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A Review on Heat Transfer Enhancement of a Solar Air Heater by providing Artificial Roughness of Different Shape

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Abstract: By using the artificial roughness in an absorber plate surface of solar air heater the heat transfer rate to fluid flowing though solar air heater duct can be effectively enhanced. Artificial roughness of various geometries has been used and investigated on heat transfer and friction characteristics. In this paper, an attempt has been make to review on roughness element geometries used in a solar air heater in order to enhance the heat transfer capacity of solar air heater ducts.

I. INTRODUCTION

Energy is used in various forms throughout the world for different purposes, playing an important role in the economic and industrial development of the nation. Since the conventional non-renewable sources of energy have limited reserves, their conservation has been become necessary. Due to this reason, it has been become necessary to utilize the non-conventional inexhaustible sources of energy to fulfill the energy needs. Sun is known as the source of all energy. Sunlight reaching the earth surface is a wide source of energy, if only 5% of the solar radiation reaching the earth surface can be utilized, it will fulfill our energy demand for the next 50 year. The most simple and effective way of utilizing is to convert it in to thermal energy by application of solar collectors. Due to simplicity in construction, the solar collector have been widely used for space heating, grain drying, seasoning of timber, curing of industrial products treatment of saline water, curing/drying of concrete/clay building components. The solar air heater is one of the most known solar device used for heating the air which can be utilized in grain drying, space heating, gas turbine etc.

Thermal performance of the solar air heater depends upon the intensity of the incident radiation and losses from the absorber plate surface.

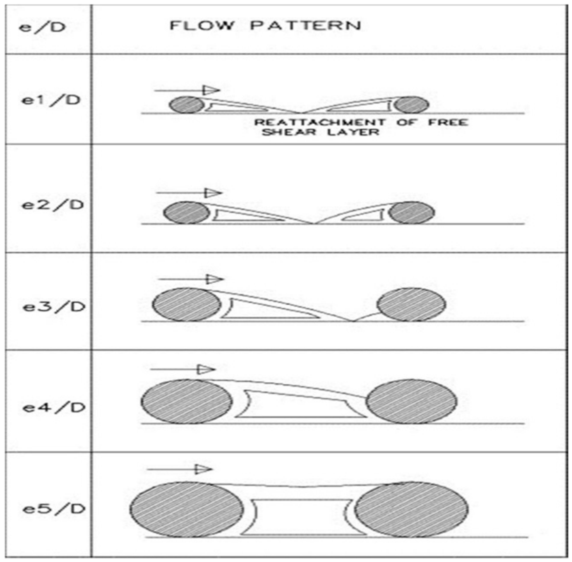
The thermal coefficient of solar air heater is mostly affected by the low heat transfer coefficient between the air and absorber plate. The heat transfer coefficient can be increased by two methods. The first method involves the use of corrugated surface or extended surface called fins so that the heat transfer area is increased and hence more heat is transferred. The second method involves the enhancement of heat transfer coefficient by creation of turbulence at heat transferring surface by providing artificial roughness on the lower surface of the absorber plate. Many investigators and researchers have attempted to increase the heat transfer through the solar air heater duct by providing artificial roughness on the underside surface of the absorber plate.

II. CONCEPT OF ARTIFICIAL ROUGHNESS

In order to attain higher heat transfer coefficient, it is desirable that the flow at heat transferring surface is make turbulent. The main reason for low convective heat transfer is the formation of laminar sub layer near the absorber plate which acts as an insulator. and hence not only decreases the heat transfer coefficient but also increases the pumping power requirement for the flow to take place inside the duct. It is therefore desirable that the turbulence must be created only in the region very close to the heat transferring surface i.e. in the laminar sub layer Only where the heat exchange takes place and the flow should not be unduly disturbed so as to avoid excessive frictional losses. This can be done by keeping the height of roughness element smaller in comparison to the duct dimension, the shape and arrangement of roughness element is characterized by several parameters: roughness height(e) and roughness pitch(p).These parameters are specified in terms of dimensionless parameters, namely, relative roughness height(e/D) and the relative roughness pitch(p/e). The geometry of artificial roughness can be of different shapes and orientations. These may be either two dimensional or three dimensional geometries. These may be used as protrusion, embedded thin wires or welded in form of ribs. Relative roughness pitch , relative roughness height, shape and orientation of ribs are the important parameters that effect the performance characteristics of ribbed solar air heater duct

III. EFFECT OF RIB PARAMETERS ON FLOW PATTERN

The most important effect produced by the presence of rib on the flow pattern , is the generation of two flow separation regions, one on each side of the rib, The vortices so generated are responsible for the turbulence and hence the enhancement in heat transfers as well as in the friction losses takes place. It has been observed by Prasad and Saini[1] that due to flow separation over a rib in downward direction , reattachment of shear layer does not occur for a relative roughness pitch ratio valueless than 8.In the vicinity of the reattachment point, the amount of heat transfer has been obtained maximum . However, an increase in the value of relative roughness pitch beyond 10, will also results in decrement in heat transfer enhancement.



