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Modeling And CFD Simulation Of Flat Plate Solar Collector By Using Ansys Fluent

Nishikant J. Gondane, M.Tech (Heat Power Engineering)
G. H. Raisoni College of Engineering & Management, Pune, India

Dr. Anil Sahu (Professor)
Department of Mechanical Engineering,
G. H. Raisoni College of Engineering & Management, Pune, India

Abstract:
Flat plate solar collectors are used in solar water heaters and it is one of the most widely used solar thermal systems for water heating applications. This project focuses on Modeling & simulation of the flat plate solar collector performance using ANSYS Fluent. The objective was to understand how the collector behaves under different solar radiation flux and water mass flow rates, & study the effects of solar irradiance, flow rate, and collector efficiency on system performance through computational fluid dynamics (CFD) simulations. Results showed that the collector works effectively during mid-day hours, with the highest efficiency reaching over 97%. At 01:00 pm. It was also observed that lower flow rates result in higher water temperatures (up to 82.52°C). This project demonstrates how simulation tools like Ansys Fluent can be advantageous to improve the design and performance of solar collectors.

***Index Terms* - Flat plate solar collector, CFD, Ansys Fluent, solar radiation, collector efficiency,**

I. Introduction

Solar thermal energy is a main frame of renewable energy that uses solar radiation to generate heat for uses in various applications. It is widely used for domestic & industrial applications like water heating, space heating, and photovoltaic (PV) systems. Solar thermal systems focus on utilizing heat energy, & Flat plate solar collectors are one of the most common user-friendly technologies nowadays. The modern Flat plate collectors are designed in such an optimal way that absorb and transfer solar energy efficiently. These systems help in reducing dependency on fossil fuels, helping to lower greenhouse gas emissions, and also promoting sustainable energy solutions worldwide. These collectors consist of three core components, an absorber plate, a transparent glass (glazing), and an insulated casing, as shown in Figure 1.

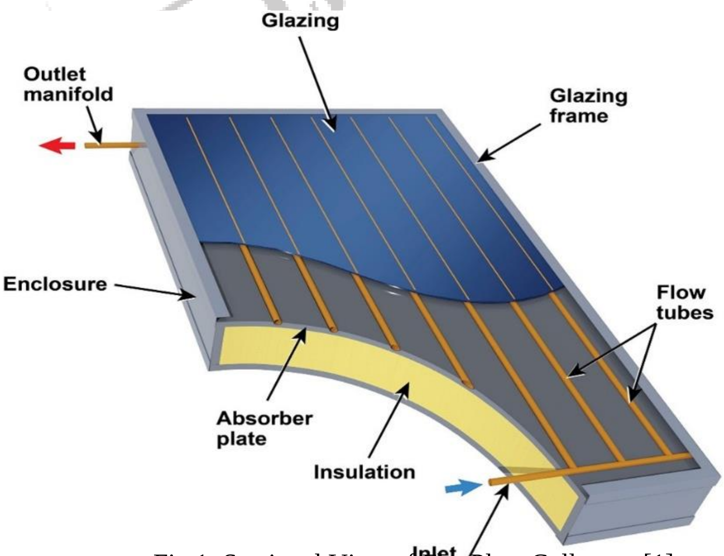


Fig 1: Sectional View of Flat Plate Collector. [1]

The absorber is a flat sheet made from metal with high thermal conductivity, such as copper or aluminum, along with tubes attached or integrated into its surface to carry the working fluid. The insulated casing helps to maintain & prevents heat loss from the back and sides and ensures durability. The glazing is generally made of glass or a transparent polymer, which allows sunlight to enter and reach up to the absorber while also reducing heat loss employing trapping air and obstructive cool air from circulating above the plate. However, some sun rays are reflected by the glass surface, maximum sun rays pass through to the absorber, which covers the entire area of the collector to utilize the maximum solar energy to be captured. The solar collector works on the basic usual, it absorbs the maximum possible amount of solar radiation, & transfers the absorbed heat to the working fluid with minimal temperature difference, by keeping neglected heat loss to the surroundings.

