Journal of Renewable Energy Science, Technology and Economics
ISSN 2395 – 2644 (print) Vol 1, Issue 1 - May 2015

A review on Effect of Artificial Roughness on Thermal Performance of aSolar Air Heater- "A State of Art"

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Abstract: -The performance characteristics of solar air heater can be effectively improved by providing artificial roughness in different forms such as ribs, wire mesh, dimple shape roughness, baffles, turbulators etc on heat transfer surface. Basically on implementing artificial roughness, surface area of absorber plate of solar air heater increases, which result in higher value of heat transfer**.** To resolve the effect of artificialroughness geometries on thermal performance of solar air heater, several experimental and numerical studies have been conducted out by various researchers that reveal the effect of shape factor of the roughness elements on thermal performance of solar air heater. In this paper, extensive review has been carried out over various roughness geometries employed in solar air heaters, resulting expressions for calculation for heat transfer and friction factor. Moreover, correlations presented for evaluating thermal performance, hydraulic performance, and thermo hydraulic performance of Solar air heater.

Keywords: Roughness geometry, Solar air heater, Thermal performance, Heat transfer, Friction factor

Introduction

In the current age, renewable energy sources are plays significant role in order to meet the continuous demand of energy for the economic progress and industrial development. The growth of world population fastened with rising material needs has accelerated the rate of energy consumption. Express increase in energy usage characteristic of the past 50–100 years cannot continue indefinitely as finite energy resources of earth are exhaustible. On the other hand, life becomes threat due to environment degradation in form of using fossil fuel. In order to overcome from this energy as well as environmental threat in future development of alternative means in form of renewable energy sources has received an impetus.For several alternatives, solar energy stands out as brightest wide range resource for meeting continuously increasing demand for energy, having large potential renewable energy source are considered to be more dominating. The freely obtainable solar radiationfacilitates an infinite and non-polluting reservoir of fuel. The simplest technique to harvest solar energy for various heating applications is to convert it into thermal energy by means of solar collectors. Solar water heaters and solar air heaters are flat plate collectors which are generally adopted for heating water and air respectively. In solar air heater Thermo hydraulic performance is evaluated in order to judge the system is working more efficient. The solar air heater the performance parameter is termed as thermo hydraulic because thermal performance relates to heat transfer in collector and hydraulic performance deals with the pressure drop in the duct.

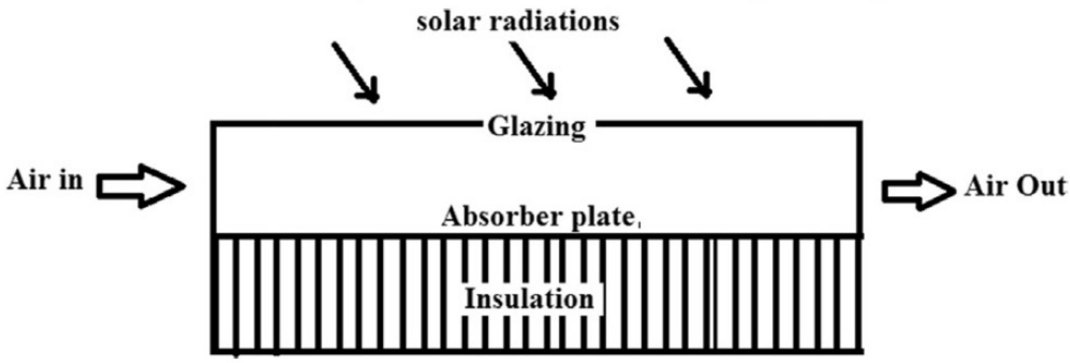


Figure.1: Simplified model of aSolarair heater

Thermal performance of solar air heater

Thermal performance of solar air heater is given [1] as below

$$Q_u = A_s F_R \left[I(\tau\alpha)_e - U_L (T_i - T_a) \right]$$

The rate of useful energy gain by the flowing air through duct of solar air heater can becalculated by using the relation

$$Q_u = mC_p F_R (T_0 - T_i) = hA_s (T_0 - T_i)$$

And the Thermal efficiency of Solar air heater expressed by equation

$$\eta_{th} = \frac{q_u}{I} = F_R \left[I(\tau\alpha)_e - \frac{U_L (T_i - T_a)}{I} \right]$$

