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Effect of Artificial Roughness on the Heat Transfer and Friction Characteristics of Solar Air Heater-A Review

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Abstract:

This study discusses the process of artificially creating roughness with repeated-ribs, or simply rib roughness, on solar air heater's (SAH's) absorber plate. There are various kinds of rib roughness: transverse, circular, triangular, rectangular,etc. These ribs are put through a thorough inspection to see whether there has been any progress in design and, as a result, whether there has been any change in results. Discussions on many of the variables that can affect SAH efficiency have been discussed in this review. The focus of this review is on the physics of HT and fluid flow nearby these ribs. Recent developments in repeated-rib roughness in SAH have been thoroughly discussed.

Keywords **—Heat Transfer, Solar Air Heater, Nusselt Number, Ribs, Reynolds Number.**

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I. INTRODUCTION

Energy is the capacity of doing work, in physics. It is the primary force in the universe or world. There are many forms in which energy exists such as Mechanical Energy, Electrical Energy, Chemical energy, Radiation energy and other many forms are available. One of such form is radiation energy[1, 2].

Solar energy is the type of radiant energy which we get from sun. Solar energy is transformation of heat or radiant energy that we get or comes from sun. It is the cleanest and renewable source of energy available in abundant amount. There are many advantages of solar energy such as renewable source, low cost of maintenance. Various application of solar energy is solar water heater, solar thermal power plant, solar cooker, Solar pumps, Solar electricity generation plantetc. One of its applications is Solar air heater (SAH) device which is used to provide warm air for domestic as well as industrial uses. This warm air is used for preheating for furnaces, dryers, in construction field can be used for heating of interior spaces, heating of building wallsetc. [3-7].

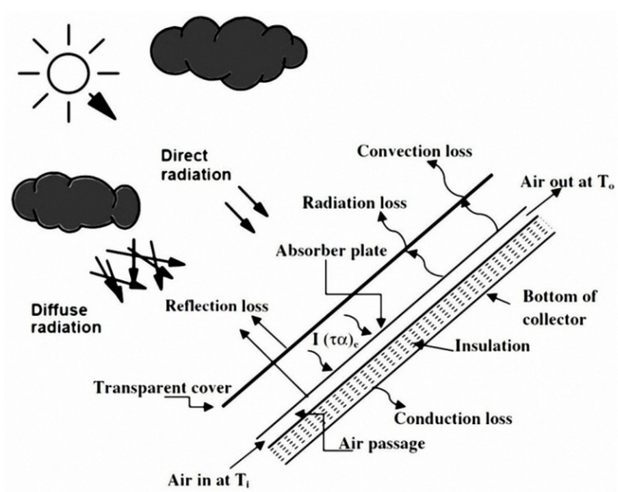

Fig. 1 Solar air heater

Solar Air heater (SAH) is the device which is widely used because of its simple and economical design and cost(Fig. 1). Solar air heater is the device which uses solar energy for its functioning. Solar air heater traps or capture solar energy emitting from sun's surface through absorbent surface or plate and utilize this energy to heat up air flowing over the surface. Solar Air heater has its main application in heating up of interior spacing, seasoning of timber, industrial process heating, etc. [8-11].

Solar air heater has poor transportation of heat or thermal energy between absorber layer and fluid flow due to low thermal efficiency because of low convective heat transfer coefficient due to development of very thin layer of laminar viscous sub layer on absorber surface. Due to which overall efficiency of Solar air heater is poor and which can be improved by developing or modifying of boundary layer formed on absorber surface. There are different well-known theoretical or experimental methods for fluid, surface and compound enhancement are developed for modification of boundary layers. Various investigations were performed on these methods and one of most common method as roughing of absorber surface or using of fins over the surface. Smooth absorber plate or surface has low thermal performance, to enhance thermal performance and efficiency of air heater surface is roughed through various natural or artificial methods such as to create ribs, grooves over surface to break or split the laminar viscous layer formed at boundary layer.Artificial roughness has various application in gas turbines, nuclear reactors, etc. The artificial roughness increases the efficiency and heat transfer rate by creating wall turbulence due to flow separation and reattachment between consecutive ribs or grooves. Heat transfer of air heater is increased but at the rate of increased frictional factor and enhance heat transfer coefficient with minimum pressure drop (i.e., power penalty). Hence, number of experiments and investigations are going on for different shape, type and size of rib and its arrangement which increases overall efficiency of air heater with less friction value and power penalty.Artificial roughness for boundary layer can be achieved by sand blasting over surface, developing grooves, ribs or wire geometry in surface, fixing ribs of different shape, size and orientation according to flow direction such as circular, rectangular, square, V-shaped ribs, etc. [12-35].