II. LITERATURE REVIEW

Numerous studies have assessed the thermal performance of flat plate solar collectors using CFD and mathematical models. Gunjo et al. (2017) validated CFD simulations against experimental data, observing less than 5% deviation. Alobaid et al. (2018) found that turbulent inlet flow enhances heat transfer, improving efficiency. Shukla and Gupta (2018) demonstrated that incorporating fin tubes increased efficiency by up to 56%. Dhakar and Jouhri (2019) showed that structured absorber fins improve thermal distribution and reduce stagnation. Wasik et al. (2018) developed a mathematical model with high predictive accuracy using the Hottel–Whillier–Bliss equation. Grahovac et al. (2010) emphasized the importance of dynamic boundary conditions for long-term performance prediction. These studies confirm CFD's reliability and precision in solar collector analysis and optimization.

III. METHODOLOGY

To simulate the thermal performance of the Flat plate solar collector, we have to establish 3D Modeling geometry, Meshing & energy equation setup, & numerical input data to conduct simulation setup using ANSYS Fluent.

3.1. Geometry

The solar collector model consists of an absorber plate, water tubes, a glass cover, and an insulation layer created in SolidWorks with basic dimensions & Inputs taken from [2], & Created 3D model imported in Ansys Fluent to set up Material properties & identification of parts location. To understand the overall geometry concept the various partwise geometry views are shown in Figures as follows

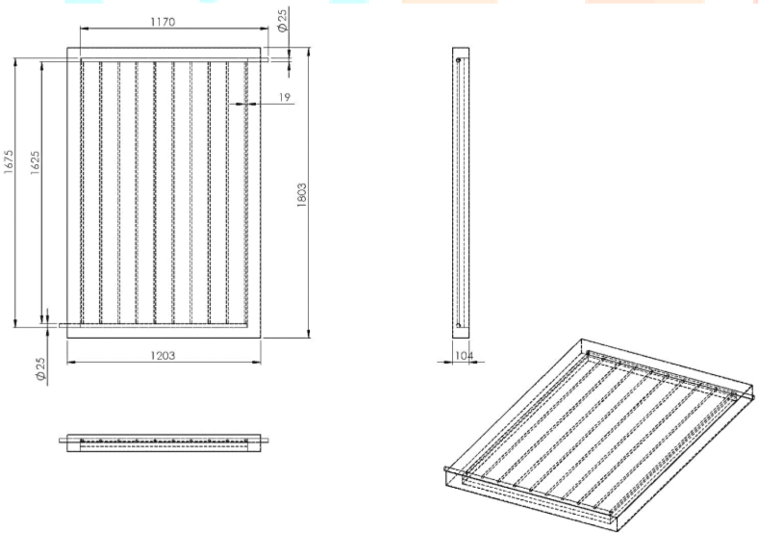


Fig 2: 2D layout & Dimension of Flat Plate Solar Collector.

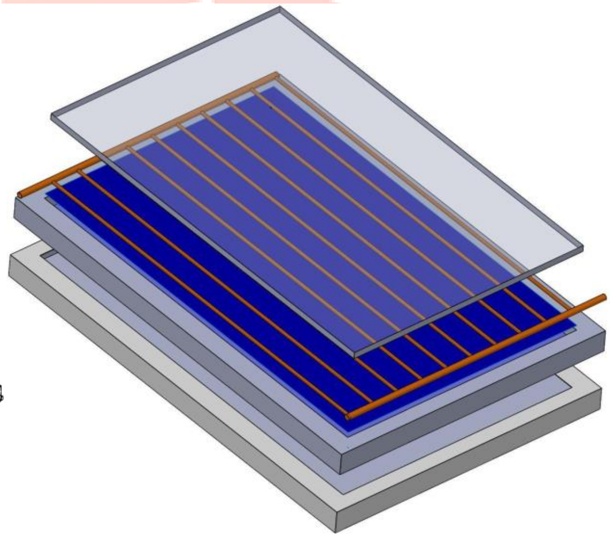


Fig 3: Flat Plate Collector Explode View

3.2. CFD Modeling:

A CFD model was developed to predict the outlet temperature and absorber plate temperature for a single straight riser tube attached to the bottom of the absorber plate. The flow rate in each riser tube was set as 1/10th of the total flow rate in the header tube, corresponding to the ratio of the total flow rate through the header tube to the number of riser tubes [2] The outlet water temperature and absorber plate temperature of the solar collector depend on the flow distribution within the riser tubes. At low Reynolds numbers (flow rate < 0.016 kg/s), the flow remains uniform, leading to a homogeneous temperature distribution in each riser tube.

