Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 11, No.1, November : 2025

A REVIEW ON PERFORMANCE OF A SOLAR AIR HEATER WITH STAGGERED C-SHAPE FINNED ABSORBER PLATE USING ANSYS

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ABSTRACT

In this review explores the performance of solar air heaters equipped with staggered C-shaped finned absorber plates, analyzed through ANSYS simulation. Solar air heaters are critical components in harnessing renewable energy, and the design of the absorber plate significantly influences their thermal efficiency. This study synthesizes existing research on fin configurations, with a focus on staggered C- shaped fins, which are known for enhancing heat transfer and improving fluid flow dynamics. The paper reviews simulation methodologies, including boundary conditions, material properties, and meshing strategies used in ANSYS to model the thermal and fluid dynamics behavior of the solar air heater. Key performance metrics such as thermal efficiency, heat transfer rates, and pressure drop are analyzed, comparing the staggered C-shaped fin configuration to traditional designs. The review also highlights the impact of fin geometry, spacing, and material on performance, offering insights into optimizing solar air heater designs for maximum efficiency. Future research directions are proposed to further enhance the understanding and application of finned absorber plates in solar air heaters. This comprehensive review aims to provide a foundation for engineers and researchers in the field of renewable energy systems, contributing to the advancement of sustainable thermal energy solutions.

Keywords:
Staggered C-shaped Fin, Absorber plates, ANSYS, Heat transfer, Fluid flow dynamics, Optimization.

I. Introduction

The growing demand for sustainable and renewable energy sources has led to increased interest in solar air heaters (SAHs) due to their potential to harness solar energy for heating applications. Solar air heaters are widely used in various applications, including space heating, drying processes, and industrial heating, owing to their simplicity, cost-effectiveness, and environmental benefits. However, the thermal efficiency of SAHs is often limited by poor heat transfer and high heat losses, necessitating innovative design enhancements to improve their performance.

One of the most effective ways to enhance the thermal performance of SAHs is by optimizing the design of the absorber plate, which plays a crucial role in capturing and transferring solar energy to the air. In recent years, finned absorber plates have gained significant attention for their ability to increase the surface area for heat transfer, thereby improving the overall efficiency of SAHs. Among various fin designs, the staggered C-shaped fin configuration has emerged as a promising solution due to its ability to disrupt the thermal boundary layer and enhance fluid flow dynamics.

This review paper focuses on the performance analysis of solar air heaters equipped with staggered C-shaped finned absorber plates, using ANSYS simulation as the primary tool for thermal and fluid flow analysis. ANSYS provides a robust platform for modeling and simulating complex thermal systems, allowing for detailed investigation of the effects of fin geometry, material properties, and operating conditions on the performance of SAHs. The objective of this paper is to synthesize existing research on staggered C-shaped finned absorber plates, highlight key findings from simulation studies, and identify design parameters that significantly influence the thermal efficiency of SAHs. By consolidating the current state of knowledge, this review aims to provide a comprehensive understanding of the factors affecting the performance of solar air heaters and to propose directions for future research and development in this field.

II. Literature Review

Alrashidi et al. (2024) They have experimented on a flat absorber plate of a solar air heater (SAH) with innovative straight interrupted fins arranged in a V- shaped pattern is analyzed using energy and exergy approaches, The aluminum finned absorption plate was designed, manufactured, and tested during the summer in Saudi Arabia, examining the effect of changing the SAH tilt angle of θ = 0°, θ = 10°, θ = 20°, and θ = 30°. The study found that tilting the SAH at θ = 10°, θ = 20°, and θ = 30° increases the hot air exit temperature by 7.5 %, 15.7 %, and 12.5 %, respectively, compared to the horizontal position at θ = 0°.

Marzouk et al. (2024) In this paper the effects of various absorber configurations of a tubular solar air heater. The models such as direct flow with a standard absorber (DF- SA), swirl flow with a standard absorber (SF- SA), swirl flow with perforated longitudinal fins (SF-PLF), swirl flow with radial fins (SF-RF), swirl flow with perforated radial fins (SF-PRF) are studied. Investigation parameters including Nusselt number, exergy efficiency, PEC, and friction factor are examined with Reynolds numbers ranging from 8488 to 25,464.

