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Performance Evaluation Of Flat Plate Collector Using Computational Fluid Dynamics For Climatic Condition Of Dehradun

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Abstract

Flat plate collectors are widely used for transferring thermal energy to fluid and used for domestic as well as commercial purpose. So, this research article deals with the detailed simulation study of performance of flat plate collector by using computational fluid dynamics. The weather data for the study was collected for Dehradun region from Indian metrological department Pune for the month of April. NX Cad software was use to design the 3D model of the flat plate collector and Ansys fluent 15.0 was used to analysis the behavior of the collector from the simulated result it was concluded that the maximum area of absorber plate exposed to the direct sunlight helps to achieve better water outlet temperature. The maximum internal energy of flat plate collector was found to be 935.1Jkg for the maximum solar flux of 353.1W/m^2 and maximum temperature of 47.5°C was obtained at the tubes due to larger surface area exposed under the sun.

Keywords: Flat Plate Collector, Thermal Energy, Solar Flux, Computational Fluid Dynamics,

1. INTRODUCTION

The demand of energy throughout the is increasing day by day. Due to increase in population and poor energy management leads to shift of interest from conventional to non-conventional sources of energy because of availability in nature, non-polluting and clean in nature[1]. Solar energy can be harnessed for electricity with the help of PV modules, thermal energy with the help of collectors[2] for the use of solar distillation[3], space and water heating[4], crop drying. Solar collectors collect solar radiation in the form heat by the principle of greenhouse effect in which glass act as atmosphere allowing shorter wavelength radiations to pass and absorber plate act as surface of earth. That heat is passed from black painted absorber plate to fluid inside copper tubes Fig.1 shows the schematic diagram of FPC. Generally, FPC are divided into two categories: (1) Liquid based FPC (2) Air based FPC. In the mid 19 century Hottel & Woertz worked on developments FPC and later many authors contributed in the field of FPC by changing material of absorber plate, varying thickness of insulation & glass, different coating on absorber plate etc. some of the recent theoretical, simulation and experimental investigation contributed in order to increase performance of FPC are listed below.

