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# Thermal Performance of Solar Air Collector: A review

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***Abstract:*** **Solar Air Heater shape the primary element of solar strength utilization gadget which absorbs the incoming solar radiation, converting it into thermal strength at the soaking up floor, and transferring the power to a fluid flowing through the collector. The performance of solar air heater has been located to be low due to low convective heat transfer coefficient among absorber plate and the flowing air which increases the absorber plate temperature, results in heat losses to the environment, ensuring in the low thermal performance of such collectors. Artificial Roughness is the handiest and financial manner of improving the thermal performance of solar air heater. This paper gives an in-depth review of the research accomplished on an artificial roughened plate of solar air heater. The objective of this paper is to study diverse studies, executed on the thermo-hydraulic performance of artificially roughened plate of solar air heater. The assessment provided in this paper might be beneficial for the researchers operating in this place.**

## 1. INTRODUCTION

Energy is a simple element needed to sustain lifestyles and development. Energy is wanted in various forms to fulfill our each day necessities. Energy consumption rate of the humans are directly associated with the prosperity or the standard of living. Two sorts of energy sources are available: Conventional and Non-Conventional [1,2]. Conventional energy resources such as fossil fuels (coal, crude oil and natural gas) are limited in amount. Total energy in recoverable conventional energy resources is estimated to be around 30–35 Q (1Q = $10^{18}$ kJ) while the global energy consumption rate is roughly 0.4–0.5 Q/yr. Consequently, conventional power sources are more or less anticipated to last for seventy five–eighty five years. This consciousness of the constrained nature of traditional strength assets gave rise to the hunt of change power resources. Non-conventional energy resources may be divided into two categories, particularly, renewable and non-renewable resources. Renewable resources are the ones that have a less period of renewal (up to a few years) including solar energy, wind energy, biomass energy, hydroelectricity, ocean and tidal energy. Solar energy is the most promising of these options. [3,4].

Solar air heaters (SAHs) form the foremost component of solar energy utilization system. These air heaters absorb the irradiance and convert it into thermal energy at the absorbing surface and then transfer this energy to a fluid flowing through the collector. SAHs are inexpensive and most used collection devices because of their inherent simplicity[5].

*Nomenclature*

$C_p$ = specific heat of air, J/kg k
D = equivalent or hydraulic diameter of duct, mm
e = rib height, mm
H = depth of duct, mm
h = heat transfer coefficient, W/m2k
I = intensity of solar radiation, W/m2
k = thermal conductivity of air, W/m k
L = length of duct, mm
m = mass flow rate, kg/s
P = pitch, mm
q = heat flux, W/m2
T = air temperature, K
$T_0$ = ambient temperature, K
$T_{am}$ = mean air temperature, K
$T_i$ = air inlet temperature, K
$T_o$ = air outlet temperature, K
$T_{pm}$ = mean plate temperature, K
$T_w$ = wall temperature, K
u = air flow velocity in the x direction, m/s
$U_0$ = mean air flow velocity in the duct, m/s
v = air flow velocity in the y direction, m/s
W = width of duct, mm
ΔP = pressure drop, Pa

*Dimensionless parameters*

B/S = relative roughness length
d/w = relative gap position
e/D = relative roughness height
e/H = rib to channel height ratio
f = friction factor
$f_r$ = friction factor for rough surface
$f_s$ = friction factor for smooth surface
g/e = relative gap width
g/P = relative groove position
$G_d/L_v$ = relative gap distance
L/D = test length to hydraulic diameter ratio of duct

Nu = Nusselt number
$Nu_r$ = Nusselt number for rough duct
$Nu_s$ = Nusselt number for smooth duct
P/e = relative roughness pitch
Pr = Prandtl number
Re = Reynolds number
S/e = relative short way length of mesh
St = Stanton number
W/H = duct aspect ratio
W/w = relative roughness width