Hydraulic performance

TheHydraulic performance of a solar air heateris related with the pressure drop in duct where energy is consumed by fan or blower to propel the required amount of air through the duct. The relationship that includes the friction factor, is given by Frankand Mark [2] in non -dimensional form as

$$f = \frac{(\Delta P) D_h}{2\rho L V^2}$$

Thermo hydraulic performance

It is desirable that a Solarcollector should be so designed that it should collect and transfer maximum heat energy to the flowing fluid with minimum consumption of fan power. Therefore, in order to analyze overall performance of a solar air heater, thermo-hydraulic performance should be evaluated by considering thermal as well as hydraulic characteristics of the collector,Hence to evaluate thermohaydraulic performance of solar air heater, it is necessary to consider effect of both heat transfer enhancement parameters and friction factor.

Lewis [3] defined a parameter called enhancement factor or efficiency parameter ($\in$) as follows:

$$\in = (Nu_r / Nu_s) / (f_r / f_s)^{0.333}$$

Effect of Rib parameters on flow pattern

a) **Effectofribheightandpitch**

Heat transfer can be enhanced by decreasing the relative roughness Pitch (P/e) for fixed relative roughness height (e/D_h) or by increasing relative roughness height (P/e) for fixed relative roughness pitch(e/D_h). Relative roughness pitch (P/e) can be increased up-to a value of 10, further increment is lead to decrease in heat transfer enhancement.

b) **Effect of inclination of rib (angle of attack)**

Angling of the rib produces span wise counter rotating secondary flows which is responsible for significant span-wise variation of heat transfer coefficient. The vortices moves along the rib subsequently join to the main stream, the fluid entering near the leading end of rib and coming out near the trailing end.

c) **Effect of V-shaping of rib**

Inclined rib resulted in better performance than transverse ribs due to increase in secondary vortices.V-shaped ribs form two secondary flow cells as compared to one in case of a straight angled and transverse rib. Resulting in higher over-all heat transfer coefficient incase of v-shaped rib.

d) **Effect of width and position of gap in continuous inclined rib**

Heat transfer enhancement is affected by the position of the gap with respect to leading and trailing edge. Position of the gap near the trailing edge, results in more contribution of secondary flow in energizing the main flow through the gap and recirculation loop in the remaining part of the rib, thereby increasing the heat transfer rate.

e) **Effect of rib cross section**

Circular cross section of the rib had less friction factor as compared to that of rectangular or square cross section ribs.This is due to reduction in the size of the separated region. As the size of the separated region reduces, heat transfer gets affected critically because of decrease in the level of disturbance in flow.

Different types of roughness geometries used in solar air heater

- **Transverse Continuous rib**

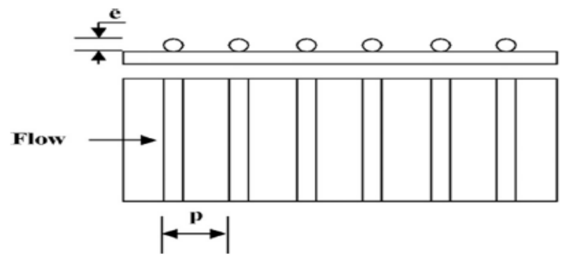


Figure.2: Transverse continuous rib [4,5,6,7]

The application of small diameter wire attached on the under-side of absorber plate as artificial roughness is used by the Prasad and Mullick [4], Prasad and Saini [5], Gupta et al. [6], Verma and Prasad [7]to improve the thermal performance of solar air heater. Prasad and Saini [5] investigated the effect of protrusions from underside of absorber surface in the form of small diameter wires to increase heat transfer and friction factor for fully developed turbulent flow in a solar heater duct. Experimental investigation is carried out using relative roughness pitch of 10, 15 and 20 and relative roughness height of 0.020, 0.027 and 0.033 to detect the effect of height and pitch of roughness on heat transfer and friction. The maximum value of Nusselt number and friction factor is reported 2.38and4.25respectively at the pitch of 10.The type and orientation of roughness geometryused is shown in above Fig.2.The correlation for Heat Transfer and Friction factor presented by Prasad and Saini [5]

Heat transfer

$$S_t = (f/2)/[1+\sqrt{f/2\{4.5(e^+)^{0.28}}\ \mathrm{Pr}^{0.57} - 0.95(P/e)^{0.53}\}]$$

