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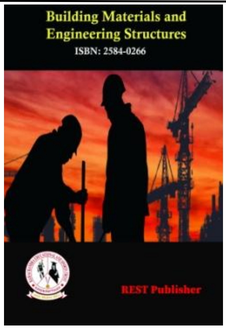

A Review on Optimization of Thermal Performance of Solar Air Heater with artificial Surface Roughness

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Abstract: *The requirement of energy across the globe is increasing at a distressing rate. The conventional sources of energy may no longer be able to meet the requisite demands. India being the second most populous country in the world having 20% of the total world population has a per capita energy consumption of 400 KWh. Hence, the need of hour is to hunt for the sources of energy which can lost longer and wouldn`t harm any forms of lives on the planet earth. Solar energy originating from sun is evolved by a series of chemical reactions that convert about $65*10^7$ tons of Hy drogen to Helium every second. The energy from sun at a distance of $1.5*10^8$ Km reaches the surfaces of collector plates installed on buildings and structures in beam and diffused forms of electromagnetic radiations. The former is called as direct radiation since they don`t change direction while travelling while as latter are subjected to scattering, absorption, re-radiations and re- reflections in the atmosphere.*

Keywords: *Artificial roughness, Solar air heater, Roughnessgeometry, Nusseltnumber, Reynolds number. Friction Factor, Absorberplate, Heattransfer efficiency*

1. INTRODUCTION

In the current period, when there is an incessant demand of energy for the economic development and industrialization, sustainable as well as renewable energy sources are playing crucial role in this regard, in order to design for the high performance eheat transfer systems. Heat tran sferaug mentation in the sether malsystem shasseverala pplicationsfor daytoday including heating of agriculture products, space heating or cooling, in electronics systems and others various industries. Solar energy is a very large inexhaustible source of energy. The power from the sun intercepted by the earth is approximately 1.8×1011 MW which is many thousands of times larger than the present consumption on the earth of all commercial energy sources. The solar energy has compared to fossil fuels and nuclear power is environmentally clean source of energy and it is free and available in adequate quantities in almost all parts of the world. A solar air heater generally consists of an absorber plate with a parallel plate below forming a passage of high aspect ratio through which the air to be heated flows. As in the case of the flat-plate collector, a transparent cover system is provided above the absorber plate, while a sheet metal container filled with insulation is provided on the bottom and sides. The air flows between the cover and absorber plate as well as through the passage below the absorber plate.

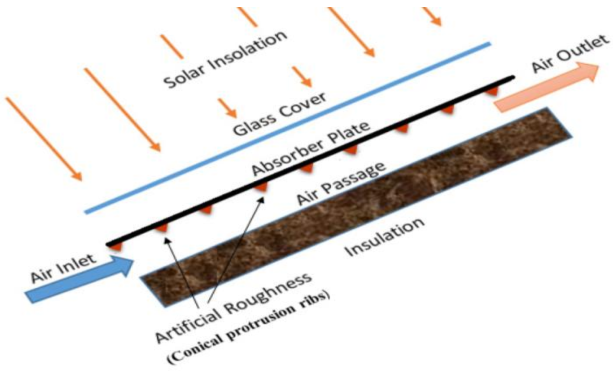

FIGURE 1. Principle View of Solar Air Heater

1.1 Solar Collectors

A solar collector is a device that collects and concentrates solar radiation from the Sun. Asolarabsorberplateisa virtualheat exchanging device which converts radiant solar energy into some useful form. The energy from sun in the form of electromagnetic waves is exchanged with the fluid (air) ina solar air heater. Solar collectors usually have two typesas concentrating collectors and flat plate collectors. The former are more efficient since a high intensity of solar radiation is made to incident on the small area of collector while as the latter has the liquid heating and air heating collectors as main types based on the convection heat transfer taking place between collector surface and air or liquid (water). The efficiency of such type of collectors is increased by raising the convective heat trans ferco efficient between collectorand fluid.

1.2 Solar Air Heaters

Conventional solar air heater consists of a flat plate collector with an absorber plate, transparent cover system at the top and insulation at the bottom and on the sides. Whole assembly is enclosed in a sheet metal container. Working fluid is air and the passage for its flow varies according to the type of air heater. Materials for the construction of air heater are similar to the liquid flat plate collectors. Transmission of solar radiation through the cover system and its subsequent absorption in the absorber plate can be taken into account by expressions identical to those of liquid flat-plate collectors. In order to improve collection efficiency, selective coating on the absorber plate can be used.

1.3 Artificial Roughness Concept

Artificial roughness is widely known passive heat transfer enhancement technique through which thermohydraulic 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.

