Analysis of Heat Transfer Performance of Flat Plate Solar Collector using CFD

K A Muhammed Yarshi[1], Dr Benny Paul[2]

Abstract— **Solar flat plate collector is a very simple device and is an efficient way to absorb energy from sun rays and use it. Therefore improvement in their operating condition & geometrical condition would definitely result in saving conventional fuel and cost. The objective of this study was to analyse the effects of variations in the shape of tubes for flat plate solar collector performance. The effect of important parameters such as mass flow rate , absorber material has also been investigated. The numerical analysis is carried out with ANSYS CFD FLUENT software. Comparison in inlet and outlet temperature was performed for different heat flux. The result shows good agreement in the effect of various parameters**

Index Terms— **CFD, Semi Circular pipe, Solar flat plate collector, Operating conditions**

I INTRODUCTION

The use of solar energy has been increased in recent years due to the declining fossil fuel resources and environmental concerns about global warming and air pollution. Although solar power is expensive relative to conventional sources of energy like natural gas, but its overall cost continues to decrease with a quick rate. One of the main applications of solar energy is solar water heating systems which sunlight is transferred to water or working fluid. The most common types of solar water heaters are evacuated tube collectors ,flat plate collectors and unglazed plastic collectors.

A typical flat plate collector is shown in Fig 1.1. When solar radiation passes through a transparent cover and impinges on the blackened absorber surface of high absorptivity, a large portion of this energy is absorbed by the plate and then transferred to the transport medium in the fluid tubes to be carried away for storage or use. The underside of the absorber plate and the side of casing are well insulated to reduce conduction losses. The liquid tubes can be welded to the absorbing plate, or they can be an integral part of the plate.

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The liquid tubes are connected at both ends by large Diameter header tubes.

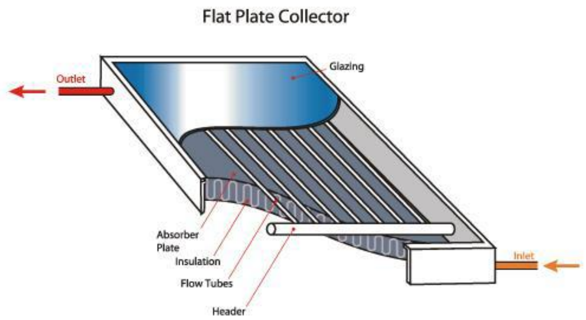

Fig I.I Flat plate collector

The main objective of the study is analyze the effects of variations in the shape of tubes for flat plate solar collector performance. The effect of important parameters such as mass flow rate, absorber material is also investigated.

II LITERATURE SURVEY

A numerical analysis of flat plate collector for circular pipe configuration by using cfd has been done by Ranjitha P et al.[1] In this study numerical and experimental investigation of flow and temperature was performed. The influence of tube shape in conventional collectors was investigated using CFD.

Performance analysis of flat plate collector with modified risers was investigated by Mohammed Saad Abbas et al[2]. In this study collector with triangular tubes with fins were investigated

Another CFD analysis was done on triangular absorber tube of solar flat plate collector by Bavanna S et al[7]. In this study solar collector with triangular riser tubes were investigated. In which triangular riser tubes shows riser in the outlet temperature

Another study was conducted to analyze the effect of variations in shapes of tubes for flat plte solar water heater by Vishal G Shelke et al[8]. In this study collectors with riser tubes of elliptical shapes where considered. In which it shows it will be beneficial in future.

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Solar Flat Plate collector analysis was conducted by Sunil K Amrutkar et al [9] theoretically. This study shows efficiency variation in different collectors and also the scope of reducing the collector area for reducing the collector cost. Marroquín-De Jesus Angel et al[4] Present the investigation describes the construction and experimentation of solar energy absorbers using water as fluid and its simulation in Computational Fluid Dynamics. For Absorber A with rectangular cross section and Absorber B with circular cross section, water temperature was calculated using solar radiation and ambient temperature measurements showing increases of up to 62.5°C for both absorbers.