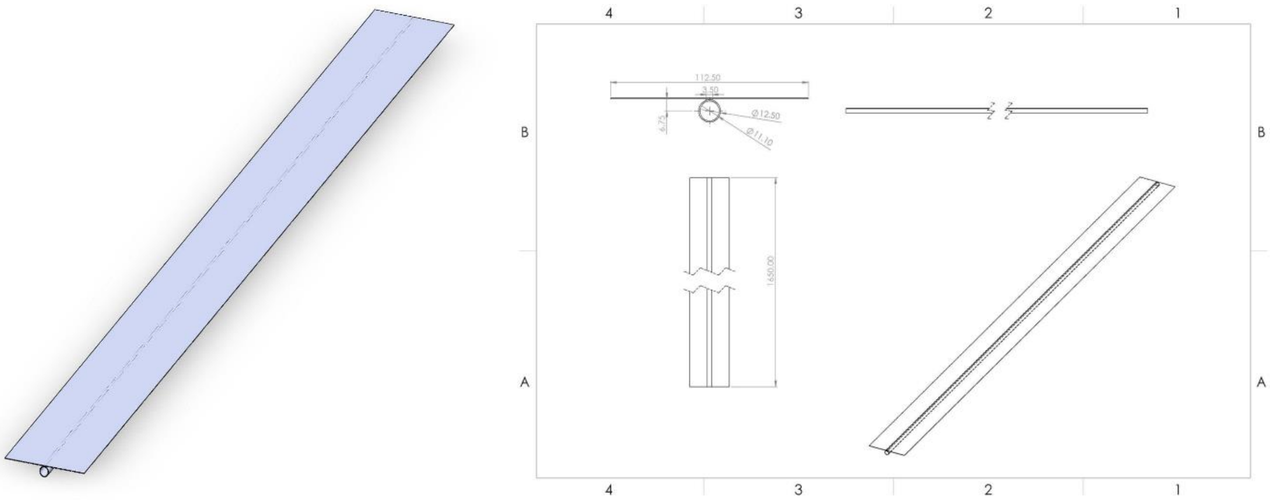


Fig 4: Flat Plate Collector Single Tube Riser 3D & 2D Dimension

3.3. Meshing:

The model meshing performed in Ansys fluent 2025. Mesh contains mixed cells per unit area having Polyhexa core typefaces at the boundaries refer to Fig: 12 for the detailed view.

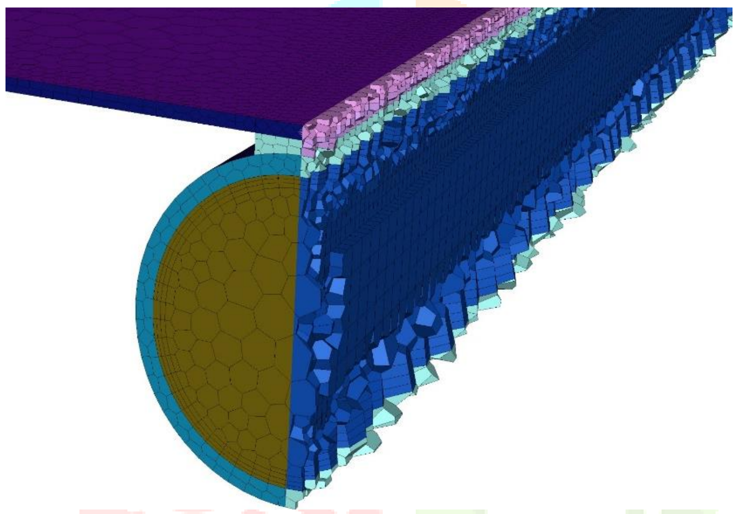


Fig 5: Mesh Model-Cross Section View Shown- Polyhexacore Mesh

The total number of mesh cells created in the entire geometry was about 7.95 lacks which is appropriate to this CFD model to simulation. In the Ansys Fluent Meshing process program volumes are specified for meshing operation, shape and topological characteristics, and type of mesh are also determined.

