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DESIGN AND CFD AND ANALYSIS OF SOLAR FLAT PLATE COLLECTOR

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Abstract:

A solar thermal energy collector operates through a delicate balance between the solar energy absorbed by the collector and the thermal energy dissipated or lost from it. If no alternative mechanism is provided for the removal of thermal energy, the heat loss from the collector must equal the absorbed solar energy. This paper focuses on thermal and Computational Fluid Dynamics (CFD) analyses using different fluids such as air and water, and various types of solar collectors, including flat plate and parabolic trough. These analyses were conducted using CATIA design software. The thermal analysis was performed on the solar collectors using different materials, namely aluminum and copper, with parameters obtained from CFD analysis. Moreover, CFD analysis was carried out to determine crucial parameters such as heat transfer coefficient, heat transfer rate, mass flow rate, pressure drop, while thermal analysis aimed to ascertain temperature distribution, heat flux, particularly with respect to different materials.

Introduction:

Solar thermal collectors serve as devices for harnessing heat by absorbing sunlight. While the term "solar collector" commonly refers to systems for solar hot water heating, it can encompass large-scale power generating installations like solar parabolic troughs, solar towers, or devices like solar air heaters. Solar thermal collectors can be classified as non-concentrating or concentrating. Non-concentrating collectors have an aperture area roughly equivalent to the absorber area, whereas concentrating collectors have a larger aperture area (with additional mirrors) focusing sunlight onto the absorber, primarily harvesting the direct component of sunlight.

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Non-concentrating collectors find application in residential and commercial buildings for space heating, whereas concentrating collectors, such as those in concentrated solar power plants, generate electricity by heating a heat-transfer fluid to power turbines connected to electrical generators.

Flat Plate Collectors:

Flat-plate collectors, prevalent in Europe, consist of an enclosure containing a dark-colored absorber plate with fluid circulation passageways and a transparent cover allowing solar energy transmission. Typically, the enclosure's sides and back are insulated to minimize heat loss. Heat transfer fluid circulates through the absorber's passageways to extract heat from the solar collector.

Parabolic Trough:

This collector type is commonly used in solar power plants. It utilizes a trough-shaped parabolic reflector to concentrate sunlight onto an insulated tube or heat pipe placed at the focal point, containing coolant that transfers heat from the collectors to the boilers in the power station.

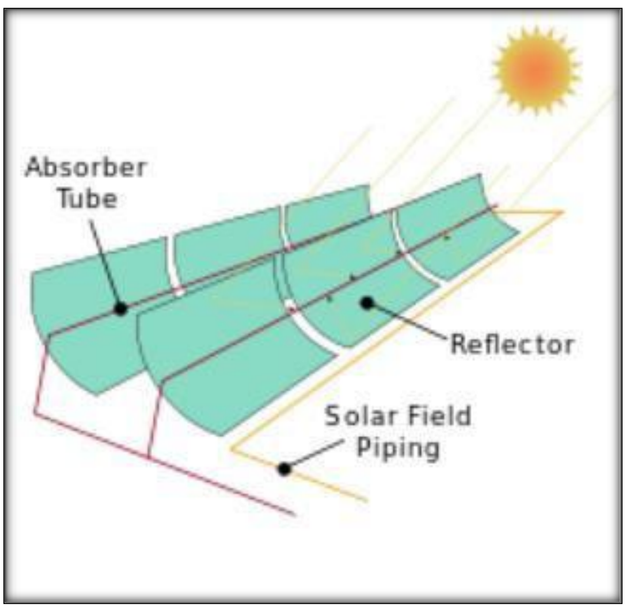

Fig: Parabolic trough

Behar, Khellaf, and Mohammedi (2015) conducted a study on the optical performance of Parabolic Trough Collectors (PTCs) under zero incident angles conditions. They investigated the effects of

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geometrical parameters such as aperture width, absorber diameter, and focal length on the optical performance of PTCs. Utilizing the Monte Carlo Ray Tracing Method (MCRT), they analyzed the SEGS

LS-2 PTC module and found that the maximum local concentration typically increases with an increase in aperture width.

Zou et al. (2017) presented a flexible and novel design for PTCs. They emphasized the design's flexibility, compactness, ease of assembly, and compatibility with various parameters such as different reflective materials, receiver materials, heat transfer fluids (HTFs), focal lengths, widths, and apertures lengths. Detailed design dimensions of different parts of the PTC structure were provided.