Number of CFD investigations are performed by different scientist involving roughness for solar air heater in order to obtain optimized arrangement of roughness element geometry. The objective of this paper is to review various CFD investigations performed for enhancement of heat transfer in solar air heater.

II. LITERATURE REVIEW

Number of CFD investigations are performed by different scientist involving roughness for solar air heater in order to obtain optimized arrangement of roughness element geometry.

Yadav and Bhagoria [36]presented the numerical prediction of fluid flow and heat transfer in a conventional solar air heater by using computational fluid dynamics (CFD). The effect of Reynolds number on heat transfer and friction factor was investigated. It has been found that the Nusselt number increases with increase in Reynolds number and friction factor decreases with increase in Reynolds number.

Yadav and Bhagoria [37] presented a numerical prediction to study heat transfer and flow frictionbehaviors of a rectangular duct of a solar air heater having triangular rib roughness on the absorber plate.They found that the maximum value of Nusselt number has been found corresponding to relative roughness pitch of 10.

A 2-dimensional CFD analysis has been carried out to study heattransfer and fluid flow behavior in a rectangular duct of a solar airheater with one roughened wall having circular transverse wire ribroughness by Yadav and Bhagoria [38]. The effect of Reynolds number, roughness height,roughness pitch, relative roughness pitch and relative roughnessheight on the heat transfer coefficient and friction factor werestudied(Fig. 2).

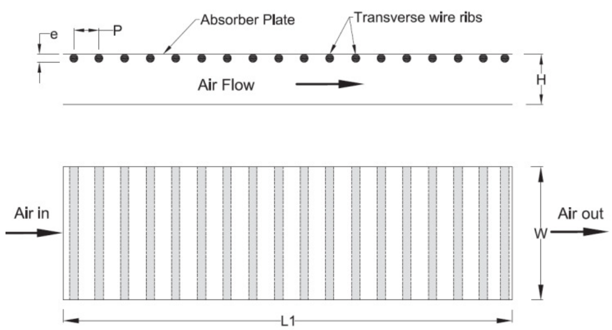

Fig. 2Circular transverse wire rib roughness

Yadav and Bhagoria [39] presented a detailed review of the literature that deals with the application of CFD in design of solar air heater. In this article a CFD investigation was carried out to select best turbulence model for the design of a solar air heater.

Yadav, et al. [40]presented the study of fluid flow and heat transfer in a rectangular duct of a solar air heater by using Computational Fluid Dynamics (CFD). Circular rib was used as a roughness element. The effect of rib pitch and Reynolds number on heat transfer coefficient and friction factor was investigated.

Yadav and Bhagoria [41]performed two-dimensional CFD analysis of a solar air heater roughened with square-sectioned transverse rib roughness on the absorber plate for four differentconfigurations of rib roughness and six different values of Reynolds number, ranging from 3800 to 18,000 (Fig. 3).

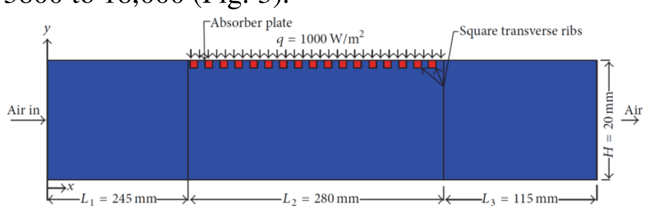

Fig. 3Computational domain

Turbulent kinetic energy, turbulent intensity, and pressure contour maps were presented for characteristic flow behaviors in artificially roughened solar air heater.

Yadav and Qureshi [42]studied the fluid flow and heat transfer in a plain rectangular duct of a solar air heater by using computationalfluid dynamics. The effect of Reynolds number on heat transfer coefficient and friction factor was investigated.

Yadav, et al. [43]focused on three approaches or methods that can be used to solve a problem of fluid flow and heat transfer in an artificially roughened solar air heater. The objective of this paper was to presents a comparison of different approaches that can be used to solve problems of fluid flow and heat transfer of an artificially roughened solar air heater.

