Investigate the impact of Riser Tube Shape Variations on Flat Plate Solar Water Heater Performance Using CFD Analysis.

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Abstract— The flat plate collectors typically consist of a large heat absorbing plate designed for operation in the low temperature range. The main factors to be considered in flat plate collector design are increasing absorption, minimizing heat losses, and effective heat transfer from the absorbing surface to the working fluids. Therefore, an improvement in their geometrical and operating condition would definitely lead to savings in cost of fuel and operating temperature range. One of the important issues is obtaining a good thermal bond between the absorber plate and riser tubes containing the heat-transfer fluids. Generally, arrays of circular cross-section riser tubes are bonded to the absorber plate. The goal of this research is to investigate how different riser tube shape affects flat plate collector performance. According to CFD studies, square and triangular riser tubes have the highest water exit temperatures compared to circular riser tubes for the same working conditions. This is because square and triangular riser tubes have more surface area in contact with the plate, which allows for more heat absorption and increased collector performance. The temperatures indicated by the CFD analysis are compared to the numerical values derived using the experimentally recorded temperatures, and it is discovered that the calculated and measured findings are very close.

Index Terms— Solar energy, Flat plate solar water heater, Shapes of tubes, Absorber plate, CFD analysis.

I. INTRODUCTION

Solar energy collectors are used to converts solar radiation energy to the internal energy of the transport medium. The solar collector is the key component of every solar system. Despite producing lower temperatures than the other solar thermal collectors, flat plate collectors have the advantage of being easier to construct and require less maintenance and capital cost. Low energy density of solar energy (w/m2) makes it difficult to use; one way to overcome this difficulty is to continually increase the operational efficiency of solar applications.

The material used for absorber surface is generally metals like copper, steel, or aluminium. The surface of the absorber plate is painted black or electroplating a layer of nickel to improve rate of heat absorption. The heat transfer fluid is directed or carried by riser tubes or fins from the inlet header to the outlet. The glazing cover is sealed to trap the heat between absorber surface and glazing and also to protect from dust and humidity. The casing of solar collector can be made of plastic, metal, or wood type insulator for minimizing heat loss. A flat plate collector's main advantage is that it uses both diffuse and beam solar light. The performance of flat plate collector is influenced by the area of collector plate, ambient temperature, solar isolation, top heat loss coefficient, emissivity of the plate, transmittance of glazing, and the number of top glass covers used.

Active solar heating systems' main part is sun collectors. The sun's energy is captured by these devices, which then convert it into heat and transport it to a fluid, usually air or water. Solar thermal energy can be utilized for solar space heating, solar cooking, solar water heating, and solar pool heating.

II. LITERATURE SURVEY

The main part of solar energy systems is the solar collector. It takes in solar energy and transforms it into a useful type of energy that can be used to meet a particular need. Modern household hot water systems still use flat plate solar collectors, which haven't undergone much development in recent years. These absorbers often have low efficiency and large heat losses through convection and radiation.

In research papers review, According to Vishal G. Shelke, elliptical tubes provide the highest water outlet temperature for a given heat flow and inlet temperature when compared to circular and other elliptical designs [4]. Basavanna S has suggested a triangular tube configuration instead of circular tube. The triangular tube increases the temperature at the discharge because the tube and plate make much better contact. The collector fluid gets hot as the fluid passes through the tube, raising its temperature [5]. P. Sivakumar talked about altering the design parameters of the existing flat plate collector system to increase the number of riser tubes and organize them in a zig-zag pattern, which would improve the performance of a flat plate solar energy collector. Copper tubing was used in experiments for header and riser with various dimensions. [7].

According to the literature review, a lot of scope is available for selecting the best riser tube configuration and the proper thermal bonding for improved contact between the tube and plate that raises the outlet temperature. As a result, this study will examine the manufacturing and design features of a collector to develop a better riser configuration for a solar thermal flat plate collector.

III. PROBLEM STATEMENT

The objective of this study is to analyze the effect of various geometry configurations of riser tubes and modeling is to be carried out with ANSYS CFD tool. Analyzing the temperature distribution of water inside the solar collector and comparing the water's exit temperature to numerical results for various riser tube geometric configurations are the major objectives of this investigation. Here, the flow domain includes a three flat plate absorber plates having circular, square and triangular riser tubes shapes as shown in Figure 1 for comparing their thermal efficiency for optimization of design.