*Greek symbols*
α = angle of attack, degree
δ = transition sub-layer thickness, mm
ε = dissipation rate, $m^2/s^3$
κ = turbulent kinetic energy, $m^2/s^2$
μ = dynamic viscosity, $Ns/m^2$
$\mu_t$ = turbulent viscosity, $Ns/m^2$
ρ = density of air, $kg/m^3$
ω = specific dissipation rate, 1/sec

*Subscripts*
a = ambient
am = air mean
f = fluid (air)
i = inlet
m = mean
o = outlet
pm = plate mean
r = roughened
s = smooth
t = turbulent
w = wall

Heat transfer enhancement techniques had been hired to enhance the overall performance of a solar air heater that is commonly used device in solar power applications, requiring low grade thermal power, consisting of drying of agricultural produce, seasoning of wood, space heating, curing of commercial merchandise. Performance of a solar air heater is adversely affected due to low thermal capacity of air and low absorber plate to air convective heat transfer coefficient, which needs design compensation. For this reason surface techniques, which at once contain the heat exchanger surface, are employed on the bottom of absorber plate that comes in contact with air. These techniques improve the thermal performance either through increasing the heat transfer area with the usage of corrugated or finned absorber surfaces or by improvement in convective heat transfer coefficient between the absorber plate and flowing air with usage of roughened absorber surfaces.[6]

### *1.1 Thermo-hydraulic considerations*

Performance of a solar air heater depends upon the heat transfer among absorber plate and air flowing through it. Heat transfer rate for turbulent flow is higher than that of laminar flow and exceptional roughness geometries are used to introduce turbulence for higher fluid mixing. However, any roughness geometry that enhances heat transfer is most possibly to growth pressure drop also. To account for the pressure drop within the performance of roughness geometry, following standards that integrate thermal and hydraulic performance (or effective performance) are normally used.

### *1.2 Thermo-hydraulic Performance Parameter*

Enhancement in heat transfer followed with increase in friction power penalty which could not give the right picture of heat transfer increment. To see the overall performance of such device, it's far consequently vital to decide the configuration of roughness geometry on the way to bring about maximum enhancement in heat transfer with minimum friction power penalty. For this reason a parameter has been investigated that's known as thermo-hydraulic performance parameter (TPP) and is proposed by Lewis (1975). This parameter evaluates the enhancement in heat transfer of an artificially roughened plate in comparison to smooth plate for the equal amount of friction penalty. This parameter is defined as,

$$\eta = \frac{St/St_s}{(f/f_s)^{1/3}}$$

## 2. EFFECTS OF PARAMETERS ON THERMAL PERFORMANCE OF SOLAR AIR HEATER

The performance of Solar Air Heater is a complex function of various parameters which can be classified as:

***i. System Parameter:*** (a) Number of glass cover – Maximum efficiency is usually obtained with one or two cover depending upon surface whether it is selective or not. (b) Glass Cover Emissivity – Low value of emissivity results in low thermal losses and thus in better efficiency. (c) Plate Spacing – Since the collectors are designed to operate at different locations with the varying tilts and under varying service conditions, an optimum value of spacing between the absorber plate and lower glass cover is difficult to specify. However, typical values of 1 to 4 cm are generally used.

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***ii. Operational Parameters :*** (a) Inlet Fluid Temperature – The efficiency of collector plate decreases with increasing value of inlet fluid temperature. (b) Mass Flow Rate – An increase in mass flow rate of the carrier fluid increases the value of collector efficiency.

***iii. Meteorological Parameters:*** (a) Incident Solar Radiation – Higher incident radiation results in higher efficiency for the given inlet fluid temperature. (b) Wind Speed – Higher the wind speed greater is the thermal loss, which causes the collector efficiency to decrease. (c) Dust on the Top Cover – Dust collected on the top cover reduces the transmitted components of incident solar radiation and thus the efficiency of collector decreases.

