A Review of Experimental study & analysis of solar air heater

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Abstract *- Heat energy plays most important role in the field of power generation which involves the heat transfer in domestic as well as industrial purposes. Literature shows the heat transfer coefficient between heat transferring surface and air is low which leads to lower thermal efficiency of the system. Therefore it is important to increase heat transfer coefficient between heat transferring surface and air. Literature shows a large number active and passive technique for the same. The most promising technique to enhance heat transfer coefficient is artificial roughness on heat transfer field. This paper covers the types of technique used in enhance heat transfer coefficient in field of heat transfer and review a variety of papers dealing with artificial roughness on heat transfer field.*

***Key Words*: *artificial roughness, solar air heater, grooved shaped roughness*.**

1.INTRODUCTION

The energy produced and radiated by the sun, more specifically the term refers to the sun's energy that reaches the earth. Solar energy, received in the form of the radiation, can be converted directly or indirectly into other forms of energy, such as heat and electricity, which can utilize by man. Solar energy as we know is non-conventional source of energy so because of that we can use this energy without any trouble. Sun acts as a spherical black body of temperature around 6000°C. It radiates energy at all possible directions. The sun radiates energy about 3.8×1023 Kw, of this only 2×1014 Kw reaches the earth. If 9/10th of this is lost by reflection, refraction and absorption in the outer layers of atmosphere, the quantity available at the surface is 2×1013 Kw, which is equivalent to the burning of some 17 million tons of coal. Hence it is abundant in quantity. Heat transfer enhancement techniques have been used to improve the performance of a solar air heater which is the simplest and most commonly used device in solar energy applications, requiring low grade thermal energy, such as drying of agricultural produce, seasoning of wood, space heating, curing of industrial products. The performance of solar air heater can be increased by roughened the absorber plate.

2. Method of increasing the heat transfer rate

1. Surface methods
   a. Roughened surfaces
   b. Extended surfaces
   c. Surface vibration
   d. Surface rotation
2. Fluid methods
   a. Fluid vibration
   b. Fluid additives
   c. Electrostatic fluids
3. Compound methods
   a. Vibration/ roughened
   b. Perforation/ corrugations
   c. Rotation

Nomenclature

A_c surface area of collector,m^2 ΔP_d
pressure drop across test section, Pa
A_d area of duct, m^2 ΔP_o
pressure drop across orifice meter, Pa
A_p surface area of absorber plate, m^2 Q_u
useful heat gain, W
A_o area of orifice, m^2 Re
Reynolds number, VDh/υ, dimensionless
B/S relative roughness length ratio, L/e
relative longway of mesh, dimensionless
dimensionless l/s
relative length of metal grit, dimensionless
C_d coefficient of discharge of orifice meter, R_o
rotation number, dimensionless
dimensionless S
shortway of mesh, m
C_p specific heat of air at constant pressure,

D_h hydraulic diameter of air passage, S/e
relative shortway of mesh, dimensionless
$D_h = 2WH/(W + H)$, m St
Stanton number
e rib height, mm V
velocity of air in duct, m/s
e/D_h relative roughness height,
Greek symbols: dimensionless α
rib angle of attack, degree
f friction factor, dimensionless β
ratio of orifice diameter to pipe diameter,
g/p groove position to pitch ratio,dimensionless
φ_c chamfer angle, degree
G_m mass velocity of air, kg/m^{2s}
φ_w wedge angle, degree
G momentum heat transfer function, ρ_a
density of air, kg/m3
ρ_m density of manometric fluid, kg/m
G Mass velocity of air, m/s
W width of duct, m
H height of duct, m
W/H aspect ratio (AR) of duct, dimensionless
I Heat flux, W/m2
Δρ/ρ inlet coolant-to-wall density ratio,
h convective heat transfer coefficient
Δh difference of liquid head in U-tube υ
kinematic viscosity of air, m2/s
manometer,mm
k thermal conductivity of air, W/m K
L long way of mesh, m
r rough
l projected length of metal grit perpendicular
s smooth
to direction of flow, m
Lf Length of test section for friction factor calculation, m
m mass flow rate of air, kg/s
Nu Nusselt number, dimensionless
Pr Prandtl number, dimensionless
P pitch, mm
p/e relative roughness pitch, dimensionless