Yadav and Bhagoria [44]numerically investigated to analyze the two-dimensional incompressible Navier–Stokes flows through the artificially roughened solar air heater for relevant Reynolds number ranges from 3800 to 18,000. Twelve different configurations of equilateral triangular sectioned rib (P/e = 7.14–35.71 and e/d = 0.021–0.042) have been used as roughness element. Optimum configuration of the roughness element for artificially roughened solar air heater was evaluated (Fig. 4).

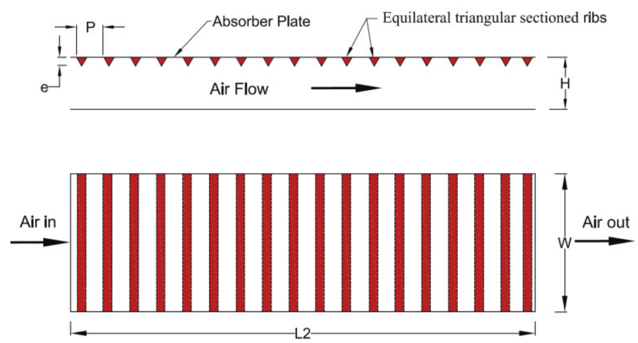

Fig. 4Equilateral triangular sectioned rib

A numerical investigation on the heat transfer and fluid flow characteristics of fully developed turbulent flow in a rectangular duct having repeated transverse square sectioned rib roughness on the absorber plate was carried out by Yadav and Bhagoria [45]. The commercial finite-volume CFD code ANSYS FLUENT (ver. 12.1) was used to simulate turbulent airflow through artificially roughened solar air heater. It was found that the square sectioned transverse rib roughened duct with P/e = 10.71 and e/D = 0.042 offers the best thermo-hydraulic performance parameter for the investigated range of parameters.

Yadav and Bhagoria [46] investigated the effect of rib (circular sectioned) spacing on average Nusselt number and friction factor in an artificially roughened solar air heater (duct aspect ratio, AR = 5:1) by adopting the computational fluid dynamics (CFD) approach. Circular sectioned transverse ribs were applied at the underside of the top of the duct, i.e., on the absorber plate. The thermo-hydraulic performance parameter for P/e = 10.71 was found to be the best for the investigated range of parameters at a Reynolds number of 15000.

Yadav, et al. [47]presented the effect of various parameters that affecting the thermo-hydraulic performance of artificially roughened solar air heater. There are several parameters that characterize the roughness elements, but for solar air heater the most preferred roughness geometry was repeated rib type.

A numerical investigation ofturbulent flows through a solar air heater roughened with semicircular sectioned transverse rib roughness was executed by Yadav and Bhagoria [48]. The physical problem was represented mathematically by a set of governing equations, and the transport equations were solved using the finite element method (Fig. 5). The thermohydraulic performance parameter was found to be the maximum for the relative roughness height of0.042.

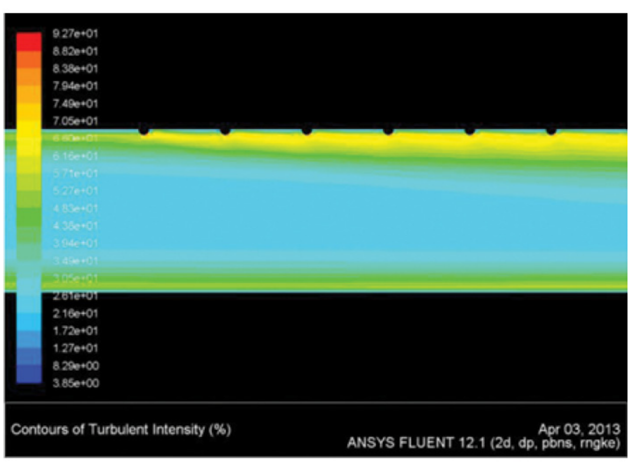

Fig. 5Contour plot of turbulent intensity

Yadav and Thapak [49]presented holistic view of different kinds of roughness geometry used for creating artificial roughness in solar air heater for performance enhancement by experimental approaches. Thirty-eight experimental studies were reported on solar air heater, roughened with different kinds of roughness geometry.

Yadav and Thapak [50]evaluated the turbulence intensity of a rectangular duct of a solar air heater with repeated ribs as roughness elements provided at the wetted side of the bottom wall. The effect of roughness on turbulence intensity was investigated for the range of Reynolds number from 3000 to 18000. It was also observed that the rib-roughened surface in a rectangular duct produces higher turbulence intensities as compared to the smooth surface.

