EXPERIMENTAL ANALYSIS OF THERMO-HYDRAULIC PERFORMANCE OF ARTIFICIALLY ROUGHENED SURFACE OF SOLAR AIR HEATER-A REVIEW

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Abstract: Applications of artificial roughness on the bottom of absorber plate in solar air heater duct have been extensively used to advance heat transfer with moderate increase of friction factor. The design of the roughness profile and arrangement is principal to optimize the roughened surfaces. The roughness parameters and ribs arrangement are responsible to alter the flow structure and heat transfer mechanisms are mainly governed by flow structure. The critical reviews on various artificial roughness elements available in literature have been conducted and the effects of the roughness patterns are discussed. The Nusselt number and friction factor correlations for various roughness elements have been summarized. A comparison study of thermo hydraulic performance of deferent roughness elements has also been reported to understand the results of applications of artificial roughness.

Keywords: Solar energy, solar air heater (SAH), artificial roughness, Heat transfer enhancement, Thermohydraulic performance

1. Introduction

Energy is a primary need to live our daily life at an expense of some valuable things such as environment degradation by using fossil fuels. Uses of fossil fuel are not only affect the environment, but also threats to human's life. The earth has fixed quantities of these fossil fuels reserved in it, which will be depleted after few years. In this view, renewable energy sources are getting more importance in the recent days. Solar energy can be utilized in number of ways. The most simple and inexpensive method to utilize solar energy is to heat the fluid by using flat plate solar collector. Solar collector converts solar radiation into thermal energy of fluid. Fluid may be water or air depending upon the applications. Solar water heater heats water as working fluid and solar air heater heats air as working fluid. Solar air heater is to be considered as simple and inexpensive and have several advantages over solar water heater such as corrosion and freezing free [1]. Solar air heater is used at moderate temperature applications like industrial HVAC system, drying crops, space heating, and textile industries [2]. Geometry of solar air heater is very simple and its main component is collector which converts solar radiation into thermal energy of air. Other parts of solar air heater are glass cover, back insulated cover and blower as shown in Fig. 1. Glass cover is used to minimize the heat through top of absorber plate and it transparent to incoming solar radiation. Back insulated cover is used to minimize heat losses through backside of the duct. Air is passed through the duct having three insulated sides and top side which is collector. In general, conventional solar air heater has very low thermal performance because smooth absorber plate offers low convective heat transfer to flowing air, leading to high heat losses to environment. The performance of solar air heater can be improved by mainly two techniques: 1. reducing the top heat losses to environment, 2. enhancing the convective heat transfer coefficient at absorber plate. Second technique is the most popular due to its wide applicability. Various techniques are available to enhance the heat transfer rate which depends on the applications. The most auspicious technique is to increase the heat transfer rate using roughened surfaces instead of smooth surface. Artificial roughness creates turbulence on the heated surface and helps to break the thermal boundary layer. Enhanced heat transfer is also accompanied with higher pressure drop, which is undesirable. The researcher always tries to optimize the roughness which provides high heat transfer at low pressure drop penalty. In this article, an attempt has been made to summarize previous investigations based on artificial roughness used in solar air heater

2. Role of artificial roughness

Normally, heat execution of smooth absorber plate is thought to be low a direct result of low convective heat transfer coefficient. Sub laminar layer is created over safeguard plate which goes about as warm impervious to streaming air. For improving the heat exchange rate, sub laminar layer is broken by making nearby turbulence which is accomplished utilizing different artificial roughness. Simulated harshness are made underside of safeguard plate by methods for little tallness wires joined to safeguard plate in rehashed nature. This issue can be explained by keeping the rib stature little in contrast with pipe tallness. Different rib courses of action have been explored and a few arrangements are transverse ribs, calculated ribs, V-ribs, W-ribs, multi V-ribs, rib with groove, amazed ribs, chamfered ribs and discrete ribs.as appeared in Fig 1.

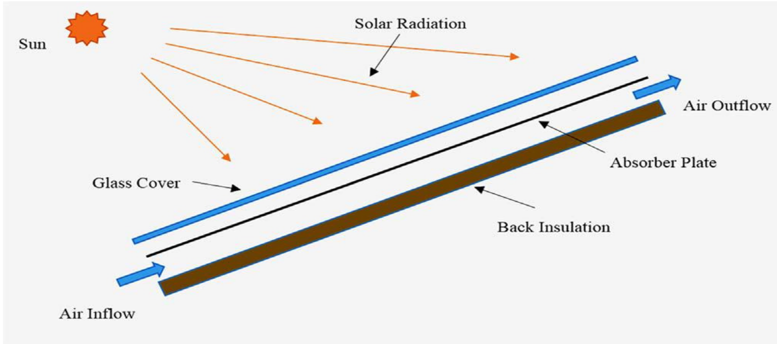

Fig. 1. Schematic diagram of conventional solar air heater.