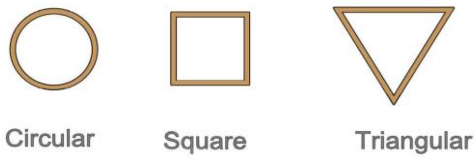

Figure1- Schematic drawing showing various geometry configurations of riser tubes

A. Circular Riser Tubes Configuration

Arrays of circular cross-section riser tubes are bonded to the absorber plate as shown in figure 2. The absorber plate absorbs heat energy from the sun and transfers it to the working fluid flowing through the circular tubes. The collector absorber plate length and width is taken as 0.7 m and 0.4 m respectively. The dimensions of simple circular absorber tubes as Length = 0.720 m, Cross section diameter = 0.0167 m and Thickness = 0.001 m

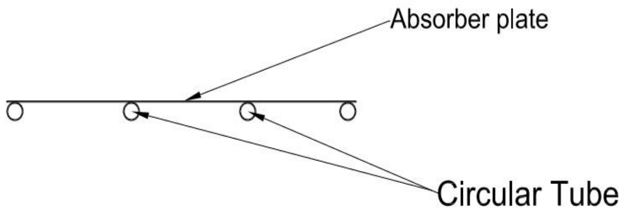

Figure 2 - Circular Riser Tubes Configuration

B. Square Riser Tubes Configuration

Arrays of square cross-section riser tubes are bonded to the absorber plate as shown in figure 3. The absorber plate absorbs heat energy from the sun and transfers it to the working fluid flowing through the square tubes. The dimensions of square absorber tubes as Length =0.720 m, each side of cross section =0.0148 m and Thickness = 0.001 m.

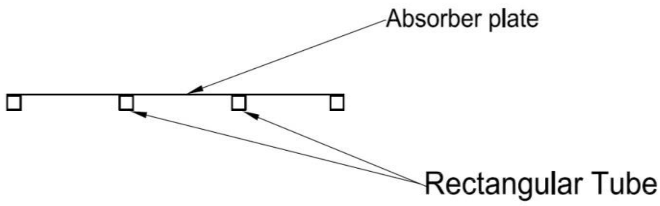

Fig. 3: Square Riser Tubes Configuration

A. Triangular Riser Tubes Configuration

Arrays of triangular cross-section riser tubes are bonded to the absorber plate as shown in figure 4. The absorber plate absorbs heat energy from the sun and transfers it to the working fluid flowing through the triangular tubes. The dimensions of triangular absorber tubes as Length =0.720 m, each side of cross section =0.0225 m and Thickness = 0.001 m.

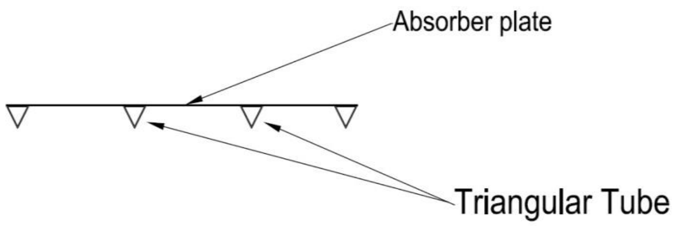

Fig. 4: Triangular Riser Tubes Configuration

In the case of square and triangular tubes, area of surface contact between the tubes and the plate is increase due to flat contact resulting in more heat absorption as compared to circular one. But only drawback of this arrangement is manufacturing process is complicated.

IV. METHODOLOGY

The temperatures estimated by the CFD analysis are compared to the numerical results that have been obtained using the experimental results temperatures. In this study, Experimentation and CFD Simulation are done for three shapes such as circular, square and triangular.

A. Experimental Method

As per design, select material and fabricate the prototype models of collector having different geometry of riser tubes to make the experimental setup as shown in figure 5.

Figure 5: Experimental Setup

In this study, the readings of solar radiation are taken by using TES - 1333 solar power meter as shown in Figure5. The solar meter is held in such a way that its sensor is co-planer with the plane of the collector so that it will detect incident radiation on the plane of the collector. For solar energy data refer following site.

https://apps.solargis.com/prospect/map

(For Shirpur location 21.34960 N, 74.87970 E)

B. Boundary conditions

A mass flow rate of 0.0038 kg/s with a constant inlet temperature is applied in the CFD analysis. The Inlet temperature is measured at 10 AM, 12 Noon and 2 PM throughout the day. Copper is the material used for both the tubes and the absorber plate. The different parameters used in the analysis are as follows.

Table 1: Input Parameters for CFD analysis (Simulation)

Parameter	**Value**
Density of copper	8978 kg/m^3
Specific Heat of Copper	381 J/kg-K
Thermal Conductivity of Copper	386 W/m-K
Density of Water	998.2 kg/m^3
Viscosity of Water	0.001003 kg/(m.s)
Specific Heat of Water	4182 J/kg-K
Thermal Conductivity of Water	0.6 W/m-K

C. Assumptions

The analysis makes the following assumptions

- Water is circulated through the riser configuration.
- Water is assumed to be incompressible and

constant medium.

