Review of Roughness Enhancement of Solar Air Heaters having Different Rib Roughness Geometries on Absorber Plate

Jitender Singh Khurana[#1], Dr.Chandresh Sharma[*2], Ramesh Parihar[#3]

[#1]*Sr. Lecturer, mechanical, Government polytechnic college, Jodhpur, India*

[#2,3]*Lecturer, mechanical, Government polytechnic college, Pali, India*

Abstract — *The value of convective heat transfer co-efficient between the air and absorber plate is the major factor responsible for low heat transfer capacity of a solar air heater. Artificial roughness in the form of repeated ribs is one of the effective ways of improving the performance of solar air heaters. A series of experimental works by various researchers have been reported in this paper, which show that heat transfer rate is increased by application of artificial roughness. In this paper an attempt is made to compare the effect of different rib roughness geometries. Different performance evaluation criteria for evaluation of solar air heater have been used in order to conclude to few optimum "System and operating parameters".*

Keywords— *solar air heater, heat transfer co-efficient, artificial roughness*

I. INTRODUCTION

Energy is the motive force of economic development. Energy demand gradually increases with population expansion and industrial development as well as more usage in domestic sector application. However energy consumption, at present generally based on fossil energy consumption (petroleum, coal and natural gas) in both developed and developing countries have led to the global greenhouse effect and air pollution, which aggravate the deterioration of living conditions. Unfortunately, low-priced fossil fuel will be exhausted in the near future. Demand of renewable energy is increasing in future. Development of new technologies utilizing solar energy for power generation in term of solar thermal and solar photovoltaic's in world wide. Beside from power generation the use of this solar energy for daily domestic application in term of heat exchanger is also a new area of research in these days.

Solar energy is free, clean and most abundant energy resource among renewable energy resources. The sun is a sphere of hot gaseous matter with a diameter of 1.39 x 10^6 km and at an average distance of l.5 x 10^8 km away from the earth. The sun creates its energy through a thermonuclear process that converts about 65 x 10^7 tons of hydrogen to helium every second. The temperature in the central interior regions is variously estimated as 8 x 10^6 to 40 x 10^6 K and the density is about 80-100 times that of water. The surface of the sun is at an effective temperature of 5777 K. Energy gets transferred to the surface of the sun and then radiated into space. The electromagnetic radiations stream out into space in all directions. Only a very small fraction of the total radiation reaches the earth and this is the indirect source of almost every type of energy used on earth today. Sun is emitting radiation into space continuously. Radiation emitted from sun surface, travel unobstructed in space until an obstacle resists. However, radiation while crossing through atmosphere, encounter air and water molecules, dust particles, clouds, gases etc. These obstacles cause change in the direction and intensity of the radiation. There are mainly two types of radiations viz. beam radiation and diffuse radiation. Solar radiation received at the earth surface without change of direction is called beam radiation or direct radiation. Solar radiation received at the earth surface after being subjected to scattering, absorption, re-radiation and re-reflections in the atmosphere is called diffuse radiation. The sum of beam and diffuse radiation is known as total radiation or global radiation.

A. *Solar collector*

Solar collector is basically heat exchangers which contain an absorbing surface it absorb the incoming radioactive energy and store it in thermal form and then deliver it to fluid that may be water, air or any other else. There are mainly two types of solar collector-Flat plate collector and Concentrated type collector. Focusing collector is a device to collect solar energy with high intensity on the energy absorbing surface. Concentration of solar radiation is achieved by using a reflecting optical system which directs the solar radiation to an absorber of smaller area which is usually surrounded by a transparent cover

Flat plate collector is mainly a flat surface which absorbs incoming solar radiation a black painted plate is used to absorb the radiation and transferring the energy to working fluid. Thermal insulation is used to prevent the heat losses from all side except front side that faces the radiation where glass is used so that radiation trap in the collector .Flat plate collectors are designed for low temperature range (60^0C) to medium temperature range (100^0C). It absorbs both beam as well as diffuse radiation. Flat plate collectors, is of two types, first is liquid heating collector and second is air heating collector

B. Solar air heater

A flat plate collector used for heating the air is generally known as solar air heater and is shown in Fig.1. A conventional solar air heater generally consists of an absorber plate with another parallel plate below it forming a passage for air with a high width to depth transparent glass covers and a proper insulation is provided on the back and side walls. The solar radiations pass through the transparent cover and impinge on the blackened absorber plate and the absorbed energy is then transferred to the air, flowing beneath the absorber plate, coming in contact with nearly the entire absorber surface for effective heat transfer. In some designs, the air flows above the absorber plate.

