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CFD Analysis with Solidworks Simulation on FPC with Various Design Parameters

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Abstract

Objectives: The main objective was to computationally model various flat bed solar collector with various inlet and outlet designs with solidworks simulation to investigate the effects of change in diameter of the tubes on pressure drop and temperature differences. **Methods**: With use of solidworks 2012 software designing of seven different type of flat plate collector has been made as 1. Normal design in which flow run conditions of the normal water which been used is set at a temperature of 18.7 °C, the pressure conditions which is taken in whole of the CFD run of the experiment is taken as 22.4. The inlet flow rate condition for the diverge-3 design is maintained at 0.05 Kg/sec. 2. Converge-1 in which Flow run conditions of the normal water which been used is set at a temperature of 38.15 °C, the pressure condition which is taken in whole of the CFD run of the experiment is taken as 3.64. 3. Converge-2 in which Flow run conditions of the normal water which been used is set at a temperature of 37.82 ˚C, the pressure condition which is taken in whole of the CFD run of the experiment is taken as 2.74 4. Converge-3 in which Flow run conditions of the normal water which been used is set at a temperature of 38.49 ˚C, the pressure condition which is taken in whole of the CFD run of the experiment is taken as 3.35 5. Diverge-1 in which Flow run conditions of the normal water which been used is set at a temperature of 37.85 ˚C, the pressure condition which is taken in whole of the CFD run of the experiment is taken as 4.49 6. Diverge-2 in which Flow run conditions of the normal water which been used is set at a temperature of 38.39 ˚C, the pressure condition which is taken in whole of the CFD run of the experiment is taken as 3.67. 7. Diverge-3 in which Flow run conditions of the normal water which been used is set at a temperature of 38.41 ˚C, the pressure condition which is taken in whole of the CFD run of the experiment is taken as 2.14. Where the inlet flow rate condition for the diverge-3 design is maintained at 0.05 Kg/sec same for all designs. **Findings:** All the designs are used to establish the input parameters with analyzing of performance of (FPC) Flat Plate Collector. In the CFD analysis findings the maximum temperature rise up has been found in converging 3 design in which Flow run conditions of the normal water which been used is set at a temperature of 38.49 ˚ C, the pressure condition which is taken in whole of the CFD run of the experiment is taken as 3.35 and effective minimum pressure drop has been found in the diverging 3 type of design in which Flow run conditions of the normal water which been used is set at a temperature of 38.41 ˚C, the pressure condition which is taken in whole of the CFD run of the experiment is taken as 2.14. Where the inlet flow rate condition for the diverge-3 design is maintained at 0.05 Kg/sec same for all designs. Important thing was that if the mass flow rate increases, corresponding temperature decreases. Material properties also play an important role in the performance of solar flat bed collector. Further improvements can be made by designing more complex designs for CFD analysis so that a better efficient FPC can be made. **Application:** All of design conditions in solidworks simulation are developed to make a effective flat plate collector in which maximum heat may be stored and large temperature conditions on the outlet may be achieved. More designs of different shapes may also be developed in other design softwares also. Applications of these effective designs after their fabrication may be in domestic water heating purposes and in large industrial facilities where large temperature conditions of water may be required.