3. Concept of artificial roughness

When the fluid flow through the duct of solar air heater, a laminar sub layer is formed over the absorber plate surface because of that it impedes the heat transfer to the flowing fluid, so it can affect the thermal performance of solar air heater. Artificial roughness's primary work is to reduce the thickness of boundary layer. Artificial roughness provided in the inner side of absorber plate that creates the turbulent effect. Secondary recirculation flows further enhance the convective heat transfer. However, energy for creating such turbulence has to come from the fan or blower and the excessive power required making the air flow through 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 friction losses. This can be done by keeping the height of the roughness element small in comparison with the duct dimension. There are several parameters that characterize the arrangement and shape of the roughness, the roughness element height (e) and pitch (p) are the most important parameters. These parameters are usually specified in terms of dimensionless parameters, namely, relative roughness height (e/D) and the relative roughness pitch (p/e).

Types of Artificial Roughness:

The basic types of artificial roughness are:

1) Three dimensional roughness (uniform roughness)
2) Ridge type two dimensional roughness (repeated ribs)
3) Groove type two dimensional roughness.

4. Literature Reviews

Abdul et al. [1] experimentally investigation of the effect of geometrical parameters of V-shaped ribs on heat transfer and fluid flow characteristics of rectangular duct of solar air heater with absorber plate having V-shaped ribs on its underside have been reported.

The maximum enhancement of Nusselt number and friction factor as a result of providing artificial roughness has been found to be respectively 2.30 and 2.83 times that of smooth duct for an angle of attack of 60^0. It was observed that the same angle of attack corresponds to the maximum values of both Nusselt number and friction factor. It appears that the flow separation and the secondary flow resulting from the presence of V-shaped ribs and the movement of resulting vortices combine to yield an optimum value of angle of attack.

It was found that for relative roughness height of 0.034 and for angle of attack of 60^0, the V-shaped ribs enhance the values of Nusselt number by 1.14and 2.30 times over inclined ribs and smooth plate case at Reynolds number of 17034. It means that the V-shaped ribs have definite advantage over the inclined ribs for similar operating conditions.

Alok Chaube et al. **[2]** computationally analysis of heat transfer augmentation and flow characteristics due to artificial roughness in the form of ribs on a broad, heated wall of a rectangular duct for turbulent flow (Reynolds number range 3000–20,000 which is relevant in solar air heater) has been carried out. Shear stress transport k-ω turbulence model is selected by comparing the predictions of different turbulence models with experimental results available in the literature. A detailed analysis of heat transfer variation within inter rib region is done by using the selected turbulence model. The analysis shows that peak in local heat transfer coefficient occurs at the point of reattachment of the separated flow as observed experimentally. The results predict a significant enhancement of heat transfer in comparison to that for a smooth surface. The highest heat transfer is achieved with chamfered ribs but the best performance index is found with rectangular rib of size 3×5 mm.

Anil Kumar et al. [3] experimentally investigated the heat transfer and friction in the flow of air in rectangular ducts having multi v-shaped rib with gap roughness on one broad wall. The investigation encompassed Reynolds number (Re) from 2000 to 20,000, relative gap distance (G_d/L_v) values of 0.24 to 0.80, relative gap width (g/e) values of 0.5 to 1.5, relative roughness height (e/D) values of 0.022 to 0.043, relative roughness pitch (P/e) values of 6 to 12, relative roughness width ratio (W/w) values of 1 to 10, angle of attack (a) range of 30° to 75° The optimum values of geometrical parameters of roughness have been obtained and discussed. For Nusselt number (N_u), the maximum enhancement of the order of 6.74 times of the corresponding value of the smooth duct has been obtained, however the friction factor (f) has also been seen to increase by 6.37 times of that of the smooth duct.

