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A Review on the Influence of Provision of Artificial Roughness on Thermal Performance of a Rectangular Solar Air Heater Duct

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Abstract: Solar air heater have low thermal efficiency due to the poor convective heat transfer coefficient between the absorber plate and flowing fluid (air).This paper presents a review of the experimental study and numerical study by using softwares like CFD, ANSYS etc. performed to enhance the thermal performance of the rectangular shaped solar air heater duct . For this purpose, several researchers used artificial roughness beneath the absorber plate .Use of the artificial roughness helps in improving the heat transfer between absorber plate and fluid by breakage of the laminar sub layer formed at thevicinity of the duct walls. The artificial roughness used were in form of ribs/baffles and wire mesh .Researchers used the different geometries and dimensions of the roughness elemnt and studied their influence on the heat transfer and flow characteristics of the solar air heater. This review present a detailed analysis of the performance factor of solar air heater with the roughness element of different shapes, sizes and orientation.
Keywords: Solar air heater; Turbulence; Heat transfer; Friction; Ribbed roughened duct.

I. INTRODUCTION

In modern era , due to the continuous depletion of the conventional soues of the energy ,it has been become necessary to search an alternative to them as they are available in limited quantity. The best alternative to these are the non-conventional sources of energy which are available in unlimited quantity and are more advantageous as they do not degrade environment. One of themost used non conventional source of energy is the solar radiation. Nowadays solar radiation are converted to thermal energy by using some collector devices to utilize it in various application such as crop drying, industrial drying, water heating etc. Solar air heater is one of such devices used to heat the air passing through its duct which can be utilized for industrial drying applications. The thermal efficiency obtained with solar air heater is considerable low due to low heat transfer coefficient between the absorber plate and the flowing fluid. This is due to the formation of laminar sub layer at the region near the walls of the absorber plate when the flow through solar air heater duct is turbulent. Laminar sub layer behaves as an insulation to the heat transfer phenomenon. Therefore it become necessary to break the laminar sub layer at the vicinity of wall and this can be done by providing some artificial roughness at the wall which will create excessive turbulence in the flow. However, providing roughness at the wall will improve thermal efficiency but it will also increase the frictional losses and pumping power requirements, therefore the roughness is provided only in the laminar sub layer zone to neglect these losses with considerable enhancement in heat transfer efficiency. The artificial roughness can be provided at the solar air heater wall by using ribs, baffles, protrusion wires etc, of different shapes and sizes. Enhancement of heat transfer efficiency of a rectangular solar air heater duct by using different shapes ribs has been a common practice in the recent years. The most common shape of a solar air heater used for various application is a rectangular duct consisting an absorber plate on the top, a back plate, insulated wall over the back plate, a glass cover exposed to solar radiation, and a passage for the flow of air between the absorber and bottom plate. Fig 1, shows the thermal network of a solar air heater.

II. DIFFERENT ROUGHNESS ELEMENT USED BY RESEARCHERS

Prasad and Mullick[1] gave opinions about what could or should be done about a situation that for the purpose of drying cereal grains, temperature increase of 3-6oC was (good) enough. They done experiments on an unglazed rectangular shape duct, which was vented by an absorber plate at the top. Just below the absorber plate, protruding wires were provided, in order to study their effect on the friction characteristics and heat transfer properties of their solar air heater. They originate that heat transfer coefficients agreed well with the existing (related to ideas about how things work or why they happen) relationships. They further commented that the effect of sticking out protruding wires beneath the absorber plate was that it helped to grown up the unglazed collector efficiency from 63% to 72% at reynolds number 40000

Prasad and Saini[2] measured the performance of fully developed full of violently swirling disorder) flow in an (in a way where the left side doesn't match the right side in an asymmetrically heated solar air heater duct which was provided with protruded wires just below the collector plate and derivative the correlations for the calculation of average friction factor and average Stanton number. They found 6.3 % mean deviation of their friction factor results and 10.7 % of Nusselt number from the available data. They declaired that the addition of roughness to the absorber plate was to augment the heat transfer as well as the friction factor. They used two limits to measure the performance of their solar air collector, which were relative roughness pich and relative roughness height. As there was increment in the relative roughness pitch, the rate of heat transfer was observed to drop with an increase in the value of friction factor, whereas the friction factor and the heat-transfer, both reduced with the improvement in relative roughness pitch.

Liou and Hwang [3] conducted experiments on a rectangular duct, heated from the top, provided with three types of ribs, Semi-circular triangular and square. These were arranged transverse to the flow direction. The Reynolds number range was 7800-50000 and the rib height-to-hydraulic diameter ratio was 0.08. Fully developed flow conditions were established in their test section. They concluded that the three different configurations of solar air heater yielded comparable friction and heat transfer properties. Triangular ans semicircular ribs have less performance as compared to square ribs .