Keywords: CFD, FPC (Flat Plate Collector), Solidworks

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1. Introduction

1.1 Solar Flat Bed Collector

Solar [1–5] FPC is a device used for capturing solar radiation. Sun emits electromagnetic radiation with an average irradiance of 1353 W/m^2 on the earth's surface. Solar energy is the most considerable energy source in the world. Sun, which is 1.495x1011 m far from the earth and has a diameter of 1.39x109 m. The world receives 170 trillion kW solar energy and 30% of this energy is reflected back to the space, 47% is transformed to low temperature heat energy, 23% is used for evaporation/rainfall cycle in the Biosphere and less than 0.5% is used in the kinetic energy of the wind, waves and photosynthesis of plants. Solar energy is the radiation produced by nuclear fusion reactions in the core of the sun. This radiation travels to Earth through space in the form of energy called photons[6–8]. Even though only 30% of the solar power actually reaches the Earth, every 20 minutes the sun produces enough power to supply the Earth with its needs for an entire year. Unfortunately, the atmosphere and clouds absorb a large amount of this sunlight. So the amount of light that reaches any point on the ground depends on the time of day, the day of the year, the amount of cloud cover, and the latitude at that point, with the solar focus directly dependent on three of these factors. The history of using the sun for energy goes way back to the Ancient Greeks and Romans as their buildings were constructed such that the rays of the sun provided light and heat for indoor spaces. The Greek philosopher Socrates wrote, "In houses that look toward the south, the sun penetrates the entrance in winter"[9]. Romans advanced this art by covering the openings to south facing building with glass, in order to retain the heat of the winter sun. The history of utilising solar energy in recent times dates from 1861 when Mouchout developed a steam engine powered entirely by the sun and in 1883 American inventor Charles Fritts described the first solar cells made of selenium wafers[10,11]. Throughout the 20th century, scientists developed large cone-shaped collectors that could boil ammonia for refrigeration. In the United States, John Ericsson designed the "parabolic trough collector" a technology which functions more than a hundred years later on the same basic design[12–14]. In the 1970's it was thought that through massive investment in funding and research, solar photovoltaic costs could drastically reduced, such that eventually solar cells could become competitive with fossil fuels[15–17]. By the 1990s, the reality was that the costs of solar energy had dropped as predicted and the huge PV market growth in Germany and Japan from the 1990s to the present has boosted the solar industry[18] who are creating steadily lowering costs. The heating of water by solar energy is an increasingly cost effective means of lowering gas and electricity demand[19,20].

1.2 Computational Fluid Dynamics (CFD)

Computational Fluid Dynamics (CFD) is an efficient numerical solution of the partial differential equations that describe fluid dynamics[21–24]. CFD techniques are used to analyse fluid behaviour. Numerical analysis applied to fluid flow and heat transfer problems.

Numerical models made possible to find and optimise solutions without creating a large and expensive series of models[25]. The design of thermal equipment must focus on a combination of numerical and experimental techniques. A model for virtual prototyping of thermal equipment must be detailed enough in order to consider all the main physical phenomena that are taking place as well as giving results in a reasonable computational time[26]. Consequently, a compromise needs to be made between detailed simulations of CFD models and a fast resolution. CFD use made feasible to analyse more complex geometries and designs within a reasonable computational time. Investigations in to solar thermosiphon systems have been conducted, but they are limited to a small range of heat exchanger configurations, flow visualisation and heat transfer. CFD models are even fewer in the case of flat plate solar water collectors. Initially, only low Rayleigh numbers and small aspect ratios were investigated. Attempts had been made to develop models to describe the physical and geometrical complexity of the system more accurately. The models were fitted to a set of measured data and the resulting collector parameters were compared. The total daily energy yield predicted by the models for a number of days of different weather conditions was calculated using a reference collector parameter set. Specially designed mantle tanks have been evaluated using a transient three dimensional CFD model[27,28]. CFD calculations made easy to illustrate the fluid thermal behaviour and the fluid dynamics in the mantle and in the inner tank[29]. A solar collector is basically a flat box and is composed of three main parts. 1) A transparent cover 2) Tubes which carry a collant 3) An insulated back plate which works on natural thermosyphone or forced circulation[30]. Model of FPC on which i had worked is simulated in SolidWorks Software 2012 having 6 header pipes and whole of the system has to undergo certain radiation of 800 Watt[31]. Design types of 7 type namely 1. Normal Design 2. Converging a, b and c type 3. Diverging a, b and c type are designed in Figure 1.