## 3. VARIOUS INVESTIGATIONS FOR IMPROVEMENT OF HEAT TRANSFER BY USING ARTIFICIAL ROUGHNESS ON ABSORBER PLATE

Prasad and Mullick [7] suggested the use of artificial roughness in the form of small diameter wires in a solar air heater duct to improve the thermal performance of the collector by way of improving the heat transfer coefficient from absorber plate to air. The wire used was 0.84 mm in size having relative roughness height (e/D) of 0.019 and relative roughness pitch (p/e) of 12.7 and Reynolds number ranged between 10000 to 40000. The plate efficiency factor with roughened absorber plate at Reynolds number of 10000 improved from 0.24 to 0.264 whereas the Reynolds number of 40000, it increase from 0.55 to 0.557.

Hans et al. [8] investigated the rib-roughened surface for effects of rib shape, angle of attack, spacing and pitch to height ratio. They developed the relation for friction factor and heat transfer, in order to define a roughness geometry which gives the best heat transfer performance for a given flow friction.

Jaurker et al. [9] developed the correlation for Nusselt number and friction factor, for rib grooved artificial roughness on one broad heated wall. They carried out the thermo-hydraulic performance analysis of solar air heater, based on efficiency index, and concluded that rib-grooved arrangement is better than rib only.

Similar investigations for heat transfer and fluid flow characteristics have been carried out by Gupta et al. [10] for transverse wire roughness; Momin et al. [11] for V shaped ribs; Bhagoria et al. [12] for wedge shaped rib; Sahu and Bhagoria [13] for broken transverse ribs; and Layek et al. [14] for chamfered red rib-groove roughness.

Mittal et al. [15] evaluated and compared the effective efficiency of solar air heaters having different roughness geometry on absorber plate, for set of fixed system and operating parameters. They determined the effective efficiency by using the correlations for heat transfer and friction factor developed by various investigators. They plotted the variation of effective efficiency with Reynolds number for smooth absorber plate, as well as roughened absorber plate solar air heaters for different relative roughness height. The Reynolds number for maximum effective efficiency was in the range 10000-14000 for the set of parameters investigated.
Saini and Saini [16] carried out an experimental investigation to study the effect of wire mesh roughened absorber plate on Nusselt number augmentation and friction factor characteristics of solar air heaters. The investigation considered relative long way length of mesh, L/e, in range of 25–71.87, relative short way length of mesh, S/e, in range of 15.62–46.87, relative roughness height, e/D, in range of 0.012–0.039 and Reynolds number, Re, in range of 1900–13000. It was reported that the maximum heat transfer of order 4 times over the smooth duct were obtained corresponding to angle of attack of 61.91, relative long way length of mesh, L/e, value of 46.87 and relative short way length of mesh, S/e, value of 25. Maximum value of friction factor was reported for angle of attack of 721, relative long way length of mesh, L/e, value of 71.87 and relative short way length of mesh, S/e, value of 15.

Varun et al. [17] carried out a comparative experimental study of augmented heat transfer and friction in a rectangular duct having rectangular cross-section ribs arranged in transverse, inclined, v-shaped continuous and v-shaped discrete pattern for duct aspect ratio, W/H, range of 7.19–7.75, relative roughness pitch, P/e, value 10, relative roughness height, e/D, range of 0.0467–0.050 and Reynolds number, Re, range of 2800–15000. The enhancement in the Stanton number over the smooth duct was reported to be in range of 65–90%, 87–112%, 102–137%, 110–147%, 93–134% and 102–142% for transverse, inclined, v-shaped up continuous, v-shaped down continuous, v-shaped up discrete and v-shaped down discrete rib arrangement respectively. The friction factor ratios corresponding to these arrangements were found as 2.68–2.94, 3.02–3.42, 3.40–3.92, 3.32–3.65, 2.35–2.47 and 2.46–2.58 respectively.

