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A Literature Survey of Different Shapes of Ribs at Constant Pitch Ratio in Solar Air Heater

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Abstract— ***Solar air heater has low thermal efficiency as heat transfer coefficient is poor between absorber plate and working fluid (air). In this study, a review on solar air heater performance is presented. For improving heat transfer in solar air heater, several researchers recommended use of Artificial Roughness Element in rib and fine wire form. Use of Artificial Roughness Element helps in breaking laminar sub layer developed on surface of absorber plate. Different Roughness geometries are studied and Their results are observed. This review presents a detail analysis of performance factor of solar air heater with Artificial Roughness Element. An examination of shape, size and orientation of Artificial Roughness Element is presented.***

Keywords— Solar Air Heater, Artificial Roughness Element, Rib Geometry, Heat Transfer Enhancement and Constant Pitch Ratio , etc

I. INTRODUCTION

In the arena's depleting gasoline reserves, that the most offer of energy, the event of non-traditional assets has acquired partner impetus. Energy, that's surroundings friendly, is renewable and would possibly operate a property energy offer. Hence, it's on the point of extremely become a awfully necessary a section of the tip of the day energy structure with the hundreds of and numerous dehydration of. However, the decrease electricity density and seasonal doing with geographical dependence unit of degree the foremost challenges in different appropriate programs. Consequently, exploring high performance energy awareness technology is noticeably vital and sensible [Xie et al., 2011]. However is not any sun inside the dark. Its total accessible value is seasonal and depends on the condition of the position. Underpin a chromatic colour is that the foremost necessary retarding issue for thorough energy utilization. Of course, responsibility of varied energy is raised by storing its portion once it's in rather quite the load and apply the keep energy whenever needed.

The foremost applications of star air heaters ar house heating; seasoning of timber, action of business merchandise, and these could to boot be effectively used for curing/drying of concrete/clay building components. The star air heater occupies a very important place among star heating thanks to smallest use of materials and worth. so on sort the star air heaters economically viable, their thermal potency ought to be improved by enhancing the warmth transfer constant. There unit 2 basic ways in which for raising the warmth transfer constant between the absorbent plate and air. the primary methodology involves increasing the world of warmth transfer by exploitation wrinkled surfaces or extended surfaces stated as fins whereas not touching several investigators have tried to vogue a roughness half, that may enhance convective heat transfer with minimum increase in friction losses.

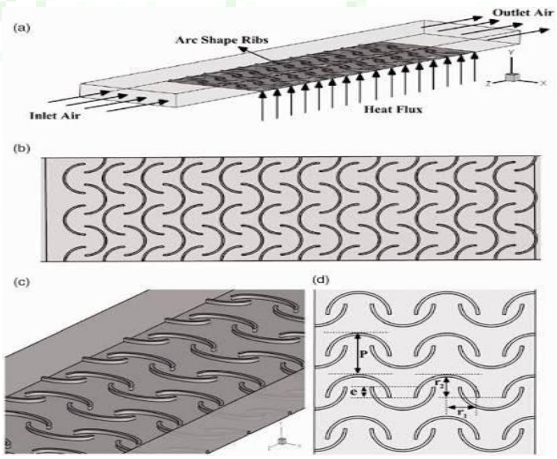

Fig. 1 Solar Air Heater

Solar air heater is a system used to increase the temperature of air with the assist of warmness extracted from photo voltaic energy. These are cheap, have easy design, require much less renovation and are eco-friendly. As a result, they have most important purposes in seasoning of timber, drying of agricultural products, area heating, curing of clay/concrete constructing elements and curing of industrial products [2, 3]. The structure of a photo voltaic air heater of traditional software is that of rectangular duct encapsulating an absorber plate at the top, a rear plate, insulated wall below the rear plate, a glass cowl over the sun-radiation uncovered surface, and a passage between the backside plate and absorber for air to glide in [4, 5]. The exact constructional details of a photo voltaic air heater are proven in parent 1.1. Solar air heaters have greater thermal effectivity when the Reynolds variety of air drift thru their passage is 3000-21000 [3]. In this range, the duct glide is typically turbulent. Hence, all the lookup work pertaining to the sketch of an wonderful photo voltaic air heater includes turbulent flow. Conventional photo voltaic air heaters with all the interior partitions being easy commonly have low efficiency. The photo voltaic air heater's inside floor can be artificially roughened by using mounting sure ribs/obstacles of unique shapes such as round wires, skinny rectangular bars, etc. periodically on the decrease facet of collector plate. This consequences in a sizable augmentation in the warmth switch rate, however at the equal time leads to enlarge in friction component thereby bettering the pumping energy requirements.