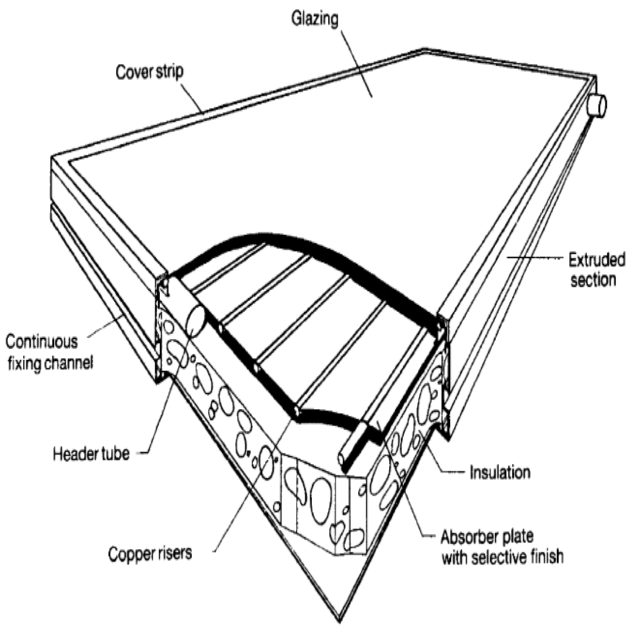


Figure 1.1 Flat plate collector.

2. Research Objective

The main objectives of this work are as follows:

1.To model computationally the flat bed solar collector.

2.Establish the input parameters and analyze the performance of flat-bed solar collector.

3.To find appropriate outlet temperature for varying inlet temperatures at a given flow rate and with given intensity of radiation.

4.To analyse the performance of the flat bed solar collector with water as a fluid with different designs in simulation.

3. Methodology

The efficiency of solar collector mainly depends on the fluid that is absorbing the heat. The fluid that is passing through the collector plays an important role to make the system more effective as well as the amount of intensity of radiation falling over the surface. Mass flow rate is another important factor for the calculation of performance of flat bed solar collector. The given designs are of seven type are made to undergo seven different temperature conditions given mainly to normal design as 18.7 °C, to converging 1 as 38.15 °C, to converging 2 as 37.82 °C, to converging 3 as 38.49 °C, to diverging 1 as 37.85 °C, to diverging 2 as 38.39 °C, to diverging 3 as 38.41 °C. Pressure conditions which the simulated FPC has to undergo were as firstly to the normal design as 22.4, to converging design 1 as 3.64, to converging design 2 as 2.74, to converging design 3 as 3.35, to diverging design 1 as 4.49, to diverging design 2 as 3.67, to diverging design 3 as 2.14.

4. Analysis

The analysis part consists of 7 design conditions which are designed in solidworks software and CFD analysis is done: -

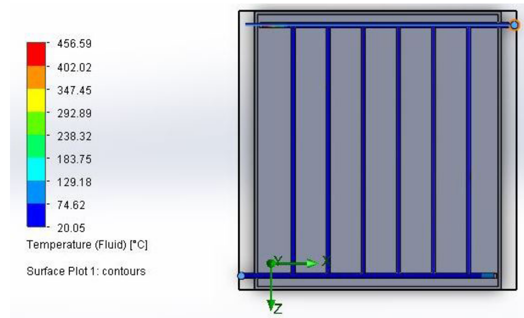
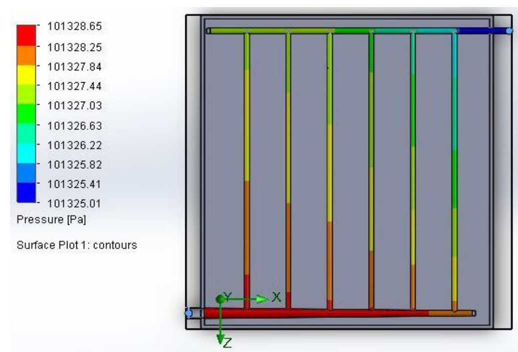
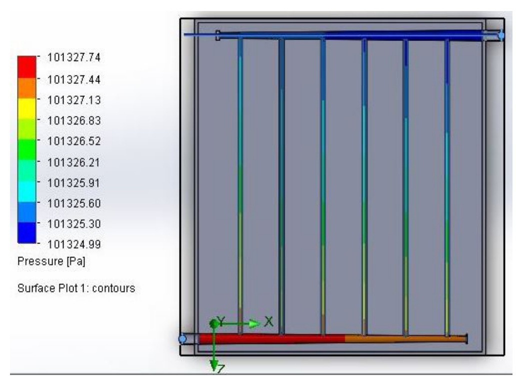
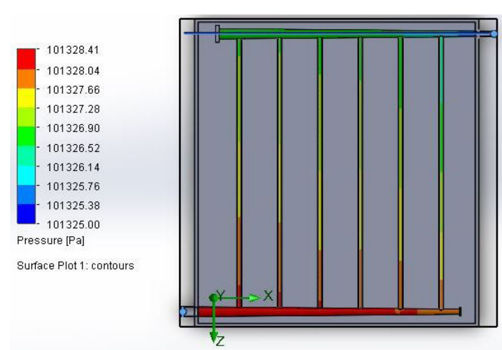
4.1 Normal Design