- Flow is assumed to be steady and laminar.

The absorber plate, the water, and the riser tube all have thermal-physical characteristics that are independent of temperature [4].

D. CFD Analysis

With the use of the ANSYS Design Modeler programme and the ANSYS Meshing Software, the geometric model and fluid domain for CFD analysis are created. CFD Simulation is done for all three shapes such as circular, square and triangular.

As shown in figure 6, a three-dimensional computational domain is created.

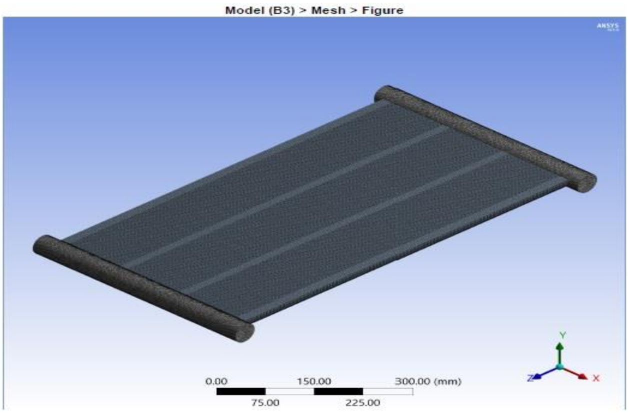

Figure 6: Mesh model for circular tube absorber configuration

CFD simulation is first performed on circular riser tubes configuration and the temperature distribution for 706 W/m2 radiations at 12 pm is shown in figure 7.

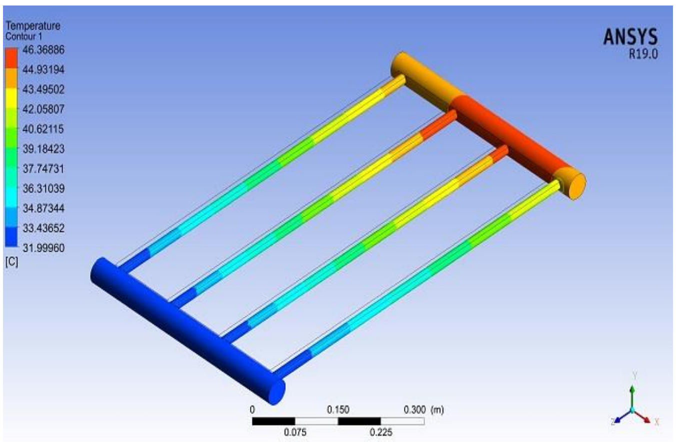

Figure 7: Temperature distribution in circular riser tubes

CFD Meshing of square tube absorber configuration as shown in figure 8.

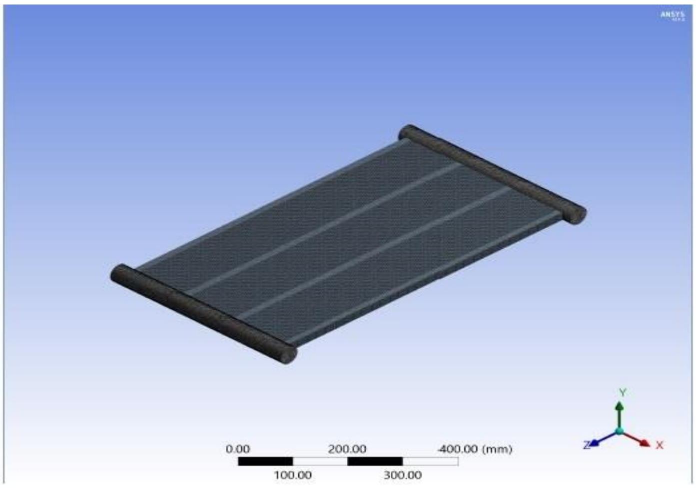

Figure 8: Mesh model for square tube absorber configuration

CFD simulation is performed on square riser tubes configuration and the temperature distribution for 706 W/m2 radiations at 12 pm is shown in figure 9.