A.R. Jaurker et al. [4] experimentally investigated the heat transfer and friction characteristics of rib-grooved artificial roughness on one broad heated wall of a large aspect ratio duct shows that Nusselt number can be further enhanced beyond that of ribbed duct while keeping the friction factor enhancement low. The experimental investigation encompassed the Reynolds number range from 3000 - 21,000; relative roughness height 0.0181–0.0363; relative roughness pitch 4.5–10.0, and groove position to pitch ratio 0.3–0.7. The effect of important parameters on the heat transfer coefficient and friction factor has been discussed and the maximum heat transfer occurs for a relative roughness pitch of about 6.0. and the presence of rib grooved artificial roughness yields Nusselt number up to 2.7 times while the friction factor rises up to 3.6 times in the range of parameters investigated as compared to the smooth surface.

Arvind Kumar et al. [5] experimentally investigation has been carried out to study the heat transfer and friction characteristics in solar air heater by using discrete W-shaped roughness on one broad wall of solar air heater with an aspect ratio of 8:1, the roughened wall being heated while the remaining three walls are insulated. The maximum enhancement of Nusselt number was found to be 1.44, 1.54, 1.67 and 1.61 times that for smooth duct for angles of attack of 30^0, 45^0, 60^0 and 75^0 for relative roughness height of 0.0168. Whereas for relative roughness height of 0.0338, the maximum enhancement in Nusselt number was found to be 1.88, 1.99, 2.16 and 2.08 times for corresponding angles of attack of 30^0, 45^0, 60^0 and 75^0. Solar air heaters with roughened absorbers perform better as compared to smooth heaters. Discrete ribs have significant effect on heat transfer.

Atul Lanjewar et al. [6] experimentally 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. Range of parameters for this study has been decided on basis of practical considerations of system and operating conditions. Nusselt number increases whereas friction factor decreases with increase of Reynolds number. Values of friction factor and Nusselt number are higher as compared to those for smooth absorber plate. This is due to change in flow characteristics because of roughness that causes flow separation, reattachments and generation of secondary flow. Maximum enhancement of Nusselt number and friction factor as result of providing artificial roughness has been found to be 2.36 and 2.01 times respectively that of smooth duct for angle of attack of 60°.

Gupta et al. [7] experimentally investigated 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 a roughened solar air heater for transitionally rough flow region ($5 < e+ < 70$).For a roughened solar air heater, maximum enhancement in heat transfer and friction factor was reported to be of the order 1.8 and 2.7 times respectively corresponding to angle of inclination values of 60^0 and 70^0, respectively. Best thermo hydraulic performance was reported for relative roughness height (e/D) value of 0.023 and Reynolds number (Re) value of 14,000.

K.R. Aharwal et al. [8] experimentally investigation of heat transfer and friction factor characteristics of a rectangular duct roughened with repeated square cross-section split-rib with a gap, on one broad wall arranged at an inclination with respect to the flow direction. A gap in the inclined rib arrangement enhances the heat transfer and friction factor of the roughened ducts. The increase in Nusselt number and friction factor is 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. The maximum values of Nusselt number and friction factor are observed for a gap in the inclined repeated ribs with a relative gap position of 0.25 and a relative gap width of 1.0. The thermo-hydraulic performance analysis of roughened ducts shows that the relative gap width of 1.0 and a relative gap position of 0.25 results in a higher value of efficiency parameter.

Rajendra Karwa et al. [9] experimentally investigation of an experimental study of thermo-hydraulic performance of a solar air heater with 60° v-down discrete rib roughness on the airflow side of the absorber plate along with that for a smooth duct air heater. The enhancement in the thermal efficiency due to the roughness on the absorber plate is found to be 12.5% - 20% depending on the airflow rate; higher enhancement is at the lower flow rate. The experimental data have been generated and utilized to validate a mathematical model, which can be utilized for design and prediction of performance of both smooth and roughened air heaters under different operating conditions. The results of a detailed thermo-hydraulic performance study of solar air heater with v-down discrete rib roughness using the mathematical model are also presented along with the effect of variation of various parameters on the performance.