In the present paper the analysis is represented in the Table 1. Solidworks computer software is used to simulate the design parameters of the flat plate collector. First type of the design which is made is named as normal design. The main feature of the design is that the inlet and outlet pipe diameter is kept same. The hose pipes which are taken six in number are also been kept at same diameter and length. Flow run conditions of the normal water which been used is set at a temperature of 18.7 ˚C, the pressure condition which is taken in whole of the CFD run of the experiment is taken as 22.4. The inlet flow rate condition for the diverge-3 design is maintained at 0.05 Kg/sec shown in Table 2. Inlet flow temperature of water as fluid in pipes is at temperature of 20 °C. Heat source radiation is made to emit 800 Watt.

4.2 Converge

1 Design: In converge-1 design the analysis is represented in the Table 1. Solidworks computer software is used to simulate the design parameters of the flat plate collector. Second type of the design which is made is named as Converge - 1 design shown in Table 1. The main feature of the design is that in lower hose the inlet pipe fluid flow diameter is made of converge type-1 as left entry with

Table 1. Design analysis report with temperature and pressure

S.NO	TEMPERATURE	PRESSURE	DESIGN TYPE	DESIGN
1	18.7	22.4	NORMAL DESIGN	
2	38.15	3.64	CONVERGE 1	
3	37.82	2.74	CONVERGE 2	
4	38.49	3.35	CONVERGE 3	

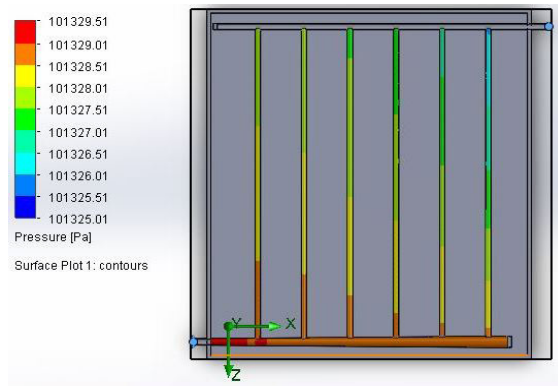
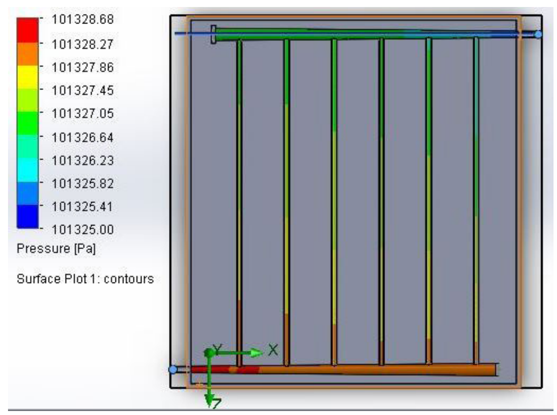
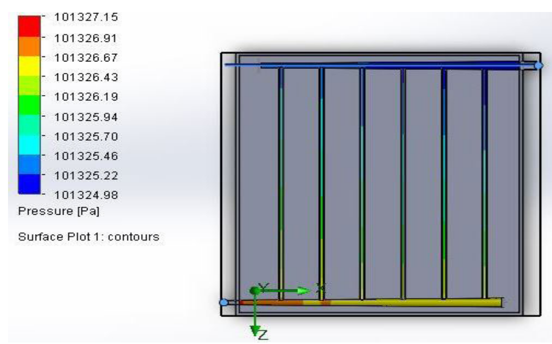
5	37.85	4.49	DIVERGE 1	
6	38.39	3.67	DIVERGE 2	
7	38.41	2.14	DIVERGE 3	