A structured **Polyhexa core mesh** was generated for accurate heat transfer calculations. Element Number of elements: 795463 cells, Minimum Orthogonal Quality = 1.96655e-01, Maximum Aspect Ratio = 3.63459e+01

3.4. Simulation Setup Material Properties

Material properties: Copper (absorber), Insulation (Glass wool), Water (working fluid)

Table No 1: Material properties of flat plate collector materials

Material	Density (kg/m³)	Specific Heat (J/kgK)	Thermal Conductivity (W/mK)
Absorber Plate	8954	385	386
Insulation (Glass Wool)	200	840	0.044
Water	1000	4180	0.6

3.5. Boundary conditions:

By using **mathematical modeling and ANSYS Fluent simulations**, this methodology provides a comprehensive analysis of the thermal efficiency and heat transfer performance of the flat plate solar water heater.

3.6. Simulation Setup in ANSYS Fluent

- Solver: Pressure-based
- Turbulence Model: Laminar
- Radiation Model: Rosseland
- Discretization: Second-order upwind scheme
- Pressure- Velocity Coupling - SIMPLE (Semi Implicit Pressure Linked Equation)

3.7. Flat Plate Solar Collector Geometric Dimensions

Table No 2: Flat Plate Solar Collector Dimension Table [2]

Parameter	Value	Unit
Length of collector	1.8	m
Width of collector	1.2	m
Length of the absorber plate	1.65	m
Width of the absorber plate	1	m
Thickness of absorber plate	0.0005	m
Number of riser tubes	10	-
Diameter of riser pipe	0.0125	m
Diameter of the header pipe	0.025	m
Riser and header pipe thickness	0.0007	m
Tube center-to-center distance	0.1125	m

3.8. Inlet Boundary Conditions:

Table No 3: Simulated Applied boundary condition for laminar flow

Parameter	Value	Unit
Mass Flow Rate (Total)	0.095	kg/s
Mass Flow Rate per Riser	0.0095	kg/s
Water Inlet Temperature	25	°C
Inlet Diameter	0.0111	m
Reynolds Number	1198.8	
Wind Velocity	1	m/s
Ambient Temperature	25	°C

3.6.2 Location of Simulation

The location for performing the simulation is chosen as Platinum Pallazo, Premlok Park Rd, Premlok Park, Akurdi, Pimpri-Chinchwad, Maharashtra 411033 shown in Fig 13. The Coordinates for the location are 18.640598°N, & 73.780629° E. The location is suitable to simulate because the area receives a sufficient amount of sun radiation. Solar heat flux formation rate for the date 30th March 2025.

3.9. Ansys Fluent Simulation Setup for Variation in Water Flow

Table No 4: Inlet and Outlet Conditions for Variation in Flow [3].

Parameter	Value	Unit
Inlet Temperature (T_in)	25	°C
Outlet Temperature (T_out)	Pressure outlet	Pa
Maximum Mass Flow Rate	0.0095	kg/s
Ambient Temperature (T_amb)	25	°C
Side Walls	Adiabatic	-
Absorber Plate	Heat flux $(q)=G\cdot\tau\cdot\alpha$	-
Bottom Layer	$h = 2.8 + 3V_w$	W/m²K
Wind Speed	1	m/s

3.10. Static Temperature Profile.

The temperature was initially measured along a line (rake) placed at the central axis of the pipe to evaluate the temperature variation along its length. However, this method does not accurately represent the outlet temperature due to possible non-uniform temperature distribution. Therefore, a **mass-weighted average** was used to more accurately determine the outlet temperature.