2. LITERATURE REVIEW

Saini and Saini [1] investigate solar air heater having artificial roughness in the form of arc-shape parallel wire. The effect of system parameters such as relative roughness height (e/d) and arc angle (a/90)have been studied on Nusselt number (Nu) and friction factor (f) with Reynolds number (Re) varied from 2000 to 17000. The maximum enhancement in Nusselt number has been obtained as 3.80 times corresponding the relative arc angle (a/90) of 0.3333 at relative roughnessheightof0.0422.However,theincrementin frictionfactorcorrespondingtotheseparametershas been observed 1.75 times only.

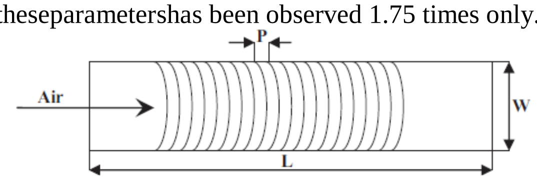

FIGURE. 2 Arc Shaped Rib Roughness

ForHeattransfer,

$\boldsymbol{Nu=0.001047(e/D)^{0.3772}(a/90)^{-0.1198}Re^{1.3186}}$ **ForFrictionFactor,** $\boldsymbol{f=0.14408(e/D)^{0.1765}(a/90)^{0.1185}Re^{-0.17103}}$

It is essential to determine the geometry that will results in the maxi mumenhancementinheattrans fer and minimumincrease in friction factor. This is done using a factor developed by Lewisknownase fficiencyparameter,η whiche valuates the enhancementofheattransferforsamepumpingpower requirement.

Karmare and Tikekar [2]investigated optimum thermo hydraulic performance of metal rib grits roughness. The rate of increase of useful energy gain is relatively higher at low range of Reynolds number, whereas it is a bit lower at higher range of Reynolds number. But the rate of increase of power consumption is low for lower range of Reynolds number and increases relatively at high rate as Reynolds number increases. The thermal efficiency lies within ±8% witha standard deviation of ±6%.

Bopche and Tandale[3]using artificial roughness in the form of specially prepared inverted U- shaped tabulators on the absorber surface of an air heater duct. As compared to the smooth duct, the turbulator roughened duct enhances the heat transferand friction factor by 2.82 and 3.72 times, respectively. At low Reynolds number too (Re < 5000) where ribsare inefficient. At Reynolds number, Re = 3800, the maximum enhancement in Nusselt number and friction factor are of the order of 2.388 and 2.50, respectively

Saini and Verma [4]had used dimple-shape artificial roughness on the underside of the absorber plate. The maximum value of Nusselt number has been found corresponds to relative roughness height (e/D) of 0.0379 and relative pitch (p/e) of 10. While minimum value of friction factor has been found correspond to relative roughness height (e/D) of 0.0289 and relative pitch (p/e) of 10.

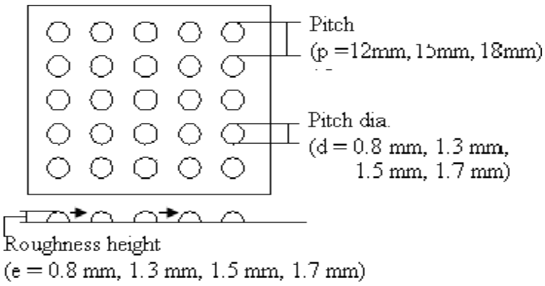

FIGURE 3. Schematic Diagram of Dimpled Shape Geometry

Alok Chaube et al[5]Using nine different rib- shapes of roughness geometry like Rectangular rib(2X3 mm, 4X3 mm, and 5X3 mm), Square rib (3X3 mm), Chamfered rib (Chamfer angle 11 0, 13 0, and 150), Semicircular rib (radius r=3 mm), Circular rib (diameter d=3 mm) have been analyzed for similar duct parameters. They selected Shear stress transport k-ώ turbulencemodelcomparingthepredictionsofdifferent turbulence models with experimental results availablein the literature. The highest heat transfer is achieved with chamfered ribs but the best performance index is found with rectangular rib of size 3X5 mm. It is observed that the 2D analysis model itself yieldsresults, which are closer to the experimental ones as compared to 3D models. The turbulence intensity is found maximum at peak of the local heat transfer coefficient in the inter-rib regions

Eiamsa-ard and Promvonge[6]investigate turbulence model effects, computations based on afinite volume method, are carried out by utilizing four turbulence models: the standard k−ε, the Renormalized Group (RNG) k−ε, the standard k−ω, and the shear stress transport (SST) k−ω turbulence models. It is found that the grooved channel provides a considerable increase in heat transfer at about 158% over the smooth channel and a maximum gain of 1.33 on thermal performance factor is obtained for the case ofB/H=0.75.

