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

THERMAL PERFORMANCE ESTIMATION OF "S" SHAPED RIBS IN SOLAR AIR HEATER USING ANSYS – "A REVIEW"

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ABSTRACT
Solar air heaters are an efficient and sustainable way to harness renewable energy, reducing dependency on fossil fuels and lowering greenhouse gas emissions. Solar air heaters are widely used for heating applications due to their simplicity and cost-effectiveness. This study investigates the thermal performance and fluid flow characteristics of an improved solar air heater equipped with "S" shaped ribs with gaps, using ANSYS simulation software. The primary objective is **to** enhance the efficiency of solar air heaters by optimizing the heat transfer and minimizing pressure drop. The "S" shaped ribs with gaps are strategically designed to disrupt the boundary layer, thereby increasing turbulence and enhancing heat transfer. Simulation results indicate a significant improvement in thermal efficiency compared to conventional designs, demonstrating the potential of this innovative approach in solar thermal applications.

Keywords: Thermal Performance, Fluid flow, Solar air, "S" shaped ribs, ANSYS, Heat Transfer, Fluid Flow Dynamics, Optimization.

I. Introduction

Solar air heaters are devices designed to absorb solar energy and convert it into heat, which is then used to increase the temperature of air. This heated air can be utilized for a variety of applications, including space heating, drying agricultural products, and preheating ventilation air in industrial and commercial buildings. Solar air heaters are an efficient and sustainable way to harness renewable energy, reducing dependency on fossil fuels and lowering greenhouse gas emissions.

1.1 Challenges in Conventional Solar Air Heaters

Despite their simplicity, ease of fabrication, and cost-effectiveness, conventional solar air heaters often face significant performance limitations. Two of the most persistent challenges are:

- Low thermal efficiency, primarily due to poor convective heat transfer between the absorber plate and the air flowing through the duct.
- High-pressure drop, which increases the power requirement for air movement and can negate the gains in thermal performance.

To tackle these issues, researchers have explored numerous enhancement techniques. These include introducing artificial roughness elements on the absorber surface, employing extended surfaces such as fins or ribs, and optimizing air flow passages using baffles and turbulence promoters.

1.2 Innovations in Rib Design

Among the various enhancement strategies, the incorporation of ribs on the absorber plate has emerged as a particularly promising technique. Ribs serve to disrupt the laminar sublayer, promote turbulence, and enhance the convective heat transfer rate. However, this increased turbulence often comes at the cost of higher friction losses and pressure drop.

1.3 Role of Computational Fluid Dynamics (CFD)

Computational Fluid Dynamics (CFD) has become an indispensable tool in analyzing and optimizing the performance of enhanced solar air heaters. CFD enables detailed investigation of complex heat transfer and fluid flow mechanisms that are otherwise difficult to study through experimental setups alone.

Through CFD simulations, one can visualize temperature gradients, flow separation, recirculation zones, and pressure distributions. This allows for rapid prototyping and evaluation of different rib and fin geometries under varying operating conditions, leading to more efficient and reliable solar heating systems.

1.4 Significance of the Study

Given the urgent global need for sustainable energy technologies, enhancing the performance of solar air heaters is more critical than ever. The proposed study aims to evaluate the thermal and fluid dynamic performance of a novel I-type shaped vertical fin configuration using CFD analysis. The goal is to contribute to the ongoing development of more efficient, cost- effective, and practical solar air heating solutions that can be deployed across diverse climatic and application scenarios.

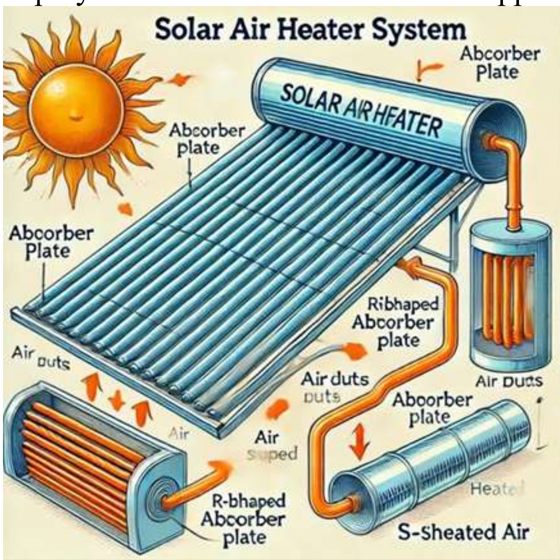

Figure 1: Solar Air Heater with S-Shaped ribs [5]

II. Literature Review

Srivastava et al. (2024) They experiment a numerical investigation comparing the impact of various rib geometries on the performance of a solar air heater. They analyzed transverse, inclined, V-shaped, and arc-shaped ribs under consistent boundary conditions using ANSYS-Fluent software. Their findings indicated that V-shaped ribs provided the highest Thermal-Hydraulic Performance Parameter (THPP) at a Reynolds number of 15,000.