Temperature distribution on riser tube

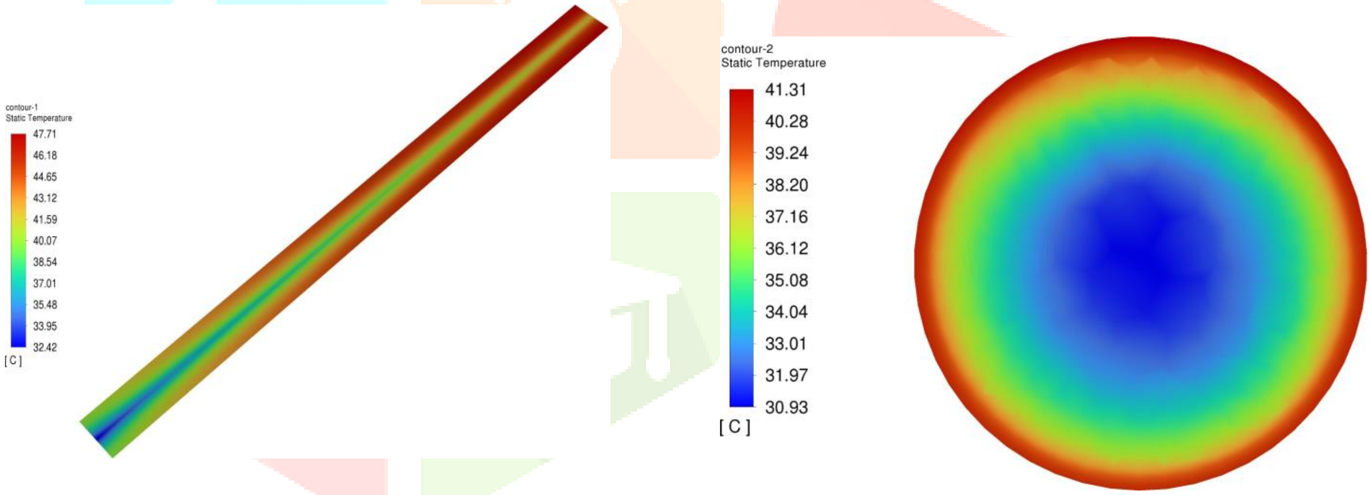


Fig 6: Static temperature distribution w.r.t Position of riser from Inlet to Outlet

IV. RESULTS AND DISCUSSION

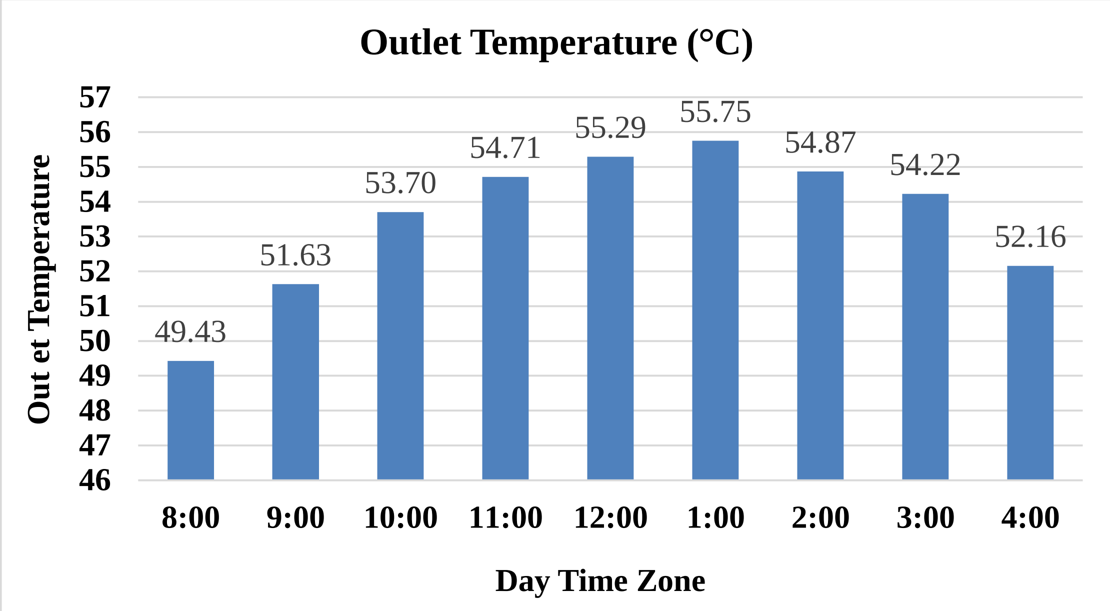
4.1 Simulation Data Post-Processing.

