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Review Article

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Comprehensive review of key parameters for improving the performance of Solar Air Heaters

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ABSTRACT

Due to declining supplies of once-affordable fossil fuels, research into renewable energy sources is being prioritized. Using solar energy for passive cooling and heating can significantly reduce the demand for primary energy sources. In this survey, we look at how changing a few variables might affect how well a solar air heater functions. It helps researchers learn more about these systems' development, properties, and potential uses. This research analyses the current literature to emphasize the value of thermal properties. Focusing on laminar sublayer creation and increasing the heat transfer coefficient, it explores ways to increase the efficiency of solar air heaters. After reviewing several articles, it has been determined that rib roughness elements and their geometric characteristics play a significant role in enhancing the thermal performance of solar air heaters. The relative roughness height, pitch, angle of attack, and width are all important factors to consider.

KEYWORDS: Renewable energy, Solar energy, Solar air heater, Thermal characteristics, Angle of attack, Rib roughness elements

INTRODUCTION

Population increase, industrial advancement, and home consumption are all driving forces behind the world's rising energy demand, which presents substantial hurdles. In emerging nations, relying too much on fossil fuels increases pollution and greenhouse gas emissions. To address these problems, using renewable energy sources is now crucial. Solar thermal and photovoltaic systems, two types of solar energy technology, are currently being developed for electricity generation worldwide. The use of solar energy for common household tasks like passive cooling and heating has also emerged as an exciting field of study. Due to air's poor heat transfer qualities, solar air heaters provide poorer thermal performance than solar water heaters (Figure 1). Still, they nevertheless have the potential to lessen reliance on primary energy sources.

Two key factors contributing to their suboptimal performance must be addressed to enhance solar air heaters' efficiency and economic viability. The first factor is the formation of a laminar sublayer near the absorber plate surface, impeding further heat transfer. Stirring up the flow and interrupting this layer is crucial to overcoming this limitation. The second factor is the low heat transfer coefficient, which can be improved by increasing the contact surface area or introducing artificial roughness in small wires or fins. These roughness elements disrupt the laminar sublayer and enhance convective heat transfer. Geometric parameters, such as relative roughness height, pitch, angle of attack, and width, are commonly employed to define roughness elements like ribs as shown in Figure 2. By utilizing these methods, the thermal performance of solar air heaters can be significantly enhanced.

Different rib geometries have been explored, including arc-shaped cables, dimples, cavities, and compound rib-grooved roughness elements. While square ribs are commonly used, circular, rectangular, semi-circular, and chamfered ribs have also been studied for their thermo-hydraulic effects. V-shaped ribs have shown superior thermo-hydraulic efficiency compared to other rib geometries.

LITERATURE REVIEW

Numerous experimental and numerical studies have been conducted to assess the effectiveness of solar air heaters. Researchers have explored various rib styles and orientations on the absorber plate's top or bottom to increase heat transfer and friction factor. An experimental study by Momin *et al.*