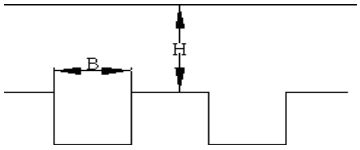

FIGURE 4. Grid Arrangements for Grooved Channel Flow

Lanjewar A.M. et al [7] investigated heat transferinrectangularductusingrepeatedribsinW- continuous pattern. The W- pattern ribs have beentested for both pointing upstream and down tream directions to the flow. The parameters usedwere Reynoldsnumberrange2300-14000,relativeroughness height (e/ Dh) = 0.03375, relative roughness pitch (p/e) 10, rib angle of attack (α) = 45°, thickness of plate 1 mm, channel aspect ratio (W/H) 8, test length 1500mm, hydraulic diameter 44.44 mm. and find the W- shaped ribs pointing downstream have better performance than W – shaped ribs pointing up streamtotheflow. TheStantonnumber isenhanced 2.39 times for W- down and 2.21times for W- up ribs respectively compared to smooth p

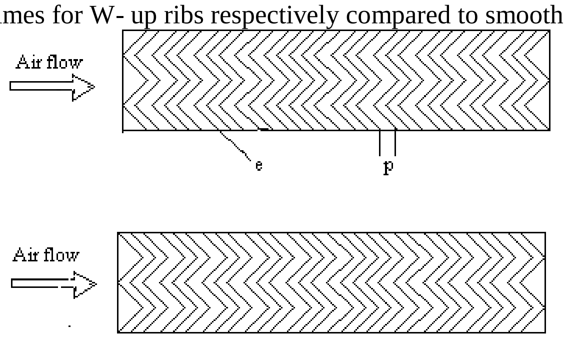

FIGURE 5. Roughness Geometry of W-Up Ribs

Karwa and Solanki [8]hadexperimentallyinvestigatedtheeffect of repeated rectangular cross-section ribs on heattransfer and friction factor for duct aspect ratio (W/H) range of 7.19–7.75, relative roughness pitch (p/e)value of 10, relative roughness height (e/D) range of 0.0467–0.050, Reynolds number (Re) range of 2800–15,000 as shown in Fig. It was explained that vortices originating from the roughness elements beyond the laminar sub-layer were responsible for heat removalaswellasincreaseinfrictionfactor.Theenhancement in the Stanton number was reported to be 65–90% while friction factor was found to be 2.68–2.94 times over smooth duct.

Aharwal et al [9] studied the effect of width and position of gap in inclined split-ribs having square cross section on heat transfer and friction characteristics of a rectangular air heater duct.Theincreasein Nusseltnumberandfriction factorwasin therangeof1.48–2.59timesand2.26–2.9timesofthe smooth duct respectively for the range of Reynolds numbers from3000 to 18,000. Corresponding to a relative gap width (g/e) value of 1.0 and relative gap position (d/W) value of 0.25, values of heat transfer, friction factor ratio (f/fs) and thermo hydraulic perfor-mance parameters were found to be maximum .Itwasinvestigated thatrelative gapwidth beyond 1.0 reduces the flow velocities through the gap and which reduces heat transfer as compared to continuous ribs. If the relativegap widthwastakenlowerthan1.0,thenitshrinksthe passage for secondary flow release which reduces the turbulence intensity behind the gap and hence reduces heat transfer.The geometry investigated has been shown in Fig.5