Kumar et al. [18] showed that discrete multi V-ribs on the underside of the absorber plate of an solar air heater duct amplifies thermal as well as hydraulic efficiencies. They concluded that the higher heat transfer rate is attributed to the interaction of secondary flow released through the

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discrete in multiple V-rib roughness with the main flow. The higher thermal performance is attributed to the interaction of the secondary flow released through the discrete with the main flow. This increases effective efficiency through the discrete width area behind the discrete. Discrete multi V-ribs performed better than non-discrete multiple V-ribs.

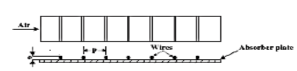
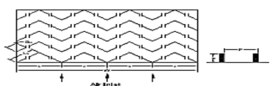
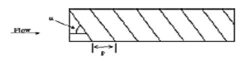
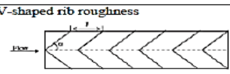
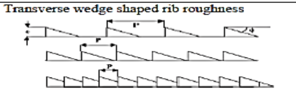
Singh et al.[20] experimentally compared the exergetic efficiency of flat plate solar collector having absorber plate of different shapes and orientations and reported that the optimum value of exergetic efficiency is obtained in case of a conventional collector. It can be seen from that the highest thermal efficiency is obtained at d/w of 0.65 for Re < 13,000, and for Re > 415,300 the smooth conventional solar air heater results in the highest thermal efficiency. For Reynolds number in the range of 13,000 to 15,300 different d/w are observed to result in the highest thermal efficiency depending on the Reynolds number.

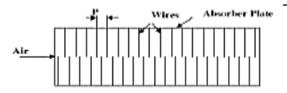
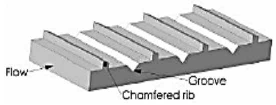
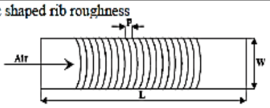
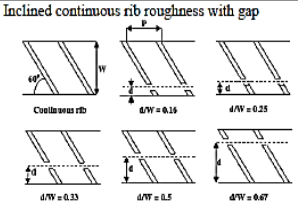
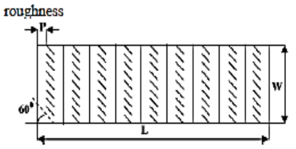
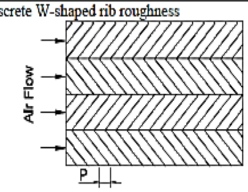
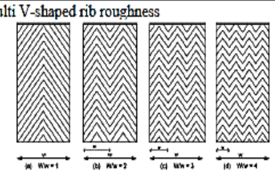
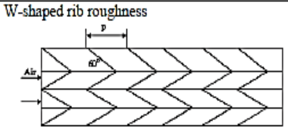
Anil and Varun [21] experimentally investigated the effect of geometrical parameters of multiple arc shaped roughness element on heat transfer and friction characteristics of rectangular duct solar air heater having roughness on the underside of the absorber plate have been studied. The parameters were selected on the basis of practical considerations and operating conditions of solar air heaters. The experiments carried out encompasses Reynolds number (Re) in the range of 2200–22,000, relative roughness height (e/D) range of 0.018–0.045, relative roughness width (W/w) ranges from 1 to 7, relative roughness pitch (p/e) range of 4–16, and arc angle (α) ranges from 30º to 75º The thermo-hydraulic performance parameter was found to be best for relative roughness width (W/w) of 5.

Mukesh and Prasad [22] conducted a comprehensive investigation on thermal and thermo-hydraulic performance of solar collector for heating air having circular wire rib roughness in the form of arc shape on the back side of absorber plate, has been carried out. A mathematical model incorporating the operating and system parameters has been developed and the results have been computed by using MATLAB for specified range of these parameters. A conventional solar air heater working under similar conditions has also been considered for the purpose of comparison. At rib height-to-duct hydraulic diameter ratio = 0.0422 and flow-attack-angle = 0.3333 the values of maximum thermal and effective efficiencies were found to be 79.84% and 75.24% respectively.

