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Solar Air Heater Integrated with Different Shaped Turbulators: A Review

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ABSTRACT

The thermo-hydraulic efficiency of any device is determined by the flow route arrangement and the fluid's interaction with the heated surfaces inside the crossing. The effectiveness of a solar air heating system is mostly determined by the absorber design and the fluid-through duct. Many scientists have studied the various aspects of SAHs, particularly the absorber plate and duct containing various rib or turbulator shapes, such as circular and square ribbon cross-sections, tapered recto-cross sections, different configurations of V-shaped ribs, wavelength delta wings, anchor shaped inserts, and perforated vortex winglets. The current study provides an in-depth examination of experimental and numerical investigations on solar air heater integrated with different shaped turbulators.

KEYWORDS: *Artificial roughness, shape of rib, solar air heater, heat transfer, friction factor, and CFD*

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I. INTRODUCTION

Non-renewable fuel supplies, such as coal, crude oil, and other non-renewable fuel supplies, have become important in the development of successful technologies for devices using renewable sources of energy, such as solar energy, due to their finite availability and non-renewable nature of energy generation prices [1]. Because flat platform SAH is used in a wide range of home and industrial applications, including room heating, grain drying, desalination, and other heating applications, higher thermal efficiency designs would make a substantial contribution to our expanding energy needs.

Moreover, if solar insolation is only available for 4–6 hours per day, the SAH must be thermally efficient in order to make the most of it. The absorber plate and the flow drain are two crucial components of the SAH design [1], where cold air enters and creates energy from the heating plate before exiting the route. One of the classic passive ways was to disturb a laminar sub-layer by employing ribs or grooves on the inner surface of the heat exchangers and generate a turbulent, local wall due to flow isolations and the relationship between the subsequent corrugation, which minimises thermal resistance and enhances thermal transfer rates. To enhance SAH's heat transmission and fluid flow, a lot of CFD work has been done. The research's major purpose is to investigate the effect of flux and rugging parameters on the average thermal transfer and flux friction characteristics of an intentionally roughed solar air heater with various curved ribs.

1.1. Solar air heater

In 2018, the total surface space of all the collector units used for solar thermal conversion in the world amounted to 686Mm^2, resulting in a built volume of 480GW (i.e., an increase of 770 percent compared to the year 2000). In 2018 solar thermal energy provided 396TWh a year, resulting in 137.5Mt CO_2 savings. Solar air heater is a high-potential technology for solar thermal. They have been used for a variety of thermostats, such as room heating, drying and pre-heating, requiring low to moderate air temperatures. Solar air heaters use air to absorb solar energy and transform it into working fluid, i.e., an absorbing material absorbs available solar radiation and then heats the air by induced convection. The traditional solar air heater is a flat platform collector with an absorber layer, a clear top cover system, and a bottom/sides insulation. The whole mounting is enclosed in a jar of metal plate. Although air is the working fluid, the flow rate is depending on the air heater type.

The following can be listed as solar air heaters:
- The first type has an absorber, which does not fluidize the air stream over the absorber layer. Air passes through the plate and/or beneath the absorber.
- The second type includes a porous absorber from which the airflow reaches the absorber plate.

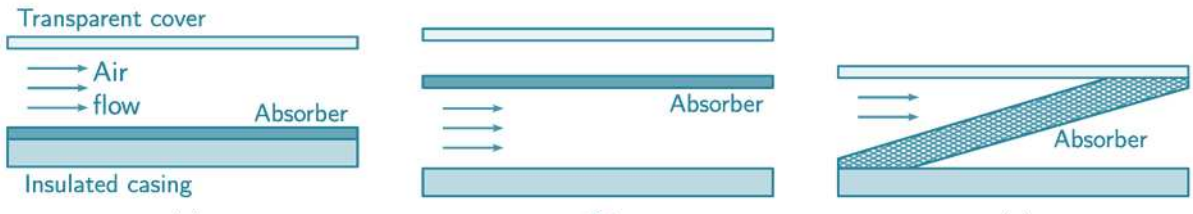

Figure 1. Solar air collector. (a) Air flow above the absorber. (b) Air flow below the absorber. (c) Air flow through the absorber (porous absorber).