Based on the results on the available literature, there is a lack of information on the effect of various operating and geometrical parameters on the overall performance of solar collector. Therefore, it was decided to perform a comprehensive numerical study on a flat plate solar collector and investigate on improvement of thermal efficiency. The aim of this work is to study the effect of operating and design parameters on the efficiency of flat plate solar collectors using cfd. Effects of geometrical characteristics of absorber, tubes, and were considered. The commercial ANSYS FLUENT software was used to solve numerically. Results were validated with the experimental data reported by Ranjitha P et al [1]

III THEORETICAL BASIS

The laminar, incompressible, three dimensional and steady constant-properties viscous Newtonian flow inside a solar collector is governed by the usual continuity, momentum and energy equations. For the above assumptions, the continuity equation may be written as:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \qquad (1)$$

The momentum equations in x, y and z directions can be written as:

$$\rho u \frac{\partial u}{\partial x} + \rho v \frac{\partial u}{\partial y} + \rho w \frac{\partial u}{\partial z} = -\frac{\partial P}{\partial x} + \mu\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right] \qquad (2)$$

$$\rho u \frac{\partial v}{\partial x} + \rho v \frac{\partial v}{\partial y} + \rho w \frac{\partial v}{\partial z} = -\frac{\partial P}{\partial y} + \mu\left[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right] \qquad (3)$$

$$\rho u \frac{\partial w}{\partial x} + \rho v \frac{\partial w}{\partial y} + \rho w \frac{\partial w}{\partial z} = -\frac{\partial P}{\partial z} + \mu\left[\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right] - \rho g_z \qquad (4)$$

The energy equations for fluid and the frame of collector are as following:

$$\rho C_p u \frac{\partial T}{\partial x} + \rho C_p v \frac{\partial T}{\partial y} + \rho C_p w \frac{\partial T}{\partial z} = k\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right] \qquad (5)$$

$$\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right] = 0 \qquad (6)$$

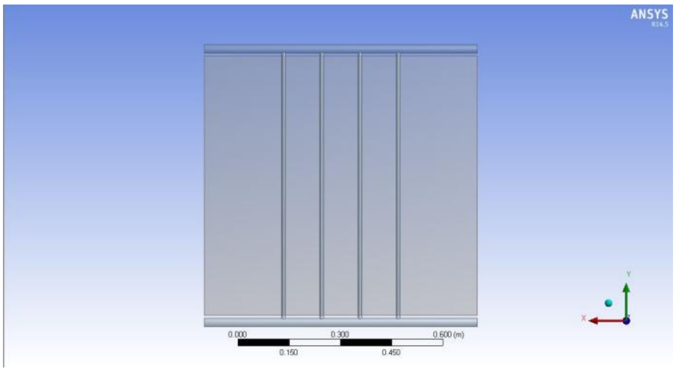
The instantaneous collector efficiency relates the useful energy to the total radiation incident on the collector surface by:

$$\eta_i = \frac{\text{Useful heat gain}}{\text{Radiation incident on the collector}} = \frac{q_u}{A_c I_T} \qquad (7)$$

The performance relation, Eq. (7), assumes that the sun is perpendicular to the absorber plate of the collector, which infrequently occurs.

IV NUMERICAL INVESTIGATIONS

3-D numerical investigations of the solar flat plate collectors were performed by CFD technique and the governing equations were solved using the commercial ANSYS FLUENT software version 14.5. Geometric model and domain of the circular tube absorber is created using ANSYS CFD. The domain created for circular tube configuration is shown



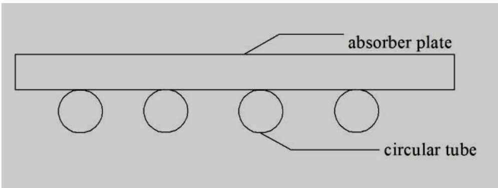


Fig 4.1 Modeling of circular tube- absorber configuration

Collector configurations for the analysis

The collector tube is 0.8 m long and has aq inner diameter of 0.012 m. The distances from pipe to pipe are 0.10 m and consists of header pipe at both inlet and outlet of 0.24 m diameter and 0.8 m long. The overall diamension of the collector is 1.0*0.5*0.1 and the effective glazing area is 0.5 m².

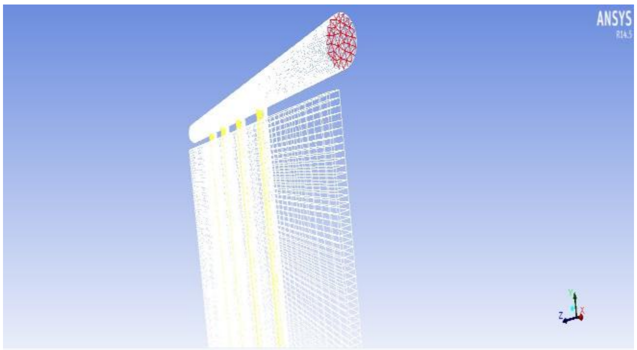


Fig 4.2 Meshing of circular tube configuration

Boundary conditions and assumptions

In this analysis mass flow rate of 0.25 kg/s with constant inlet temperature is introduced at the inlet while a pressure outlet condition is applied at the exit. The physical properties of the working fluid (water) have been assumed to remain constant at mean bulk temperature. Impermeable boundary and no-slip wall conditions have been implemented over the channel walls. The time dependent heat flux was given at absorber plate wall while the opposite side was kept at adiabatic wall condition.