Gupta [4] Did an experimental study on a solar air heater to find the fluid flow and thermal features in the changing from one thing to another) rough flow regime. The range of Reynolds number was 3000-18000 and the rectangular duct aspect ratio was varied from 6.8 to 11.5 whereas the relative roughness height was increased from 0.018 to 0.052. The value of relative roughness pitch was continued constant at 10. Stanton number behavior is different in case of rough. flow regims and fully rough flow regims . Also they developed a set of correlations that could forecast the thermal and flow characteristics in the transitionally rough flow regime.

Saini and Saini[5] Experimentally examined fully developed turbulent flow in an unequally heated and artificially roughened rectangular duct. The duct was covered with the help of an absorber plate that was integrated with expanded metal mesh. The mesh length (L/e) was varied from 25 to 71.87, the short-way length of mesh from 15.62 to 46.87 and the height of mesh (e/Dh) varied from 0.012 to 0.039. The experiments were managed and done within the range of Reynolds number 1900 to 13000.

The authors found that the change in the geometry of the extended metal mesh had a strong effect on the thermal and frictional resistance of the solar air heater. From their experimental results, the authors successfully created friction factor and Nusselt number correlations as a function of these parameters.

Karwa [6] Investigated experimentally the performance of their solar air heater when its collector plate was roughened with the help of repeated chamfered ribs. The rectangular duct aspect ratio was changed from 4.8 to 12.0 and the Reynolds number was varied from 3000 to 20000. The e/D_h range was 0.0141 - 0.0328, p/e range was 4.5-8.5 and chamfer angle range 15^o-18^o. Fully developed turbulent flow conditions were established in the rectangular duct's test section. The authors found that at chamfer rib angle of 15^o, the frictional resistance and heat transfer values were the highest. They further concluded that these were strongly dependent on the duct aspect ratio. The authors successfully established correlations for the calculation of these parameters in terms of various parameters and observed that the highest Stanton number occurred with 20-25 as the Reynolds number range.

Verma and Prasad [7] conducted experiments on an artificially roughened rectangular duct heated from the top. Intermittently repeated arrangement of thin wires, transverse to the flow direction, served the purpose of increasing the roughness of the absorber plate. The thermohydraulic performance at optimal conditions was observed when the roughness Reynolds number was 24.They further concluded that the thermal performance parameter at optimal conditions was 71 %.

Murata and Mochizuki [8] Numerically studied the effect of angled and transverse ribs on both laminar and turbulent flow in a solar air heater. The domain was a rectangular duct heated only on the top wall. The remaining walls were insulated. The angles of the ribs chosen were 60^o and 90^o. They found that in case of turbulent flow, high heat transfer coefficients spots were spotted at locations exactly between any two consecutive ribs. They additionaly commented that the effect of the disturbances in case laminar flow was small as compared to that of turbulent flow. As a result, the heat transfer improvement in case of laminar flow was very less as compared to that of turbulent flow.

Ahn [9] Experimentally studied on a rectangular duct, the effect of five different shaped ribs on the thermal and fluid flow characteristics of turbulent flow (fully developed). The channel aspect ratio was 2.33 and was constant heat flux was supplied only at the top face of the test section of the duct. The rib p/e and e/D_h values are fixed at 8 and 0.0476 respectively. The various geometries used as ribs were semicircular square, circular (wire),and triangular. They found that the triangular shaped rib give highest heat transfer coefficient and the square crosssectioned ribs gave the maximum friction factor value.

Momin [10] conducted experiments on a v-shaped ribbed solar air heater to study its heat transfer and friction properties. The varied Reynolds number was from 2500 to 18000, angle of flow attack from 30 to 90^o and relative roughness height (e/D_h) from 0.02 to 0.034. The pitch of the arrangement was kept fixed at 10. The authors determined that the presence of disturbances improved the heat transfer coefficient as well as the friction factor, on comparison to that of a smooth duct operating under the same flow conditions. It was indirect from the experimental results that the Reynolds number improvement resulted in the increase in Nusselt number and a decreases in friction factor. The experimental results also shown that as the Reynolds number increased, the Nusselt number enhancement rate was less as compared to the friction factor enhancement rate. Moreover, it was observed that the highest increase in friction factor and Nusselt number was 2.83 and 2.30 respectively at 60^o angle of attack. Also, the authors claimed that the v-shaped ribs gave the best thermo-hydrodynamic performance as compared to other shaped ribs. The authors were also successful in developing correlations for Nusselt number and friction factor as a function of different rib parameters and Reynolds number, where Reynolds number had a stronger effect as compared to other parameters.

III. CONCLUSION

With the incorporation of the artificial roughness in different shapes , an enhancement in the performance characteristics of the solar air heater was observed by the different researchers. Moreover, the researchers concluded that the convective heat transfer coefficient between the absorber plate and the flowing fluid are influenced by the performance parameters like relative roughness pitch, relative roughness height, geometry of ribs and the inclination of the ribs. Roughness element increases the Nusselt number and friction factor. Thus, the application of roughness element is desirable to improve the thermal performance of the heater. This paper will be helpful for the future researches concerned with the improvement of the heat transfer efficiency of the solar air heater.

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