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USAGE OF ARTIFICIAL ROUGHNESS TO INCREASE THE EFFICIENCY OF SOLAR AIR HEATERS-REVIEW

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ABSTRACT

Solar energy is free and is a renewable source of energy. One useful way to use solar power is by using solar collectors to turn it into thermal energy. Solar collectors absorb solar radiation incident and turn it into usable heat for water or air heating. Due to the thermal resistance between the absorber and moving air, the solar air heater has a poor thermal efficiency. Various techniques were employed to boost solar air heater performance. In recent years, scientists have used artificial roughness and on-corrugated absorber plate to improve solar air heater performance. Artificial roughness is a crucial tool for enhancing air heat transport flow rates in solar air heating systems on the plain surface. By artificial roughness in the form of protrusions and dimples of varying sizes, scale and orientations on the underside of the heated Surface, the performance characteristics of a solar air heater can be enhanced effectively. Diverse rib geometries were developed over the years to analyse solar air heater heat transfer and friction characteristics. This paper seeks to analyse the creation of various rib geometries used to produce artificial roughness.

Keywords: Artificial roughness, solar air heater, Rib geometry, heat transfer, friction factor.

I. INTRODUCTION

Energy plays a crucial role in global economic development and brings fuel to industrialisation. In the near future, the decline of non-renewable energy sources has given way to the development of renewable energy sources. Solar air collectors serve to use solar energy in the form of hot air for heating, drying, desalinization, ventilation and heating applications in space. Because of the weak thermos-physical properties of the air, which result in low thermal efficiency, the convectional heat transfer coefficients between air and absorbers are low. There have been many research attempts to perform solar air collector enhancements using heat storage devices, create roughness, use obstacles, ribs, fins over the absorber surface, and use jet impingement techniques. Artificial roughness is a critical method for improving air heat flow rates on the plane in solar air heating systems. The efficiency characteristics of a solar air heater can be effectively improved by artificial roughness in the form of protrusions and dimples of various dimension, scale and orientation to the underside of the heated surface.

1.1. Performance representation of SAHs

Performance analysis is essential in order to design an efficient and optimal solar air heating system. Heat-transfer process is a measure of the thermal performance and the pressure drop in the duct tells about the hydraulic performance. The overall performance of the system is represented by the thermo-hydraulic performance and it helps in optimization of geometrical and operational parameters of the system. Performance parameters of a SAH are discussed in the following subsection.

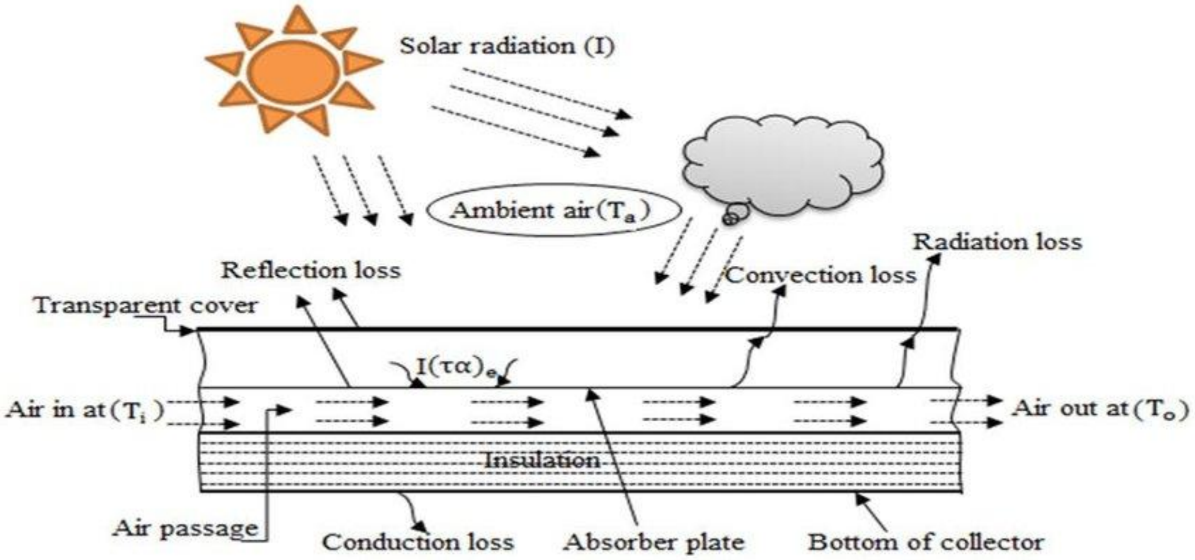

Fig.-1: Conventional solar air heater.

