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COMPARATIVE ANALYSIS OF THERMAL PERFORMANCE OF A SOLAR AIR HEATER WITH FLUID FLOW ABSORBER PLATE

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Abstract

Solar thermal energy is an abundant and freely available resource, presenting substantial potential for sustainable energy solutions.Solar air heaters (SAHs) are commonly used in applications such as space heating and drying. However, their efficiency is often limited by poor heat transfer between the absorber plate and the air. This study investigates the thermal performance of a solar air heater equipped with a zigzag-shaped absorber plate. The performance is analyzed by comparing two fluid flow channels: one above and one below the absorber plate. The results indicate that fluid flowing above the zigzag absorber plate achieved a higher temperature difference (30–55°C), outperforming fluid flow below the plate by approximately 5–15%. The findings highlight the benefits of modifying absorber plate geometry to improve heat transfer and enhance overall system efficiency, offering a promising solution for optimizing solar air heater performance.

Key Words- Solar Air Heater (SAH),Solar Thermal Energy, Thermal Performance, Zigzag Absorber Plate, Fluid Channel

I. INTRODUCTION

The use of renewable energy sources has increase significant attention in recent years due to their potential for sustainable development and reduction of environmental pollutants[1]. Among these, solar energy stands out as a cost-effective and clean alternative. Solar air heaters (SAHs), which are designed to convert solar energy into thermal energy for applications such as space heating and drying, are a popular choice. The efficiency of SAHs, however, is often hindered by inadequate heat transfer between the absorber plate and the air[2]. To defeat this limitation, the current study explores the impact of modifying the absorber plate geometry. By introducing a zigzag design, the system aims to improve fluid turbulence, enhancing heat transfer and ultimately boosting thermal performance. This study compares the different configurations of SAHs, considering the fluid flow channels above and below the absorber plate and assessing their performance through temperature variations and efficiency [3].

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II. Literature Review

Table 1: Related Literature Review

Authors and Year	Method	Key Findings	Suggestions
Dilbag Singh Mondloe, Harish Kumar Ghritlahre & Gajendra Kumar Agrawal (2025)[4]	Experimental study with transverse wire rib roughness on absorber plate; analyzed energetic and exergetic performance.	Found maximum energetic efficiency of ~83.5% and exergetic efficiency of ~3.67% for a configuration with transverse wire ribs.	Suggests further optimizing rib geometries to enhance efficiency, and considering system integration for real-world applications.
G. R. K. Sastry, L. B. Bharath Raju, S. K. Gugulothu & Ümit Ağbulut (2025)[5]	Numerical simulation optimizing triangular roughness for heat transfer in SAHs.	Showed up to ~141% heat transfer improvement using equilateral triangular roughness on absorber plates.	Recommends applying the triangular roughness design in large-scale applications and comparing with other roughness configurations.
N. Van Hap, Phan Thanh Nhan & Nguyen Minh Phu (2025)[6]	Combination of numerical analysis and experimental testing for SAH with fins and latent heat storage.	Absorber plate with fins plus latent heat storage increased daily efficiency by ~13.7% over smooth duct.	Suggests further investigation on the integration of phase change materials for better thermal storage and efficiency.
E. Vengadesanet al. (2024)[7]	Experimental setup with hybrid rectangular tubular and V-corrugated finned absorber plate for heat transfer analysis.	Hybrid V-corrugated finned absorber plates improved heat transfer and overall efficiency in comparison to flat plate designs.	Suggests exploring different fin shapes and geometries for optimizing heat transfer in real-world applications.
P. P. Borah, K. K. Pathak, A. Gupta, S. Roy & B. Das (2023)[8]	Experimental testing on solar air heater with modified absorber plate using square obstacles and pin fins.	Modified absorber plate with square obstacles and pin fins improved outlet temperature and efficiency compared to flat plate designs.	Suggests testing with different types of obstacles and configurations to optimize performance in varying conditions.