Agagna et al. (2018) reported on numerical and experimental investigations of a prototype parabolic trough power plant named 'MicroSolR'. They conducted preliminary tests to evaluate the optical and thermal performance of PTCs and presented three numerical models of different complexities, which were validated and compared. Their tests included three modules, with one facing north–south direction and the others facing east–west direction.

Sa et al. (2013) focused on transient modeling of PTCs using molten salt as an HTF instead of conventional thermal oil. They utilized the 'Modelica' modeling language and validated their transient model against data obtained from the 'SOLTERM' facility in Casaccia, Rome, Italy. Their study achieved a maximum temperature of 520°C and an average minimum temperature of 352°C.

Hussein (2016) provided a comprehensive overview of recent advances in applying nanotechnology to various types of solar collectors. They summarized a significant amount of literature, highlighting the role of nanotechnology in enhancing efficiency. Nanofluids such as SiO2-H2O, Al2O3/synthetic oil, MWCNT/mineral oil, and gas-based nanofluids were discussed, with MWCNT/mineral oil nanofluid showing a 4%–5% enhancement in efficiency for parabolic trough collectors.

Antonopoulos (2016) examined different working fluids for solar collectors using the EES tool for thermal analysis. They found that liquid sodium exhibited the highest performance (47.48%) at an inlet temperature of 527°C, while carbon dioxide, helium, and air showed performances of 42.06%, 42.21%, and 40.12%, respectively. Pressurized water was deemed optimal for moderate temperatures, while helium and carbon dioxide were better suited for higher temperatures.

In the field of modeling and analysis, CATIA (Computer Aided Three-dimensional Interactive Application) stands as a prominent tool. Developed by Dassault Systems, a French engineering giant with a significant presence in aviation, 3D design, digital mock-ups, and product lifecycle management (PLM) software, CATIA is renowned across various industries, including aerospace, automobile, and consumer products.

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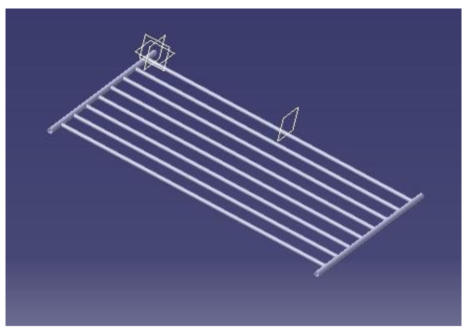
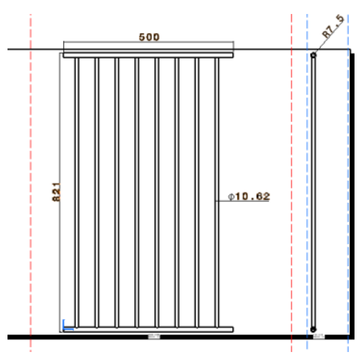
CATIA is a comprehensive 3D software suite that encompasses Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM), and Computer-Aided Engineering (CAE) functionalities. Its multi-platform capabilities make it versatile and widely used for creating, analyzing, and simulating complex three-dimensional models and systems. One of the key features of CATIA is its ability to generate detailed 3D models of components and systems. These models are crucial for visualizing designs, assessing functionality, and identifying potential issues before production. Additionally, CATIA facilitates the creation of precise 2D drawings derived from the 3D models, providing essential documentation for manufacturing and assembly processes. In the context of solar energy applications, CATIA can be utilized to model and analyze solar flat plate collectors. These collectors play a crucial role in harnessing solar energy for various purposes, including heating water and generating electricity. By leveraging CATIA's capabilities, engineers and designers can develop detailed 3D models of flat plate collectors, simulate their performance under different operating conditions, and optimize their design for enhanced efficiency and functionality.