Singh et al. (2024) Explored the performance enhancement of solar air heaters using two- sided curvilinear rib roughened absorber plates. Both experimental and numerical investigations were conducted, revealing that curvilinear ribs significantly improved thermal characteristics.

Al-Chlaihawi et al. (2024) Utilized numerical simulations to analyze turbulent heat and flow properties within a solar air heater duct featuring various transverse rib shapes. The RNG k-ε turbulence model was employed to solve the transport equations of turbulent kinetic energy and dissipation rate.

Haldia et al. (2024) Conducted a numerical assessment of solar air heater performance with broken arc and S-shaped ribs. They observed significant improvements in heat transfer characteristics with optimal gap and pitch configurations, demonstrating the effectiveness of numerical simulations in predicting performance outcomes.

Dutt et al. (2024) Carried out an investigation on roughness parameters of radius of rib to transverse pitch (r/Ptv) ratios of 0.1–0.35 and longitudinal pitch to radius of rib (Plg/r) ratios of 4–10 under varied operating circumstances of Reynolds number (Re) from 10,200 to 20,200. The study identified the maximum Nusselt number (Nu) and friction factor (f) at specific parameters, highlighting significant thermal performance improvements.

Iqbal et al. (2023) Conducted a numerical investigation on the thermo-hydraulic performance of a solar air heater duct roughened with discrete D-shaped ribs using ANSYS Fluent 2020 R2. The results demonstrated the impact of varying rib dimensions on heat transfer and fluid flow characteristics, with validations against experimental data.

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Deshpande et al. (2024) Performed both computa tional and experimental performance assessments of solar air heaters with curved ribs. The results from numerical simulations closely aligned with experimental data, validating the effectiveness of the proposed rib designs.

Jain et al. (2024) Conducted an experimental investigation on a rectangular duct in a solar air heater with staggered V-ribs and aligned gaps. Their findings highlighted the importance of experimental validation in corroborating numerical predictions.

Kumar et al. (2023) In this paper an indoor experimental examination of Nusselt number (Nu) and friction factor (f) characteristics of a solar air heater using novel discrete double arc reverse form roughness on the bottom side of the absorber plate. The study found significant enhancements in heat transfer and friction characteristics compared to smooth ducts.

Kumar et al. (2024) In this experimental investigation a comparative study of solar air heaters roughened with S-shaped ribs and protrusions. They analyzed various design parameters, including relative pitch roughness and gap between ribs, to identify configurations that maximize thermal performance.

Prasad et al. (2024) Investigated the effect of different miniature rib shapes combined with dimples on an absorber plate. Their study demonstrated that V-miniature ribs provided superior thermohydraulic performance compared to other configurations.

Agrawal et al. (2024) Examined the effect of attaching broken V-shaped ribs on the heating surface of a triangular-shaped solar air heater duct. They observed enhancements in convective heat transfer and frictional effects, indicating a significant increase in performance.

Arya et al. (2023) In this paper a novel transverse trapezoidal staggered ribs configuration using CFD to understand fluid flow and heat transfer behaviors. Their findings showed that staggered ribs outperformed continuous ribs, offering insights into optimizing rib arrangements.

Singh et al. (2023) Conducted numerical simulations on a rectangular duct featuring trapezoidal ribs. The study highlighted the impact of varying Reynolds numbers and rib parameters on Nusselt number, friction factor, and thermal performance factor (TPF).

Al-Chlaihawi et al. (2023) Examined a novel solar air heater configuration combining impinging air jets and rectangular sectioned V-ribs. The study evaluated the effects of varying roughness parameters on Nusselt number and friction factor.

Dutt et al. (2023) Investigated solar air heaters with polygonal-shaped ribs and grooves, showing that increasing rib height improved heat transfer rates but also increased pressure drops.

Arya et al. (2023) Examined a novel transverse trapezoidal staggered ribs configuration as artificial roughness using CFD to understand the fluid flow and heat transfer behaviors for improving the performance of a solar air heater. In addition, experimental validation of Nusselt numbers for smooth duct against CFD results is established. The staggered ribs arrangement outperforms the continuous ribs and insights obtained from the thermal-fluid flow behaviors are further applied to optimize the staggered arrangements of the rib.

