a wide range of solar engineering applications. The mathematical models representing these applications may comprise a large system of equations caramelized by complexity, non-linearity, and implicitly. With a flexible computer program, a large number of flow sheeting problems can be tackled. These problems can be generally divided into three classes: (i) performance problems, (ii) design problems, and (iii) optimization problems (Abmed Safwat Nafey [7]).

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