Table 2. Simulated designed model analysis results

S.NO.	FPC DESIGNS	FLOW RATE	INLET TEMP.	HEAT SOURCE RADIATION
1	NORMAL DESIGN	0.05 Kg/sec	20° C	800 Watt
2	CONVERGENT 1	0.05 Kg/sec	20° C	800 Watt
3	CONVERGENT 2	0.05 Kg/sec	20° C	800 Watt
4	CONVERGENT 3	0.05 Kg/sec	20° C	800 Watt
5	DIVERGENT 1	0.05 Kg/sec	20° C	800 Watt
6	DIVERGENT 2	0.05 Kg/sec	20° C	800 Watt
7	DIVERGENT 3	0.05 Kg/sec	20° C	800 Watt

widen diameter on left side and upper hose outlet pipe diameter is made of normal diameter on both left and right sides. The hose pipes which are taken six in number are also been kept at same diameter and length. Flow run conditions of the normal water which been used is set at a temperature of 38.15 ˚C, the pressure condition which is taken in whole of the CFD run of the experiment is taken as 3.64. The inlet flow rate condition for the diverge-3 design is maintained at 0.05 Kg/sec shown in Table 2. Inlet flow temperature of water as fluid in pipes is at temperature of 20 °C. Heat source radiation is made to emit 800 Watt. The colour contours shown in the Table 1. shows the temperature and pressure variations occurred during CFD analysis in running software.

4.3 Converge

2 Design: In converge-2 design the analysis is represented in the Table 1. Solidworks computer software is used to simulate the design parameters of the flat plate collector. Second type of the design which is made is named as Converge - 2 design shown in Table 1. The main feature of the design is that the inlet pipe fluid flow diameter is made of converge type - 2 with left entry as widen diameter and normal diameter at right end in the upper hose right side outlet pipe diameter is made of widen diameter with left end with normal diameter. The hose pipes which are taken six in number are also been kept at same diameter and length. Flow run conditions of the normal water which been used is set at a temperature of 37.82 ˚C, the pressure condition which is taken in whole of the CFD run of the experiment is taken as 2.74. The inlet flow rate condition for the diverge-3 design is maintained at 0.05 Kg/sec shown in Table 2. Inlet flow temperature of water as fluid in pipes is at temperature of 20 °C. Heat source radiation is made to emit 800 Watt. The colour contours shown in the Table 1 shows the temperature and pressure variations occurred during CFD analysis in running software.

4.4 Converge

3 Design: In converge-3 design the analysis is represented in the Table 1. Solidworks computer software is used to simulate the design parameters of the flat plate collector. Second type of the design which is made is named as Converge - 3 design shown in Table 1. The main feature of the design is that the inlet pipe fluid flow diameter is made widen of converge type-3 at left side of section and in upper hose section outlet pipe diameter is made of normal diameter on right end with widen diameter on left end of pipe. The hose pipes which are taken six in number are also been kept at same diameter and length. Flow run conditions of the normal water which been used is set at a temperature of 38.49 ˚C, the pressure condition which is taken in whole of the CFD run of the experiment is taken as 3.35. The inlet flow rate condition for the diverge-3 design is maintained at 0.05 Kg/sec shown in Table 2 (Simulated designed model analysis results). Inlet flow temperature of water as fluid in pipes is at temperature of 20 °C. Heat source radiation is made to emit 800 Watt. The colour contours shown in the Table 1 shows the temperature and pressure variations occurred during CFD analysis in running software.