Friction factor

$$f = 2/[0.95(P/e)^{0.53} + 2.5\ln(D/2e) - 3.75$$

- **Inclined Continuous ribs**

Investigators found out that inclined rib gives better heat transfer than transverse ribs due to generation of secondary flow which helps in breaking of the laminar sub-layer. The effect of relative roughness height (e/D), inclination of rib with respect to flow direction and Reynolds number (Re) on the thermo hydraulic performance of roughened solar air heater for transitionally rough flow region (5< e^+ >70) is studied by Guptaetal. [8]. The experimental result shows that maximum heat transfer and friction factor was in the order of 1.8 and 2.7timesrespectively, corresponding to values of angle of inclinationas60° and 70°, respectively. At relative roughness (e/D) valueof0.023andReynoldsnumbervalueof 14,000, a comparatively best thermo hydraulic performance was reported by investigator. The type and orientation of roughness geometry used is shown in Fig.3.The correlation for Heat Transfer and Friction factor presented by Gupta et al. [8]

Heat transfer

$$Nu = 0.000824(e/D)^{-0.718}(W/H)^{0.284}\,\mathrm{Re}^{0.284}\exp[-0.04(1-\alpha/60)^2](k/D)$$

Friction factor

$$f = 0.06412(e/D)^{0.019}(W/H)^{0.237}\,\mathrm{Re}^{-0.185}\exp[-0.0993(1-\alpha/60)^2]$$

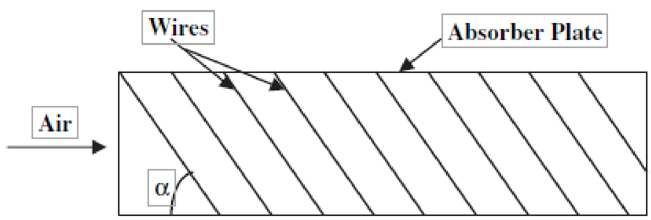


Figure.3. Inclined Continuous ribs [8]

- **Transverse broken ribs**

Sahu and Bhagoria [9] investigated effect of 90°s broken Transverse ribs on heat and fluid flow characteristics using roughness heightof1.5mm, duct aspect ratio value of 8, pitch in the Range of 10–30 mm and Reynolds number in the range of3000 –12,000.Heat transfer enhancement was reported to be 1.25–1.4 Times over smooth duct. From the experiment maximum thermal efficiency was found in the order of 83.5%. The type and orientation of roughness geometry used is shown in above Fig.4

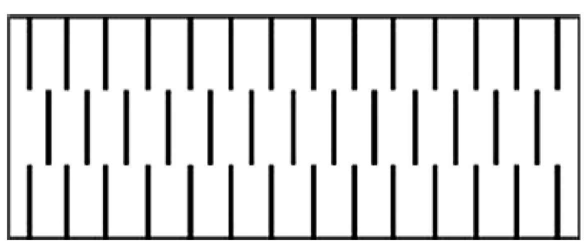


Figure.4. Transverse broken ribs [9]

- **Inclined rib with gap**

Aharwaletal. [10], Kumar et al. [11] studied the effect of width and position of gap in inclined split-rib shaving square cross section on heat transfer and friction characteristics of a rectangular air heater duct. The increase in Nusselt number and friction factor was in the range of 1.48–2.59 times and 2.26– 2.9 times of the smooth duct respectively for the range of Reynolds numbers from 3000 to 18,000. Corresponding to a relative gap width (g/e) value of 1.0 and relative gap position (d/W) valueof0.25, values of heat transfer, friction factor ratio (f/fs) and thermo hydraulic performance parameters were found to be maximum. It was investigated that relative gap width beyond 1.0 reduces the flow velocities through the gap and which reduces heat transfer as compared to continuous ribs. If the relative gap width was taken lowerthan1.0, then it shrinks the passage for secondary flow release which reduces the turbulence intensity behind the gap and hence reduces heat transfer. The type and orientation of roughness geometry used is shown in above Fig.5.

