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A Review on Artificially Roughened Solar Air Heater and air Impingement Techniques

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ABSTRACT: The artificial roughness on the heated surface of solar air heater is an cost effective and economical way to significantly enhance the heat transfer rate. There are several roughness geometries provides in different forms such as ribs, wire mesh, baffles etc. which is used to enhance the heat transfer from the surface of the solar air heater. Experimental investigation shows that artificial roughness can give essential enhancement in heat transfer rate which improves the thermal performance of solar air heater. It has been observed that with the use of jet impingement on the base plate three times higher heat transfer coefficient is achieved due to highly turbulent impingement boundary layers. It is required to understand how the flow is been affected with the use of different roughness geometries in the form of repeated ribs with jet impingements.

Keywords: Solar air heater, artificial roughness, Jet impingements, Thermal performance, Thermo-hydraulic performance

I. INTRODUCTION

Due to fast growing population & advancement in technology in each & every field such as Industrial, Agriculture & Research, energy is the prime requirement that is increasing day by day. Conventional energy sources are exhaustible and are depleting fast. In the present time as the need for energy is growing faster and increasing the concern for envoirment is making solar energy as a best alternative to be used these days. Solar energy is quite simply the energy produced directly by the sun and collected elsewhere, normally the Earth. Devices which are designed on the concept of utilization of this solar energy and works on a principle of conversion of solar energy into thermal energy are heat exchangers and solar air heaters. This type of solar thermal systems are widely used in many thermal applications such as drying of agriculture products, seasoning of wood, space heating, curing of industrial products etc .

Solar air heater is a device designed to absorb the incoming solar radiations from sun and then converting these absorbed solar radiations in to thermal energy at the absorbing surface. The thermo-hydraulic performance of the solar air heater is very low due to lower convective heat transfer coefficient. This is because of the formation of laminar viscous sub layer which resist the heat transfer.

Several active and passive heat transfer enhancement techniques have been employed to improve the performance of solar air heater.

Artificial roughness is widely known passive heat transfer enhancement technique through which thermo-hydraulic performance of a solar air heater can be improved. Artificial roughness enhances the heat transfer rate of solar air heaters. As the air flowing through the duct of a solar air heater, a laminar sub layer is formed over the absorber surface that obstruct heat transfer to the flowing air, thereby adversely affecting the thermal performance of the solar air heater. In order to attain higher heat transfer coefficient, it is required that flow at the heat transferring surface is made turbulent. So artificially roughened absorber plate is considered to be a good methodology to increase the heat transfer coefficient since it break laminar sub layer in order to reduce thermal resistance.

Studies have also reported that with the use of jet impingements high heat transfer coefficient is achieved due to the thin impingement boundary layers generated in the vicinity of the heat transferring surface. The impinging jets after impingement serve to turbulate the surrounding fluid and thus improve performance of solar air heater.

II. THERMAL PERFORMANCE OF SOLAR AIR HEATER

To calculate the thermal performance of solar air heater Hittel-whilliers–bliss equation reported by duffle Beckman is used:

$$Q_u = A_S \, . F_R[I(\tau\alpha)_e - U_L \, (T_i \, - T_a)] \quad (1)$$

Where $q_u = Q_u/A_S$

$$= F_R[I(\tau\alpha)_e - U_L \, (T_i \, - T_a)] \quad (2)$$

The rate of useful energy gain is calculated by using

$$Q_u = m \, c_p\left(T_{fo} \, - T_{fi}\right) \quad (3)$$

The heat transfer coefficient is calculated:

$$h = \frac{Q_U}{A_P(T_{Pm} - T_{fm})} \quad (4)$$

Nusselt number is calculated as:

$$N_U = \frac{hL}{k} \quad (5)$$

Further the thermal efficiency of solar air heater can be calculated

$$\eta_{th} = \frac{q_U}{I} = F_R[(\tau\alpha)_e - U_L \, (T_i \, - T_a)/I] \quad (6)$$