Kumbhare et al. (2024) Examined a review analysis of absorber models to improve the thermal performance in solar air heaters. Rough Surfaces and different obstacles play a key role in the improvement of thermal parameters. By review, it is identified that the impact of obstacles over the surface of the absorber plate is more than the flat surface of the absorber plate. Turbulence generated by roughened Surface and obstacles over the surface area and boundary of the channel breaks the laminar flow improving the internal temperature of the flowing air of solar air heater.

Aldawi et al. (2024) In this paper the heat transfer and performance characteristics of a solar air heater (SAH) equipped with spring-wire turbulators using a 3D verified CFD simulation process. Five different shapes of spring-wire (as shown in the graphical abstract) are investigated and compared to a flat SAH (without turbulator). The effects of helical diameter, pitch, and wire diameter on the performance of the system are comprehensively analyzed for all five mentioned geometries.

Shankar et al. (2024) Conducted experimental investigation on ribs or roughness on the absorber plate creating turbulence in the airflow, resulting in significant improvements. The research investigates various rib configurations, the influence of rib parameters, performance methods, and arrangements to evaluate their HT and friction characteristics. Among these rib configurations, a comparative analysis is done on various factors such as the Nusselt number ratio, thermal enhancement factor, friction factor ratio, and thermal efficiency to optimize distinct roughness parameters and rib arrangement patterns.

Ghanem et al. (2024) They investigated numerical and experimental investigations to examine the effectiveness of a honeycomb pattern as a form of the geometry of artificial roughness in solar air heaters. Utilizing Computational Fluid Dynamics (CFD) through three-dimensional simulations, the study explores how Thermo- Hydraulic Performance Parameter (THPP) is affected by variations in honeycomb geometry.

Nojavan et al. (2024) In this paper C-shaped and V-shaped patterned pinfins over the heated surface in a microchannel geometry for the laminar flow regime. The working fluid in the simulations is water mixed with graphene nanoplatelet nanoparticles where three different concentrations of particles are considered. The effect of the inertia of the fluid is considered at three distinct values of specified inlet velocities. Three cross- sections including circular, square, and triangular cross-sections have been utilized to show individual pinfin effects on the flow field as well as the temperature distribution.

Machi et al. (2024) Presented the effect of entrance flue conditions on the performance of solar air collectors (SAC) with a single pass channel, focusing on two configurations: a front entrance solar air collector (FESAC) and a side entrance solar air collector (SESAC). The FESAC, introduced to optimise air distribution across the absorber plate, demonstrated higher performance, with higher outlet and lower absorber plate temperatures than the SESAC across various mass flow rates.

Kumar et al. (2024) Utilized the performance of a solar-thermal heat exchanger consisting of a flat-plate collector by producing roughness on the heat- absorbing surface. A repeated pattern of staggered arc roughness is introduced along the streamlines and the roughness is characterized using height ratio,