After giving all the necessary inputs i.e. properties of materials table No. 1, Inlet – Outlet conditions table No. Boundary condition table No. 3, & table No. 4, of the collector to the ansys fluent software, it performed post-processing by the calculations inside it and provide the related output in the form of user graphics interface for distribution of parameters, reports which include data at various temperature profile as shown in Fig 6.

4.2 Solar Ray Tracking -Temperature Variation & Collector Efficiency

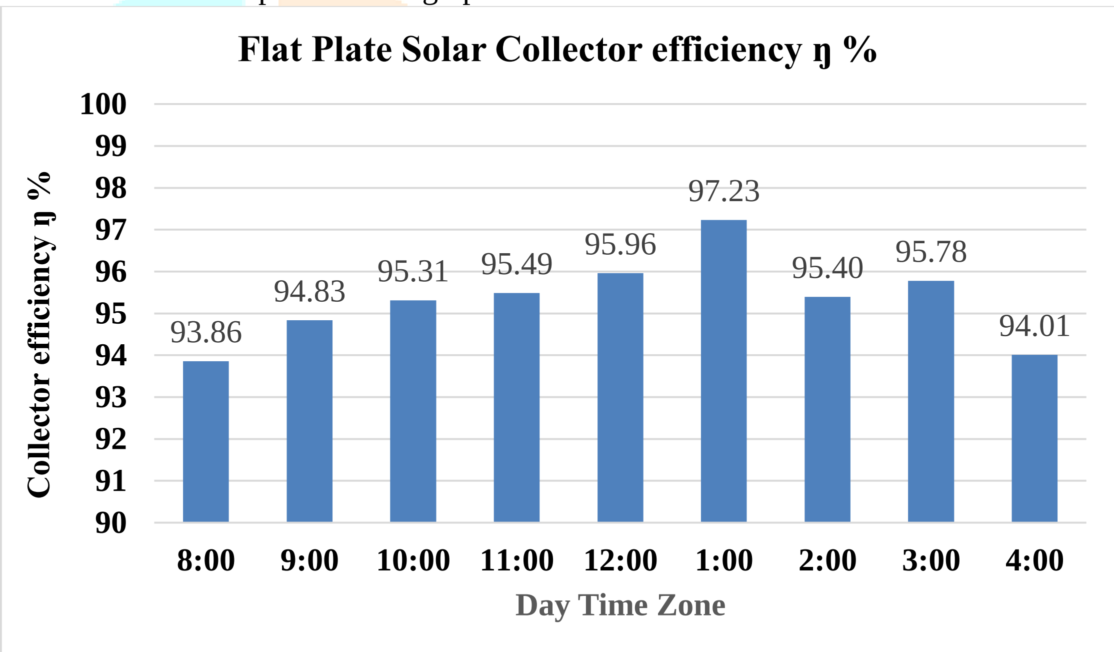
The outlet temperature of the water increases with higher solar heat flux and varies with different mass flow rates. For this analysis, the mass flow considered per riser was **0.00125 kg/s** as per the reference paper [2], by evaluating the simulation in the daytime from 8 am to 4 pm, the results of weather conditions at 1.00 pm show better results as compared to rest day timing.

By simulation of flat plate solar collector, we observed maximum outlet temperature at 1 pm i.e., 55.75 °C at an inlet temperature of the water is 25 °C, therefore, rise over in temperature is 30.75 °C, also it is observed that as day time increases w.r.t that Flat plate solar collector outlet temperature decreases as presented in graph 1



Graph 1: Flat Plate Collector Outlet Temperature Variation w.r.t Day time hrs.