To determine the thermo-hydraulic performance of a solar air heater this concerns with the pressure drop. Pressure drop can be represented in non dimensional form by using the relation of friction factor:

$$f = \frac{\Delta P . D_h}{2pLV^2} \quad (7)$$

III. DIFFERENT ARTIFICIAL ROUGHNESS GEOMETRIES AND AIR JET IMPINGEMENTS

In solar energy applications, solar air heater is the heat exchanger which is simple and most commonly used to convert the incoming solar radiation in to thermal energy, where thermal energy is extracted by air flowing under the absorbing surface. The use of artificial roughness is suggested by researchers which enhance the heat transfer coefficient. The concept of artificial roughness was used by Prasad and Mullick [1] applying transverse rib roughness on the absorber plate and investigated the heat transfer and fluid flow characteristics. The elementary type of roughness is used in the form like small diameter circular wire ribs and arranged in the transverse direction, due to which a considerable enhancement in heat is obtained as compared to the non ribbed duct of the solar air heater. Prasad and Saini [2] also used transverse rib roughness and discussed the effect of relative roughness height (e/D) and relative roughness pitch (P/e) on Nusselt number and Friction factor. The enhancement in Nusselt number and friction factor was found to be increase up to 2.38 to 4.25 times respectively in comparison with the smooth duct. Further With the use of inclined ribs reported by Gupta et al. [3] enhances the heat transfer coefficient and friction factor of order 1.8 and 2.7 times, respectively. It was obtained occurring at angles of attack of 60° and 70°, respectively. In the investigation Researchers have obtained that maximum thermo-hydraulic performance is occurring corresponding to the relative roughness height (e/D) of 0.023 and a Reynolds number (Re) of 14,000.

Artificial roughness in the form of wedge shape ribs were also investigated by Bhagoria et al. [4] in this a rectangular duct is used with wedge shaped ribs and compared with a smooth duct and found an enhancement in Nusselt number of order 2.4 times and friction factor of order 5.3 times .The use of chamfered ribs was investigated by Karwa R. [5, 6] to study its effects on thermo-hydraulic performance of solar air heater.

Inclined rib roughness in the form of circular wires has further increased the heat transfer enhancement as compared to transverse ribs. Saini and Saini [7] obtained that corresponding to angle of attack of 61.9° and 72° respectively the enhancement in heat transfer and friction factor is of order 4 and 5 times more as compared to the smooth duct. Muluwork [8] compared the thermal performance of staggered discrete V-apex up and down rib with corresponding transverse staggered discrete ribs. V-down discrete ribs performed better when compared with V-up and transverse discrete ribs. With the application of V-shaped rib roughness a noticeable enhancement in heat transfer is achieved. However, with increase in the rate of heat transfer higher frictional losses were accompanied.

Momin *et al.* [9] Carried and experimental investigation and studied the effect of V- shaped roughness on flow through duct. From the experimental investigation it is observed that the Nusselt number increases with increase in Reynolds number. It was obtained that for angle of attack of 60° and relative roughness height of 0.034, the V-shaped ribs enhance the values of Nusselt number by 1.14 and 2.3 times respectively over smooth plate and inclined ribs at Reynolds number of 17034. Further the results have also been compared with those of smooth duct under similar flow conditions to determine the enhancement in heat transfer coefficient and friction factor. Hans et al. [10] have also reviewed on performance of artificially roughened solar air heaters. Hans et al. [11] studied the effect of multiple V-rib roughness experimentally and collected data on heat transfer and fluid flow characteristics of a roughened duct. In the study the enhancement in Nusselt number and friction factor was found to be 6 to 5 times when it is compared with that of the smooth duct. The maximum enhancement in heat transfer is achieved at relative roughness width (W/w) of 6 and maximum value of Nusselt number is obtained at angle of attack 60°

An experimental investigation carried out by Promvonge [12] to evaluate the turbulent forced convection heat transfer and friction losses behavior for air flow through a duct fitted with a multiple 60° V-baffle tabulators. The results obtained shows that with the use of V-baffle there is a drastic increase in Nusselt number, friction factor and thermal enhancement factor values when compared with the smooth wall channel. This is achieved due to better flow mixing from the formation of secondary flows induced by vortex flows generated by the V-baffle.