Fig,1 Effect of rib roughness pitch on flow pattern through a solar air heater

Relative roughness height should be such that it results in an increase in heat transfer without increasing friction factor .The relative roughness height value should be greater than laminar sublayer thickness otherwise no enhancement will take place in heat transfer .Hence, the minimum roughness height should be selected according to the laminar sub layer thickness at lowest flow reynold number.

Cross-section of the ribs affects the size of separated region and level of disturbance in the flow. Reduction in size of separated region results in decrease in inertial losses and increase in skin friction and hence decreases the friction factor. As the size of separated region decreases , level of disturbance in flow also decreases which affects the heat transfer adversely.

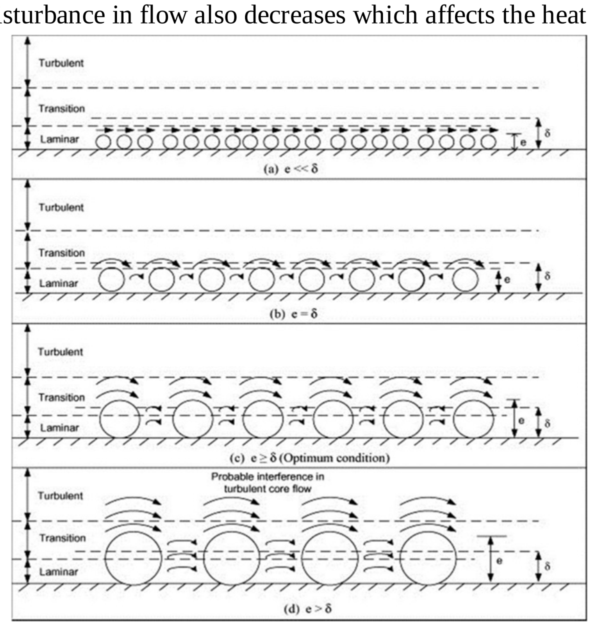


Fig.2. Effect of rib roughness height on flow pattern in a solar air heater

IV. ROUGHNESS GEOMETRIES USED IN SOLAR AIR HEATER DUCTS

For heat transfer enhancement in a solar air heater , the roughness element is provided only on the heated side of duct that receives the solar radiation. This is the reason that the solar air heater duct is modeled as a rectangular channel having one side with roughness provided on it and three smooth walls. Different geometries of roughness elements studied by investigators are discussed in the following section of the paper:

A. *Traverse Continuous Ribs*

Prasad and Mullick[2] studied the effect of protruding wires on heat transfer, friction factor and plate efficiency factor of a solar air heater which is used for drying of agricultural products. They obtained and compared these parameters (Nusselt number, friction factor and plate efficiency factor) of roughened corrugated absorber plate with corrugated and without roughness and smooth absorber plates. By providing wires, heat transfer coefficient and plate efficiency factor enhanced significantly.

Prasad and Saini[1] studied the effect of roughness parameters such as relative roughness height (e/Dh) and relative roughness pitch (p/e) and flow parameters such as Reynolds number on heat transfer and friction characteristics. They developed correlations for the heat transfer and friction factor for a fully developed turbulent flow. It was observed that maximum heat transfer occurred in the vicinity of reattachment points and reattachment of free shear layer does not occur if relative roughness pitch is less than around 8 to 10. The maximum enhancement in Nusselt number and friction factor was reported to be 2.38 and 4.25 times respectively as compared to smooth duct. The type and orientation of roughness geometry used has been shown in Figure 3. Optimal thermo-hydraulic performance is achieved for relative roughness height value of 0.033 and relative roughness pitch value of 10 .

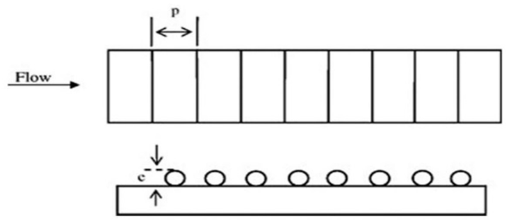


Fig.3.Roughness geometry used by Prasad and Saini[1]

Verma and Prasad[3] have carried out experimental investigation for thermo-hydraulic optimization of the roughness parameters, i.e. relative roughness pitch and relative roughness height in the range of 10-40 and 0.01-0.03 respectively. The optimal value of roughness Reynolds number (e+) was found to be 24 and corresponding to this value, thermo-hydraulic efficiency parameter value was found to be 71%. Correlations for heat transfer and friction factor were also developed.