III. Method and Analysis

The experimental setup involves a solar air heater constructed with a wooden frame, a zigzag-shaped floor glass absorber plate painted black for high absorptivity, and acrylic glazing for high transmissivity. The system is insulated with glass wool to minimize heat loss.

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Two fluid flow channels are considered: one above and one below the absorber plate. The absorber plate can be either flat or zigzag, with fluid passing through the channels in a unidirectional flow. A blower maintains an air flow rate of 5 m/s throughout the experiments.

Thermocouples, connected to a data logger, record temperature measurements at various points along the air passage. Solar intensity is measured using a Solcast meter. Experiments were conducted from 11 AM to 12:30 AM in Oct 2025, with solar radiation ranging from 500 to 750 W/m². Data on temperature differences, air flow rates, and system efficiencies were recorded and analyzed for various configurations.

Figure 1:SAH showing Fluid Flow Channels

The instruments utilized in this study include an air blower.An anemometer was used to measure the flow rate at the outlet section of the air passage. Temperature measurements were recorded using thermocouples, which were connected to a data logger, as shown in above Figure 1. The solar intensity was recorded with the help of Solcast (2022)[9]. The instruments used in this study are detailed below. The Data Logger (Sunsui, DL-35W) was use for temperature data recording. An Air Blower with a power rating of 650 W and a voltage range of 220–230 V, operating at a no-load speed of 13,000 rpm. For measuring air velocity, an Anemometer (METRAVI AVM01 Mini) was utilized. The Thermocouple, a J-type sensor, was used for temperature measurements, capable of operating in the range of -40 to 750 °C[10]

IV. EXPERIMENTATION RESULTS

All experiments were carried out at a constant air flow rate of 5 m/s. Solar radiation levels varied between 500–750 w/m²

4.1 Temperature Variation

A comparative analysis was performed for different fluid channels: above and below the absorber plate, with configurations using zigzag-shaped absorber plates to assess the temperature variations and overall efficiency.

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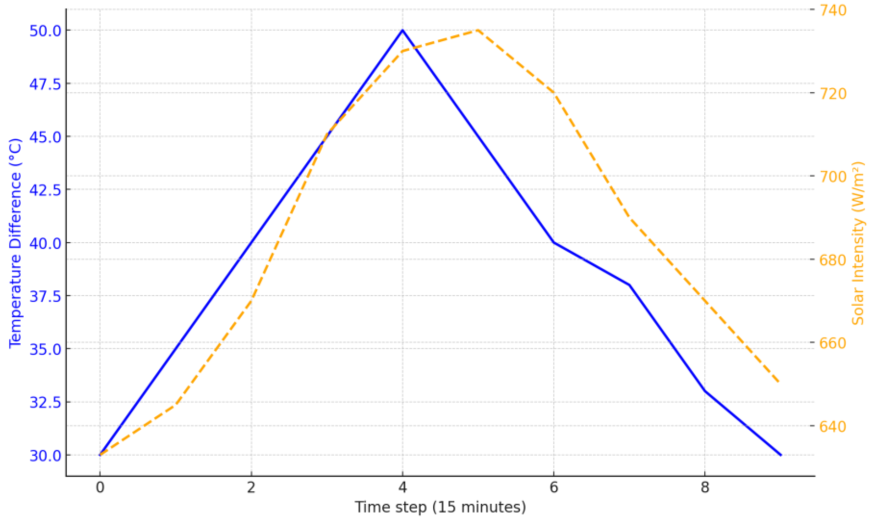

Figure 2: shows the thermal performance for fluid flowing above the zigzag absorber plate

From above Figure 2 shows the thermal performance for fluid flowing above the zigzag absorber plate. The temperature difference achieved in this case ranged from 30°C to 50°C, with an average of 40°C. The maximum outlet temperature achieved in this case was 75°C, while solar radiations ranged from 633–735 W/m², averaging 691 W/m².