The effect of the gap width and gap position on the heat transfer and friction characteristics of solar air heater ducts was studied by Aharwal et al. [13]. They result obtained from the investigation shows that the broken inclined rib roughness enhances the Nusselt number and friction factor up to 2.83 and 3.60 times, respectively, than that achieved with the smooth surface. In the case of V- ribs used with gap had also shown a considerably higher order of heat transfer and friction factor when compared to that of continuous V-ribs. Singh et al. [14] found that the application of broken V- down ribs can achieve 3.04 and 3.11 times increase in Nusselt number and friction factor respectively, as compared with that to the smooth duct.

Kumar et al. [15] used artificial roughness in the form of 60° inclined discrete ribs and on investigation found a considerable enhancement in the heat transfer coefficient of the solar air heater. The correlations have been established to predict the values of friction factor and Nusselt number with an average absolute standard deviation of 3.4% and 3.8% respectively. Kumar et al. [16] experimentally investigated and analyzed the effect of geometrical parameters of multi –V shaped ribs with gap on heat transfer and fluid flow in a rectangular duct. The maximum enhancement in Nusselt number was of order 6.32 and friction factor was obtain to be 6.12 times that of the smooth duct, respectively. The use of gap in the multi-V shaped ribs results in higher heat transfer rate and friction factor in comparison to the continuous multi V-shaped rib roughness.

The review on the different types of roughness geometries was carried out by Patil et al. [17] and investigated the value of heat transfer coefficient between the absorber plate and flowing air is low, subsequently value of thermal performance is also low. So, the provision of using artificial roughness in the form of thin wires of varying diameters at different relative roughness pitch, relative roughness height and at different angle of attack on the absorber plate has resulted in increase of the value of heat transfer coefficient leading to increase the value of thermal efficiency of such collectors compared to the smooth ones.

Karwa et al.[18] investigated multi V-shaped roughness for solar air heater and developed the correlations for Nusselt number and friction factor. Study found 12.5-20% enhancement in thermal efficiency for 60° V-down discrete rib roughness in solar air heaters. The review on heat transfer and thermal efficiency of solar air heater having artificial roughness carried by Saurabh et al. [19] .Studies have reported that distinct roughness geometries result in the enhancement of heat transfer which is accompanied by considerable rise in pumping power. In the designing of the roughness geometry designer need to carefully examine the shape and orientation of the element in order to choose the best fit roughness geometry for intended application. In the investigation some distinguished roughness geometry has been analysed on the basis of heat transfer enhancement and thermo hydraulic performance. The objective of this paper is to review various studies, in which different artificial roughness elements are used to enhance the heat transfer rate with little penalty of friction. Various researchers have developed Correlations with the help of experimental results for heat transfer and friction factor for solar air heater ducts by taking different roughened surfaces geometries are given in tabular form. These correlations are used to predict the thermo hydraulic performance of solar air heaters having roughened ducts.

Artificially roughened solar air heaters have been analysed for fully developed turbulent flow by Prasad and Saini [20] and found it to perform better both quantitatively and qualitatively compared to the smooth ones under the same operating conditions. Optimal thermo-hydraulic performance of such solar air heaters has been analyzed .In the analysis enhancement in Nusselt number and friction factor over smooth duct of the order of 2.38 and 4.25 times, respectively, corresponding to relative roughness height value of 0.033 and relative roughness pitch value of 10.