B. *Inclined Continuous Ribs*

Gupta et al.[4] experimentally investigated the effect of relative roughness height (e/Dh), inclination of rib with respect to flow direction and Reynolds number(Re) on the thermo hydraulic performance of a roughened solar air heater for transitionally rough flow region. It was reported that with increase in relative roughness height the value of heat transfer coefficient increases. The thermo hydraulic performance also increases with the increase in Insolation. For a roughened solar air heater, maximum enhancement in heat transfer and friction factor was reported to be of the order of 1.8 and 2.7 times respectively for an angle of inclination of 60 and 70 degree respectively. Best thermo-hydraulic performance was reported for relative roughness height value of 0.023 and at Reynolds number value of 14000. The correlations for the same were also been developed.

Karwa[5] investigated the effect of 60 degree inclined rectangular cross-section ribs on heat transfer and friction factor for aspect ratio (W/H) in the range of 7.19-7.75, relative roughness height in the range of 0.0467-0.050, Reynolds number ranges from 2800-15000 and for fixed value of relative roughness pitch value of 10. The enhancement in the heat transfer coefficient (Stanton number) was reported to be 1.65-1.90 times and increase in friction factor was of the order of 2.68-2.94 over smooth duct.

C. *Wedge Shaped Ribs*

Bhagoria et al. [6] experimentally investigated the heat transfer and flow characteristics in a solar air heater having absorber plate roughened with wedge shaped transverse integral ribs as shown in Figure 4. The parameters investigated were Reynolds number, relative roughness height, rib wedge angle ranges from 3000-18000, 0.015- 0.033 and 8-12 degree respectively. It was reported that Nusselt number and friction factor increased by 2.4 and 5.3 times over smooth duct in the range of parameters investigated. The correlations for Nusselt number and friction factor were also developed.

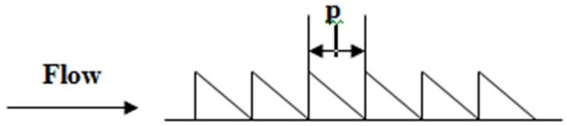


Fig.4. Wedge shape ribs used by Bhagoria et al.[6]

D. V-shaped Ribs

Momin et al.[7] experimentally investigated the heat transfer coefficient and friction characteristics of a rectangular duct of a solar air heater provided V-shaped ribs on absorber plate as shown in Figure 5. This investigation covered several parameters i.e. Reynolds number (Re) in the range of 2500-18000, relative roughness height (e/Dh) range of 0.02-0.034 and arc angle range of 30-90 degree for a fixed relative roughness pitch (p/e) of 10. The maximum enhancement of Nusselt number and friction factor as a result of providing artificial roughness had been found out to be 2.30 and 2.83 times respectively over the smooth duct for an arc angle value of 60 degree. Correlations for heat transfer and friction factor were also developed.

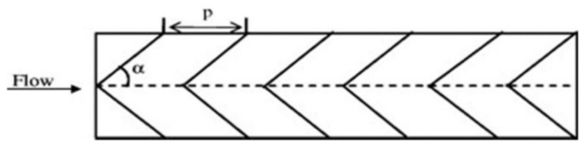


Fig.5. Rib geometry used by Momin et al.[7]

Mulluwork et al.[8] compared the thermal performance of staggered discrete V-up and V-down ribs. They had studied the effect of relative roughness length ratio (B/S), relative roughness segment ratio (S’/S), relative roughness staggering ratio (P’/P) and arc angle on heat transfer and friction factor. Nusselt number for V-down discrete ribs was found to be higher than the corresponding V-up and transverse discrete roughened surfaces. Nusselt number increases with the increase in relative roughness staggering ratio (P’/P) and attained a maximum value of Nusselt number for relative roughness staggering ratio value of 0.6. Correlations for Nusselt number and friction factor were also developed.

E. W-shaped Roughness

Lanjewar et al.[9] had carried out experimental investigation of heat transfer and friction factor characteristics of rectangular duct roughened with W-shaped ribs on its underside on one broad wall arranged at an inclination with respect to flow direction as shown in Figure 6. The parameters investigated for this study were relative roughness pitch (p/e) of 10, relative roughness height (e/Dh) 0.018-0.03375 and arc angle of flow 30-75 degree. Air flow rate corresponds to Reynolds number in the range of 2300-14000. The maximum enhancement of Nusselt number and friction factor has been found to be respectively 2.36 and 2.01 times that of smooth duct for arc angle of 60degree. Correlations were also developed for heat transfer coefficient and friction factor for roughened duct.