Below are representations of a 3D model and a 2D drawing of a solar flat plate collector created using CATIA:



3D Model of Flat Plate Collector:



2D Drawing of Solar Flat Plate Collector:

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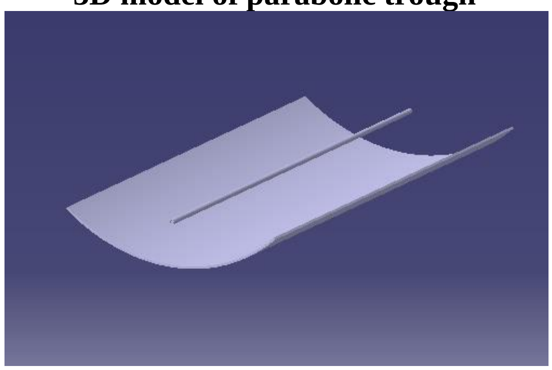
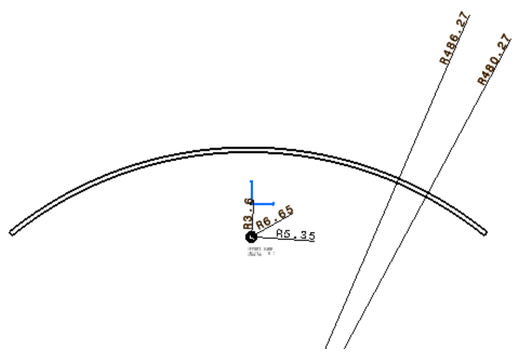
These models and drawings serve as valuable tools for engineers and researchers working in the field of solar energy, allowing them to visualize, analyze, and refine the design of solar collectors to meet specific performance and efficiency requirements.

3D model of parabolic trough



2Dmodel of parabolic trough



The ANSYS software is capable of performing both steady-state and transient thermal analyses on solid objects with specified thermal boundary conditions. Steady-state thermal analyses are used to calculate the effects of constant thermal loads on a system or component. Typically, users conduct a steady-state analysis before performing a transient thermal analysis to establish initial conditions. It can also serve as the final step of a transient thermal analysis once the transient effects have stabilized.

Computational Fluid Dynamics (CFD) is a specialized branch of fluid mechanics that utilizes numerical methods and algorithms to solve and analyze fluid flow problems. CFD simulations involve using computers to perform calculations to simulate the behavior of liquids and gases interacting with surfaces defined by boundary conditions.

Material Properties:

- Specify the material properties relevant to the analysis, such as thermal conductivity, density, and specific heat capacity.

Boundary Conditions:

- Define the boundary conditions for the analysis, including temperature values and mass flow rates.

Example Boundary Conditions:

- At 10 am: Temperature (K) = 307
- At 12 pm: Temperature (K) = 311
- At 2 pm: Temperature (K) = 314
- Mass flow rate (kg/sec) = 0.015

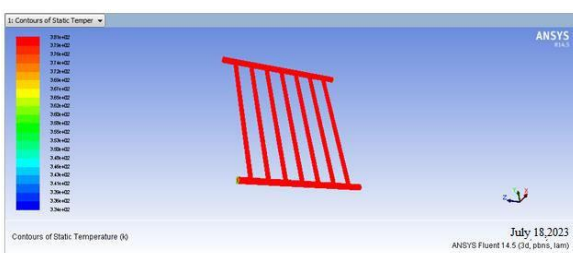
CFD Analysis of Solar Flat Plate Collector:

- Perform CFD analysis of the solar flat plate collector to simulate fluid flow and heat transfer phenomena.
- The analysis should consider the specified boundary conditions, such as temperature variations throughout the day and mass flow rates.

At Time 2 pm:

- Evaluate the temperature distribution within the solar flat plate collector at 2 pm, considering the specified boundary conditions and fluid flow characteristics.

The CFD analysis will provide insights into the thermal performance and efficiency of the solar flat plate collector under different operating conditions, aiding in the optimization of its design for improved energy capture and utilization.



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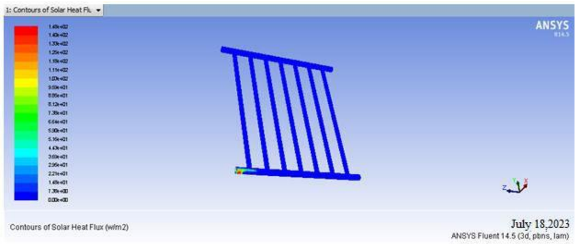


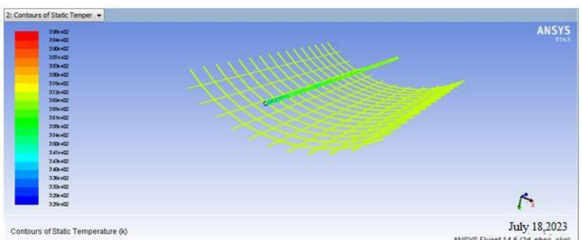
Heat transfer coefficient.