relative pitch, number of gaps, etc. The influence of the roughness characteristics is studied on the thermal performance by computational fluid dynamics. The developed model is validated with well-established relations before predicting the results for the proposed design. Hegde et al. (2023) They represented the usage of various fin forms, systems, and operational characteristics of SAH for better comprehension of heat transfer phenomena. Some of the heat transfer correlations that are developed by various researchers related to SAH are presented in detail for easy computation of heat flow characteristics. Solar energy is a time- dependent and intermittent energy source. Hence, solar energy-based heating systems can benefit more from PCM-based thermal energy storage (TES) systems.
El-Bialy et al. (2023) Presented A 2-D computational analysis of heat transfer augmentation and fluid flow characteristics with B-shaped and D-shaped artificial roughness under the Reynolds number (Re) range from 4000-20000. Comparing the predictions of different turbulence models with experimental results available in the literature, the renormalization group k-Ɛ (RNG) turbulence model is selected for the present study.
Burye et al. (2023) In the recent investigation advances in practical and theoretical studies on solar air heaters. Solar air heaters have proven in previous years to be a good option for obtaining hot air that can be used in daily life purposes and several industries. The low thermal efficiency is considered the main drawback of the solar air hear. Numerous studies have been conducted to improve the thermal efficiency of the solar air heater. Where two techniques are commonly investigated: first, increasing the heat transfer between the flowing air and the absorber plate, and using thermal storage material.
Shaik et al. (2023) In this paper the effects on the flow and heat transfer characteristics of the SAH channel, which is designed for residential space heating. The finite volume- based solver Ansys Fluent is used for finding the field variables. The confinement height is varied from 25 to 150 mm, and the transition length is varied from 250 to 1000 mm. The suction and blowing effect is investigated by changing the flow direction across the channel.
Hassan et al. (2023) They investigated solar air heaters to enhance their performance by introducing artificial roughness on absorber plates using alternative dimple intrusions and protrusions. To improve the performance of the air heater, one of the effective techniques is roughness. Roughness is introduced on the heat-absorbing side in the form of ribs. A CFD (computational fluid dynamics) model has been used to simulate the heat augmentation and flow characteristics caused by dimple ribbed through the triangular passaged SAH.
Yadav et al. (2023) Presented that Solar air heating (SAH) is a low-cost method for air heating using solar energy. An energy and exergy performance is performed experimentally on new designed tubular SAH having tubular absorber of adjacent tubes forming flat pack. Each tube of the absorber contains three adjacent internal tubes forming nabla shape (∇).
Hasan et al. (2023) In this paper the influence of two geometrical parameters, namely jet pitch ratio (P/Dh) and jet angle ratio (α/90), on the heat transfer, frictional losses, and overall performance of the solar air heater with jet impingement (SAHJI) under various flow conditions, represented by Reynolds numbers (Re) ranging from 3500 to 17500. The simulations are conducted using the RNG k-ε model with second-order upwind discretization.
An, Byeong-Hwa et al. (2023) In this investigation a summarized review of the recent studies that deal with the application of computational fluid dynamics (CFD) to enhance the thermohydraulic performance of SAHs by utilizing different designs of artificial roughness ribs. This includes the selection of a high-performance turbulence model based on Reynolds Averaged Navier Stokes (RANS) approach.
Dwivedi et al. (2022) In this investigation the heat transfer augmentation and friction factor of a novel type of solar air heater (SAH), which incorporates longitudinal fins and rectangular turbulators, were investigated numerically with different arrangements of the turbulators. The effects of arrangements of rectangular turbulators placed in a finned air channel on its heat transfer augmentation and friction factor are discussed for Reynolds numbers ranging from 3000 to 15,000 using commercial ANSYS 17.2 software. Four different arrangements are investigated, including Array A, which places

turbulators on both the fin's side and base surfaces at the same position; Array B, where turbulators are sequentially placed on the fin's side and base surfaces; Array C, where turbulators are only placed on the side surface; and Array D, where turbulators are placed only on the base surface.

Yadav et al. (2022) In this paper a comprehensive review of the literature on computational fluid dynamics (CFD) in SAH design. To figure out how heat, mass, and momentum will move in different types of heat transfer and fluid flow processes, and to make sure that the design is the best; CFD approach can be used. CFD is a type of simulation that makes use of advanced computer technology and applied mathematics to predict fluid flow conditions. Many CFD research work have been conducted in which various ribs shapes have been employed to increase heat transfer coefficient (HTC) while at the same time reducing the impact of friction.

Kumar et al. (2022) In this paper a new curved design of a counter flow double- pass solar air heater with arched baffles placed in the second duct. Due to high inertia of the flow and curved nature of design, fluid in second channel tend to move away from the absorber plate and thus, reduces the thermal efficiency significantly. In order to overcome this deficiency, new design parameters are introduced in the second duct in terms of arched baffles and their design is optimized for various geometric parameters such as angle of attack, variable pitch ratio etc. for best thermo-hydraulic performance.

Kumar et al. (2022) They investigated the impact of single discrete arc-shaped ribs (SDASR)-type artificial roughness on the performance of a jet impingement solar thermal collector (JISTC). The impact of parametric variations of SDASR on the Nusselt number ($Nusdr$)(Nusdr), friction factor ($fsdr$)(fsdr), and thermohydraulic performance (ηsdr) (ηsdr) is examined.