Correspondingly the efficiency is also best at day time of 1:00 pm i.e., 97.23%, and gradual reductions in efficiency as time increases as presented in graph 2.

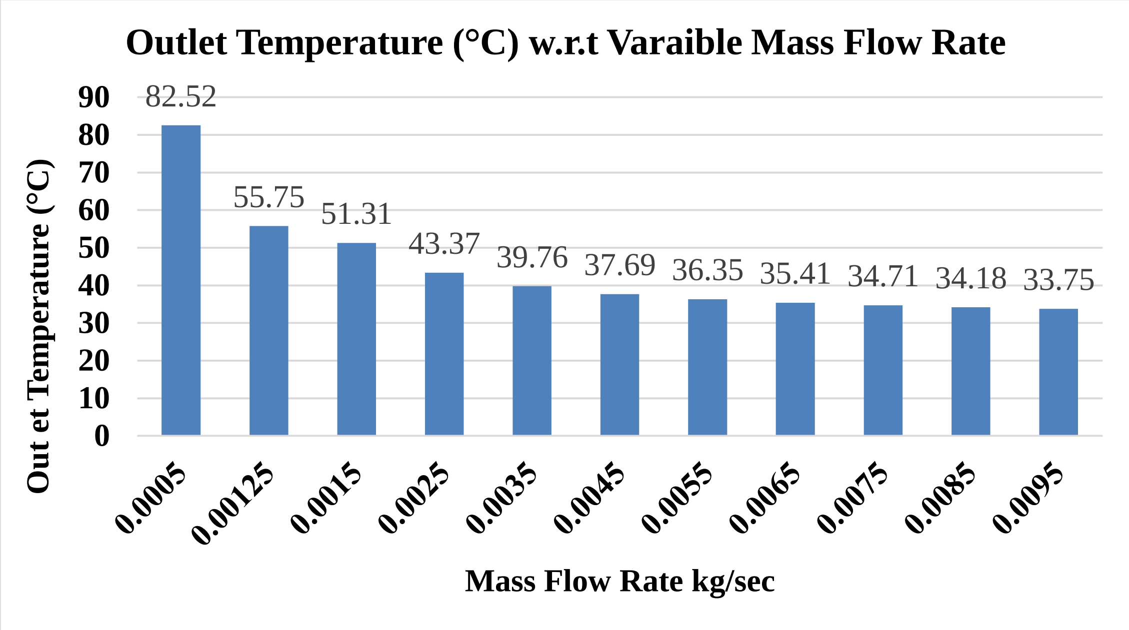


Graph 2: Flat Plate Collector Efficiency w.r.t Day time Hrs.