3. Heat and flow characteristics of roughened surface

With a specific end goal to build up the logical model, marvel of turbulent stream on roughened surfaces are thought to be extremely intricate, also some researchers [3– 5] have designed the scientific model. Three region of flows were defined based on the roughness flow Reynolds number (e^+) as discussed below and
presented in Fig. 2. In hydraulic smooth flow region ($5 > e^+ > 0$), the flow resis-tance in term of friction factor is not a function of roughness height and flow behaves as laminar in such roughened pipe. The following correlation was proposed as given below:

$$Re\,(e^+) = 5.5 + 2.5 ln\,(e^+) \text{for } 5 > e^+ > 0 \qquad \bullet$$

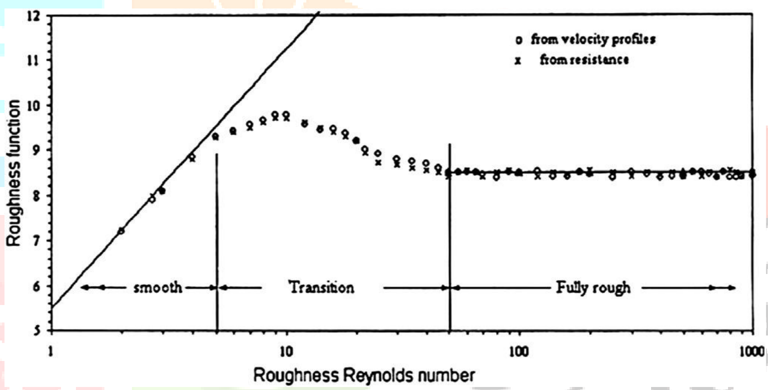

Fig. 2. Variation of roughness function with roughness Reynolds number [4]

4. Performance evaluation of conventional solar air heater

Roughened surfaces improved the convective heat exchange coefficient alongside contact factor as after effects of turbulence in the stream. Most proficient and monetary suitable plan of gatherer can be accomplished to upgrade the heat exchange rate with least weight drop fault. In such manner, different authority exhibitions have been proposed which give the unmistakable picture of roughness outline.

4.1. Thermal performance

Thermal performance of solar air heater determines the capability of heat transfer from absorber plate to air. Following Hottel–Whillier– Bliss equation is used to determine actual heat gain to air in solar air heater duct [1].

$$q_u = F_R [I (\tau\alpha)_e - U_l (T_i - T_a)] \qquad (1)$$

Since, collector works on open loop configuration, in such a situation the inlet air (drawing air) temperature is equal to the ambient air (T_i=T_a). Bondi et al. [12] have suggested that actual heat gain of a solar collector, which draws ambient air, should be expressed by the following equation:

$$q_u = F_o [I (\tau\alpha)_e - U_l (T_o - T_i)] \qquad (2)$$

An expression for thermal performance can be written as:

$$\eta = q_u / I \qquad (3)$$

4.2. Hydraulic performance

Pressure drop in duct is measured in term of hydraulic performance of solar air heater duct which is associated with excess energy provided by fan. The non-dimension form of pressure drop is represented by friction factor (f). The following Darcy-Wiesbach [9] equation determines the friction factor.

$$F_{air} = (2\, \Delta P \rho D_h / 4 L G_{air}^2) \qquad \textbf{(4)}$$

4.3. Thermohydraulic performance

Lewis [13] presented the thermo-hydraulic performance parameter (η) which shows the enhancement of heater transfer of roughened duct relative to smooth duct operating under similar conditions and requires same pumping power. The thermo-hydraulic performance parameter (η) has been given by Eq. (5).

$$\eta = \frac{(Nu / Nu_s)}{(f/f)^{1/3}} \qquad \textbf{(5)}$$

5. Effect of roughness parameters on flow structure

The effect of roughness parameters on flow pattern lead to change the heat transfer and friction characteristics and, consequently, performance of the collector and Relative rib height, Relative rib, Angle of attack, Gap in continuous rib, Rib cross-section are also play major role.

6. Application of artificial roughness in solar air heater duct

Various ribs arrangements have been investigated experimentally which affected the friction and heat transfer characteristics. Effect of various roughened surfaces used in solar air heater duct have been discussed below. Various researchers investigated the transverse ribs fig .3, Inclined ribs fig. 4, V-shape ribs fig. 6, Multi V-shape ribs, W shape ribs, Arc shape ribs, Multi arc ribs, Combination of ribs Fig. 9, Dimple rib Fig.10, Continuous ribs, Broken ribs Fig.7, Continuous ribs, ribs with gap Fig. 8. Effect of different ribs on heat transfer and friction characteristics are shown below:

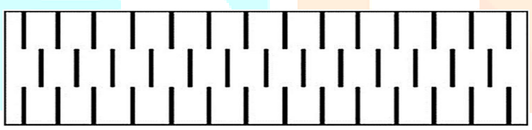

Fig. 3. Transverse broken ribs [21].