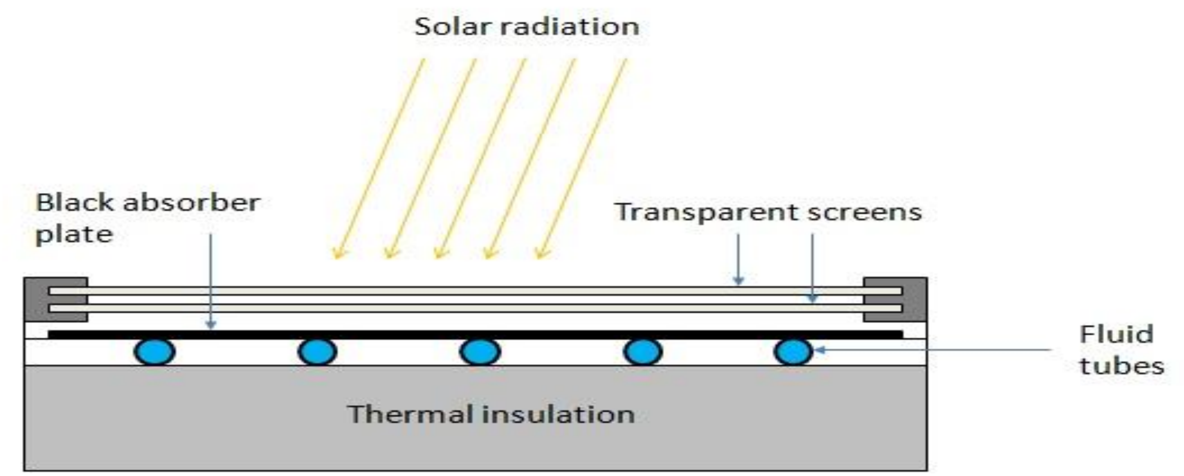

Fig.1 Schematic diagram of double-glazed Flat Plate Collector

Khan et al.[4] performed a theoretical investigation by addition of PCM with FPC and ETC. The outlet fluid temperature was enhanced as the contact area of absorber plate and PCM was increased. Kansara et al.[5] performed a simulated study on FPC and results shows porous media to be optimum compared to internal fins with FPC, with porous media the FPC shows 16.17% more outlet temperature compared to fins. Thakur et al.[6] performed a theoretical investigation on CFD based FPC. The studies show using 60mm of PCM can enhance the thermal efficiency heat gain by twice and by use of aluminum foil to trapezoidal glass based PCM can enhance thermal efficiency by 60% - 70% compared to CFPC. Badiei et al.[7] performed a simulated investigation over FPC, study shows increase in collector efficiency by 33% - 46% during summer with PCM and fins. Addition of fins increases the storage capacity of PCM. Zhou et al.[8] performed a simulated study on FPC with PMMA transparent sheet at the front and the results were validated with experimental results. The study shows collector efficiency of 11.3% for the ambient temperature condition of -20˚C. Selmi et al.[9] performed a simulated study on FPC and obtained results were approx. same as experimental results. The difference in outlet and inlet of temperature is found to be 9˚C. Gopi et al[10]. analyzed enhancement in heat transfer rate of solar air heater by introducing cylindrical fins with the help of CFD simulation. The result shows increase in surface area by introducing cylindrical fins to the SAH that helps to enhance efficiency of SAH. Xu et al.[11] performed a numerical investigation over FPC with water based Al_2O_3 nano particles. Results shows various sizes of nano particles to enhance the thermal and overall efficiency of FPC. Nabi et al.[12] analyzed effect of hybrid SWCNT + CuO and MWCNT + CuO at concentration varying from 1% - 5% with the help of CFD. The result shows hybrid nano particles SWCNT at 1% concentration shows 5.16% increase in thermal efficiency. Gunjo et al.[13] simulated study and results shows maximum variation by 5.4% and 2% for output water temperature and absorber plate temperature when validated by experimental results. Pandey et al.[14] performed a theoretical investigation on FPC and point out the areas of further development to enhance the productivity. Ebrahimi et al.[15] performed a simulation on solar air dryer by varying the position of PCM the study shows PCM at bottom decreases drying time by 21.87%. According to position of PCM the thermal efficiency varies from 21.92% - 25.72%. Negi et al.[16] performed an experimental investigation on MSS with FPC and CSS the productivity of MSS with FPC was found to be 3.997kg/m^2.day while for CSS the productivity was found to be 2.894kg/m^2.day. Dondapati et al.[17] performed a simulation on honeycomb polycarbonate collector but there was approx. no change in efficiency compared to normal FPC. Jiandong et al. performed a numerical investigation over FPC with 700W/m^2 solar intensity, 4m/s of wind speed and thickness of plate varied from 0.1mm to 2.1mm. The Instantaneous varied with thickness from 46.57% to 64.03% respectively.

On the basis of coined literature review, many authors have contributed in developments in flat plate collector by simulation, numerical and experimental investigation for different locations but from the best knowledge of the author there were no study reported on the performance evaluation of FPC using CFD for the climatic condition of Dehradun, Uttarakhand, India.

2. Methodology of Proposed Work

The present work focuses on simulation study of the FPC with the help of CFD for the climatic condition of Dehradun, Uttarakhand, India. The latitude, Longitude of the location is 30.3165˚N, 78.0322˚E. The 3-D modelling of the FPC was carried out using NX CAD as shown in Fig.2a, and complete simulation was performed in Ansys fluent 15.0 version. A mesh study was performed over FPC model by varying minimum to maximum mesh size between 0.001mm to 0.01mm as shown in Fig2b. The materials used were made in the engineering data in Ansys and properties of materials are shown in Table 1 and Table 2 shows the outer dimension of the FPC.