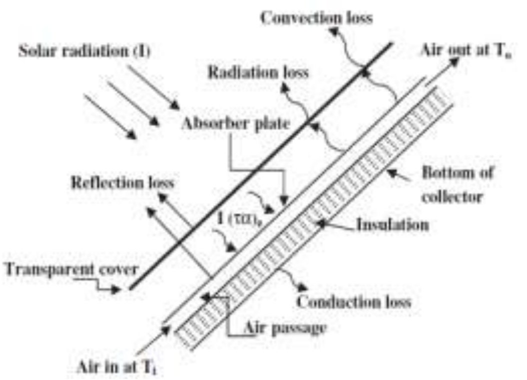

Fig 1 Conventional solar air heater

II. PERFORMANCE OF SOLAR AIR HEATER

Thermal efficiency of solar air heater in comparison of solar water heater has been found to be generally poor due to poor heat transfer properties of air and formation of laminar sub layer nearer to absorber plate surface which resists the further heat transfer. In order to make the solar air heaters economically viable, their thermal efficiency needs to be improved. There are mainly two modes of performance enhancement of solar air heater, by increasing heat transfer coefficient (using packed bed, artificial roughness in form forms of small wires) or by increasing the contact surface area (using extended surfaces i.e. fins). The following are some performance enhancement techniques for the solar air heater.

A. *Extended surfaces-*

The extended surfaces in the form of fins or v-corrugations on the absorber plate helps in two ways; firstly by increasing turbulence and secondly by increasing the area of heat transfer, which result in more heat transfer.

B. *Packed bed-*

A packed bed is a volume of porous media obtained by packing materials of selected material into a duct. Packed bed matrix absorbs solar radiation 'in depth' and has high ratio of heat transfer area to volume and high heat transfer capability, resulting in relatively low absorber temperature. This will result in an increase in the efficiency of the collector.

C. *Artificial roughness on heat transfer surface-*

Roughness elements have been used to improve the convective heat transfer by creating turbulence in the flow to disturb laminar sub layer. However it would result in an increase in friction loss and hence greater power requirement by fan or blower in order to keep the friction in laminar sub layer. The surface roughness can be provided by several methods such as sand blasting, machining, casting, forming and welding ribs and wires along the surface.

D. *Artificial roughness in the forms of rib-*

Use of an artificial roughness on the underside of absorber plate is an effective technique to enhance the rate of heat transfer. However, it would result in an increase in frictional loss leading to more power required by fan or blower. In order to minimize the friction loss, the turbulence must be created only in the region very close to the duct surface i.e., in the laminar sub-layer. Dimensionless geometric parameters commonly used to describe "roughness" or type of roughness as explained and shown in fig-2

- **Relative roughness height (e/D_h)**
  Relative roughness height (e/D_h) is the ratio of rib height 'e' to equivalent diameter 'D_h' of the air passage. Here equivalent or hydraulic diameter (D_h) is given by
  $$D_h = \frac{4\times \text{Cross-sectional area of duct}}{\text{Wetted perimeter}}$$
- **Relative roughness pitch (p/e)**
  Relative roughness pitch (p/e) is defined as the ratio of distance between two consecutive ribs'p' to height of the rib 'e'.
- **Angle of attack (α)**
  Angle of attack is an inclination of rib with the direction of air flow in duct
- **Relative roughness width *(W/w)***

Ratio of width of duct to width of artificial roughness is called Relative roughness width.