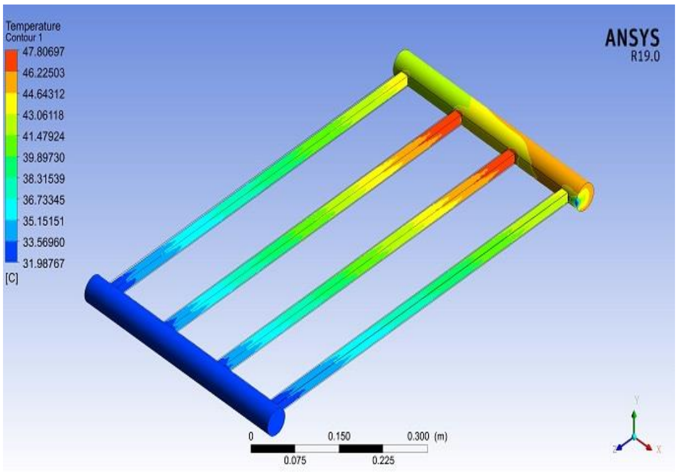

Figure 9: Temperature distribution in square riser tubes

CFD Meshing of triangular tube absorber configuration as shown in figure 10.

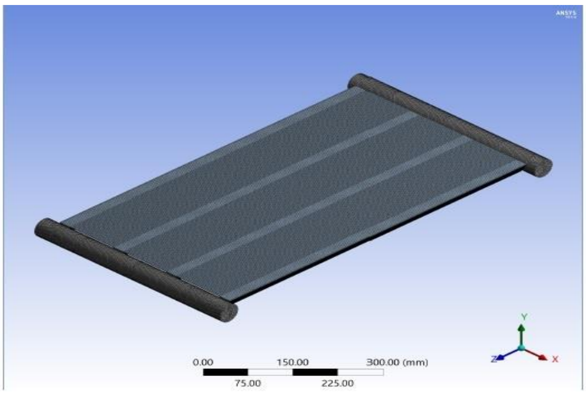

Figure 8: Mesh model for triangular tube absorber configuration

CFD simulation is performed on triangular riser tubes configuration and the temperature distribution for 706 W/m2 radiation at 12 pm is shown in figure 11.

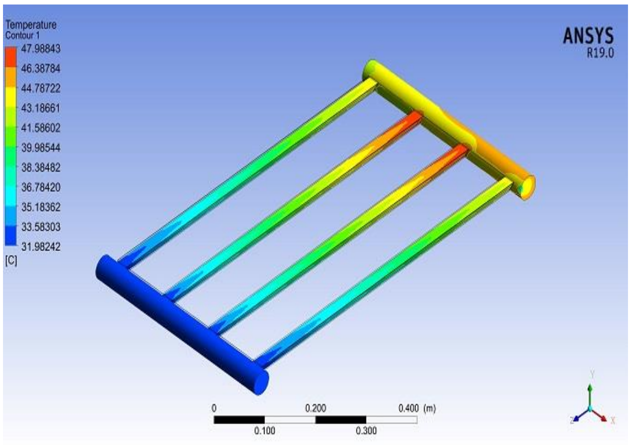

Figure 11: Temperature distribution in triangular riser tubes

E. Efficiency of flat plate collector

Following formula can be used to determine the flat plate collector's efficiency.

Efficiency (η) = (Qu) ÷ (IT X Ac)

Where,

Qu = Useful heat gain (W).

IT = Total solar radiation that reached the collector's top cover (W/m2)

Ac = Collector gross area (m2)

The following formula can be used to calculate the useful heat gain (Qu) for a flat plate collector.

Useful heat gain (Qu) = m Cp (T_{out} - T_{in})

Where,

m = Mass flow rate (kg/s)

Cp = specific heat of water (kJ/kg.k)

Tout = Outlet temperature of fluid (^{0}C)

Tin = Inlet temperature of fluid (^{0}C)

V. RESULTS AND DISCUSSION

A. CFD Simulation Data Results

Useful heat gain in circular, square & triangular absorber tubes configurations is obtained is given in table 2.

Table 2: Comparison of Useful Heat Gain

Time	Qu of Circular (W)	Qu of square (W)	Qu of Triangular (W)
10 am	183.92	203.33	205.40
12 pm	228.63	251.70	254.56
2 pm	179.78	197.76	200.47

Variation of useful heat gain in circular, square & triangular absorber tubes configurations is shown by the graph as shown in figure 12.

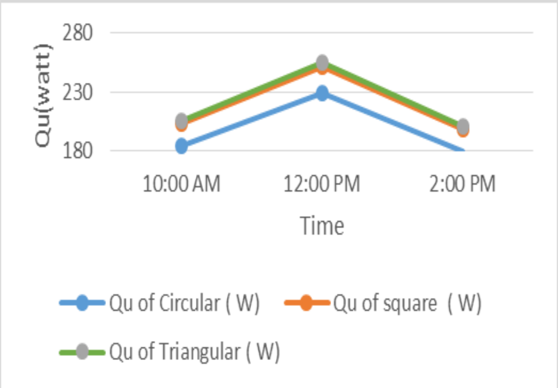

Figure 12; Comparison of useful heat gain

From the above graph, it is seen that maximum heat gain is obtained in square & triangular riser tubes configurations as compared to circular tubes.