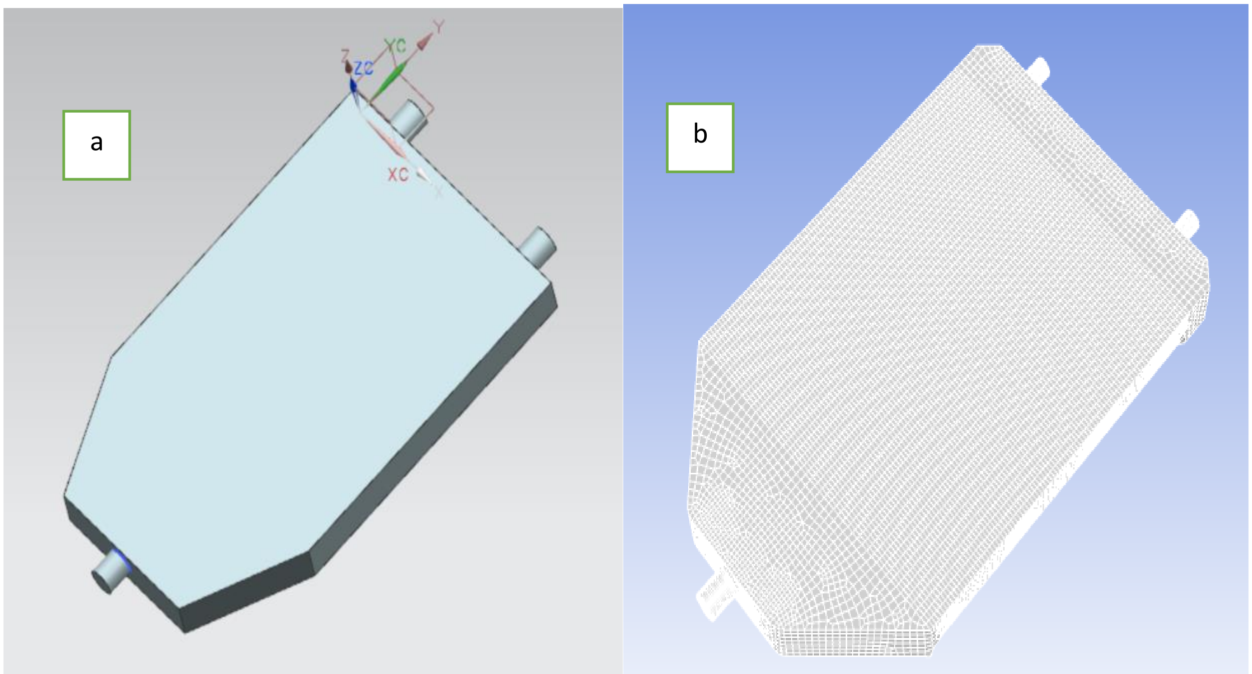

Fig 2. (a) 3-D modelling of a FPC in NX CAD (b) Meshing Grid in Ansys fluent 15.0

Table 1 Material Properties

Materials	Density (kg/m^3)	Specific Heat (J/kg/K)	Thermal Conductivity (W/mK)
Aluminium	2702	903	237
Copper	8933	385	401
Glass	2800	401	0.7

Table 2 Dimensions of the Flat Plate Collector

Length (mm)	1800
Width (mm)	150

Height (mm)	20
Thickness (mm)	2.5
Inlet and Outlet Diameter (mm)	5

Energy balance equations that are used in simulation is discussed below

The useful energy output by the collector in per unit time is given by eqn. 1

$$\dot{Q}u = A_C \dot{q}u \quad \text{———} \quad 1$$

where $\dot{q}u$ is given below

$\dot{q}u = A_c [\dot{q}_{ab} - U_L (T_p - T_a)]$

where A_c denotes area of the collector, U_L denotes overall thermal losses and the instantaneous efficiency of the FPC is given by eqn. below.

$\eta_i = \frac{\dot{Q}u}{I(t)}$

3. Results and Discussions

This section comprises of results for the simulated analysis that are presented. The results show the variation in pressure, inner wall temperature, total temperature, Static Enthalpy, Total Enthalpy, Internal energy and absorbed solar flux of FPC.