Use of energy and its generation, consumption and application consistently evolve the design and fabrication of an efficient heat exchange device. Use of solar test rig of solar air heater in different aspect ratio and sizes are common way to analyze the performance of solar air heater. Kumar et al. [21] gives the information regarding different configurations and geometries of roughness elements producing different quality and quantity of heat transfer is available in literature. They reviewed the comparative rate of heat transfer quantitatively and qualitatively in artificially roughened solar air heaters of various configurations. Analytical and experimental result as well as worked out values of result with respect to heat transfer data in terms of Nusselt number, utilizing the equations or correlations developed by various researchers and investigators have been represented with respect to the roughness and flow parameters (p/e, e/D and Re), for the comparison of rate of heat transfer. The experimental values of average Nusselt number for multi V-roughness has been found to be the highest. However, the analytical values of average Nusselt number in the end of side roughened solar air heaters are the maximum. In the designing of the solar air heater the absorber plate plays an important role as it determines the heat transfer rate between the absorber plate and the air which in turn leads to the performance of the solar air heater. The best way to increase the heat transfer is by increasing the contact area and for that many types of area enhancement techniques were investigated by many researchers. Some of the best examples are fins, baffles, roughened surfaces, extended surfaces, porous absorber plates with wire mesh, iron fillings, glass tubes, etc. These modifications done on the absorber plate were successful in increasing the heat transfer rate but it also increased the pumping power as well, therefore optimized levels of modifications are to be developed and implemented for better performance of the solar air heater.

Experimental investigation carried out by Maithani and Saini [22] in a solar air heater duct roughened with V-ribs and having symmetrical gaps to evaluate the performance and enhance the heat transfer. For enhancing heat transfer from the absorber plate subsequent enhancement in pressure drop is achieved due to increased friction. The duct has a relative roughness height (e/D) of 0.0433, a relative roughness pitch (P/e) of 10 and an angle of attack (α) of 60°. Relative gap width (g/e) and number of gaps (Ng) were varied in the range of 1–5. The maximum enhancement in the Nusselt number and friction factor was obtained to be 2.59 and 2.87 times, respectively, when it is compared with the results obtained from smooth duct .The relative gap width of 4 and the number of gaps of 3 gives the maximum value of thermo-hydraulic performance parameter.

Experimental analysis have been carried out to investigate the heat transfer behavior and optimum relative width parameter of the solar air channel of aspect ratio of 10.0 with 60° angled broken multiple V-type baffles Kumar et al.[23].This investigation enclosed a wide range of parameter such as Reynolds number varied from 3000 to 8000,relative width W/w 1.0 to 6.0,relative baffle height of 0.5,relative baffle pitch of 10.0,relative discrete distance of 0.67 and relative gap width of 1.0.The results obtained experimentally showed that higher overall thermal performance occurred at a relative baffle width of 5.0. The results also reveal that the broken multiple V-type baffles are thermo-hydraulically superior when compared to the other baffles shaped solar air channel. Solar air heating is a solar thermal technology in which the energy from the sun is captured by an absorbing medium and used to heat air. Concept of artificial roughness on the plane paper (absorber plate) is an important technique, used to improve thermal performance of solar air heater at the cost of low to moderate friction penalty.

Jet impingement technique is also an established method of convective heat transfer from the heated surface to the carrier fluid. Investigation shows that by using impinging jets higher heat transfer rates are achieved in solar air heater duct but with the cost of increased friction power penalty. Experimental investigation has been carried out to study heat transfer and friction factor characteristics using impinging jets in solar air heater duct by Chauhan et al. [24] in the investigation the effect of flow and geometrical parameters, the jet diameter, streamwise and spanwise pitch has been carried out. The experiments varies the flow Reynolds number in the range 3800–16,000. The jet diameter, streamwise pitch and spanwise pitch each normalized by hydraulic diameter of the duct are in the range: 0.043–0.109; 0.435–1.739; 0.435–0.869 respectively. The air through the jets is impinged normally on to the absorber surface which was heated with uniform heat flux of 1000 W/m^2. The data obtained for heat transfer and friction factor is compared with that of parallel flow solar air heater under similar geometrical and flow conditions. The results show that there is considerable enhancement in heat transfer and friction factor by 2.67 and 3.5 times respectively. The Correlations were developed for Nusselt number and friction factor in terms of above parameters which reasonably correlated to the experimental data. Chauhan et al [25] investigated the thermo-hydraulic performance of impinging jet solar air heater in the form of effective efficiency and compared the same with that of conventional solar air heater. The study analyzed the effect of Reynolds number, diameter of the jet, streamwise and spanwise pitch on effective efficiency. Based upon the study, it has been concluded that impinging jet solar air heater performs better than the conventional solar air heater for specified range of parameter in order to obtain optimum effective efficiency for desired value of Reynolds number. The effective efficiency has been computed based upon the correlations developed by the investigators and maximum effective efficiency of 70% has been achieved for impinging jet solar air heater in the range of investigated system and operating parameters. In the study plots have been prepared for each jet parameter with temperature rise.