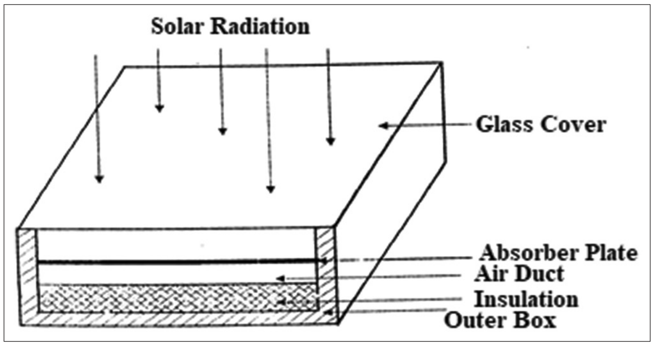

Figure 1: Schematic diagram of a solar air heater

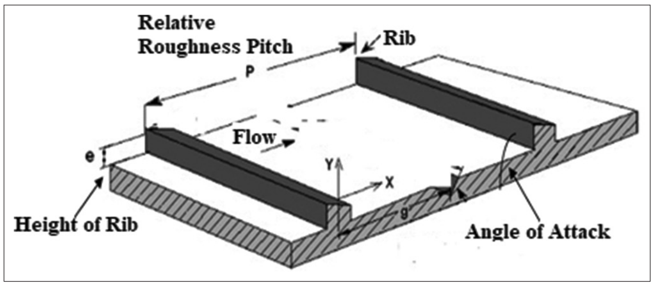

Figure 2: Schematic view of rib roughness parameters

(2002) focused on rectangular solar air heater ducts with V-shaped ribs on the underside of the absorber plate. The study investigated a range of Reynolds numbers (2500-18000) and roughness parameters like relative roughness height, angle of attack, and relative roughness pitch (e/D_h = 0.02-0.034, α = 30°-90°, and p/e = 10). Results showed that roughness significantly altered flow characteristics, leading to flow separation reattachment and secondary flows that enhanced heat transfer. However, the free shear layer did not reattach at a greater relative roughness height, causing increased heat transmission out of proportion to the frictional resistance. Nusselt number and friction factor increased by 2.30 and 2.83 times, respectively, compared to a smooth duct, at a relative roughness height of 0.034 and an angle of attack of 60°, V-shaped ribs were more effective when both V-shaped and inclined ribs were tested. The absorber panel of a solar air heater duct studied by Hans *et al.* (2010) featured several V-shaped ribs. The greatest improvement in heat transfer was observed at a relative roughness width (W/w) of 6, whereas the greatest friction factor was observed at a W/w = 10 value. The optimum Nusselt number was recorded at an angle of attack of 60 degrees and a relative pitch of P/e of 8. Promvonge *et al.* (2011) numerically analyzed turbulent square duct flow with inclined V-shaped discontinuous ribs using a heat transfer model. At low Reynolds numbers, heat transmission was quadrupled compared to a smooth duct due to the attachment fluxes caused by the ribs. The derived data from square ribs agreed with the numerical results. Lee and Abdel-Moneim (2001) conducted computational research on heat transfer in turbulent flow across horizontal surfaces with two-dimensional ribs. Their findings showed that the heat transfer coefficient was affected by turbulence qualities, with the first rib region displaying more turbulent kinetic energy than the later parts. Liou *et al.* (1993) investigated turbulent heat transfer enhancement in a channel with periodic ribs on one wall using numerical simulations. Their research demonstrated how flow velocity and turbulence strength significantly affect the heat transfer coefficient. Using Reynolds number, rib height, and spacing, a heat transfer correlation was established. Lau *et al.* (1991) researched turbulent heat transfer in a square channel with different rib configurations and found that V-shaped ribs with an angle of 60 degrees and a p/e ratio of 10 provided the best thermal efficiency. Velraj *et al.* (1997) used experimental and theoretical methods to enhance heat transfer through rib configurations. They found that placing V-shaped ribs with a height of approximately half the tube radius inside the tube produced better heat transfer than configurations without ribs. Chaube *et al.* (2006) conducted a numerical investigation of the impact of artificial rib roughness on flow parameters and heat transfer in a rectangular duct, while Gupta *et al.* (1997) studied the effect of angular circular ribs on the efficiency of a flat plate heater compared to a smooth plate. Their findings showed that higher insolation levels resulted in better heater efficiency when the Reynolds number was greater than 10000, but the performance decreased when it was less than 10000. The most efficient thermal performance was observed at a Reynolds number of 13000-19000. Sahu and Bhagoria (2005) studied a solar air heater that featured 90° broken transverse ribs on the absorber plate. They found that the best performance was achieved with a 20 mm pitch, resulting in a maximum hat recovery efficiency of 83.5%. At higher Reynolds numbers, the heat transfer coefficient increased by 1.25-1.4 times compared to a flat plate. The researchers looked at conditions for solar air heaters with Reynolds numbers between 3000 and 20000. According to research by Karwa (2002), the best heat transfer performance was discovered for chamfered ribs, while the best efficiency index was found for 3 mm x 5 mm rectangular ribs. Han and Zhang (1992) studied the effects of rib configuration on pressure drop and heat transmission in a square channel and found that heat transfer was greater for 45° angled and 60° V-shaped ribs than for 900 transverse ribs. Maximum heat transmission and friction factor for both angled and V-shaped ribs were seen