V. S. Hans et al. [10] experimentally investigation carried out to study the effect of multiple v-rib roughness on heat transfer coefficient and friction factor in an artificially roughened solar air heater duct. A maximum enhancement of Nusselt number and friction factor due to presence of such an artificial roughness has been found to be 6 and 5 times, respectively, in comparison to the smooth duct for the range of parameters considered. It has also been found that Nusselt number and friction factor attain maximum corresponding to angle of attack (α) value of 60^0. The maximum heat transfer enhancement has been found to occur for a relative roughness width (W/w) value of 6 while friction factor attains maximum value for relative roughness width (W/w) value of 10.

Table 1 Heat transfer coefficient and Friction factor core relations for different roughness geometries

Authors[1]	Roughness geometry[2]	Parameters[3]	Correlations[4]	
			Heat transfer	Friction factor
Abdul-Malik Ebrahim Momin et al. [1]	V shape rib	Re= 2500–18,000 p/e = 10 e/Dh = 0.02 – 0.034 α=30°- 90°	$Nu = 0.023\, Re^{0.8} Pr^{0.4}(2R/D)^{-0.2}$	$f = 0.085(Re)^{-0.25}$
Alok choube et al. [2]	Rectangle rib, square rib, chamfer rib, circular rib, semi circular rib	Re= 3000–20,000 Rib height (e)=3mm Pitch (p)= 40mm p/e=13.3 Aspect ratio (AR)=5	$Nu = 0.024\, Re^{0.8} Pr^{0.4}$ $ή = \frac{St/Sts}{\left(\frac{F}{Fs}\right)1/3}$	$f = 0.085(Re)^{-0.25}$
Anil kumar et al. [3]	Multi V – shaped rib with gap	Re: 2000 - 20,000 (Gd/Lv): 0.24-0.80 (g/e): 0.5-1.5 (e/D): 0.022-0.043 (P/e): 6-12 (W/w): 1-10 (α) : 30°-75°	Nu= hD/k Re=VD/v	$f = 2(\Delta P)D/4\rho LV^2$

A.R. Jaurker et al. [4]	Rib grooved	Re= 3000–21,000 p/e= 4.5–10.0 e/D=0.0181–0.0363 g/p= 0.3–0.7	Nu = 0.002062 $Re^{0.936}$ $(e/D)^{0.349}$ $(p/e)^{3.318}$ x exp[-0.868{ln(p/e)}^{2}] $(g/p)^{1.108}$ x exp[2.486{ln(g/p)}^{2} + 1.406{ln(g/p)}^{3}]	f = 0.001227$(Re)^{-0.199}$ $(e/D)^{0.585}$ $(p/e)^{7.19}$$(g/p)^{0.645}$ x exp(-1.854 {ln(p/e)}^{2}) x exp (1.513 {ln(g/p)}^{2} +0.8662 {ln (g/p)}^{3})
Arvind Kumar et al. [5]	discrete W-shaped ribs	Re: 3000-15000, p/e: 10, e/D_h: 0.0168-0.0338, α:30^0-75^0	Nu = 0.105 $Re^{0.873}$$(e/Dh)^{.453}$$(α/60)^{-0.081}$ ×[exp (-0.59(In (α/60))^2]	f= 5.68 $Re^{-0.40}$ $(e/D_h)^{0.59}$ $(α/60)^{0.081}$ ×[exp (-0.579(In(α/60))^2]
Atul Lanjewar et al. [6]	W-shaped ribs	Re: 2300-14000, p/e: 10, W/H: 8:0 e/D_h: 0.03375, α:30^0-75^0	Nu= 0.0613 $Re^{0.9079}$$(e/Dh)^{.4487}$$(α/60)^{-0.1331}$ ×[exp (-0.5307 (In (α/60))^2]	f_s= 0.6182 $Re^{-0.2254}$ $(e/D_h)^{0.4622}$ $(α/60)^{0.0817}$×[exp (-0.28(In(α/60))^2]
Gupta et al. [7]	Inclined continuous ribs	Re: 3000-18000, p/e: 7.5 and 10, e/D_h: 0.020-0.05, α:30^0-90^0	Nu=0.024$(e/D_h)^{0.001}$$(W/H)^{-0.06}$$Re^{1.084}$× exp[-0.004(1-α/60)^2, for e^+<35 Nu=0.071$(e/D_h)^{-0.24}$$(W/H)^{-0.028}$$Re^{0.88}$× exp[-0.47(1-α/60)^2, for e^+ ≥35	f= 0.1911$(e/D_h)^{0.196}$$(W/H)^{-0.093}$ $Re^{1.084}$× exp [-0.993(1- α/70)^2]