CONCLUSION

In the present study an attempt is done to review an artificial roughened surface with different types of roughness geometries. It is found to be the most effective technique which enhances the heat transfer rate of a solar air heater. Different roughness geometries are analysed in order to determine which technique is best to use and gives less penalty of friction. The jet impinging solar air heater is also a technique which used to enhance the heat transfer rate and shows a considerable rise in Thermo-hydraulic performance compared to conventional solar air heater. Solar air heater has a very vast application .depending upon the energy requirement different types of geometries can be used.

Table 1: Different Roughness Geometries.

S.NO	INVESTIGATORS	ROUGHNESS GEOMETRY	ROUGHNESS PARAMETERS
1.	Prasad and Mullick[1]	Transverse rib roughness	e/D:0.020-0.033
2.	Prasad and saini[2]	Transverse rib roughness	P/e:10-20,e/D:0.020-0.033,Re:5000-50000
3.	Karwa et al [5]	Chamfered ribs	P/e:4.5-8.5,e/D: 0.014-0.0320,,Re:2000-20000
4.	Gupta et al[3]	Continuous transverse rib	e/D: 0.018-0.052,Re:3000-18000
5.	Bhagoria et al[4]	Wedge shaped ribs roughness	e/D: 0.015–0.033 ,p/e: 7.57,α: 8–15° Re: 3000–18,000
6.	Saini and saini[7]	Expanded wire mesh metal ribs	P/e:4.5-8.5,e/D:0.014-0.0320,Re:2000-20000
7.	Muluwork et al.[8]	V-shaped staggered Discrete wire ribs	e/D: 0.02 ,α: 60°,B/S: 3–9,Re: 2000–15,500
8.	Momin et al.[9]	V-shaped ribs	e/D: 0.02–0.034 ,P/e: 10,α: 30–90°,Re: 2500–18,000
9.	Hans et al [11]	Multiple V shaped	e/D: 0.019–0.043 ,p/e: 6–12,α: 30–75°, Re: 2000–20,000,W/w: 1–10
10.	Promvonge[12]	Multiple 60° V shaped baffles	e/H:0.10, 0.20, 0.30 ,P/H: 1, 2, 3, Re: 5000–25,000
11.	Aharwal et al.[13]	Inclined discrete ribs	e/D: 0.0377 ,p/e: 10,W/H: 5.87, d/w: 0.167–0.5,α: 60°,Re: 3000–18,000
12.	Singh et al.[14]	Discrete V-down ribs	Re: 3000–15,000 ,p/e: 4–12,α: 30–75°, d/w: 0.2–0.8,g/e: 0.5–2.0,e/D: 0.015–0.043
13.	Kumar et al.[15]	60° inclined continuous discrete rib	Re: 4105.2–20,526.2 ,e/D: 0.0249, 0.0374 and 0.0498,p/e: 8, 12 ,16 ,d/W: 0.15, 0.25 and 0.35 g/e: 1
14.	Kumar et al.[16]	Multi V shaped ribs with gap	Re: 2000-20000, α: 60°, e/D: 0.043,p/e: 10 , W/w:6,G d/Lv:0.24-0.80, g/e: 0.5-1.5
15.	Maithani and Saini [22]	V-ribs with symmetrical gaps	e/D: 0.0433, p/e: 10, α :60°, g/e:1-5,N_g:1-5
16.	Kumar et al.[23]	60° angled broken multiple V-type baffles	Re:3000 – 8000, H_B/H_D :0.5,W_B W_D :1.0–6.0, P_B/H_B: 10.0 ,D_d/L_v :0.67, Gw/H_B :1.0, α_a :60°
17.	Chauhan et al [24]	Impinging jets	Re: 3800–16,000 , x/D_h: 0.435–1.739,y/D_h: 0.435–0.869,W/Z: 11.6,D_j/D_h: 0.045–0.109

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