1.1.1. 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).

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

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

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:

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

It is evident from the above equation that useful heat gains and hence thermal efficiency of the SAH depend on heat transfer coefficient (h) between absorber plate and air. Therefore, the thermal performance of the SAH can be improved by increasing the value of the heat-transfer coefficient, which can be enhanced by the application of several active and passive enhancement methods. A heat-transfer characteristic is represented by a non-dimensional quantity, Nusselt number.

For smooth duct, the Nusselt number can be predicted from Dittus–Boelter equation as given below:

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

1.1.2. Hydraulic performance

The hydraulic performance of a SAH depicted about the power needed to induce the air in the duct. It is indicated in terms of the drop in pressure across the duct. Energy required for maintaining the airflow depends on friction factor between air and surface of flow channel. The pressure drop through a SAH with Reynolds number less than 50,000 for a fully developed turbulent flow is given 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:

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

1.1.3. Thermo-hydraulic performance

The SAH should be designed in such a way that it consumes minimum energy for inducting the air in duct and transfers maximum thermal energy to the fluid flowing in it. The thermal as well as hydraulic performance of a SAH is expressed with a non-dimensional quantity η, which is known as the thermo-hydraulic performance parameter defined as the following equation:

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

For rationalizing the use of artificial roughness, it is desirable to have a higher value of η (>1) in the SAHs. It shows rise in the heat-transfer rate i.e., Nusselt number to the pumping power i.e., friction factor of rough surface duct as related to without rough or plain surface duct.

1.2. Concept of artificial roughness

The flat plate solar air heater performance is poor due to the low heat transfer coefficient of the flat plate and the fluid air. Higher thermal resistance raises temperature of the absorber plate, resulting in higher thermal losses. The limited value of the coefficient of heat transfer is due to the laminar subsurface that is broken by artificial ruggedness of the heat transfer surface [1]. Efforts have been geared towards the artificial destruction of laminar sub-layer for enhanced heat transfer. Artificial roughness induces wall instability and splits the sub-layer laminar.

However, high friction losses contribute to increased power demands for fluid flowing due to artificial roughness. Thus, an area above the heat transfer surface needs to generate turbulence. The pumping power need should not be unreasonably disrupted by the central fluid flow. The result is that the height of the element roughness is limited relative to the dimensions of the duct [2]. The roughness element height (e) and pitch are essential parameters that define the roughness element (p). These are represented in dimensional-free parameters such as relative rudity (e/D_h) and relative roughness (p/e).

1.3. Effect of roughness parameters on the flow pattern

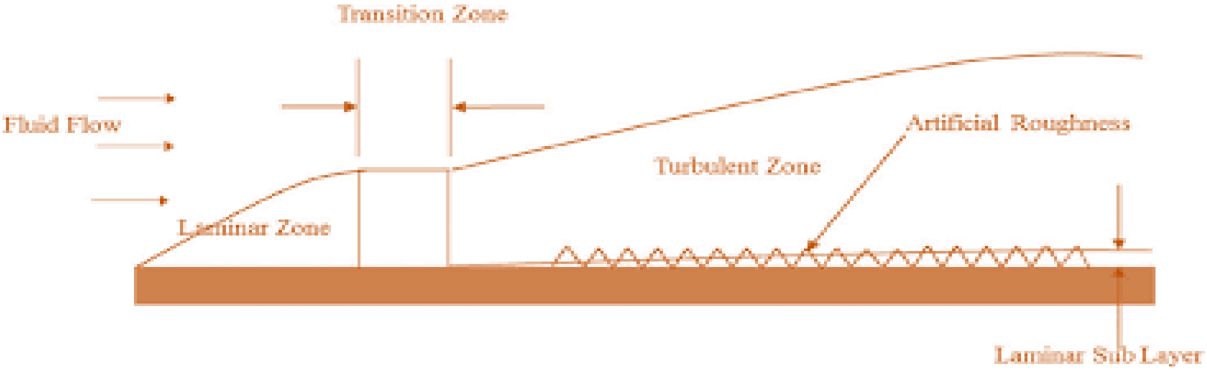

Fig.-2: Location of artificial roughness.

The thermal-hydraulic efficiency of the SAH duct is significantly influenced by the key geometrical parameters, such as the fluid-flowing fluid (W/H), rib to hydraulic diameter ratio (e/D), angle of rib attack (α), rib height ratio (P/e), and relative width gaps (g/e). (Attacking angle of the SAH duct, P/e). Different researchers have researched many additional parameters based on the type of roughness geometry.