Singh et al. (2023) In this paper they experiment on numerical simulations to examine the turbulent heat and flow characteristics within a rectangular duct of a solar air heater (SAH) featuring trapezoidal ribs as roughness elements. The governing equations were numerically solved using the finite-volume method and ANSYS FLUENT. The transport equations of turbulent kinetic energy and its dissipation rate were addressed by the RNG k-ε turbulence model. The Nusselt number (Nu), friction factor (f), and thermal performance factor (TPF) were computed across a broad range of conditions, including Reynolds number ($6{,}000 \le Re \le 18{,}000$), relative roughness height ($0.021 \le e/Dh \le 0.043$), and relative roughness pitch ($5 \le P/e \le 20$) under constant heat flux conditions.

Kumar et al. (2023) In this paper an indoor experimental examination of Nusselt number (Nu) and friction factor (f) characteristics of a Solar air heater using novel discrete double arc reverse form roughness bottom side of the absorber plate was carried out. The range for criterion, relative roughness pitch (p/e) of 6.67, relative roughness height (e/Dh) of 0.027, angle of arc (α) of 30°,45°, 60°, 75°,

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Reynolds number (Re) of 3000 to 14000, aspect ratio (W/H) of 8 were applied in between the laboratory test.
Agrawal et al. (2023) In this paper a trapezoidal rib was used to enhance the thermal performance of the solar air heater. The characteristics of flow and heat transfer were numerically analyzed using a RNG k-ε turbulent model based on the Reynolds number range of 5000, 10000, 15000, 20000, 25000, and 30000. Eight different types of trapezoidal ribs, arranged in shapes that increase in height towards or against the direction of flow, were studied. Four case studies included a solar collector with attached trapezoidal ribs, while another four case studies included a solar collector with detached trapezoidal ribs.
Hamad et al. (2023) They development of solar air heater technique that makes a suitable designed model for increasing heat transfer without increasing the global warming in environment. The rectangular solar air heater model is designed by Ansys fluent software. The Ansys fluent software is generally used for investigating heat energy by using RNG k-e model method for the fluid (air or liquid) and also has perfect information about flowing fluid ($3000 \leq Re \leq 18,000$) and then gives the perfect physical information relevant to design model.
Singh et al. (2022) In past they research the effect of geometry modification of a rectangular rib on the Nusselt number and friction factor characteristics of a rectangular duct solar air heater system under constant heat flux conditions using computational fluid dynamics (CFD) methodology. The rectangular rib geometry is modified to obtain four new rib configurations, such as T- rib, inverted T-rib, modified T-rib1, and modified T-rib2. The relative pitch is set as 15, and the rib height is fixed as 2 mm for all the rib configurations.
Shetty et al. (2022) In this research they comparative study of smooth and rough absorber surfaces with V ribs to improve triangular solar air heater performance. The absorber plate coated with graphene nanoparticles doped into the black paint in both cases. The investigation incorporated rib roughness parameter as P/e = 1.4 for the arrangement and investigated at different parameters of the solar intensity. The roughness effect on friction factor and heat transfer characteristics has been investigated numerically and experimentally.
Kumar et al. (2022) A thermo-hydraulic performance analysis for a fully developed turbulent flow through rib-roughened solar air heater (SAH) is presented by employing computational fluid dynamics. Both 2- dimensional geometrical modeling and numerical solutions were performed in the finite volume package ANSYS FLUENT. The renormalization-group (RNG) k- ε turbulence model was used, as it is suitable for low Reynolds number (Re) turbulent flows.

III. Objectives of The Study

1. To evaluate the effectiveness of various rib geometries, particularly the innovative "S" shaped ribs with gaps, in enhancing the thermal efficiency of solar air heaters.
2. To identify and assess critical design parameters such as rib height, pitch, and gap size that significantly influence the thermal performance and pressure drop in solar air heaters.
3. To explore the latest advancements in ribbed absorber plates, focusing on how different rib configurations impact the overall efficiency of solar air heaters.
4. To highlight existing gaps in the research on solar air heater designs, particularly in the context of "S" shaped ribs, and propose areas for future study.
5. To contribute to the development of more efficient and sustainable solar air heater technologies, reducing reliance on non- renewable energy sources and minimizing environmental impact.

IV. Research Gap

Previous research have predominantly focused on straight or uniformly spaced rib designs. The impact of "S" shaped ribs with gaps on the thermal performance and fluid flow dynamics has not been extensively explored. Furthermore, most existing studies rely on experimental setups, which can be costly and time-consuming. There is a lack of comprehensive numerical simulations that can provide detailed insights into the heat transfer mechanisms and fluid dynamics involved. This research addresses these gaps by employing ANSYS to simulate and analyze the performance of a solar air heater with "S" shaped ribs with gaps. The study not only provides a deeper understanding of the thermal and fluid flow behavior but also offers a cost-effective and efficient alternative to experimental methods.

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