at an angle of attack of 60°, as opposed to 45° and 90°. Tanda (2004) compared the thermal and flow behavior of continuous and broken V-shaped ribs and found that continuous ribs produced better heat transfer performance. A study conducted by Markam and Maiti (2023) analyzed the use of fins, ribs, and grooves as enhancements in solar air heaters to improve heat transfer efficiency. The authors examined various shapes, patterns, and positions of the enhancers and studied how they affected the Nusselt number and friction factor. They found that the dimple shape and V-staggered rib were particularly effective. These results could help create more efficient small-scale designs for solar air heaters that can be used in a wider range of applications. In their study, Varun *et al.* (2008) analyzed the effects of inclined and transverse ribs in a solar air heater. Their research revealed that a roughened surface with a P/e value of 8 exhibited the highest thermal efficiency of all the tested configurations. Similarly, Saini and Saini (2008) explored arc-shaped roughness in a duct with an aspect ratio of 12. They found that implementing arc-shaped roughness resulted in a 3.8 times increase in heat transfer compared to a smooth duct. Additionally, the friction factor increased by 1.75 times. The specific parameters used in their study were a relative arc angle of 0.3333 and a roughness height of 0.0422. Braun *et al.* (1999) compared the local heat transfer coefficient in a rib-roughened channel wall under turbulent flow between experimental and numerical results. Their research proved that numerical simulations are viable for studying dynamic fluid flows. Using experimental and numerical approaches, Karmare and Tikekar (2010) studied heat transmission and fluid flow in a solar air heater with metal grit ribs. Strong agreement between CFD and experiment results demonstrates CFD's potential for optimizing and evaluating complex surfaces. Using CFD analysis, Sharma *et al.* (2021) analyzed six types of baffles (transverse, inclined transverse, dimple, inclined dimple, arc, and sine wave) in a solar air heater. Their findings indicate that the shape and placement of the baffles significantly affect the thermo-hydraulic performance. The most effective baffle design was the sine wave, which achieved a thermal performance factor of 2.05 at a Reynolds number of 15000. Using computational fluid dynamics, Bhagoria *et al.* (2002) evaluated the effectiveness of a solar air heater duct with arc-shaped wire ribs. All permutations of relative roughness height and relative arc angle showed an increase in Nusselt number as Reynolds number increased. The study also observed an increased heat transfer rate after the fluid was removed, swirled, and reattached, all working together. Results from the CFD model agreed with those from experiments and empirical correlations.

CONCLUSION

The world's energy needs are increasing due to population growth, industrialization, and household consumption. Consequently, renewable energy sources, such as solar energy, are becoming more critical. Solar energy has vast potential for generating electricity and can be used for everyday tasks like heating and cooling. Solar air heaters are a promising solution to reduce dependence on primary energy sources and decrease pollution and greenhouse gas emissions. Researchers have studied rib designs and orientations extensively to improve solar air heater efficiency and economic viability. V-shaped ribs have proven to be the most effective in terms of thermo-hydraulic efficiency. The studies have also identified crucial heat transfer factors, such as the laminar sublayer and the low heat transfer coefficient. We can improve solar air heater performance by introducing artificial roughness and altering flow characteristics. This analysis shows how various artificial roughness parameters affect solar air heaters' efficiency. Optimizing geometric characteristics can significantly increase the heat transfer coefficient between the heat-transferring surface and the air. Developing more efficient solar air heaters, particularly in developing countries, can contribute to a sustainable energy future. By embracing renewable energy technologies and expanding solar energy applications, we can tackle the challenges posed by increasing energy demand and minimizing environmental impacts. This review paper includes guidelines for the construction, qualities, and uses of solar air heaters, making it a valuable resource for researchers.

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