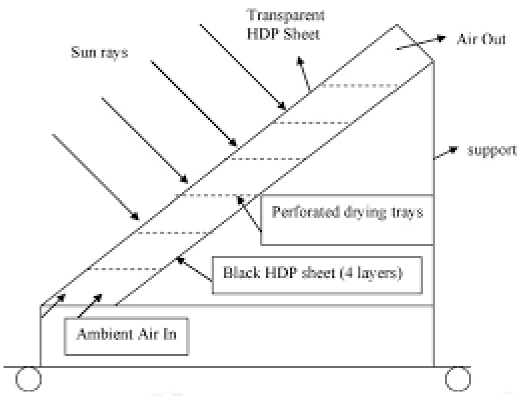

Fig. 2 Solar Duct

II. LITERATURE REVIEW

Tamrat, Bimrew, Dessie et. al. (2026): investigated the performance of a solar air heater (SAH) integrated with continuous V-shaped rib roughness and external flat-plate reflectors. Both experimental and CFD analyses showed that the reflector increased incident solar radiation by approximately 40%, while the combined effect of ribs and reflectors improved thermal efficiency and achieved a thermo-hydraulic performance enhancement of up to 1.45. The study demonstrated that integrating artificial roughness with solar augmentation significantly improves heat transfer and overall system performance [1]

Singh, Jitendra, et al. (2025): In this research work presented an experimentally studied a solar air heater employing symmetrical gap arc rib roughness with staggered segments. The proposed geometry effectively disrupted the boundary layer and enhanced fluid mixing, resulting in a Nusselt number enhancement of 2.31 times and a maximum thermo-hydraulic performance parameter (THPP) of 1.60. The study concluded that segmented arc ribs are effective turbulence promoters for SAH applications [2].

Singh Rohit et al. (2025) presented a comprehensive review of advanced artificial roughness geometries in solar air heaters. The review reported that artificial roughness techniques could increase the Nusselt number by 1.25–6.3 times and improve thermal efficiency by 20–35% compared to smooth absorbers. The authors identified relative roughness heights between 0.02 and 0.05 as the optimum range for achieving superior thermo-hydraulic performance [3].

Alam, Tabish, et al. (2024) Authors presented an experimentally investigated hybrid rib patterns combining V-shaped and arc-shaped ribs in a solar air heater. The hybrid roughness significantly enhanced heat transfer characteristics, producing a maximum Nusselt number enhancement of 3.08 and a thermo-hydraulic performance of 2.18 under optimum geometric conditions. The study demonstrated that combining different rib geometries can effectively improve SAH efficiency [4].

Singh, Jitendra, et al. (2024) Authors proposed a discrete symmetrical arc rib with staggered rib roughness for solar air heaters. Experimental investigations revealed that the optimum performance occurred at a roughness pitch ratio of 10 and Reynolds number of 6000. The additional gaps introduced in the arc rib successfully reduced boundary layer reformation and enhanced thermal performance [5].

Rajendran, Vijayakumar, et al. (2023) enhanced the performance of a solar air heater using broken V-shaped ribs on the absorber plate. Experimental results indicated that the ribbed configuration provided higher useful heat gain and thermal efficiency compared with a conventional flat absorber plate. The study concluded that broken V-ribs effectively increase turbulence and improve heat transfer characteristics in SAHs [6].

Dubey, Manoj Kumar, et al. (2023) experimentally investigated a discrete V-rib geometry with gaps for heat transfer enhancement in solar air heaters. The results showed increases of 3.62 times in Nusselt number, 3.22 times in thermo-hydraulic performance, and 2.85 times in friction factor compared with a smooth absorber plate. The proposed geometry outperformed several existing rib configurations [7].

Kumar, Rahul, et al. (2023) conducted experimental and numerical analyses of a solar air heater with V-shaped rib roughness on the absorber plate. Using graphene nanoparticle coating and CFD simulations, the study demonstrated that rib roughness substantially improved heat transfer and friction characteristics. The numerical results agreed well with experimental observations, confirming the effectiveness of V-shaped roughness in enhancing SAH performance [8].

Rajendran, Vijayakumar, et al. (2022) experimentally evaluated a solar air heater integrated with multi-geometry arrangements consisting of rectangular ribs, slits, and cylinders. The modified absorber plate achieved thermal efficiencies ranging from 40.8% to 77.4%, which were significantly higher than those of a conventional SAH. The study demonstrated that combining different roughness elements can considerably improve energy gain and reduce top heat losses [9].

Alsaiari et al. (2022) performed a computational investigation on heat transmission and airflow friction in a solar air heater with V-symmetry ribbed absorbers. The study showed that the ribbed configuration enhanced the Stanton number and friction factor by 1.13 and 1.19 times, respectively, compared with a smooth duct. The results confirmed the potential of V-shaped ribs for improving thermal performance [10].

Alam et al. (2021) investigated the thermo-hydraulic performance and optimization of conical protrusion rib roughness in solar air heaters. The analytical study reported a maximum net effective efficiency of 70.92% at an optimum rib pitch ratio of 10. The results indicated that conical protrusion ribs offer substantial thermal enhancement with comparatively lower pressure losses [11].

Kazemi Moghadam et al. (2021) numerically modeled an innovative arc-shaped rib-based solar air heater. The study evaluated the effects of rib cross-section, pitch, aspect ratio, and inter-rib distance on thermal efficiency. Quadrangular ribs with lower pitch and an aspect ratio of 0.5 provided the best thermal performance, demonstrating the significance of rib geometry optimization in SAHs [12].

