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Thermal Performance Evaluation of Solar Air Heaters with Various Absorber Geometries

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Abstract
In this study, computational fluid dynamics (CFD) simulations were conducted to evaluate the thermal and hydraulic performance of solar air heaters (SAHs) with three different absorber geometries: flat plate, triangular, and trapezoidal configurations. The results demonstrate that absorber geometry plays a critical role in determining heat transfer rates, flow behavior, pressure losses, and thermal efficiency. The trapezoidal design yielded the highest thermal efficiency, while the flat plate exhibited the lowest friction factor and pressure drop. The CFD predictions were validated with experimental data, showing excellent agreement within a margin of 5%. These findings offer valuable insights for optimizing SAH designs to achieve higher energy conversion efficiencies while maintaining acceptable pressure drops.

Keywords: *Solar air heater; CFD simulation; Absorber geometry; Heat transfer; Pressure drop; Efficiency; Turbulence.*

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I. Introduction

Solar air heaters (SAHs) represent an essential technology within the domain of solar thermal energy, offering a sustainable solution for space heating, drying, and low-temperature industrial processes. The performance of SAHs heavily depends on design parameters such as absorber geometry, flow configurations, and operating conditions. Enhancing heat transfer while minimizing pressure losses remains a key design challenge. Computational fluid dynamics (CFD) has emerged as a powerful tool for analyzing complex flow and heat transfer phenomena within SAHs, enabling detailed evaluation of various design configurations.

II. Methodology

The present study investigates three absorber geometries: - Flat plate absorber. - Triangular absorber. - Trapezoidal absorber.

The simulations were performed over a range of Reynolds numbers with varying mass flow rates. Key parameters studied include: - Mass flow rates: 0.0049 kg/s to 0.0089 kg/s. - Inlet temperatures: July (41.8°C), August (42.3°C), November (24.5°C). - Ambient temperatures: seasonal variations were considered. - CFD modeling was validated against experimental data, with maximum deviation not exceeding 5% for both Nusselt number and friction factor.

III. Results and Discussion

3.1 Effect of Reynolds Number and Turbulence Intensity - Increasing Reynolds number leads to higher air velocities and turbulence levels, enhancing convective heat transfer. - The trapezoidal absorber showed the highest turbulence intensity, followed by triangular and flat configurations. - Grooved surfaces induced strong localized vortices that improved mixing and thermal diffusion.

3.2 Temperature Distribution - Eddy formation near the absorber plate enhanced thermal diffusion due to high shear stress within the boundary layer. - The trapezoidal geometry demonstrated the most uniform and extensive temperature distribution.

3.3 Outlet Temperatures

The following maximum outlet temperatures were recorded at 0.0049 kg/s:

Configuration	July (°C)	August (°C)	November (°C)
Trapezoidal	66.0	69.8	39.6
Triangular	Lower than trapezoidal		
Flat Plate	Lower than triangular		

Figure 1: Variation of Outlet Temperature for Different Geometries and Months.

3.4 Pressure Drop and Friction Factor - Trapezoidal absorber experienced the highest pressure drop due to complex vortex structures and flow resistance. - Flat plate configuration exhibited the lowest pressure drop. - Friction factor decreased with increasing Reynolds number, following their inverse relationship.
Figure 2: Variation of Friction Factor with Reynolds Number.

3.5 Thermal Efficiency
The thermal efficiency was calculated for each configuration as:

Configuration	July (%)	August (%)	November (%)
Trapezoidal	73.2	77.0	30.8
Triangular	62.4	60.3	24.7
Flat Plate	48.1	53.0	19.4

Figure 3: Thermal Efficiency vs. Mass Flow Rate for Different Geometries.
3.6 Exergy Analysis - Exergy losses were inversely proportional to thermal efficiency. - The trapezoidal configuration showed the lowest dimensionless exergy loss, achieving 1.6–1.89 times lower losses compared to the flat plate in November.
3.7 Validation - Experimental data for Nusselt number and friction factor showed excellent agreement with CFD predictions, with deviations within 5%.

IV. Conclusion

The CFD analysis demonstrated that absorber geometry significantly influences both thermal and hydraulic performance of SAHs. The trapezoidal configuration offers superior thermal efficiency but incurs higher pressure losses. The validated CFD model provides a reliable platform for future optimization studies, balancing heat transfer enhancement with acceptable flow resistance.

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