3.1 Pressure & Temperature variation in FPC

The variation at inlet and outlet of the FPC are shown in Fig.3. Fig.4&5 shows the variation of the inner wall temperature and total temperature of the FPC. From the temperature figures it can be seen that the temperature of the copper tubes at center is maximum due to maximum surface area exposed under the sun compared to inlet and outlet and the temperature of the tube reaches up to 47.5°C.

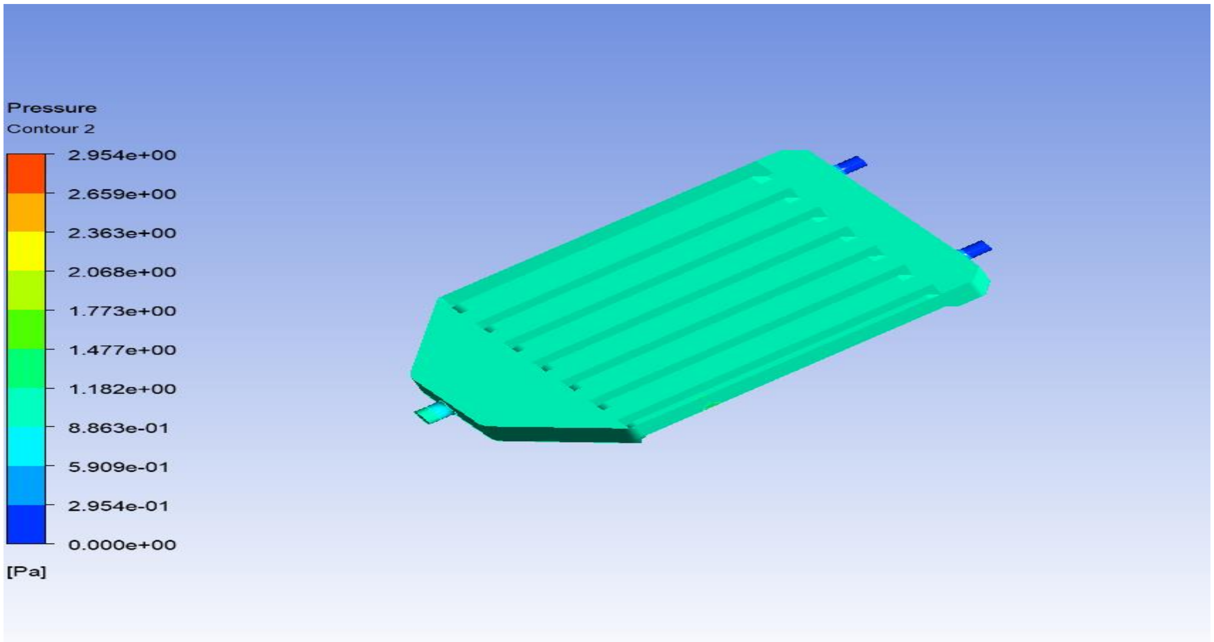