TABLE - 1: Shows Comparative Analysis of Literature

Authors & Year	Roughness Geometry	Methodology	Reynolds Number Range	Maximum Heat Transfer Enhancement	Maximu m THPP	Major Findings
Tamrat et al. (2026)	Continuous V-shaped ribs with reflectors	Experimental + CFD	–	Thermal efficiency improved by 3.87%	1.45	Combined reflector and rib roughness significantly enhanced heat transfer.
Singh et al. (2025)	Symmetrical gap arc ribs with staggered segments	Experimental	3000–14000	Nu increased by 2.31 times	1.60	Boundary layer disruption improved thermal performance.
Singh & Narayanan (2025)	Review of advanced roughness geometries	Review	10000–18000	Nu increased by 1.25–6.3 times	–	Artificial roughness improves thermal efficiency by 20–35%.
Alam & Gupta (2024)	Hybrid V and arc-shaped ribs	Experimental	2000–16000	Nu increased by 3.08 times	2.18	Hybrid rib configuration showed superior thermo-hydraulic performance.
Singh & Lanjewar (2024)	Discrete symmetrical arc ribs with staggered ribs	Experimental	3000–15000	Optimum Nu at p/e = 10	–	Additional gaps reduced boundary layer reformation.
Rajendran et al. (2023)	Broken V-shaped ribs	Experimental	Air velocity: 15–25 m/s	Higher useful heat gain and efficiency than flat plate	–	Broken ribs improved turbulence and heat transfer.
Dubey & Prakash (2023)	Discrete V-ribs with gaps	Experimental	4000–14500	Nu increased by 3.62 times	3.22	Outperformed existing V-rib geometries.
Kumar et al. (2023)	V-shaped rib roughness with graphene coating	Experimental + CFD	–	Significant enhancement in heat transfer	–	Numerical and experimental results were in good agreement.
Rajendran et al. (2022)	Multi-geometry baffles (ribs, slits, cylinders)	Experimental	Flow rate: 0.01–0.04 kg/s	Thermal efficiency up to 77.4%	–	Multi-geometry arrangement significantly improved energy gain.

Alsaiari et al. (2022)	V-symmetry ribbed absorber	Computational	–	Stanton number increased by 1.13 times	–	Ribbed absorber enhanced heat transfer with moderate friction penalty.
Alam et al. (2021)	Conical protrusion ribs	Analytical	–	Net effective efficiency of 70.92%	–	Optimum performance obtained at p/e = 10.
Kazemi Moghadam et al. (2021)	Innovative arc-shaped ribs	Numerical	6000–12000	Significant thermal enhancement	–	Quadrangular ribs with low pitch produced best performance.
Rajendran et al. (2022)	Multi-geometry roughness elements	Experimental	Flow rate: 0.01–0.04 kg/s	Efficiency improvement of 12.8–13.5%	–	Combined roughness elements reduced top heat losses and improved efficiency.

III. Research Gap

Although numerous studies have investigated artificial roughness techniques for improving the thermal performance of solar air heaters, most of the existing research has focused on conventional rib geometries such as V-shaped ribs, arc-shaped ribs, broken ribs, and discrete ribs. While these geometries have shown significant improvements in heat transfer, the majority of studies have been limited to individual roughness configurations. Comprehensive investigations on innovative and optimized hybrid roughness geometries that can simultaneously maximize heat transfer and minimize friction losses are still scarce.

Another significant limitation in the literature is the lack of integrated experimental and numerical studies. Several researchers have either performed experimental investigations or computational analyses independently, resulting in limited validation of the proposed designs under real operating conditions. Moreover, most studies have concentrated primarily on thermal efficiency and thermo-hydraulic performance, whereas exergy analysis, entropy generation, and economic feasibility have received comparatively less attention despite their importance for practical implementation.

Furthermore, the optimization of roughness parameters, including rib height, pitch, gap width, and attack angle, has not been comprehensively explored using advanced optimization techniques and intelligent algorithms. The application of artificial intelligence, machine learning, and multi-objective optimization methods for designing high-performance solar air heaters remains largely unexplored. Consequently, there is still considerable scope for developing novel roughness configurations and optimization methodologies that can further improve the overall efficiency and commercial viability of solar air heater systems.

Finally, most of the available studies have been conducted under controlled laboratory conditions and short-term testing periods. Limited research has been carried out to evaluate the long-term performance, durability, and climatic adaptability of roughened solar air heaters under actual environmental conditions.

IV. Conclusion & Future Scope

In this research work discuss the survey heat transfer in solar air heater. In the last decade there are different research work are proposed to improving heat transfer in solar air heater. In which researchers recommended use of artificial roughness element in rib and fine wire form. Use of artificial roughness element helps in breaking laminar sub layer developed on surface of absorber plate. Different Roughness geometries are studied and Their results are observed. This review presents a detail analysis of performance factor of solar air heater with Artificial Roughness Element. An examination of shape, size and orientation of Artificial Roughness Element is presented**.**

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