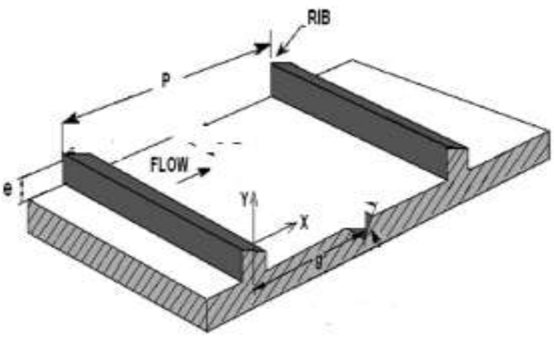

Fig- 2 Schematic view of parameters of rib roughness

III. PRACTICAL SHAPES OF ROUGHNESS GEOMETRY

The roughness elements can be two-dimensional ribs or three-dimensional discrete elements, transverse or inclined ribs or any shaped continuous or broken ribs with or without gap. As shown in Fig-3. The various shapes of ribs are shown with their orientation

IV. SOLAR AIR HEATER PERFORMANCE WITH VARIOUS RIB GEOMETRY

A series of experimental works have been performed by various researchers, which show that heat transfer rate is increased by application of artificial roughness. Artificial roughness comprises of using different geometries of ribs, baffles etc. with the purpose of breaking the laminar sub-layer, thus increasing the heat transfer coefficient by reduction in thermal resistance caused due to boundary layer.

Artificial roughness geometries with their different shapes, size, arrangement and orientation have been extensively used in solar air heaters. A researcher wise summary of various rib-geometries, range of parameters and their findings is being presented below in a tabular form in Table -1.

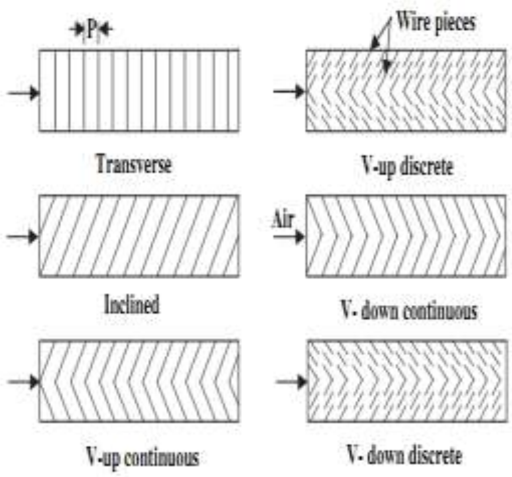

Fig-3(a)Roughned absorber plate with transverse, inclined discrete and continous ribs

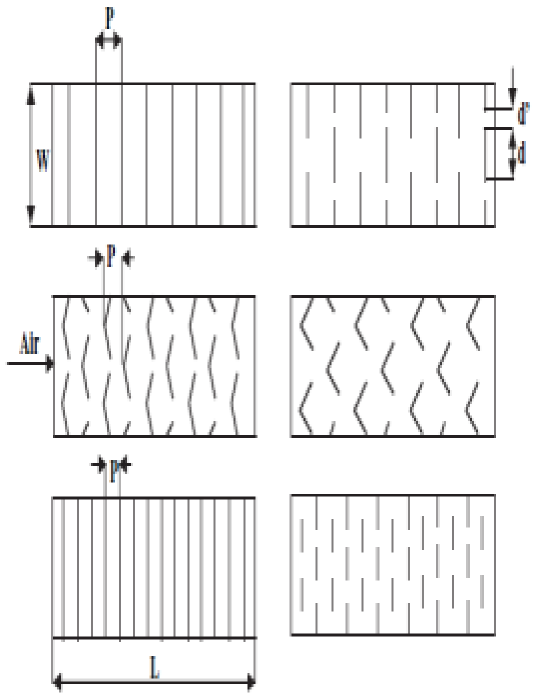

Fig-3(b)Roughness geometry in rectangular channel with tranverse and V-Shaped broken ribs