II. LITERATURE REVIEW

In the present framework, the availability of energy is becoming a big issue in everyday life. A quantitative methodology is needed to forecast the supply of energy supplies due to the decline of traditional energy sources and the environmental risks it presents. Solar energy is a cost-effective and feasible renewable energy supply that can satisfy the continuous growth in energy demand. The flat plate solar air heaters (SAHs) are basic in nature and have less maintenance on the thermal route of their application. SAHs are commonly used for a range of industrial and domestic uses, such as room heating, moisture removal of agricultural products, heating of industrial products, wood/timber seasoning, etc.

One of the key problems of the SAH is its poor performance due to lower air transport capacity. A large amount of the thermal energy is lost to the ambient atmosphere from the absorber plate instead of being passed to the moving air. Researchers have reported various methodologies to resolve this. In the last few years, the interest in increasing the thermo-hydraulic efficiency (THEP) of SAH by the use of various active or passive techniques has become very important. The active approach is focused on the full turbulent flow produced and the local turbulence generated in these systems. The passive technique is based on the surface form of the adjusted and enhanced absorber.

Among these research articles, we can cite the work of Alam and Kim (2017), Kalogirou et al. (2016), Sharma, and Kalamkarar, among important review papers dealing with theoretical, computational and experimental studies for new proposed and enhanced prototypes for solar air heaters (2015).

For instance, **Alam and Kim (2017)** gave an analysis of SAH collectors with different criteria and different ribs. They suggested that the use of forced artificial roughness raised the volume of Nusselt but similarly increased the drop in pressure [1].

In their analysis report, **Kalogirou et al. (2016)** listed various groups of collectors of which the first category contains a parabolic dish and parabolic trough collector, and the second classification consists of SAH, evacuated tube collectors and flat-plate collectors. They found that the exergy analysis offers a helpful way of analyzing and assessing the various configurations of SAH [2].

A detailed thermal hydraulic efficiency study of artificially roughened collectors submitted by **Sharma and Kalamkar (2015)** later stated that there are a number of geometric structures that can be used to facilitate the heat transfer in SAH, such as artificial roughness, baffles, ribs, fins, and various shapes and configurations of groves. They also argued that the use of a limited turbulator height increased the number of Nusselt turbulators and reduced the decrease in pressure [3].

A review analysis of SAH with distinct artificial roughness geometry was performed by **Arunkumar, Karanth,** and **Kumar (2020).** The findings obtained indicated that the productive method of using turbulators as ribs roughness raises the temperature of the outlet air but also the friction factor. The THEP of the SAH decreases, however, as the amount of Re increases [4].

Gabhane and **Kanase-Patil (2017)** performed an experimental analysis on a SAH that has a double airflow pass and multiple C shape roughness on the heated wall for experimental studies. For a set height ratio (e/D = 0.02), the characteristics of a duct aspect ratio (W/H) equal to 10, Re number vary from 3000 to 15,000, rib pitch ratio (P/e) varied between 8 and 40 are considered. For a pitch ratio equal to 24, the highest increase in heat transfer (about 2.8 times relative to the smooth plate solar heater) with the lowest friction factor is obtained [5].

Anil Singh Yadav and **J.L. Bhagoria (2017)** performed an analysis on a SAH with square-sectioned transverse ribs considered at the underside of the top wall, where continuous heat flux conditions are applied, a numerical investigation is performed to examine the heat transport and flow friction characteristics. The influence of the relative roughness pitch was investigated on the average number of Nusselt, the average friction factor and the thermohydraulic efficiency parameter (THPP). Relative roughness pitch in the range of $7.14 \le P/e \le 17.86$ and relevant Reynolds numbers in the range of $3800 \le Re \le 18{,}000$ are protected by this inquiry. With the finite volume process, the two-dimensional steady, turbulent flow, and heat transfer governing equations are solved. In order to analyse the overall influence of the relative pitch of roughness, the THPP under the same pumping power constraint is determined. The overall THPP of 1.82 for the existing set examined is obtained by using the ribs with a P/e of 10.71 [6].

For a SAH that has non-circular holes such as rectangular and square types that are positioned on the V-shaped blockages, **Alam et al. (2014)** experimentally investigated the difference of Nusselt number and friction losses. Findings have shown that for relative pitch P/e = 8 and 4, respectively, maximal flow resistance and Nu number are obtained. In the case of a rectangular hole with a circularity equal to 0.69 and an attack angle similar to 60 °, thermal enhancement may be accomplished [7].