4.3 Mass Flow Variation- -Effect on Outlet temp Temperature

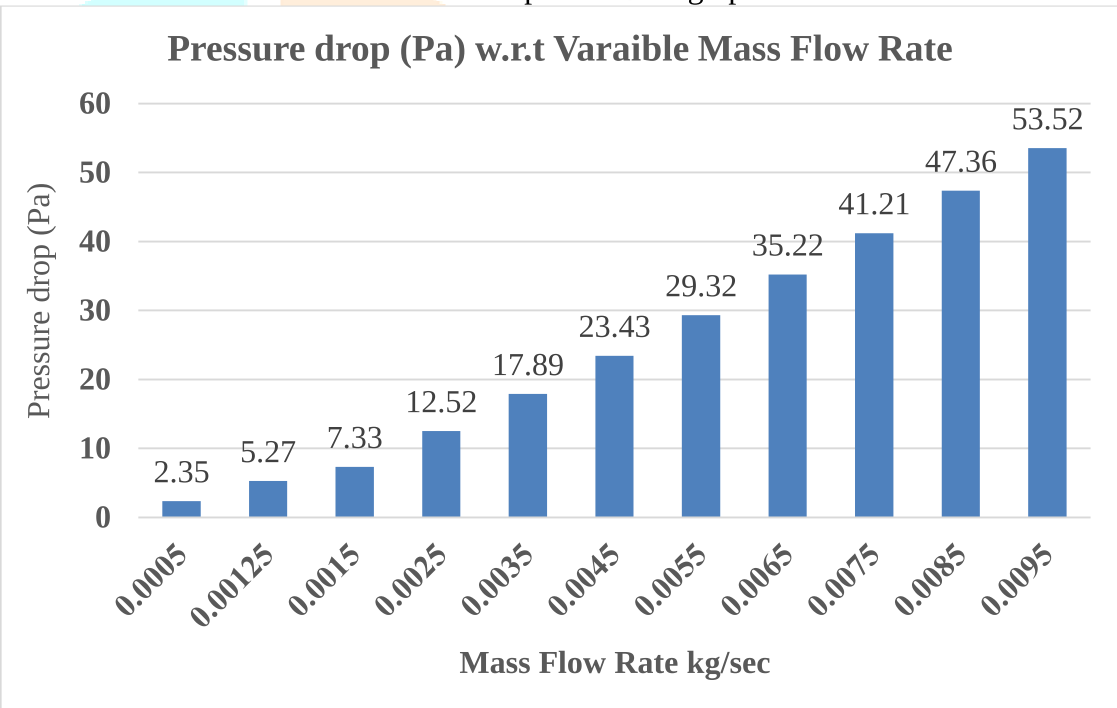
Simulation for effects of the mass flow variation we considered the maximum outlet temperature at 1 pm i.e., 55.75 °C from graph No. 1 & solar heat flux of 989.098 (W/m^2) from ANSYS simulation both values keep constant & vary mass flow rate to evaluate the outlet temperature of the flat plate solar collector. Ansys Fluent Simulation run and results post-process as shown in graph No. 3.

By evaluating the simulation on the mass flow rate variation from 0.005 kg/s to 0.0095 kg/s the results with minimum mass flow rate show better results as compared to rest variation in mass flow rate. In the simulation of a flat plate solar collector in Ansys fluent we observed that the maximum outlet temperature is 82.52 °C at 0.0005 kg/s mass flow rate at an inlet temperature of the water is 25 °C, therefore, rise over in temperature is 57.52 °C, also it is observed that as increases mass flow rate w.r.t that Flat plate solar collector outlet temperature decreases as presented in graph 3



Graph 3: Outlet Temperature w.r.t variation in Mass flow rate

Similarly, the system pressure drop is also minimum at a mass flow rate of 0.0005 kg/s and observed to gradually increase with increases in mass flow rate presented in graph 4



Graph 4: Pressure drop (Pa) w.r.t variation in Mass flow rate

V. CONCLUSION AND FUTURE WORK

5.1 Conclusion

The simulation and analysis of the flat plate solar collector show the following observation insight.

1) **Daytime Thermal Performance:** The outlet water temperature increases with higher solar heat flux and the solar collector achieved its highest efficiency of **97.23% at 1:00 PM**, with a consistent trend of high performance between 10:00 AM and 2:00 PM.
2) **Effect of Mass Flow Rate:** As the mass flow rate increased, outlet temperature dropped due to reduced residence time of the fluid, while pressure drop across the risers increased due to higher frictional losses. A maximum outlet temperature of **82.52°C** was recorded at a flow rate of **0.0005 kg/s** during peak solar hours i.e. 1:00 PM.
3) **CFD Validation:** The simulation model showed good agreement with theoretical predictions and literature benchmarks, validating the use of CFD for the design and optimization of solar thermal systems.

This project successfully demonstrates that ANSYS Fluent is a powerful tool for analyzing the thermal behavior of solar collectors and optimizing parameters such as flow rate and collector design to optimize performance.

5.2 Future Work Scope

However this project focused on a steady-state analysis using a fixed location and basic design, there's still a lot that can be explored going forward. For example, running simulations that take into account time-based changes—like the collector's performance across an entire day for a week or throughout different seasons—would offer a more complete picture.

Testing the design with real-world experiments would be the next step to validate the simulation results.

VI. ACKNOWLEDGMENTS

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