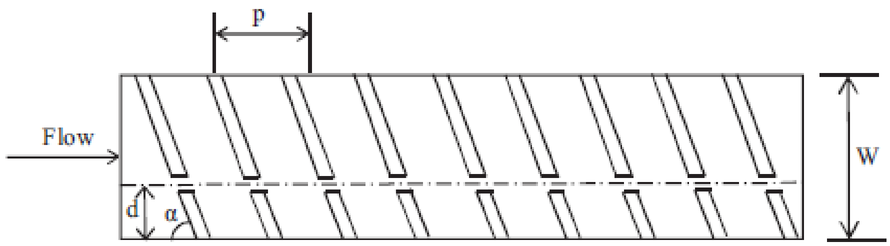


Figure.5. Inclined rid with gap [10, 11]

- **Arc shaped ribs**

An experimental study has been carried out by Saini et al. [12] for enhancement of heat transfer coefficient of a Solar air heater having roughened air duct provided with artificial roughness in the form of arc-shape parallel wire as roughness element as shown in Fig. 6. The maximum enhancement in Nusselt number has been investigated as 3.80 times corresponding to the relative arc angle (α/90) of 0.3333 at relative roughness height of 0.0422. On the other hand, the increment in friction factor corresponding to these parameters has been observed 1.75 times only**.**The correlation for Heat Transfer and Friction factor presented by Saini et al. [12]

Heat transfer

$$Nu = 0.001047(e/D)^{0.3772}(\alpha/90)^{-0.1198}\,\mathrm{Re}^{1.3186}$$

Friction factor

$$f = 0.14408(e/D)^{0.1765}(\alpha/90)^{0.1185}\,\mathrm{Re}^{-0.17103}$$

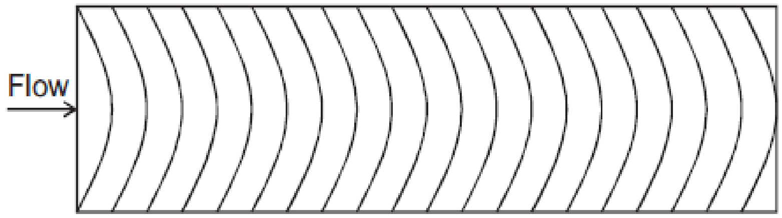


Figure.6.Arc shaped ribs[12]

- **Combined inclined and transverse rib**

Concept of combination roughness of transverse and inclined ribs was investigated by Varun et al. [13].Experimental investigation encompassed Reynolds number from 2000 to 14,000, relative roughness pitch 3–8 and relative roughness height as 0.030. They reported that roughened collector having roughness pitch of 8 gave best performance. The type and orientation of roughness geometry used is shown in above Fig.7

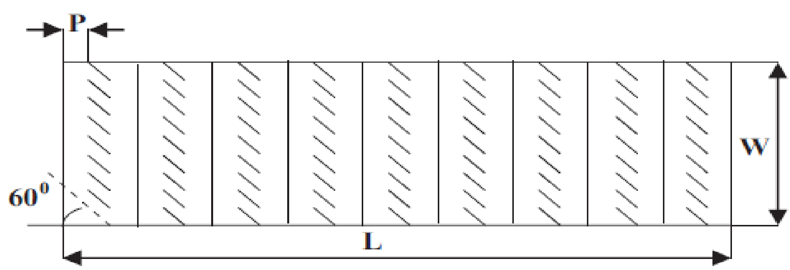


Figure.8. Combined inclined and transverse rib [13]

- **Continuous V-ribs**

Inclined continuous V- rib [14] resulted in better performance than transverse ribs due to increase in secondary vortices. The number of secondary vortices was increased by V-shaping of angled rib by Momin et al. [15]. They investigated V-shape rib roughness as shown in Fig. 9 and studied thermo hydraulic performance of solar air heater for Reynolds number as 2500–18,000, relative roughness height (e/D_h) as 0.02–0.034, angle of attack of flow (α) as30–90° for fixed relative roughness pitch of 10. Maximum enhancement of Nusselt number and friction factor was reported as 2.30 and 2.83 times as compare smooth Solar air heaterduct plate. The type and orientation of roughness geometry used is shown in above Fig.9.The correlation for Heat Transfer and Friction factor presented by Momin et al. [15]

Heat transfer

$$Nu = 0.067(e/D)^{0.424}(\alpha/60)^{-0.077}\,\mathrm{Re}^{0.888}\exp[-0.782\ln(\alpha/60)^{2}]$$

Friction factor

$$f = 6.266(e/D)^{0.565}(\alpha/60)^{-0.093}\,\mathrm{Re}^{-0.425}\exp[-0.719\ln(\alpha/60^{2})]$$