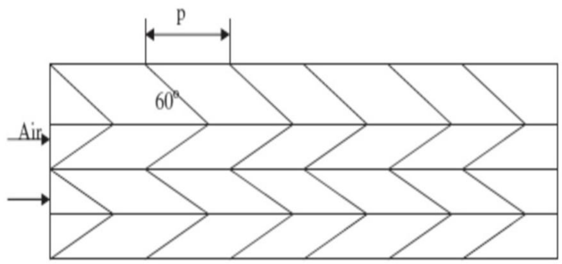


Fig.6.Roughness geometry used by Lanjewar et al.[9]

V. CONCLUSION

From the researches carried out by different authors by employing the roughness elements of different geometries, arrangement and orientations, it has been concluded that the provision of the artificial roughness results in an enhancement in heat transfer and friction characteristics of the solar air heater by increasing the value of the convective heat transfer coefficient between the absorber plate and the fluid flowing through solar heater duct. Thus, there is a heavy scope of increasing the thermal performance of solar heater by using roughness elements of some other shape in future.

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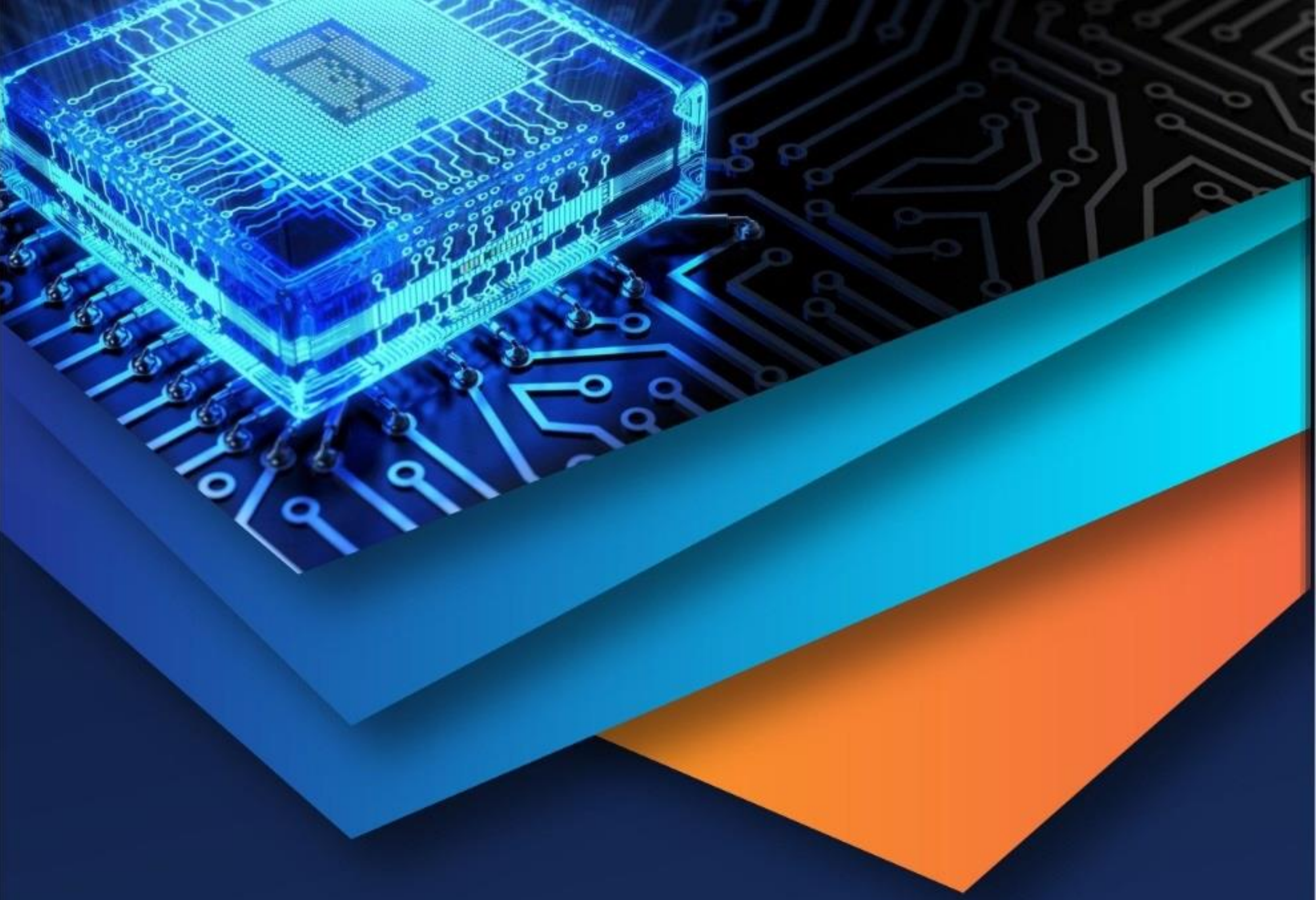

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