TABLE -1

SOLAR AIR HEATER PERFORMANCE WITH VARIOUS RIB GEOMETRIES

S.no	Author/year	Roughness geometry	Range of parameters	Findings
1.	S.Singh et.al/2011 [1]	V-Shaped discrete ribs	L/W/H – 1.5/1/0.025 *Re* – 3000-15000 p/e – 4-12 e/D_h- 0.015-0.043 α - 30°-75° d/w – 0.020-0.080 g/e – 0.5-2.0 I - Constant	• Thermo and hydraulic performance Maximum Nussent number *Nu* enhancement at p/e = 8, d/w = 0.65, α=60°,g/e = 1.0, e/D_h = 0.043 at *Re* = 12000.
2.	Atul Lanjewar et.al/2011 [2]	W – Shaped rib	*Re* - 2300 – 14000 p/e - 10 e/D_h - 0.018, 0.0225, 0.02925, 0.03375 α - 30°, 45°, 60°, 75° I – 0-1500	• Thermo-hydraulic performance Maximum enhancement in *Nu* was at *p/e* = 10, α = 60°, e/D_h = 0.3375. *Nu* was improved by 2.36 times at *Re* =14000. Thermo-hydraulic performance was best in *Re* range 6000 - 8000.
3.	G.Tanda / 2011[3]	Angled continuous ribs	α = 45° p/e = 6.66 - 10 -13.33 -20 e/D_h = 0.09 *Reynolds number Re* = 0-40000	*Nu* enhanced by 2 times at p/e=10 for all values of *Re*. Effective efficiency was maximum in *Re*=9000-13000 with improvement by 1.12 times to the smooth plate. Degree of heat transfer enhancement N_1 improved by 1.4 times at all values of Re. Relative effective efficiency N_2 was above than unity for *Re* up to 15000.
4.	G.Tanda / 2011[3]	Transverse continuous ribs	α = 90° p/e = 13.33 e/D_h = 0.09 *Re* = 0-40000	*Nu* enhanced by 2.1 times at *Re*=35000. Effective efficiency was maximum in *Re* =9000-13000. N_1 improved by nearly 1.02 times for all values of Re. N_2 was advantageous at Re <15000.
5.	G.Tanda / 2011[3]	Transverse broken ribs	α = 90° p/e = 13.33	*Nu* enhanced by 2.2 times *Re*=35000. Effective efficiency was maximum

S.no	Author/year	Roughness geometry	Range of parameters	Findings
			e/D_h = 0.09 d' = 20 *Reynolds number* *Re* = 0-40000	in *Re* =9000-13000. N_1 improved by nearly 1.02 times for all values of Re. N_2 was advantageous at Re <15000.
6.	G.Tanda / 2011[3]	V-Shaped discrete ribs	α = 45° & 60° p/e = 13.33 e/D_h = 0.09 d' = 20 *Re* = 0-40000	• Entropy generation analysis At α=60° *Nu* enhanced by 2 times at *Re*=35000. Effective efficiency was maximum in *Re* =9000-13000. N_1 was advantageous at Re <20000 N_2 was advantageous at Re <15000
7.	R.Karwa et.al/ 2010 [4]	60° V-Shaped down discrete ribs	L/W/H - 1-4/1/5-20 *Re* - 1070-26350 p/e – 10(fixed) e/D_h - 0.02-0.07 α - 60°(fixed) ß -0°-45° G – 0.1-0.6 I -500-1000	• Thermo – hydraulic basis At e/D_h = 0.07 and ß=0° effective efficiency was max^m At e/D_h = 0.03 effective efficiency was max^m when collector's slope was equal to the latitude of the place.
8.	S.V.Karmare et.al/2008 [5]	Metal ribs	*Re* - 3600-17000 p/e -15-17.5 e/D_h - 0.35-0.44 α - 60° I -570-900	• Thermo – hydraulic basis • For maximum effective '*n*'- flow must be adjusted to Reynold no. as shown for Optimum condition e/D_h Re I 0.035 16000 900 0.038 15000 900 0.044 14000 900 Maximum effective efficiency was 74% at p/e=15, e/D_h=0.44 and Re=15000.
9.	Varun et.al/2008[6]	Inclined and Transverse ribs	W/H -10 *Re* - 2000-14000 P/e – 3-6-8 e/D_h – 0.030(fixed) α - 60°	• Thermal efficiency was maximum at p/e=8 with the value of 76%.