Following assumptions are made in the analysis

- Water is a continuous medium and incompressible
- The flow is steady and posses laminar flow characteristics
- The thermal physical properties of absorber plate, water, absorber tube are independent of temperature

The input parameters used in the analysis are shown in table

Parameter	Value
Density (Copper)	8978 kg/m³
Specific Heat (Copper)	381 J/kg-K
Thermal Conductivity (Copper)	386 W/m-K
Density(Water)	998.2 kg/m³
Viscosity(Water)	0.001003 kg/(ms)
Specific Heat (Water)	4182 J/kg-K
Thermal Conductivity	0.6 W/m-K

V RESULTS AND DISCUSSION

The results obtained from the CFD analysis of solar collector is presented in the section. The simulation is carried out with timely interval of heat flux.

Figure 5.1 shows the temperature contours of the absorber plate when the collector fluid enters with 0.025 kg/s and 306 heated by solar irradiation of 878.5 W/m². The riser in temperature is purely indicated as it flows from inlet to outlet header due to absorption of solar radiation. As the fluid flows through the tubes the fluid gains heat and its temperature increases

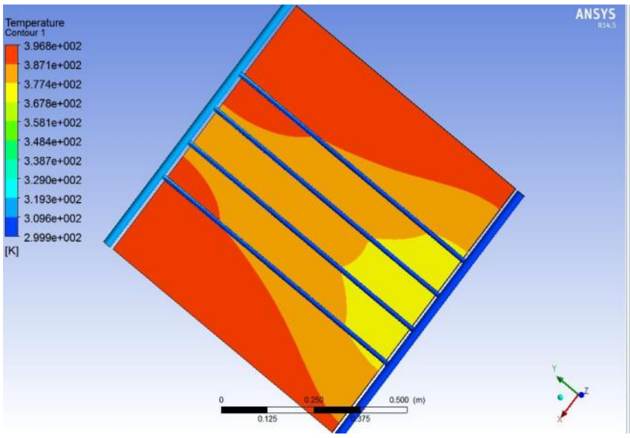


Fig 5.1 Temperature contours of inlet 306

5.1 Validation of CFD Model

Numerical results were verified with the experimental data reported by Ranjitha P et al. Timely heat flux and the output temperature is utilized for the validation

Time	Radiation W/m²	Inlet Temp	Experimental outlet temp (Ranjitha P)	CFD Outlet Temperature
8	878.5	306	306	311.12
10	1316.8	308.6	312.8	316.28
11	1444.3	310.4	320.6	318.82
13	1485.8	315.1	329.2	323.76
14	1397.3	323	332.3	331.15
16	1025.3	316.5	325.1	322.4

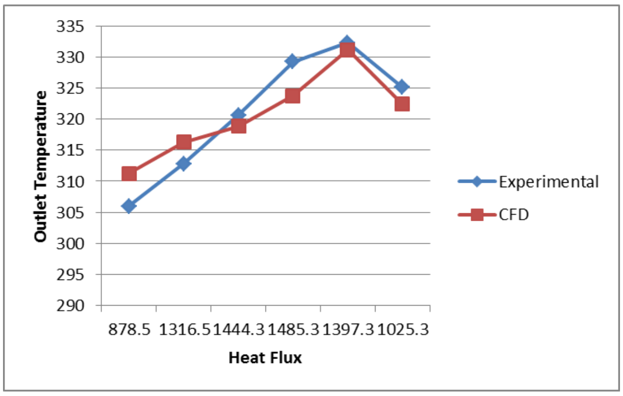


Fig 5.2 Outlet Temp from Experimental data and CFD data

The small variation observed in the outlet temperature of the experimental and CFD results is due to the fact that in experimental observation, the outlet temperature is measured at one particular location of the outlet header, while in CFD analysis the average temperature of the fluid flow through the outlet header is indicated. Hence there is variation in the outlet temperature. This results in a good comparison between experimental and CFD studies.

5.2 Effect of Riser shape on collector performance

For the investigation on the effect of non circular riser tube on the heat transfer in flat plate collectors, collectors with semi circular risers have been studied.