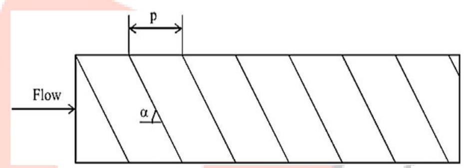

Fig. 4. Continues inclined ribs [22].

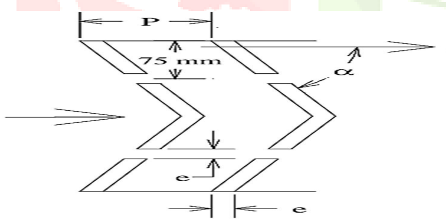

Fig. 6. V-ribs with gap [27].

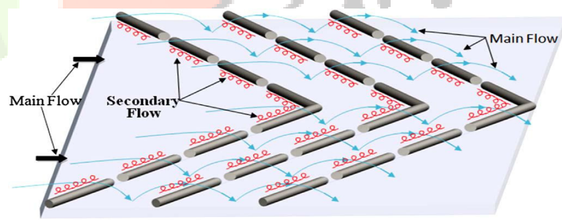

Fig. 7. V-shape ribs with multiple gaps [31]

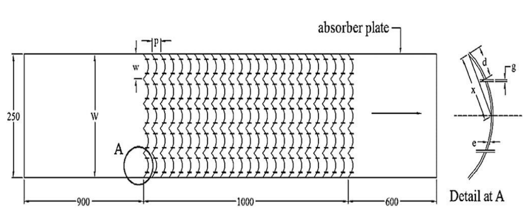

Fig. 8. Roughness investigated by Pandey et al. [34]

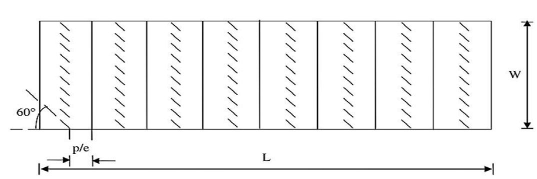

Fig. 9. Combination of inclined and transverse ribs [24].

Table 1
Summary of roughness investigated by various researchers.

Investigators	Year	Roughness	Parameters	Key Results
Prasad and Saini [4]	1988	Continuous transverse ribs	e/D=0.02–0.033, P/e=10–20,	$(Nu/Nu_s)_{max}$=2.35, $(f/f_s)_{max}$=4.25,
Sahu and Bhagoria [12]	2005	Broken Transvers ribs	e/D=0.0338, p=10–30 mm,	(h/h_s)=1.25–1.4,
Gupta et al. [14]	1997	Continues inclined ribs	e/D=0.023–0.050, W/H=6.8–11.5, α=60°,	(η/η_s)=1.16–1.25,
Maithani and Saini [17]	2016	V-ribs with symmetrical gap	g/e=1–5 N_g=1–5, p/e=6–12, α=30–75°	$(Nu/Nu_s)_{max}$=3.6, $(f/f_s)_{max}$=3.67,
Hans et al. [22	2010	Continuous multi V-ribs	e/D=0.019–0.043, p/e=6–12, W/w=1–10 α=30–75°	$(Nu/Nu_s)_{max}$ ~6, $(f/f_s)_{max}$ ~4.3,
Singh et al. [24]	2014	Multi arc ribs	0.666 e/D=0.018–0.045, p/e=4–16, W/w=1–7 α=30–75°	$(Nu/Nu_s)_{max}$=5.07, $(f/f_s)_{max}$=3.71,
Pandey et al. [27]	2016	Multi arc ribs with gap	e/D=0.016–0.044, p/e=4–16, W/w=1–7, g/e=0.5–2, d/x=0.25–0.85 α=30–75°	$(Nu/Nu_s)_{max}$=5.85, $(f/f_s)_{max}$=4.96,
Patil et al. [25–27]	2011, 2012	V-rib with gap combined with staggered rib	e/D=0.0433, p/e=10, r/e=1–2.5, p'/p=0.2–0.8, s'/s=0.2–0.8, α=60°	$(Nu/Nu_s)_{max}$=3.18,
Deo et al. [28]	2016	Multi V-rib with gap combined with staggered rib	e/D_h=0.026–0.057, p/e=4–14, n=2, g/e=1, w/e=4.5, p/P =4.5 α=60°	$(Nu/Nu_s)_{max}$=3.34, $(f/f_s)_{max}$=2.45,
Juarker et al. [31]	2017	Rib-groove roughness	e/D_h=0.0181–0.0363, p/e=4.5–10, g/p=0.3–0.7	$(Nu/Nu_s)_{max}$=2.7, $(f/f_s)_{max}$=3.6,
Layek et al. [35]	2017	Chmapfered rib combined with	e/D_h=0.022–0.04,	$(Nu/Nu_s)_{max}$=3.24,