S.no	Author/year	Roughness geometry	Range of parameters	Findings
10.	R.P.Saini et.al / 2008 [7]	Dimple shaped ribs	*Re* - 2000-12000 p/e - 8-12 e/D_h - 0.0189-0.038 I – 0-1000	• Thermo–hydraulic performance *Nu* enhanced by 2.5 times at e/D_h = 0.0379 , *p/e* = 10 with *Re* = 12000
11.	M.M Sahu et.al / 2005[8]	90° broken transverse ribs	W/H - 8 *Re* - 3000-12000 p/e – 6.67-13.33-20 e/D_h - 0.0338(fixed) α - 90° I - 750-880	• Thermal performance Thermal efficiency was 83.5% at p/e = 13.33 for *Re* > 5000. *Nu* was enhanced by 1.25 – 1.4 times for *Re* = 3000 to 12000.
12.	Abdul-Malik et.al/2002 [9]	V-Shaped continuous ribs	W/H – 10-15 Re - 2500-18000 p/e – 10(fixed) e/D_h - 0.02-0.034 α -30°-90° I – 0-1500	• Thermo-hydraulic perform-ance *Nu* was enhanced by 2.3 times at e/D_h = 0.034, α=60° and *Re* = 17034 in compa -rison to smooth plate. thermo-hydraulic performa-nce parameter was approx. 1.78.

V. CONCLUSION

In this paper an attempt has been made to report regarding the effect of roughness on absorber plate through 'literature and research work' of various researches and compared the effect of different artificial roughness geometries with their different shape, size, arrangement & orientation using different performance evaluation techniques.

Based on literature review following conclusions are drawn –

1. There are various roughness geometries which are being used in solar air heater depending upon shape, size, arrangements and orientations on the absorber plate.
2. General arrangements of different roughness geometries are achieved by fixing wires and rib formation by machinery operation.
3. Performance increased due to flow separation and generation of vortices on the upstream and downstream of the rib and reattachment of flow in the inter rib spaces in case of transverse ribs.
4. Angle of attack also enhances performance of the transverse rib due to movements of vortices along the rib and formation of a secondary flow cell.

Table – II

RELATIVE PERFORMANCE OF VARIOUS RIB GEOMETRIES AT GLANCE

Roughness geometry	***Nu*/thermal 'η'/effective'η'**	***p/e***	***e/D_h***	**α**	***Re***
V-Shaped discrete	*Nu* improved by 3.04 times in comparison to smooth plate.	8	0.043	60°	12000
Dimple Shaped ribs	*Nu* improved by 2.5 times in comparison to smooth plate.	10	0.0379	-	12000
90° broken transverse ribs	Thermal efficiency = 83.5%, *Nu* improved by 1.4 times in comparison to smooth plate.	13.33	0.0338	90°	12000
W-Shaped ribs	*Nu* improved by 2.36 times in comparison to smooth plate. Thermo-hydraulic performance parameter was approximately 2.	10 10	0.03375 0.03375	60° 60°	14000 6000
V-Shaped continuous ribs	*Nu* improved by 2.3 times in comparison to smooth plate. Thermo-hydraulic performance parameter was approximately 1.78.	10	0.034	60°	17034
Inclined and transverse ribs	Thermal efficiency = 76%	8	0.030	60°	14000
Metal ribs	Effective efficiency = 74%	15	0.44	60°	15000

5. V-Shaping of a rib helps in the formation of two secondary flow cells resulting in higher heat transfer rate.
6. Producing a gap in the inclined rib causes to break the secondary flow and producing higher level of turbulence in the fluid downstream of the rib resulting in higher heat transfer rate.
7. All types of ribs performed thermo-hydraulically better upto range of 15000 with p/e = 8 to 10, e/D_h = 0.03 to 0.045 and α=60°.
8. On the basis of thermo-hydraulic performance with *Re* upto 15000, V-Shaped discrete rib (down) perform better in comparison to other roughness rib geometries in consideration.
9. From analysis based on first law (relative effective efficiency) or second law (augmentation entropy generation number), it was found that all rib configuration performed better than a smooth surface in the medium – low range of Reynolds number *(Re* < 15000). Transverse broken rib appeared to be the most promising enhancement technique. Here *Nu* enhanced by 2.2 times even *Re* was up to 13000 and effective efficiency was maximum for *Re* = 9000 to 13000 for the same rib.

The Table - II shows relative performance of various rib geometries at glance

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