Fig.3 Variation of Pressure in FPC

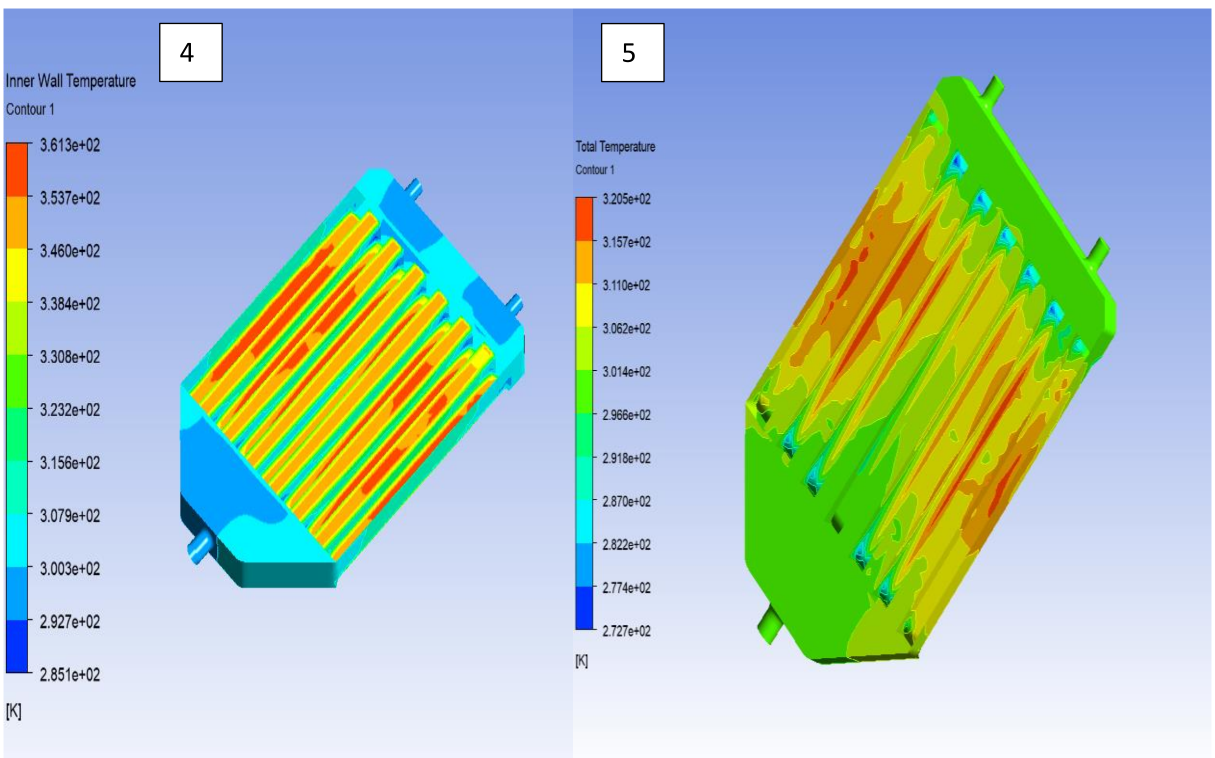

Fig. (4) Variation of Inner Wall Temperature (5) Variation in Total Temperature of FPC

3.2 Variation in Static Enthalpy & Total Enthalpy Variation of FPC

The variation of static and total enthalpy is shown in Fig.6 & 7. From the fig.6 it can be shown the red line denotes the maximum static pressure and found to be 936.7J/kg while the maximum total enthalpy was found to be 936.1j/kg as shown in Fig.7