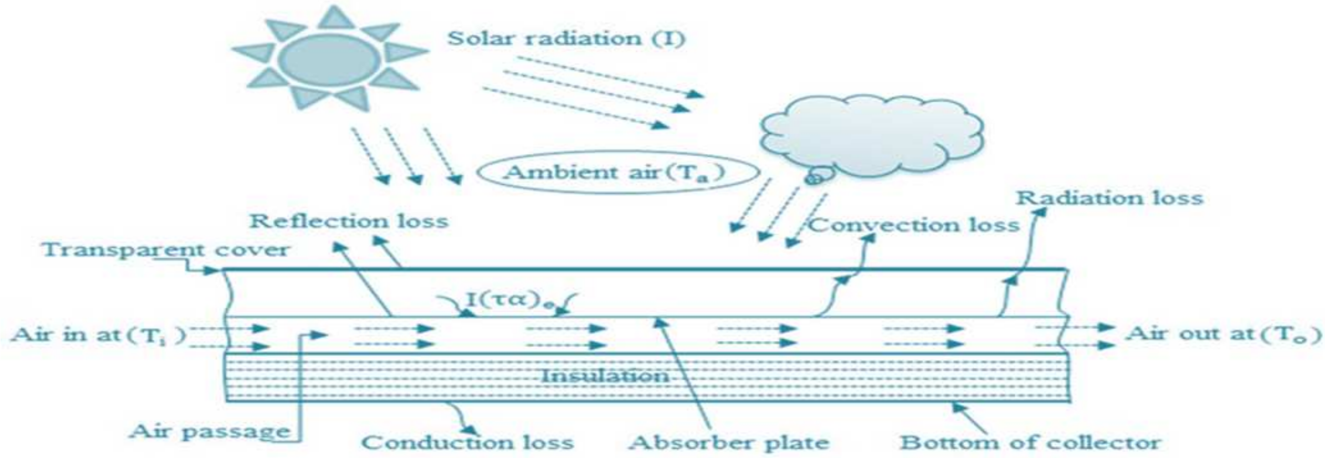

Figure 2. Schematic diagram of conventional solar air heaters.

SAHs are used on a broad scale for energy efficiency applications with low to moderate air temperatures. It is effectively used for some applications including in-situ cooking, textiles, marine products, solar water desalination and grain drying. SHAs have many advantages in conjunction with liquid heaters by eliminating issues of freezing or dehydration, corrosion, environmental or health threats, and heat transfer difficulties. In addition, they reduce the rate of energy usage for the application concerned. The noise of low temperature range and fans and of the open-air lines is constrained by the SAH (air =0.0003 kWh/m^3 K; water = 1.16 kWh/m^3 K).

In order to compensate for its poor heat transfer properties, the amortizer should be configured to maximise the thermal flow from the amortizer into the air stream. In the collector and heat transfer absorber field the key explanation for this is the rise in air turbulence. This can be done by modifying the absorbers plate in non-porous absorbers with fines, barriers, raw surfaces or splintered surfaces. Porous absorbers are used to enhance heat transfer properties of the absorber by using porous materials, including wire mesh or perforated plates.

1.2. Performance representation of SAHs

The efficient and optimal solar air heating systems need to be studied in performance. Heat transfer is a measure of the thermal efficiency, and the hydraulic efficiency is shown by the pressure drop. The overall system efficiency is reflected by the thermo-hydraulic performance and helps to maximise the system's geometrical and operating parameters. In the following paragraph, SAH efficiency criteria are addressed.

1.2.1. Thermal performance

The thermal performance of a SAH is expressed in terms of its useful heat gain (Q_u), specific heat gain (q_u), and thermal efficiency (η_{th}). According to Bliss (1959).

$$q_u = \frac{Q_u}{A_c} = F_R \left[I < \tau\alpha >_e - U_L \frac{(T_{in} - T_a)}{I} \right]$$

$$\eta_{th} = F_R \left[< \tau\alpha >_e - U_L \frac{(T_{in} - T_a)}{I} \right]$$

The heat removal factor (F_R), which is known as Hottel–Whillier–Bliss equation, is defined as the ratio of actual useful heat gain to useful heat gain if the whole heat-absorbing surface is at the inlet temperature (T_{in}) of the fluid.

The amount of useful energy gains by the air streaming through the SAH is expressed by the following energy balance equation:

$$Q_u = mc_p(T_{out} - T_{in}) = hA_c(T_{pm} - T_{am})$$

The above equation indicates that useful heat gains and consequently thermal efficiency of the SAH depend on coefficient of heat transfer (h) between the absorber plate and air. Thus, the heat transfer coefficient of the SAH can be increased by increasing its value, which can be enhancing by using a variety of active and passive methods of enhancement. The non-dimensional quantity, Nusselt number, is symbolic of a heat transfer characteristic.