7. Thermohydraulic performance of roughened surfaces

Roughened surfaces dependably improve heat exchange rate due to stream detachment and reattachment which prompt actuate turbulence in the region of hot surfaces. Turbulence stifles the 'no man's land' where heat exchange rate is low because of low air movement. A heat transfer enhancement technique is also responsible for high pumping power requirement because comparatively high pressure drop is obtained due to turbulence in the flow. High heat transfer and low pumping power requirement are basic need to design efficient and compact solar air heater. In such manner, thermohydraulic performance parameter (η), examined prior, picks ideal roughness parameters and rib courses of action.

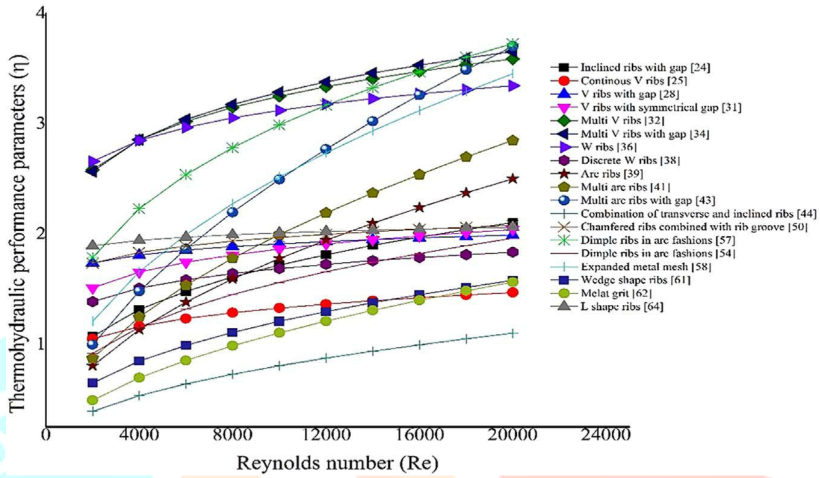

Fig. 12. Comparison of thermohydraulic performance parameters of various roughened surfaces

It has been appeared in Fig. 12 that thermohydraulic execution parameters have wide range and its esteems change from 0.49 to 3.70. Slightest estimations of thermohydraulic parameter are watched for extended metal work and most astounding esteems are watched for multi V ribs with hole and multi circular segment with hole In any case execution of multi circular segment ribs with hole isn't impressive at low Reynolds number, yet execution increment altogether with increment in Reynolds number. Idea of hole in constant ribs is to discharge optional stream which is shaped because of development of vortices upstream side of ribs. This auxiliary stream makes additional turbulence when it blended with fundamental stream.

8. Conclusions

This paper declared broad review by excellence of manufactured unpleasantness connected in sun based air heater channels. Impact of roughness parameters close by rib blueprint in various examinations on grinding components and heat transfer characteristics have been discussed. The major part of stream responsible for heat transfer has also been analyzed. In perspective of the investigated occurs, conclusions have been drawn as given underneath:

1. Artificial roughness shapes as little diameter wire is great decision for heat exchange improvement, on the other hand, claim of roughness was also responsible for amplified friction factor
2. Effect of different roughness parameters like. relative rib height, relative rib pitch, angle of attack and ribs arrangement i.e. transverse, inclined, single V-ribs, multi V-ribs, arc shape ribs, multi arc shape ribs, W-shape ribs and L-shape ribs were investigated.
3. Multi V-ribs with gap provide utmost enhancement in friction factor and Nusselt number and followed by multi arc ribs with gap.
4. Gap in persistent V-ribs, Multi V-ribs, circular segment ribs, multi bend ribs considerably improved warmth exchange rate and grating element. Because of presenting hole in continuous V-ribs, multi V-ribs, curve ribs, multi bend ribs, most extreme Nusselt number were increased by 1.32, 1.12, 1.33 and 1.15 times, separately and comparing friction factor were expanded by 1.08, 1.48, 2.12 and 1.34 times.
5. Dimple ribs were found to be hydraulically better because it offered small growth in friction factor as compared to percentage increase in heat transfer rate.
6. . Greatest addition in Nusselt number and friction factor because of different roughened surfaces over smooth conduit have been outlined and recorded in Table 1.

7. Comparison of thermohydraulic performance parameter with respect to Reynolds number has been presented. Maximum thermo-hydraulic performance parameters are found for W-ribs, multi V-ribs with gap and multi arc with gap in different range of Reynolds number.

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