Mor et al. (2022) In this experiment a parametric study using ANSYS (ver.19.0) for a solar air-heater (SAH) roughened using multi-V ribs having trapezoidal slots. The computational results are drawn for Reynolds number (3000 to 15000), e/Dh (0.0258 to 0.056) and angle of attack (30˚ to 75˚). The results from FLUENT of the present roughened geometry are compared with that of smooth duct. For the proposed roughness geometry, the optimum value of relative rib roughness (e/Dh) and angle of attack ( ) obtained is 0.056 and 60˚ respectively at Reynolds number of 15,000. The maximum Nusselt number and friction factor for roughened geometry is found to be 142.6 and 0.033 respectively.

III. Objectives of The Study

1. To analyze the thermal performance of solar air heaters (SAHs) equipped with staggered C-shaped finned absorber plates using ANSYS simulation tools.
2. To evaluate the impact of fin geometry, spacing, and material properties on the heat transfer rate, thermal efficiency, and pressure drop in SAHs.
3. To compare the performance of staggered C-shaped fin configurations with traditional flat and finned absorber designs.
4. To synthesize and review existing literature on fin-enhanced absorber plate designs to identify design trends and performance benchmarks.
5. To highlight effective simulation methodologies including boundary conditions, meshing strategies, and turbulence models used in ANSYS for analyzing solar thermal systems.
6. To propose optimization strategies for fin configurations that can enhance the efficiency and fluid flow characteristics of solar air heaters.
7. To identify gaps in current research and recommend directions for future investigations to advance the design of high-performance SAHs.

IV. Research Gap

Despite significant advancements in the design and analysis of solar air heaters (SAHs), several research gaps remain in understanding the performance of staggered C-shaped finned absorber plates. While numerous studies have explored various fin configurations, limited research focuses on the comprehensive analysis of staggered C- shaped fins using advanced simulation tools like ANSYS. There is a need for more detailed investigations into the impact of fin geometry variations, material selection, and operating conditions on thermal efficiency and pressure drop. Additionally, most existing studies primarily focus on steady- state conditions, leaving a gap in the analysis of transient thermal behavior and long-term performance under varying environmental conditions. Furthermore, experimental validation of simulation results is often lacking, which is crucial for verifying the accuracy and reliability of numerical models. Addressing these gaps can provide deeper insights into the design optimization of SAHs and contribute to the development of more efficient and sustainable solar thermal systems.

References

[1] Alrashidi, Abdullah, Ahmed A. Altohamy, M. A. Abdelrahman, and Ismail MM Elsemary. "Energy and exergy experimental analysis for innovative finned plate solar air heater." Case Studies in Thermal Engineering 59 (2024): 104570.

[2] Marzouk, S. A., Maisa A. Sharaf, Ahmad Aljabr, and Emad MS El-Said. "Assessing the effects of different finned absorbers with swirl flow on the performance of solar air heater." Energy Sources, Part A: Recovery, Utilization, and Environmental Effects 46, no. 1 (2024): 3245-3262.

[3] Kumbhare, Nitin, and Pranay Bagde. "An analysis of absorber models for enhancement of thermal performance of solar air heater." In AIP Conference Proceedings, vol. 3108, no. 1. AIP Publishing, 2024.

[4] Aldawi, Fayez. "Effect of spring-wire turbulators with different shapes on heat transfer improvement of solar air heaters; A numerical simulation." Cleaner Engineering and Technology 21 (2024): 100777.

[5] Shankar, Ravi, Rajeev Kumar, Arun Kumar Pandey, and Deep Singh Thakur. "A comprehensive review of rectangular duct solar air heaters featuring artificial roughness." Clean Energy 8, no. 5 (2024): 186-217.

[6] Ghanem, Somar Rajeh, and Amit C. Bhosale. "Honeycomb-Shaped Artificial Roughness in Solar Air Heaters: CFD- Experimental Insights into Thermo- Hydraulic Performance." Renewable Energy (2024): 120829.

[7] Nojavan, Farnaz, and Ersin Sayar. "Numerical study of implemented eco- friendly nanofluid in the pinfin-equipped heatsinks with novel C-shaped and V- shaped patterns." Thermal Science and Engineering Progress (2024): 103134.