Mass flow rate

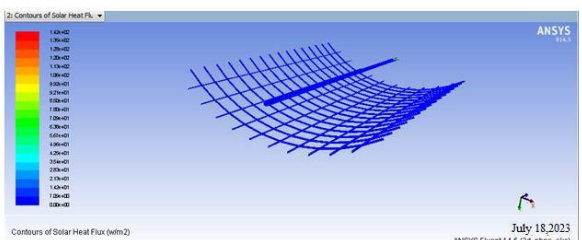
Mass Flow Rate	(kg/s)
inlet	0.015
interior-partbody	0.31217888
outlet	-0.01493196
wall-partbody	0
Net	6.8039633e-05

CFD ANALYSIS OF PARABOLIC TROUGH

At time -2pm Temperature



Solar heat flux



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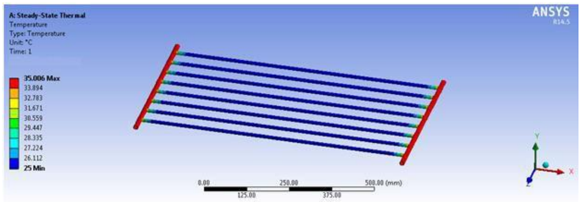
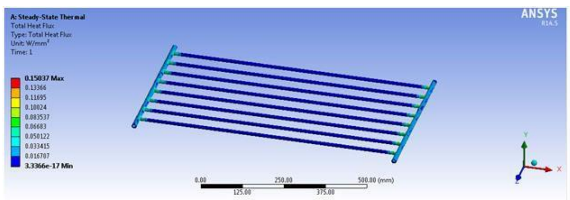
THERMAL ANALYSIS OF SOLAR FLAT PLATE COLLECTOR

Temperature distribution

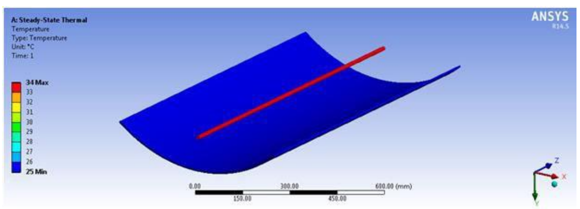


Heat flux



THERMAL ANALYSIS OF SOLAR PARABOLIC TROUGH

Material: Copper Temperature distribution



Heat flux

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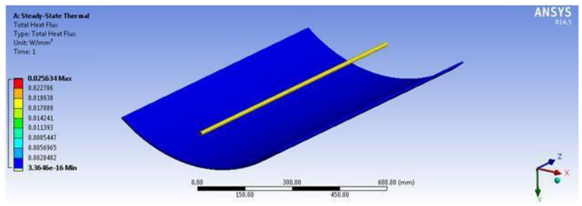
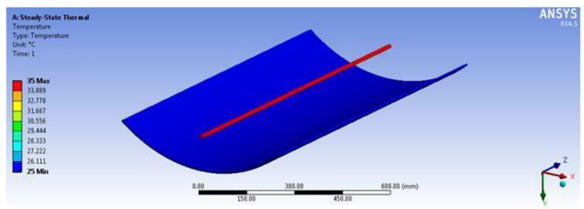
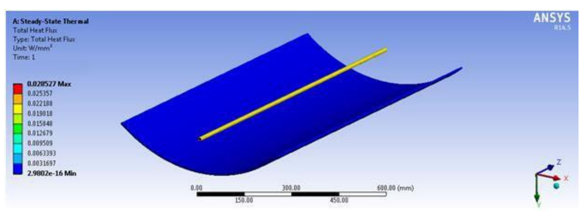


Material –silicon carbide Temperature



Heat flux



Here are the presented results in table format:

Table: CFD Analysis Results of Solar Flat Plate Collector

Fluid	Time	Temperature (K)	Solar Heat Flux (W/m²)
Air	10:00 am	325	117
	12:00 pm	352	142
	2:00 pm	381	148
Water	10:00 am	327	118
	12:00 pm	356	142.1
	2:00 pm	384	151