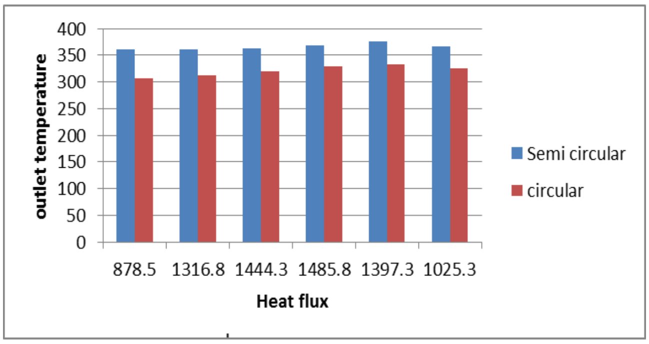


Fig 5.3 Comparison between Circular and Semi circular risers

By comparing with semicircular riser tubed collector it has been examined that there is a great increase in the outlet temperature than the conventional model. The flat plate collector with semi circular cross sectional tube has absorbed more heat than that of circular cross sectional area tube, due to increasing absorbing area of tube, reducing the resistance due to the bonding material between the plate and the tube and the resistance due to the wall thickness of the tube.

5.3 Effect of Mass flow rate on Thermal efficiency

To investigate on flow rate effects, circular model was considered with flow rate of 0.025 - 0.05 kg/s. Fig 5.4 presents the variations of collector efficiency versus the reduced temperature parameters, (Ti-Ta)/G, for different mass flow rates. As shown in Fig.5.4 by increasing the fluid flow rate from 0.025 to 0.05 kg/s, the collector efficiency increases.

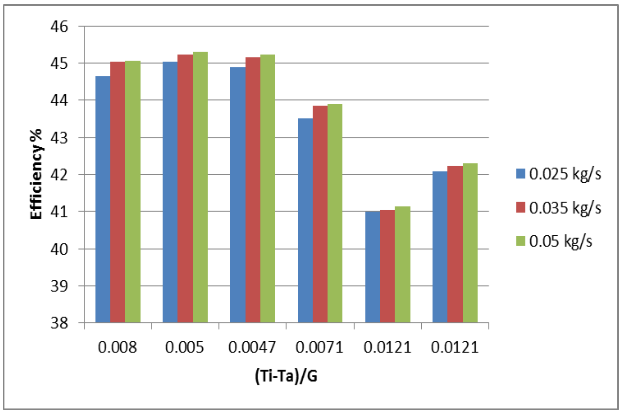


Fig 5.4 Collector Efficiency with different fluid flow rate

Hence by increasing the fluid flow rate the efficiency of collector increases.

5.4 Effect of Absorber Material on Thermal Efficiency

One of the most important sections in a solar flat plate collector is absorber plate, which absorbs the solar radiation and transfers heat to the risers and fluid medium. Therefore, the material properties of absorber plate play an important role in conduction heat transfer from the absorber to the riser tubes.

Within this study, different absorber plates of copper, aluminum and steel with various thermal conductivities were used and results are demonstrated in 5.5. As shown in this figure, by increasing the absorber conductivity, the collector efficiency increases.

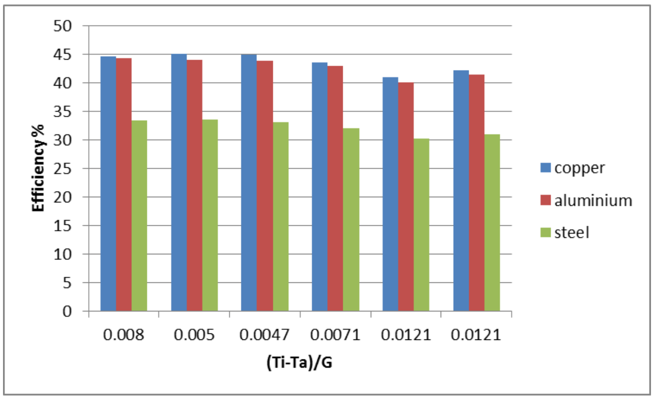


Fig 5.5 Collector efficiency of various absorber materials

VI CONCLUSION

A 3-D numerical simulation was carried out to investigate about the efficiency of a flat plate solar collector. Various geometries and operating conditions were examined in order to assess the influence of shape of tube area section on collector performance and effect mass flow rate and absorber material on thermal efficiency.

The flat plate collector with semi circular cross sectional tube has absorbed more heat than that of circular cross sectional area tube, due to increasing absorbing area of tube, reducing the resistance due to the bonding material between the plate and the tube and the resistance due to the wall thickness of the tube. So, this method improves the efficiency of flat plate collector. The increase in mass flow rate increases the efficiency of collector too.

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