A numerical investigation was conducted to analyze the heat transfer and flow friction characteristics in an artificially roughened solar air heater having square-sectioned transverse ribs considered at underside of the top wall by Yadav and Bhagoria [51]. The effect of relative roughness pitch on average Nusselt number, average friction factor, and thermohydraulic performance parameter (THPP) was investigated (Fig. 6).The maximum THPP of 1.82 was achieved by the use of the ribs with P/e of 10.71.

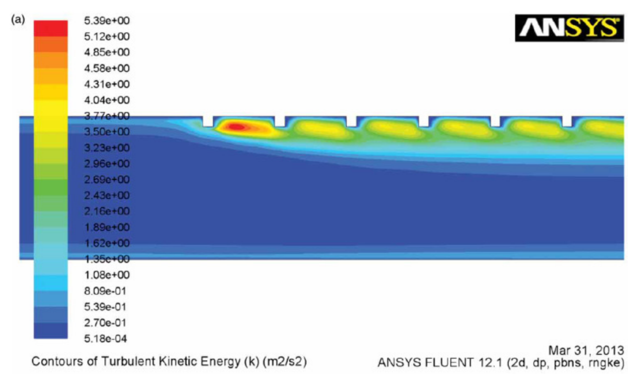

Fig. 6The contour plot of turbulent kinetic energy

Effect of relative roughness height on Nusselt number and friction factorin an artificially roughened solar air heater having circular-sectioned transverse rib roughness (duct aspect ratio,AR = 5:1) was studied by adopting CFD (computational fluid dynamics) approach[52].The thermal enhancement factor for e/D = 0.042 was found to be the best for the investigated range ofparameters and is about 1.635 (Fig. 8).

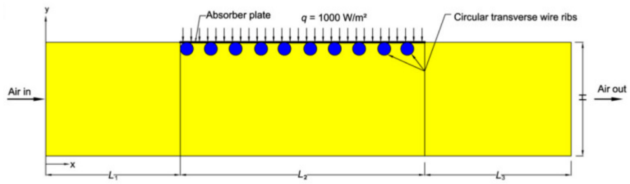

Fig. 7Schematic of 2D computational domain

A 2-dimensional CFD analysis was carried out to study heat transfer and fluid flow behavior in a rectangular duct of a solar air heater with one roughened wall having circular and square rib roughness[53]. The effect of Reynolds number and relative roughness pitch on the heat transfer coefficient and friction factor was studied. It was found that the thermal enhancement factor values vary between 1.42 and 1.74 for circular rib and between 1.51 and 1.762 for square rib.

Yadav and Thapak [54]presented holistic view of various roughness geometries used for creating artificial roughness in solar air heater for heat transfer enhancement. Authors presented a comparative study of thermo-hydraulic performance of 21 different types of artificial roughness geometries attached on the absorber plate of solar air heater in terms of thermo-hydraulic performance parameter.

Yadav [55]presented the study offluid flow and heat transfer in a plain rectangular duct having artificial roughness on the absorber plate by using Computational Fluid Dynamics (CFD). The effect of Reynolds number on heat transfer coefficient and friction factor was investigated. A commercial finite volume package ANSYS FLUENT was used to analyze and visualize the nature of the flow across the duct of a solar air heater. It was found that the Nusselt number increases with increase in Reynolds number and friction factor decreases with increase in Reynolds number.

Yadav, et al. [56] presented a complete review on modifications made on the absorber plate of solar air heaters in order to improve the turbulence and heat transfer rate, thereby efficiency. Corrugated sheets, fins, extended surfaces, wire mesh, porous medium, etc. were a few of the modifications used. Most of such alterations in the absorber plate resulted with an increase in efficiency but associated with drawback of increased pumping power due to raising friction factor.

Yadav [57]presented the effect of chamfer rib roughness on the absorber plate due to its superior thermo-hydraulic performance. The analysis was carried out using relative roughness pitch in the range of 7.143-17.857, relative roughness height of 0.042 and for a relevant Reynolds number, ranges from 3800- 18000. The effect of relative roughness pitch and Reynolds number on heat transfer enhancement and friction characteristics was studied and presented for chamfered rib.

Prasad, et al. [58]presented the improvement of warmth conveying rate by creating harshness underside of onlooker surface in sun-powered air warmer. CFD examine was, to appraise warm course through convection and grinding factor in SAH pipe in which symmetrical triangular formed transverse rib. Computational outcomes were accomplished utilizing CFD apparatus Ansys-Fluent. The most extreme value of Nu and f in this present work were accomplished 2.94 and 3.27 individually.