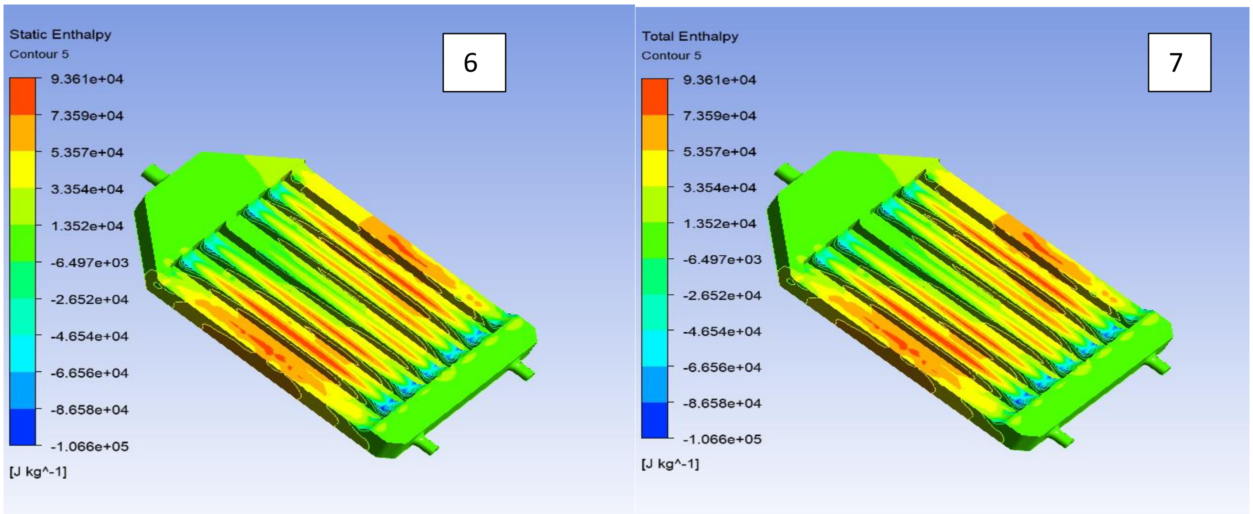

Fig. Variation in (6) Static Enthalpy of FPC (7) Total Enthalpy of FPC

3.3 Variation in Internal energy and absorbed solar flux of FPC

The variation in internal energy and absorbed solar flux is shown in Fig. 8&9. The maximum internal energy 935.1 J/kg was found at the copper tubes due to maximum surface area exposed under sun when the maximum solar flux absorbed by the tubes are 353.1W/m^2 as shown in Fig.9.

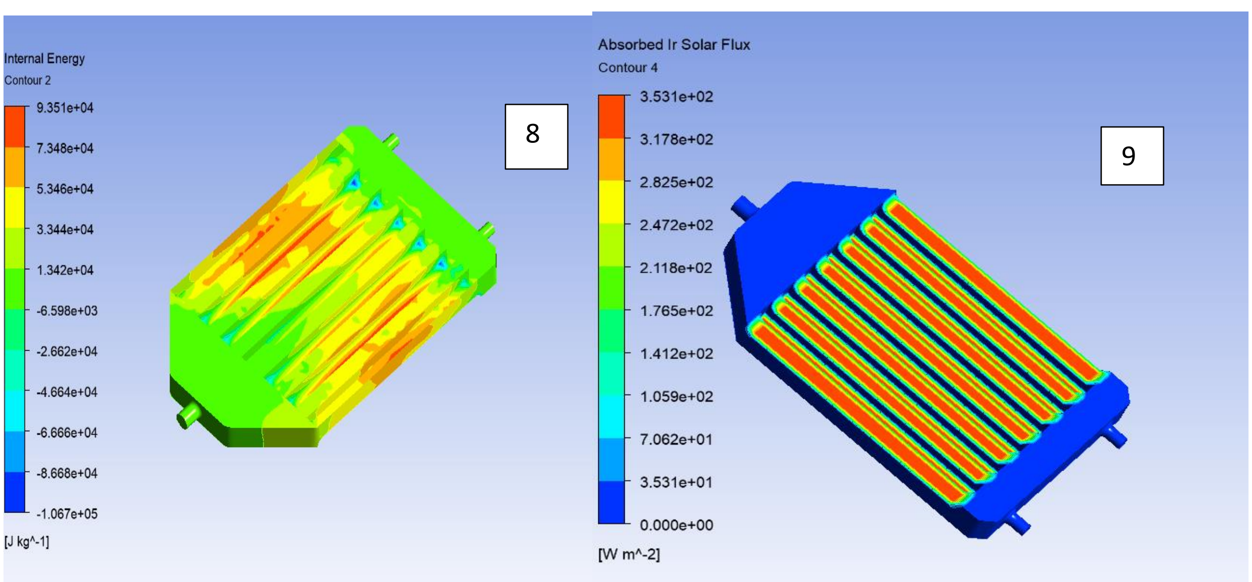

Fig. Variation in (8) Internal energy of FPC (9) Absorbed Solar Flux by FPC

Conclusions

On the basis of the results obtained from the simulation studies some conclusions were made:

1. The increase in exposed surface area under sun helps to achieve better outlet temperature of the water from FPC.
2. The maximum internal energy of FPC was found to be 935.1Jkg for the maximum solar flux of 353.1W/m^2.
3. The maximum temperature of 47.5˚C was found at the tubes due to larger surface area exposed under the sun.
4. The maximum pressure was found at the outlet of the FPC.

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