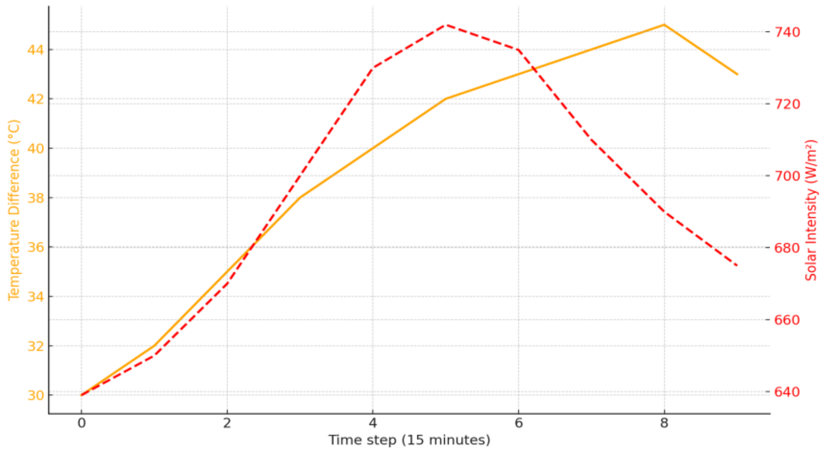

Figure 3: show the thermal performance for fluid flowing below the zigzag absorber plate

From above Figure 3 show the thermal performance for fluid flowing below the zigzag absorber plate . In this case, the temperature difference ranged from 30°C to 45°C, with an average of 37°C. The maximum outlet temperature achieved was 70°C, and solar radiations were in the range of 639–742 W/m², averaging 706 W/m².

The fluid flow above the zigzag absorber plate achieved a temperature difference of up to 55°C, while below the plate, the maximum temperature difference was 50°C. The absorber plate enhances heat transfer by creating turbulence in the fluid.

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4.2 Efficiency Comparison

Table 2: Comparison Result of Efficiency

The highest efficiency (58%) was observed in the fluid flow above the zigzag absorber plate, which directly correlates with the larger temperature differences and more effective heat transfer. The rectangular shaped significantly improves the flow interaction with the absorber, optimizing heat absorption.The fluid flow below the zigzag absorber plate showed an efficiency of 50%, which is lower than the above configuration but still notable due to the enhanced fluid-absorber interaction provided by the design.

4.3 Max Outlet Temperature

The maximum outlet temperature achieved was 80°C in the fluid flow above the zigzag absorber plate, indicating that the system is highly effective at converting solar energy into thermal energy. The fluid flow below the zigzag absorber plate achieved a lower maximum outlet temperature of 72°C, suggesting that while the rectangular shaped improves performance, the fluid flow above the absorber plate remains the optimal configuration.

Configuration	**Min Temperature Difference (°C)**	**Max Temperature Difference (°C)**	**Average Temperature Difference (°C)**	**Max Outlet Temperature (°C)**	**Solar Radiations (W/m²)**	**Efficiency (%)**
Fluid Flow Above Zigzag	35	55	45	80	640–745	58%
Fluid Flow Below Zigzag	32	50	42.5	72	622–735	50%

4.4 Solar Radiation

Solar radiation ranged between 633 W/m² and 745 W/m², providing a consistent energy input. The differences in performance are thus attributed primarily to the absorber plate geometry and fluid flow configuration.

V. CONCLUSION

The results highlight the effectiveness of using a zigzag-shaped absorber plate in improving the thermal performance of solar air heaters. The fluid flow above the zigzag absorber plate demonstrated the highest temperature difference and efficiency, making it the best-performing configuration. The fluid flow below the zigzag absorber plate also showed improved performance compared to configurations without a zigzag shape, but the fluid flow above remains optimal for maximizing heat transfer and system efficiency. Future research can explore further optimization of absorber plate geometry, such as incorporating other shapes or hybrid designs, to enhance solar air heater performance even further.

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