4.5 Diverge

1 Design: In diverge-1 design the analysis is represented in the Table 1. Solidworks computer software is used to simulate the design parameters of the flat plate collector. Second type of the design which is made is named as diverge - 1 design shown in Table 1. The main feature of the design is that at lower hose where the fluid enters the section the diameter is taken as normal on left entry with right end with widen diameter and at upper hose section outlet pipe diameter is made of normal diameter. The hose pipes which are taken six in number are also been kept at same diameter and length. Flow run conditions of the normal water which been used is set at a temperature of 37.85 ˚C, the pressure condition which is taken in whole of the CFD run of the experiment is taken as 4.49. The inlet flow rate condition for the diverge-3 design is maintained at 0.05 Kg/sec shown in Table 2. Inlet flow temperature of water as fluid in pipes is at temperature of 20 °C. Heat source radiation is made to emit 800 Watt. The colour contours shown in the Table 1 shows the temperature and pressure variations occurred during CFD analysis in running software.

4.6 Diverge

2 Design: In diverge-2 design the analysis is represented in the Table 1. Solidworks computer software is used to simulate the design parameters of the flat plate collector. Second type of the design which is made is named as Diverge - 2 design shown in Table 1. The main feature of the design is that in lower hose section at the inlet pipe fluid flow diameter is made of diverge type-2 i.e. of nor-

mal diameter with right end of pipe widen diameter and in upper hose outlet pipe diameter is made of normal diameter with widen diameter on the left hand side. The hose pipes which are taken six in number are also been kept at same diameter and length. Flow run conditions of the normal water which been used is set at a temperature of 38.39 ˚C, the pressure condition which is taken in whole of the CFD run of the experiment is taken as 3.67. The inlet flow rate condition for the diverge-3 design is maintained at 0.05 Kg/sec shown in Table 2. Inlet flow temperature of water as fluid in pipes is at temperature of 20 °C. Heat source radiation is made to emit 800 Watt. The colour contours shown in the Table 1 shows the temperature and pressure variations occurred during CFD analysis in running software.

4.7 Diverge

3 Design: In diverge-3 design the analysis is represented in the Table 1. Solidworks computer software is used to simulate the design parameters of the flat plate collector. Second type of the design which is made is named as Diverge - 3 design shown in Table – 1.1. The main feature of the design is that in lower hose section the inlet pipe fluid flow diameter is made of diverge type-3 in which pipe diameter is normal and outlet pipe diameter is widening up. In the upper hose section, the outlet flow pipe diameter is widening up but left end is maintained at normal diameter. The hose pipes which are taken six in number are also been kept at same diameter and length. Flow run conditions of the normal water which been used is set at a temperature of 38.41 ˚C, the pressure condition which is taken in whole of the CFD run of the experiment is taken as 2.14. The inlet flow rate condition for the diverge-3 design is maintained at 0.05 Kg/sec shown in Table 2. Inlet flow temperature of water as fluid in pipes is at temperature of 20°C. Heat source radiation is made to emit 800 Watt. The various conditions of temperature and pressure variations occurred during CFD analysis are shown in the Table 1 which shows the temperature and pressure variations occurred during CFD analysis.

5. Conclusions

From the results obtained by performing the computational analysis, this can be concluded that;

1. Temperature at outlet also depends upon the factors such as mass flow rate and radiation intensity.

2. If the mass flow rate increases, corresponding temperature decreases and vice-versa.

3. Outlet temperature also depends upon fluid under consideration and also its thermal properties.

4. Material properties also play an important role in the performance of solar flat bed collector.

5. In the above analysis maximum temperature rise up has been found in converging 3 design and effective minimum pressure drop has been found in the diverging 3 type of design.

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