Comparison of outlet temperature of water in circular, square & triangular absorber tubes configurations is given in table 3.

Table 3: Comparison of Outlet Temperature

Time	Temperature in ^{0}C		
	Circular tubes	Square tubes	Triangular tubes
10 AM	37.55	38.77	38.89
12 PM	46.36	47.80	47.98

2 PM	41.29	42.42	42.58

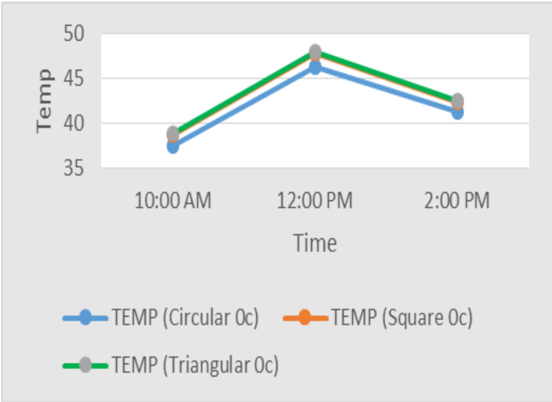

Figure 12; Comparison of outlet temperature of water

Variation of collector efficiency (η) in circular, square & triangular absorber tubes configurations is shown in table 4.

Table 4: Comparison of Collector Efficiency (η)

Time	**Collector Efficiency (**η) in %		
	Circular tubes	**Square tubes**	**Triangular tubes**
10 AM	75.48	83.45	84.30
12 PM	75.76	83.40	84,35
2 PM	75.78	86.36	84,50

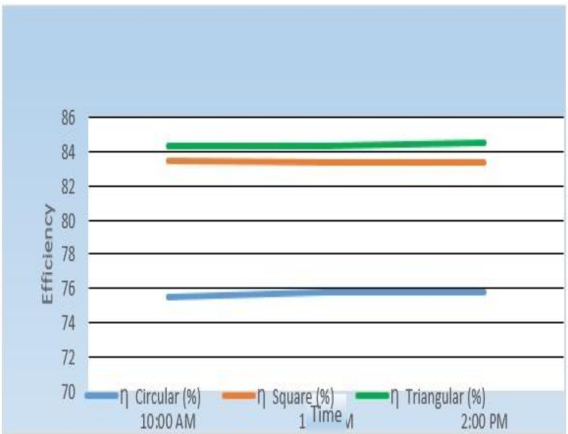

Figure 13; Comparison of collector efficiency (η)

The graph shows outlet temperature difference between square/triangular and simple circular riser tubes is almost 2^0C. The efficiency (η) is increased by 8 to 10% using square/triangular absorber tubes configuration.

B. Experimental Data and CFD Simulation Data

The experiment was conducted and recorded each value accurately. Compared experimental data with CFD simulation data for circular, square & triangular absorber tubes configurations given in table 5.

Table 5: Comparison of experimental data with CFD simulation data

For circular Model					
Time	**Ambient Temp in ^{0}C**	**Radiation (W)**	**Inlet Temp in ^{0}C**	**Expt. Outlet Temp in ^{0}C**	**CFD Outlet Temp in ^{0}C**
10 AM	26	470	25.99	38.50	37.55
12 PM	32	706	31.99	47.05	46.36
2 PM	30	555	29.99	40.98	41.29
For Square Tube Model					
10 AM	26	470	25.99	39.02	38.77
12 PM	32	706	31.98	47.92	47.80
2 PM	30	555	29.9	42.10	42.42
For Triangular Tube Model					
10 AM	26	470	25.98	39.76	38.89
12 PM	32	706	31.98	48.24	47.98
2 PM	30	555	29.98	32.48	42,58

The above table shows that, the temperatures determined by the CFD analysis and those that were measured experimentally are quite similar.

CONCLUSION

The numerical investigation on the influence of riser tube shape variations on flat plate solar water heater performance was carried out and presented. After the CFD simulation, the following conclusions were obtained.

1. Square and triangular riser tube geometries provide more water outlet temperature for the same working conditions as compared to circular one.

2. Triangular and square tubes configuration raises the outlet temperature by approximately 2^0 C due to good surface contact between tubes and absorber plate as compared with circular one.

3. The efficiency (η) is increased by 8–10% by employing a square or triangular shaped absorber tube as compared to simple circular one.

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