dFor smooth ducts, from the Dittus–Boelter equation the Nusselt number can be predicted as below:

$$Nu_s = 0.023Re^{0.8}Pr^{0.4}$$

1.2.2. Hydraulic performance

The hydraulic power of a SAH indicates how much power the air in the duct is required. The pressure drop through the conduit is indicated. The energy required for airflow maintenance is calculated by the friction factor between air and flow channel surface. For a fully formed turbulent flow, the pressure drops through a SAH with reynolds number less than 50,000 is shown by the following equation:

$$(\Delta P)_d = \frac{2f\rho l v^2}{D}$$

For smooth duct surface, friction factor can be obtained with the help of modified Blasius expression, as given below:

$$f_a = \frac{0.085}{Re^{0.25}}$$

1.2.3. Thermo-hydraulic performance

The SAH should be designed to consume the least energy for the induction of air in the duct and to transfer the maximal thermal energy into the fluid. The thermal and hydraulic efficiency of a SAH are expressed in a non-dimensional quantity η, which is defined as the following parameter of thermal and hydraulic performance:

$$\eta = \frac{Nu/Nu_s}{(f/f_s)^{(1/3)}}$$

It is ideal to have a higher value of η (>1) in the SAHs for rationalising the use of artificial ruggedness. It indicates an improvement in the heat transfer capacity, i.e. the amount of the Nusselt at pumping power i.e. the rough surface duct friction factor correlated with without raw or smooth surface ducts.

1.3. SAH with artificial roughness

Due to the evolution of the laminar sub-layer near the heated wall, the heat transfer rate from the surface of SAH remains very low. Therefore, this coating needs to be breaked to increase the rate of heat transfer from the duct.

By constructing artificial roughness geometries in the form of different format and scale, the most efficient and inexpensive way to improve the efficiency of a solar air heating system. The rough factor cracks the viscous sublayer and induces instability in local walls. This results in an upgrading of the convective coefficient from the warm surface to the moving air, since the flow isolation and reinforcement without interrupting the main centre of turbulent flows. In the other hand, though, the use of artificial roughness contributes to increased friction losses, which allows more strength to flow through the air. The generation of turbulence is beneficial very close to the heat transfer surface and can be retained by retaining a limited ruggedness height relative to the duct height.

II. LITERATURE REVIEW

The supply of resources in today's context is becoming an important topic in daily life. In the light of the depletion of conventional energy and the environmental risk it raises, a quantitative approach is needed to estimate supply of energy. Solar energy is a renewable and economic supply of energy that will meet the growing rise in demand for energy. The flat plate solar air heaters (SAH) are of fundamental type and are maintained less thermally. SAHs are widely used for various industrial and home applications, for example in room heating, the removal of moisture from agricultural products, industrial heating, etc.

One of the SAH's main issues is its poor air traffic capability efficiency. Instead of being absorbed into the flowing air a great deal of thermal energy is lost to the environment from the absorber plate. Several methodologies have been documented to overcome this. In recent years, there has become very significant an interest to improve the thermo-hydraulic productivity of SAH by the use of a variety of active and passive techniques. The active approach focuses on generated total turbulent flow and local turbulence. The passive technique is based on an adjusted and improved absorber surface architecture.

These review papers include Alam and Kim (2017), Kalogirou et al. (2016), Sharma, and Kalamkarar among the main study papers on theoretical, analytical and experimental studies of new and modified prototypes for solar air heating systems (2015).

For instance, **Alam and Kim (2017)** doing a SAH collector study with various parameters and ribs. They proposed that the use of artificial forced roughness improved Nusselt's volume but also increased the pressure drop [1].

In their analysis report, **Kalogirou et al. (2016)** the numerous collector classes have been classified, the first class of which includes a parabolic platter and parabolic trough collector, and the second classification is composed of SAH, evacuated tube collectors and flat plate collectors. The exergy analysis was found to be a beneficial way to interpret and compare the different SAH setups [2].

A detailed thermal hydraulic efficiency study of artificially roughened collectors submitted by **Sharma and Kalamkar (2015)** Later, it stated the presence of a variety of geometric constructs, such as artificial ruggedness, ribs, fines, and different types and configurations of groves, which can be exploited for fast heat transfer in SAH. They also argued that the application of a small height of the turbulator increases the number of turbulators and decreases pressure reduction [3].

Arunkumar, Karanth, and Kumar (2020) performed a review analysis of SAH with distinct artificial roughness geometry**.** The results reveal that the efficient form of ribs with turbulators increases the outlet air temperature but also the friction factor. However, the THEP in SAH decreases with the increasing volume of Re [4].

Gabhane and **Kanase-Patil (2017)** Experimental research has been conducted for experimental experiments on a SAH with a double pass airflow and multiple C roughness in the heated wall. The characteristics of a pipeline aspect ratio (W/H) equal to 10, the number is known to differ between 3000 and 15,000 for a fixed height ratio (e/D = 0.02), the ratio of rib pitch (P/e) ranged from 8 to 40. For a pitch ratio equal to 24, the lowest friction factor increase is achieved in heat transfers (approximately 2.8 times in comparison to the smooth flat solar heater) [5].