[8] Machi, Maytham H., István Farkas, and János Buzas. "Enhancing solar air collector performance through optimized entrance flue design: A comparative study." International Journal of Thermofluids 21 (2024): 100561.

[9] Kumar, Rajneesh. "Improved solar- thermal heat exchanger for space heating with surface roughness: A numerical parametric investigation and its optimization." Renewable Energy 226 (2024): 120349.

[10] Hegde, Avinash K., Raghuvir Pai, and K. Vasudeva Karanth. "Performance augmentation of solar air heaters: a comprehensive analysis." Solar Energy 253 (2023): 527-553.

[11] Rautela, Mayank, Sohan Lal Sharma, Vijay Singh Bisht, Ajoy Debbarma, and Rahul Bahuguna. "Numerical analysis of solar air heater roughened with B-Shape and D-Shape roughness geometry." Journal of Heat and Mass Transfer Research 10, no. 1 (2023): 101-120.

[12] El-Bialy, E., and S. M. Shalaby. "Recent developments and cost analysis of different configurations of the solar air heaters." Solar Energy (2023): 112091.

[13] Burye, Nishidh Naik, Ravishankar Sathyamurthy, and Deepakkumar Rajagopal. "Computational fluid dynamics–based parametric study on the performance of solar air heater channel." Environmental Science and Pollution Research 30, no. 11 (2023): 30321-30342.

[14] Shaik, Rafiuzzama, Eshwaraiah Punna, and S. K. Gugulothu. "Optimisation of thermohydraulic performance of triangular duct solar air heater with alternative dimple shaped

protrusion and intrusion on the absorber plate." Thermal Science and Engineering Progress 42 (2023): 101957.
[15] Hassan, Hamdy, Osman Omran Osman, and Mahmoud N. Abdelmoez. "Energy and exergy evaluation of new design nabla shaped tubular solar air heater (∇ TSAH): Experimental investigation." Energy 276 (2023): 127451.
[16] Yadav, Siddhita, R. P. Saini, and K. M. Pandey. "Effect of jet angle and jet pitch on the Thermo-Hydraulic performance of solar air heater having absorber plate with jet impingement." Thermal Science and Engineering Progress 45 (2023): 102146.
[17] Hasan, Zaid, and Hakim T. Kadhim. "Review analysis on performance of ribbed solar air heater by CFD approach." In AIP Conference Proceedings, vol. 2776, no. 1. AIP Publishing, 2023.
[18] An, Byeong-Hwa, Kwang-Hwan Choi, and Hwi-Ung Choi. "Heat Transfer Augmentation and Friction Factor Due to the Arrangement of Rectangular Turbulators in a Finned Air Channel of a Solar Air Heater." Energies 16, no. 19 (2023): 6891.
[19] Dwivedi, Mayank Kumar, and Manish Choudhary. "Effect of various rib geometries on the heat transfer and friction characteristics of solar air heater: A Review." Materials Today: Proceedings 63 (2022): 272-282.
[20] Yadav, Anil Singh, Abhay Agrawal, Abhishek Sharma, and Abhay Gupta. "Revisiting the effect of ribs on performance of solar air heater using CFD approach." Materials Today: Proceedings 63 (2022): 240-252.
[21] Kumar, Amit, Ajeet Pratap Singh, and O. . Singh. "Investigations for efficient design of a new counter flow double-pass curved solar air heater." Renewable Energy 185 (2022): 759-770.
[22] Kumar, Raj, Erdem Cuce, Sushil Kumar, Sashank Thapa, Paras Gupta, Bhaskar Goel, C. Ahamed Saleel, and Saboor Shaik. "Assessment of the thermo- hydraulic efficiency of an indoor-designed jet impingement solar thermal collector roughened with single discrete arc-shaped ribs." Sustainability 14, no. 6 (2022): 3527.
[23] Mor, Swati, B. S. Sikarwar, Niraj Kumar, and Gulshan Sachdeva. "Parametric analysis of a solar air-heater roughened with multi-V ribs having trapezoidal slots."