Arun Kumar Behura and Sachindra Kumar Rout[23] experimentally investigated for fully developed turbulent flow of artificially roughened solar air heaters have been established to have a better performance as compared to smooth one under the similar operating conditions. Three sides glass covers with three sides artificially roughened solar air heater has been analyzed and investigated, which result in enhancement of friction factor and heat transfer than existing one side artificially roughened ones. It has been concluded that the values of both heat transfer enhancement factor and friction loss factor increase with the improving of flow Reynolds number. For a fixed value of e/D the rate of increment of friction factor is higher than that of Nusselt number at varying values of p/e. In the range of the parameters investigated, the value of heat transfer increment factor is in the range of 0.378 to 0.487, while, it is in the range of 0.384 to 0.491 for the friction factor.

## 4. LITERATURE SURVEY

| Investigators | Types of roughness geometry | Roughness parameter range | Finding Results |
|---|---|---|---|
| Prasad and Mullick[7] | Transverse wire rib roughness | e/D: .019<br>P/e: 12.7<br>Re: 10,000-40,000 | 14% improvement in thermal performance was reported at a Reynolds number of 40,000 over smooth duct. |
| Kumar et al.[18] | Multi V-shaped rib roughness with gap | e/D: 0.043<br>g/e: 0.5-1.5<br>$G_d/L_v$: 0.24-0.80<br>P/e: 10<br>Re: 2000-20,000<br>W/H: 12<br>W/w: 6<br>α: 60° | 6.32 and 6.12 times enhancement in Nusselt number and friction factor respectively were reported over smooth duct. |
| Singh et al.[20] | Discrete V-down rib roughness | d/w: 0.2–0.8<br>e/D: 0.015–0.0.043<br>g/e: 0.5–2.0<br>P/e: 4–12<br>Re: 3000–15,000<br>α: 30°–75° | 3.04 and 3.11 times enhancement in Nusselt number and friction factor respectively were reported over smooth duct. |
| Karwa et al.[25] | Chamfered repeated rib-roughness | e/D: 0.014–0.032<br>L/D: 32 & 66<br>P/e: 4.5–8.5<br>ϕ: - 15°–18°<br>Re: 3000–20,000<br>W/H: 4.8–12 | 2 and 3 times enhancement in Stanton number and friction factor respectively were reported over smooth duct. |
| Prasad and Saini[24] |  | e/D: 0.02–0.033<br>P/e: 10–20<br>Re: 5000–50,000 | 2.38 and 4.25 times enhancement in Nusselt number and friction factor respectively were reported over smooth duct. |
| Kumar et al.[26] |  | Re: 2000–20,000<br>e/D: 0.022–0.043<br>α: 30°–75°<br>g/e: 0.5–1.5<br>$G_d/L_v$: 0.24–0.80<br>W/w: 1–10<br>P/e: 6–12 | 6.74 and 6.37 times enhancement in Nusselt number and friction factor respectively were reported over smooth duct. |
| Gupta[27] | Inclined wire rib roughness  | e/D: 0.018–0.032<br>P/e: 10<br>Re: 5000–50,000<br>W/H: 6.8–11.5<br>α: 30°–90° | 1.8 and 2.7 times enhancement in Nusselt number and friction factor respectively were reported over duct with transverse ribs. |
| Momin et al.[11] | V-shaped rib roughness  | e/D: 0.02–0.034<br>P/e: 10<br>Re: 2500–18,000<br>W/H: 10.15<br>α: 30°–90° | 2.30 and 2.83 times enhancement in Nusselt number and friction factor respectively were reported over smooth duct. |
| Bhagoria et al.[12] | Transverse wedge shaped rib roughness  | e/D: 0.015–0.033<br>P/e: 60.17x<br>ϕ: -8°–15°<br>$\phi^{-1.0264}$ <p/e<12.12<br>Re: 3000–18,000<br>W/H: 5 | 2.4 and 5.3 times enhancement in Nusselt number and friction factor respectively were reported over smooth duct. |
| Sahu and Bhagoria [13] | 90° broken rib roughness | e/D: 0.0338<br>e: 1.5<br>P: 10, 20, 30<br>Re: 3000–12,000 | 1.25–1.4 times enhancement in heat transfer coefficient |