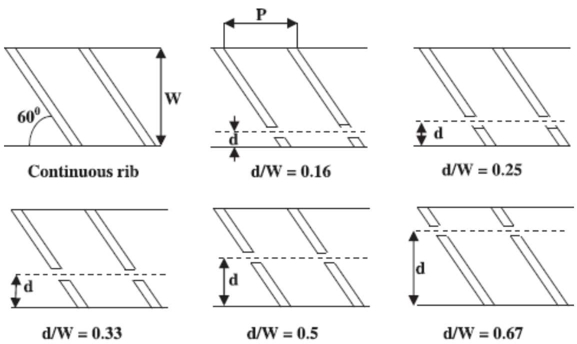

FIGURE 6. Inclined Continuous Rib Roughness with Gap

Hans et al. [10] carried out an experimental investigation to study the effect of multiple v-rib roughness on heat transfer coefficient and friction factor in an artifici allyroughened solar air heater duct as shown in Fig.7. The experimentencom passed Reynolds number (Re) from 2000 to 20,000, relativerou ghness height(e/D)valuesof0.019–0.043,relative roughness pitch (P/e) range of 6–12, angle of attack (α) range of 30–75° and relative roughness width (W/w) range of 1–10. Correlations for Nusselt number and friction factor interms of roughness geometry and flow parameters were developed. A maximum enhancement of Nusselt number and friction factor duetopresence of suchanartificialroughnes swas foundtobe 6 and 5 times, respectively, in comparison to the smooth duct for the range of parameters considered. The maximum heat transfer enhancement was found to occur for a relative roughness width (W/w) value of 6 while friction factor attains maximumvalue forrelativerough-nesswidth(W/w) valueof 10. It was also found that Nusselt number and friction factor attain maxima corresponding to angle of attack (α) value of 60°.MaximumenhancementofNusseltnumberandfriction factor was observed corresponding to relative roughness pitch (P/e) value of 8 while Nusselt number and friction factor increased monotonically with increase in the value of relative roughnessheight(e/D).The geometryinvestigatedhasbeen shown in figure.

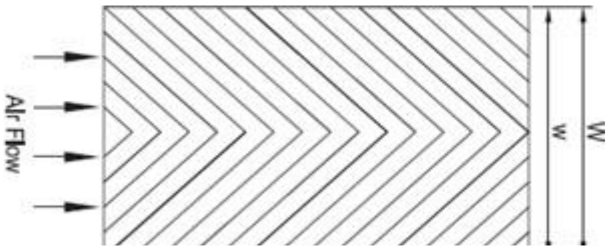

FIGURE 7. V-Shaped Rib Roughness

For Heattransfer,

$$\boldsymbol{Nu = 3.35 \times 10^{-5} Re^{0.92} (e/D)^{0.77} (W/w)^{0.43} (\alpha/90)^{-0.49}}$$
$$\times \exp[-0.1177(\ln(W/w))^2] \exp[-0.061(\ln(\alpha/90))^2]$$

$$\boldsymbol{(p/e)^{8.54} \exp[-2.0407(\ln(p/e))^2]}$$

For Friction Factor,

$$f = 4.47 \times 10^{-4} Re^{-0.3188} (e/D)^{0.73} (W/w)^{0.22} (\alpha/90)^{-0.39}$$

$$\exp[-0.52(\ln(\alpha/90))^2](p/e)^{8.9} \exp[-2.133(\ln(p/e))^2]$$

Sahu and Bhagori [11] had investigated the effect of 90°broken ribs, on thermal performance of a solar air heater for fixed roughness height € value of 1.5 mm, Relative roughness height (e/D) value of 0.0338, duct aspect ratio (W/H) value of 8, pitch (p) in the rangeof 10– 30 mm and Reynolds number (Re) range of 3000–12,000. It was found out that the maximum Nusselt number attained for roughness pitch of 20 and decreased with an increase in roughness pitch. Roughened absorber plates increased the heat transfer coefficient by 1.25–1.4 times as compared to smooth rectangular duct under similar operating conditions at higher Reynolds number. Based on experimentation it was concluded that the maximum thermal efficiency of roughened solar air heater was to be of the order of (51–83.5%) depending upon the flow conditions.

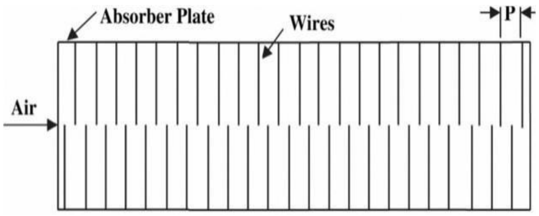

FIGURE 8. Transverse Broken Ribs

3. CONCLUSION

The literature study reveals that large amount of experimental work is done on heat transfer of roughened flow passages. From this work, swirl producers like ribs, hindersandclogs, blockagesandwingletsareconsiderably to use. various type sofartificial roughness of different shapes an dsizes such as V-shape,zig-zagshape, W-shape etc. has been investigated on the absorber plateof solarair heater and found that considerable enhancement in the heattransfer coefficientcanbeachieved with some increment of friction also the laminar sub layer breaks due to the use of artificial roughness and the flow becomes turbulent. Turbulence boosters augment the fluid mingling and obstruct the evolution of thermal boundary layer. The sturdy thwarts amplify the heat transfer following an eminent rise in friction factor. Considerable elaboration in heat exchange can be attained with less retribution of abrasion.

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