Table: CFD Analysis Results of Parabolic Trough Collector

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Table: Results of Heat Transfer Coefficient and Mass Flow Rates

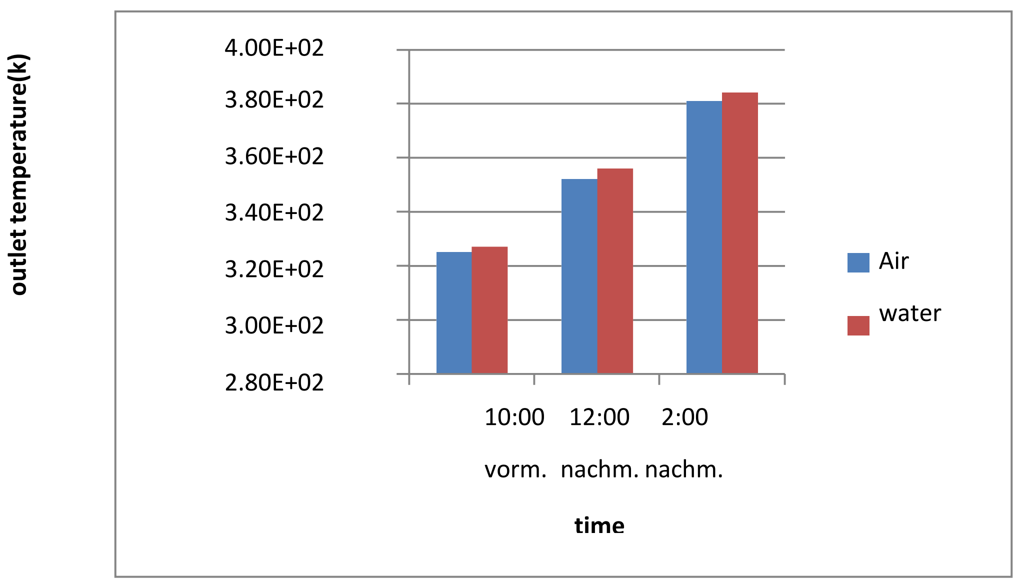
Type of Collector	Fluid	Heat Transfer Coefficient (W/m²-K)	Mass Flow Rate (kg/sec)
SFPC	Air	460	0.0001134367
	Water	11400	0.0000068309
PTC	Air	1180	5.95e-06
	Water	4110	2.57e-05

Table: Results of Heat Flux at Different Materials and Collectors

Type of Collector	Fluid	Heat Flux (W/mm²)
SFPC	Aluminum Alloy	0.15
	Copper	0.24
	Silicon Carbide	0.27
PTC	Aluminum Alloy	0.025
	Copper	0.0256
	Silicon Carbide	0.0287

Graphs

Graph 1: solar flat plate collector results (time Vs outlet temperatures)