Anil Singh Yadav and **J.L. Bhagoria (2017)** An study was carried out on an HSA with square cross ribs, considered at the base of the top wall, where conditions for continuous heat flow were applied, and a numerical analysis was carried out with regard to the heat transport and the friction characteristics of the flow. On average Nusselt number, averaging friction factors and thermohydraulic performance parameters the effect of the relative ruggedness pitch was examined (THPP). This enquiry is intended to secure relative ruggedness in the range $7.14 \leq P/e \leq 17.86$ and the required Reynold numbers in the range $3800 \leq Re \leq 18{,}000$. The two-dimensional, steady, turbulent flow and heat transfer equations are solved with the finite volume process. The THPP is determined under the same pumping power limit in order to analyse the overall effect of the relative roughness pitch. The total THPP of 1.82 is achieved by using ribs with P/e at 10.71 for the existing set being examined [6].

For a SAH which has non-circular holes such as rectangular and square types placed on the blockages in V form, **Alam et al. (2014)** The disparity in Nusselt numbers and friction losses was experimentally studied. Results revealed that maximal flow resistance and Nu numbers are obtained for relative pitch P/e = 8 and 4, respectively. In the event of a rectangular hole of 0.69 circularity and an angle of attack close to 60°, thermal adjustment can be achieved.[7].

Aldabbagh and Egelioglu (2015) conducted an experimental SAH test to test fluid movement and thermal activity for single and double pass airflows with a transverse fin to measure the different flow ranges of 11×10^{-3} to 32×10^{-3} kg/s and the inclination angle of 37 °. The authors concluded that thermal efficiency and flow resistance on double pass channels were also higher than the SAH one pass [8].

Poongavanam et al. (2018) Used the V corrugation SAH with an altered surface to carry out the Nu number and the rectangular rectangular behaviour stage of mediated disruption and improved turbulence experimental study. The thermal efficiency of SAH was shown to be strongly dependent on SAH V-corrugation and solar radiation absorption. The results show enhanced SAH efficiency in the range of 1.35 to 1.56 times, relative to the smooth absorber layer. [9].

The computational studies performed by **Yang and Chen (2014)** were used to numerically measure a SAH using vertical partition walls along the absorber plate at the tip. The authors concluded that the existence of the partition is highly efficient compared to the smooth collector, and that dimensional parameters such as length (L), thickness (B) or pitch (A) play a key role in regulating THEP [10].

Gilani et al. (2017) new conical pin protrusions have been suggested, forming turbulators to improve SAH thermal efficiency. The findings revealed that the optimal value for inclination was 45 degrees. In comparison to the smooth duct, the THEP for the rugged wall was raised by up to 26.5 percent. [11].

Priyam suggested a theoretical analysis of SAH with transverse wavy fins on the heated top surface **(2017).** Results revealed that the THEP decreases with an increase in collector length with an increased pressure reduction [12].

Latest operating conditions were recently completed in theoretical analysis of the artificially rugged SAH with arc-shaped wires arranged by the **Yadav et al solar collector (2020).** The results suggest that the thermal efficiency improvement for the parallel flow in rough SAH is considerable compared to the smooth absorber case and can be approximately 8% to 10% in value [13].

Ajeet et al. (2020) Studies show that solar air heaters (SAH) curved thermo-hydrodynamically perform better than flat SAH. In addition, down-configuration of turbulator or expanded surfaces has been found to dramatically increase thermal efficiency in a flat plate solar collector. The highest gain in thermal efficiency was observed in half-trapezoidal and four-circular shapes, i.e. 17% and 16% respectively; however, relative to trapezoidal ribs, friction losses were found to be less by around 10% for quarter circular ribs [14].

III. CONCLUSIONS

Following a comprehensive literature analysis, several experimental and analytical studies have been performed using artificial ruggedness in the area of enhanced solar air heaters thermal efficiency. In most of research, some cylindrical, oval's, squares and rectangular ribs were studied, but, with the cross end, V-corrugation, delta, stepped cylindrical ribs. Due to the variation in rib shape and flow structure which shows the susceptibility to these parameters in each design, numerous studies have noted several degrees of heat transfer and friction improvements. For this reason, the aim of improving heat transfer with the lowest pressure loss penalties must be to select any chosen roughness type and, accordingly, to perform a thermo-hydraulic analysis. Studies on curved, ripple-based SAH, which led to the study's conduct to explore the best possible rib designs for greater thermo-hydraulic efficiency are evident from the discussion described above.

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