A numerical simulation of a solar air heater (SAH) with transverse equilateral triangular ribbed surface is carried out[59].

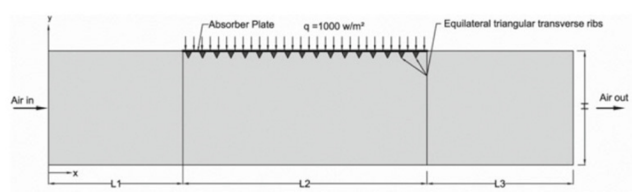

Fig. 82D computational domain

The thermal and flow properties are investigated through ANSYS FLUENT 12.1. The SIMPLE algorithm was used for coupling pressure and velocity. Second-order upwind scheme for discretization of the equations and renormalization-group (RNG) k-e model was used for simulation(Fig. 8). An optimum thermal enhancement factor (THF) obtained was 1.99

A new CFD-based correlation for rib roughened solar air heater is presented by Yadav, et al. [60]. The analysis was performed within the pitch, P from 10 to 25 mm and Reynolds number, Re from 3800 to 18,000 limits. The resulting data was reduced into correlations using a linear stepwise regression algorithm. The developed correlations predict all the data for Nu_r and f_r within ± 5% relative absolute deviation.

Yadav, et al. [61]introduced new CFD-based correlations for ribbed roughened solar air heater. An absorber plate of SAH (solar air heater) attached with circular ribs was analyzed. ANSYS Fluent v16 was utilized to analyze the turbulent airflow for different arrangements of rib (Fig. 9).The developed equations for artificially roughened heater of solar air predict all the data for friction factor and Nusselt number within ±5% relative absolute deviation.

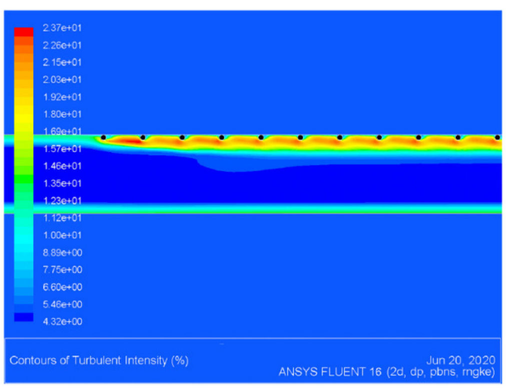

Fig. 9The contour plot of TI

Yadav, et al. [62] conducted a 2-D numerical investigation of rib implementation on smooth plates of the solar air heater (SAH) to enhance the heat-transfer coefficient. Semi-circular contrived shapes of ribs were considered for numerical investigation. Results reveal that semi-circular rib with pitch distance P = 15 mm showed the best Nusselt number and gradual reduction of friction factor.

III. CONCLUSIONS

This paper reviews about different numerical investigations performed by numerous researchers in the view to enhance the heat transfer rate, thermal efficiency of Solar air heater (SAH) by introduction or development of artificial roughness of boundary or absorber plate. It has been concluded that numerous researchers and scientists have performed number of investigations on artificial roughness of absorber plate by developing ribs or grooves of different shape, size and orientation such as rectangular rib, square rib, triangular rib,etc. with different patterns of arrangement such as longitudinal, radial, etc. to achieve maximum heat convective coefficient along with low frictional value and power penalty.

On the basis of review of article for roughness on solar air heaters, the conclusion can be summarized as: -

1. The implementation of concept of artificial roughness in surface of air heater enhances the heat transfer and overall thermal efficiency of device as compared to smooth surface design.
2. It has been experimentally found that artificial roughness geometry can be used of different shape, size and orientation for better performance.
3. It has been found that use of artificial roughness result in higher pumping power requirement because of higher frictional value. So, it is desirable to design solar air heater in such a way that it consumes less pumping power along with better thermal efficiency.
4. This review of literature reveals that a lot of work has been reported on design of solar air heater by experimental approach. This review also reveals that a few studies have been done on CFD analysis of solar air heater.
5. Several relations and equations have been developed by numerous investigators in order to forecast or calculate thermo-hydraulic efficiency of Solar air heater with roughened surface.

6. Traverse rib geometry enhances the heat transfer through flow separation and generation of vortices in both streams (i.e., upstream and downstream) of rib and reattachment of flow in inter-rib spaces.
7. It appears from the performed calculations that the Renormalization-group k–ε model yields the best results for two-dimensional flows through a conventional solar air heater.

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