A SAH experimental research was performed by **Aldabbagh** and **Egelioglu (2015)** to test the fluid flow and thermal behavior for single and double-pass airflow with transverse fin for various mass flow values ranging from 11×10^{-3} to 32×10^{-3} kg/s with an angle of inclination of 37 °. In contrast with the single-pass SAH, the authors concluded that double-pass channel thermal efficiency and flow resistance were also higher [8].

Poongavanam et al. (2018) used a SAH with a modified surface with a form of V-corrugation to perform an experimental analysis of the impact on the Nu number and the pressure drop levels of a rectangular duct of the induced disturbances and enhanced turbulence. They found that the thermal efficiency of the SAH is highly dependent on the absorption of V-corrugation and solar radiation by the SAH. Compared to the smooth absorber layer, the results showed an improved SAH performance with an ideal THEP in the range of 1.35 to 1.56 times [9].

We may cite the work of **Yang** and **Chen (2014)** for numerical studies, who carried out an optimization technique to numerically evaluate a SAH with a vertical partition wall along the absorber plate at the top end. The authors concluded that, relative to the smooth collector, the presence of the partition provides high output and those dimensionless partition parameters such as length (L), thickness (W) and pitch (A) play an important role in the control of the THEP [10].

Gilani et al. (2017) proposed new conical pin protrusions form turbulators to increase the thermal performance of a SAH. The results showed that the ideal inclination value was 45 degrees. Compared with the smooth duct, a rise of up to 26.5% was achieved for the THEP for the roughened wall [11].

A theoretical study of SAH with transverse wavy fins attached to the heated top surface was proposed by **Priyam (2017).** Results demonstrated that with an elevated pressure reduction, the THEP decreases with the rise in the collector length [12].

Theoretical study of artificially roughened SAH with arc-shaped wires arranged under the solar collector's **Yadav et al (2020)** have recently carried out operating conditions**.** The findings showed that, relative to the smooth absorber case, the increase in thermal efficiency for a parallel flow in rough SAH is significant and can achieve a value of about 8 percent to 10 percent [13].

III. CONCLUSIONS

Various theoretical and experimental analyses of artificially roughness SAH are presented in this paper. A roughness geometry is defined by many parameters. The effect on heat transfer and friction efficiency by different operational and geometrical parameters of the roughness elements is studied. The findings analysed can be useful for selecting the optimum roughness elements in various solar air duct-operating conditions. In addition, it compares the ratio of increase of the Nusselt number, improvement of the friction factor ratio and hydraulic efficiency for various types of elements of roughness, dimples and protrusion. The following conclusions are taken based on the comprehensive literature review in this paper:

- The use of roughed absorbing surfaces is a cost-effective and reliable way to enhance the efficiency of solar air heating systems. Artificially roughened SAHs have better characteristics of heat transfer than plain SAHs that function under the same conditions. Different roughness pattern designs in SAHs are used based on roughness elements' lay outing, type, sizes, and orientation on the heat collection surface.
- Artificial roughness geometry used in DPSAH improves the thermal efficiency of the SAH duct. However, there are relatively few studies available in the literature to examine the thermal efficiency of artificial DPSAH.
- Owing to the variation in the shape of the rib and the flow structure, that shows the susceptibility of each design to these parameters, multiple studies note varying degrees of improvements in heat transfer and friction factor. Therefore, the purpose of heat transfer improvement with minimal

pressure loss penalty must be based on the choice of any preferred roughness shape and therefore a thermo-hydraulic performance analysis is required.

IV. REFERENCES

[1] Alam, T., and M. H. Kim. 2017. A critical review on artificial roughness provided in rectangular solar air heater duct. Renewable and Sustainable Energy Reviews 69:387–400. doi:10.1016/j.rser.2016.11.192.

[2] Kalogirou, S. A., S. Karellas, K. Braimakis, C. Stanciu, and V. Badescu. 2016. Exergy analysis of solar thermal collectors and processes. Progress in Energy and Combustion Science 56:106–37. doi:10.1016/j.pecs.2016.05.002.

[3] Sharma, S. K., and V. R. Kalamkar. 2015. Thermo-hydraulic performance analysis of solar air heaters having artificial roughness-A review. Renewable and Sustainable Energy Reviews 41:413–35. doi:10.1016/j.rser.2014.08.051.

[4] Arunkumar, H. S., K. V. Karanth, and S. Kumar. 2020. Review on the design modifications of a solar air heater for improvement in the thermal performance. Sustainable Energy Technologies and Assessments 39:100685. doi:10.1016/j. seta.2020.100685.