K.R. Aharwal et al. [8]	Inclined rib with gap	Re: 3000-18000, g/e: 0.5-2, e/D_h: 0.0377, d/W:0.1667-0.667, W/H: 5.84,α:60^0	Nu= $0.002Re^{1.08=(p/e)}1.87 \times exp[-0.45(In(p/e))^2] (\alpha/60)^{0.006} \times exp[-0.65(In(\alpha/60))^2] (d/W)^{-0.32} \times exp[-0.12(In(d/W))^2] (g/e)^{-0.03} \times exp[-0.18(In (g/e))^2] (e/D)^{0.5}$	$f=0.071Re^{-0.133}(p/e)^{1.83}exp[-0.44(In(p/e))^2] \times(d/W)^{-0.43}\times exp[-0.14(In(d/W))^2] (g/e)^{-0.52} \times(\alpha/60)^{0.67}\times exp[0.12(In(g/e))^2] (e/D)^{0.69}$
Rajendra karwa et al. [9]	60°v-down discrete rib	Re= 2700–11,150 p/e = 10.64 e/Dh = 0.047 α=60°	Nu = hD/k Pr = μCp/k	$f = 2DpdDh/4LG_1^2$
V.S. Hans et al. [10]	multiple V-ribs	Re: 2000-20000, p/e: 6-12, α: 30^0-75^0 e/D_h: 0.019-0.043, g/e: 0.5-2.0, W/w:1-10	$Nu=3.35\times10^{-5}Re^{0.92}(e/D)^{0.77}(\alpha/90)^{-0.49} (W/w)^{0.43}exp(-0.1177(In(W/w))^2$ $Exp[-0.61(In\ \alpha/90)^2] (p/e)^{8.54} exp(-2.0407(In(p/e))^2$	$f =4.47\times10^{-4}Re^{-0.318}(e/D)^{073} (W/w)^{0.22} \times(\alpha/90)^{-0.39}\times exp[-0.52(In(\alpha/90))^{-0.39}] (p/e)^{8.9}\times exp[-2.133(In(p/e))^2]$

5. Conclusion

An attempt has been made in the present paper to report the heat transfer coefficient and friction factor characteristics of artificially roughened duct in solar air heater using of different shapes of geometry. It can be concluded that there is a considerable enhancement in heat transfer with little penalty of friction. This is interesting to see for further work that how Correlations can be developed for heat transfer and Friction factor for solar air heater ducts having artificial roughness of different geometries for different investigators. Correlations developed for heat transfer and friction factor of solar air heater duct having artificial roughness of different geometries by different investigators are also presented in tabular form. These correlations can be used to predict the thermal efficiency, effective efficiency and hydraulic performance of artificially roughened solar air heater duct. Information provided in the present paper may be useful to the beginners in this area of research to find out and optimize the new element geometries for the maximum enhancement of heat transfer.

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