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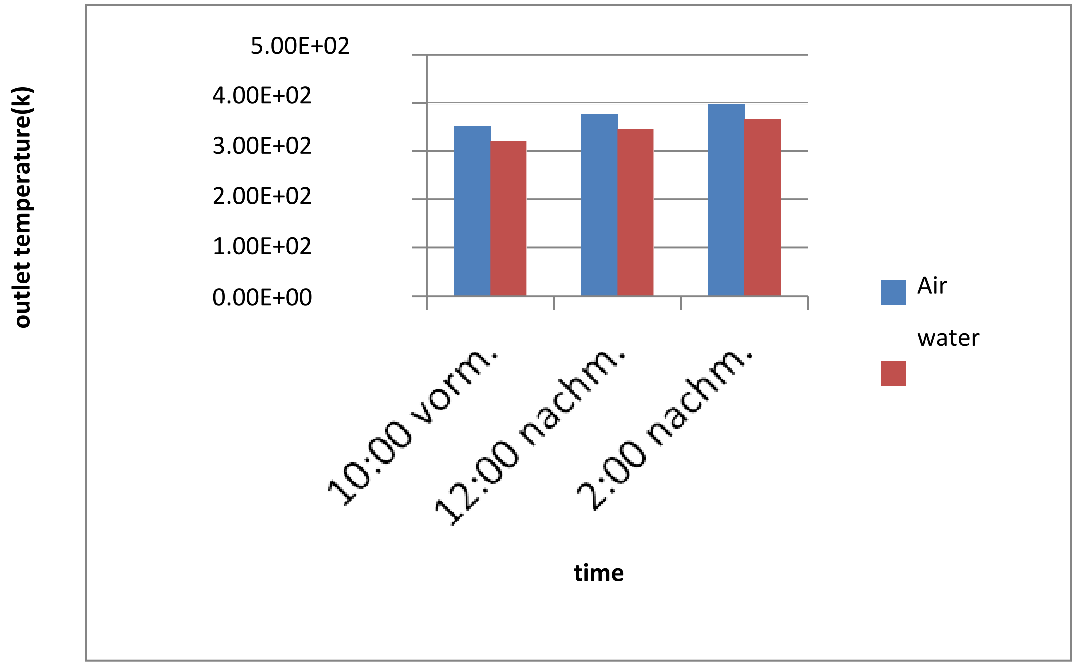
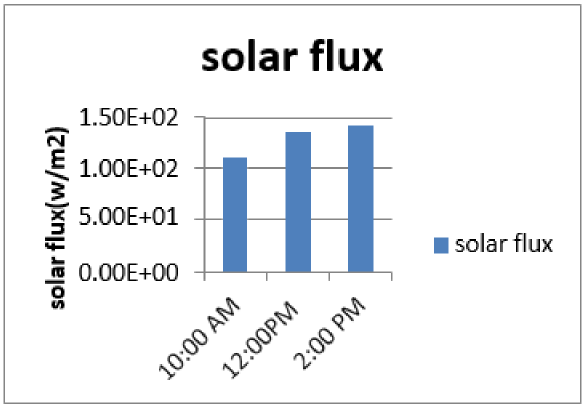
Graph 2: Parabolic trough collector results (time Vsoutlet temperatures)



Graph: 3 time Vs solar flux



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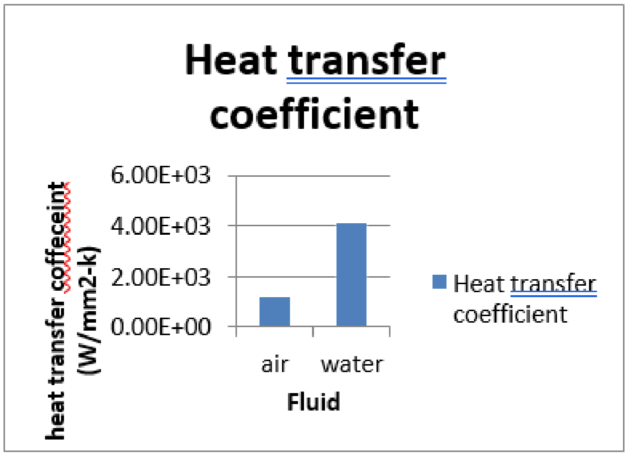

Graph: 4 Fluids Vs heat transfer coefficients

Conclusion:

This paper aimed to model the fluid flow through solar collectors, specifically flat plate and parabolic trough collectors, utilizing CATIA design software. The study focused on conducting thermal and Computational Fluid Dynamics (CFD) analyses using different fluids, namely air and water, over time intervals. Additionally, thermal analyses were performed for the solar collectors using materials such as aluminum and copper. The simulation results for the Flat Plate Collector (FPC) revealed that the output temperature peaked at 381K at 2:00 PM, with an inlet temperature of water at 334K. This represented an increase of 47K over the course of the day. Conversely, the output temperature decreased as time progressed, as illustrated in Graph 1. Furthermore, it was observed that the solar flux decreased with increasing time. Similarly, simulations for the Parabolic Trough Collector (PTC) showed that the output temperature reached its maximum at 2:00 PM, reaching 398K with an inlet temperature of air at 334K, indicating a temperature increase of 64K. As with the FPC, the output temperature decreased with time. This trend is depicted in Graph 2. Analyzing the thermal analysis results, it was noted that the heat flux was higher for copper compared to aluminum alloy, suggesting superior thermal conductivity for copper. This finding underscores the importance of material selection in optimizing the efficiency of solar collectors. In conclusion, the thermal and CFD analyses conducted in this study provide valuable insights into the performance of solar collectors under different conditions. The findings contribute to the ongoing efforts to enhance the efficiency and effectiveness of solar energy utilization, ultimately advancing sustainable energy solutions for the future.

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