[5] Gabhane, M. G., and A. B. Kanase-Patil. 2017. Experimental analysis of double flow solar air heater with multiple C shape roughness,". Solar Energy 155:1411–16. doi:10.1016/j.solener.2017.07.038.

[6] Anil Singh Yadav & J.L. Bhagoria (2017) Numerical investigation of flow through an artificially roughened solar air heater, International Journal of Ambient Energy, 36:2, 87-100, DOI: 10.1080/01430750.2013.823107

[7] Alam, T., R. P. Saini, and J. S. Saini. 2014. Effect of circularity of perforation holes in V-shaped blockages on heat transfer and friction characteristics of rectangular solar air heater duct. Energy Conversion and Management 86:952–63. doi:10.1016/j.enconman.2014.06.050.

[8] Al-Dabaggah, M., Z. A. H. Obaid, M. Al Qubeissic, D. Dixon-Hardyd, J. Cottome, and P. J. Heggsd. 2015. CFD modeling and performance evaluation of multipass solar air heaters. Numerical Heat Transfer, Part A: Applications 76 (6):438–64. doi:10.1080/10407782.2019.1637228.

[9] Poongavanam, G. K., K. Panchabikesan, A. J. D. Leo, and V. Ramalingam. 2018. Experimental investigation on heat transfer augmentation of solar air heater using shot blasted V-corrugated absorber plate. Renewable Energy 127:213–29. doi:10.1016/j.renene.2018.04.056.

[10] Yang, Y., and P. Chen. 2014. Numerical study of a solar collector with partitions. Numerical Heat Transfer, Part A: Applications 66 (7):37–41. doi:10.1080/10407782.2014.892330.

[11] Gilani, S. E., H. H. Al-Kayiem, D. E. Woldemicheal, and S. I. Gilani. 2017. Performance enhancement of free convective solar air heater by pin protrusions on the absorber. Solar Energy 151:173–85. doi:10.1016/j.solener.2017.05.038.

[12] Priyam, A. 2017. Heat transfer and pressure drop characteristics of wavy fin solar air heater. International Journal of Heat and Technology 35 (4):1015–22. doi:10.18280/ijht.350438.

[13] Yadav, K. D., and R. K. Prasad. 2020. Performance analysis of parallel flow flat plate solar air heater having arc shaped wire roughened absorber plate. Reinforced Plastics 32:23–44. doi:10.1016/j.ref.2019.10.002.

[14] Thakur, S., and N. S. Thakur. 2020. Impact of multi-staggered rib parameters of the 'W' shaped roughness on the performance of a solar air heater channel. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects 1–20. doi:10.1080/15567036.2020.1764672.

[15] Wang, L., and B. Sunden. 2007. Experimental investigation of local heat transfer in a square duct with various-shaped ribs. Heat and Mass Transfer 43 (8):759–66. doi:10.1007/s00231-006-0190-y.

[16] Webb, R. L., and E. R. Eckert. 1972. Application of rough surfaces to heat exchanger design. International Journal of Heat and Mass Transfer 15 (9):1647–58. doi:10.1016/0017-9310(72)90095-6.

[17] Yadav, A. S., and J. L. Bhagoria. 2013a. A CFD (computational fluid dynamics) based heat transfer and fluid flow analysis of a solar air heater provided with circular transverse wire rib roughness on the absorber plate. Energy 55:1127–42. doi:10.1016/j.energy.2013.03.066.

[18] Yadav, A. S., and J. L. Bhagoria. 2013b. Heat transfer and fluid flow analysis of solar air heater: A review of CFD approach. Renewable and Sustainable Energy Reviews 23:60–79. doi:10.1016/j.rser.2013.02.035.

[19] Yadav, A. S., and J. L. Bhagoria. 2014a. A numerical investigation of square sectioned transverse rib roughened solar air heater. International Journal of Thermal Sciences 79:111–31. doi:10.1016/j.ijthermalsci.2014.01.008.

[20] Yadav, A. S., and J. L. Bhagoria. 2014b. A numerical investigation of turbulent flows through an artificially roughened solar air heater. Numerical Heat Transfer, Part A: Applications 65 (7):679–98. doi:10.1080/10407782.2013.846187.

[21] Yadav, A. S., and J. L. Bhagoria. 2014c. A CFD based thermo-hydraulic performance analysis of an artificially roughened solar air heater having equilateral triangular sectioned rib roughness on the absorber plate. International Journal of Heat and Mass Transfer 70:1016–39. doi:10.1016/j.ijheatmasstransfer.2013.11.074.