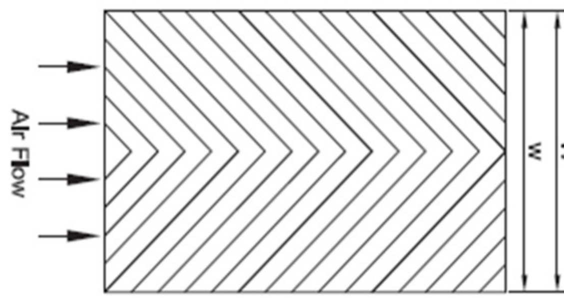
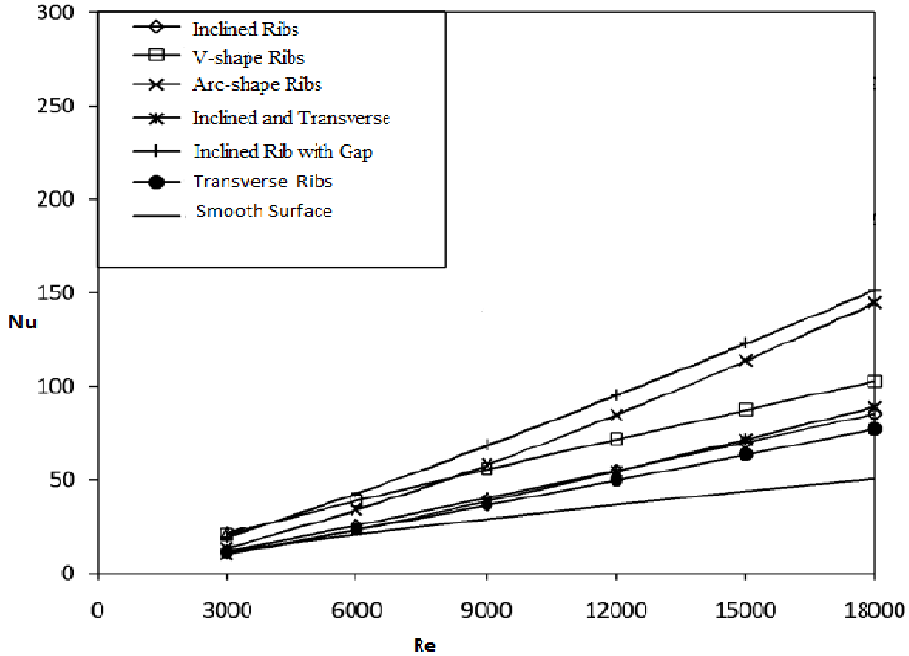


Figure.9. Combined inclined and transverse rib[14, 15]

Performance of roughness geometries

Figure.10. shows the variation in Nusselt number as a function of Reynolds number for the roughness geometries tested by different investigators. Considerable rise in Nusselt number can be seen in all the cases as compared to the smooth surface. Plot shows that the value of Nusselt number is highest in case of Arc- shape roughness and lowest in case of transverse ribs.While in case of Arc shape rib, inclined and transverse rib roughness, a sharp increment in Nusselt number has been found aroundReynolds number 12000. On the basis of this we can say the systems with low and moderate flow rates, multi V -shape roughness is the best option as far as heat transfer enhancement is concerned. A significant rise in Nusselt number can be seen in case of inclined ribs with gap as compared to continuous inclined rib roughness. It is believed that the secondary flow cells are responsible for higher heat transfer rates. Since inclined rib has only one secondary flow cell while V- rib got two secondary flow cells



Conclusion

In the present paper, an attempt is made to review about developed geometry ofartificial roughness in order to heat transfer enhancement in solar air heater over the years.Performance evaluation, efficiency parameter (∈) for solar air heater is presented.The silent features are:

1. Application of artificial roughness is effective technique for enhancement in performance of solar air heater this paper presents a review of experimental analysis carried out by the researchers.
2. Early roughness used was transverse rib roughness, which was modified asangled or inclined,broken inclined or inclination with gap, V-continuous rib, arc shape, and the combination of transverse and inclination is reported.
3. The relative roughness height (e/D_h), relative roughness pitch(P/e) , angle of attack(α) and relative gap position are some of the parameters studied for their effect on heat transfer and friction characteristics in solar air heaters.

Scope for Future work

- Gap can be applied into the various others shapes like W-Shape rib, Z-Shape rib etc.
- Combinations of others ribs, also can be applied like transverse and V-Shape rib etc.
- Various others geometries are like Wedge shape rib, Chamfered rib, U-Shaperib ,V-Shape rib with gap, W-Shape rib , Z-Shape rib, Dimple Shaperib has been investigated

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