| | | | |
|---|---|---|---|
| |  | W/H: 8 | was reported over smooth duct. |
| Layek et al.[30] | Chamfered rib-grooved roughness  | e/D: 0.022–0.04<br>g/P: 0.3–0.6<br>P/e: 4.5–10<br>ϕ: -5°–30°<br>Re: 3000–21,000 | 3.24 and 3.78 times enhancement in Nusselt number and friction factor respectively were reported over smooth duct. |
| Saini and Saini[31] | Arc shaped rib roughness  | e/d: 0.0213-0.0422<br>P/e: 10<br>Re: 2000–17,000<br>W/H: 12<br>α/90: 0.3333-0.6666 | 3.8 and 1.75 times enhancement in Nusselt number and friction factor respectively were reported over smooth duct. |
| Aharwal et al.[32] | Inclined continuous rib roughness with gap  | d/W: 0.167–0.5<br>e & b: 2mm<br>e/D: 0.0377<br>g/e: 0.5–2<br>P/e: 10<br>Re: 3000–18,000<br>W/H: 5.87<br>α: 60° | 2.59 and 2.9 times enhancement in Nusselt number and friction factor respectively were reported over smooth duct. |
| Varun et al.[28] | Combination of transverse and inclined rib roughness  | e/D: 0.030<br>e: 1.6 mm<br>P/e: 3–8<br>P: 5–13<br>Re: 2000–14,000<br>W/H: 10 | Best thermal performance was reported over smooth duct for P/e = 8. |
| Kumar et al.[29] | Discrete W-shaped rib roughness  | e/D: 0.0168–0.0338<br>e: 0.75–1.5 mm<br>P/e: 10<br>Re: 3000–15,000<br>W/H: 8:1<br>α: 30°–75° | 2.16 and 2.75 times enhancement in Nusselt number and friction factor respectively were reported over smooth duct. |
| Hans et al.[33] | Multi V-shaped rib roughness  | e/D: 0.019–0.043<br>α: 30°–75°<br>Re: 2000–20,000<br>W/w: 1–10<br>P/e: 6–12 | 6 and 5 times enhancement in Nusselt number and friction factor respectively were reported over smooth duct. |
| Lanjewar et al.[34] | W-shaped rib roughness  | e/D: 0.018–0.03375<br>e: 0.8–1.5 mm<br>P/e: 10<br>Re: 2300–14,000<br>W/H: 8<br>α: 30°–75° | 2.36 and 2.01 times enhancement in Nusselt number and friction factor respectively were reported over smooth duct. |
| Sethi et al.[19] | Dimple shaped elements arranged in angular fashion  | e/D: 0.021–0.036<br>e/d: 0.5<br>P/e: 10–20<br>Re: 3600–18,000<br>W/H: 11<br>α: 45°–75° | The maximum value of Nusselt number was reported over smooth duct for P/e = 10 and e/D = 0.036. |

## 5. CONCLUSION

The literature assessment indicates that the usage of artificial roughness in different forms and shapes is an effective and economic technique of improving the overall performance of solar air heaters.

Results of experiments of artificial roughness and experimental studied executed by diverse investigators have been discussed. Idea of thermal efficiency and thermo-hydraulic performance (effective efficiency) has been discussed. It's far determined that artificial roughness is a great approach to improve the thermo-hydraulic performance of solar air heaters.

The enhancements in the Nusselt number, friction factor and thermal performance are located to be sturdy functions of the relative roughness height. The best enhancement is found for the air heater with the highest relative roughness height. The effective efficiency of a roughened solar air heater will increase as the insolation increases for Reynolds numbers higher than 10,000–12,000. However at lower Reynolds number the thermo-hydraulic performance decreases with increasing insolation.

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