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Artificial roughened solar air heaters – a review

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Abstract: Conventional Solar air heaters have low thermal efficiency because of low convective heat transfer coefficient between the absorber plate and flowing fluid. Low value of the heat transfer coefficient is due to the presence of the laminar sub-layer which is formed on the underside of the absorber plate. To break this laminar sub-layer there is a need to provide artificial ribs on the underside of the absorber plate. Artificial roughness in the form of repeated ribs is one of the simplest method for enhancement of thermal efficiency of the conventional solar air heater. The objective of this paper is to review various experimental and analytical works done by different researchers to increase the thermal efficiency of the conventional solar air heaters by providing the different roughness geometries on the underside of the absorber plate.

Keywords: solar air heater, artificial roughness, thermal performance

1 INTRODUCTION

Solar energy is one of the non-conventional energy resources and has the advantage of being pollution free and being freely available in plenty. It can be converted into thermal energy or directly into electricity. Thermal energy conversion is divided into three categories

(i) Low (<10 ^{0}C) (ii) Medium (10-150 ^{0}C) (iii) High (>150 ^{0}C)

1.1 Solar air heater

A conventional solar air heater is essentially a flat plate collector with an absorber plate, a transparent cover system at the top and insulation at the bottom and on the sides. The whole assembly is encased in a sheet metal container. The working fluid is air, through the passage for its flow varies according to the type of air heater. The function of the collector plate is to absorb maximum possible solar radiation incident on it through the glazing, to emit minimum heat, to the atmosphere and downward, through the back of the casing, and to transfer the retained heat to the fluid. materials generally used for collector plates, in decreasing order of cost and conductance, are copper, aluminum and steel. the surface coating of the plate should be such that it has high absorptivity and poor emissivity for the required temperature range. the bottom and sides of the collector are covered with insulation to reduce the conductive heat loss. the collector is placed inclined at suitable angle to receive the maximum solar radiation.

Applications of solar air heater

1. Crop drying.
2. Comfort heating.

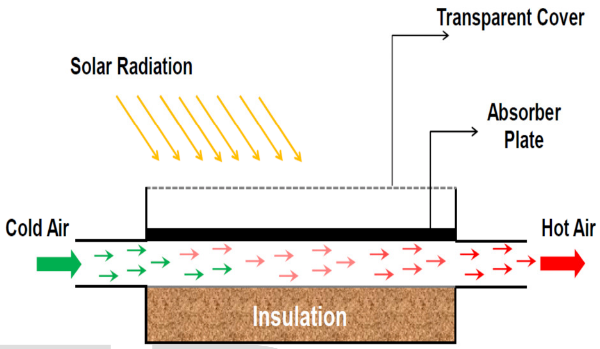

Fig.1. Solar air heater

Conventional solar air have low thermal performance because of the laminar sub layer formed on the underside of the absorber plate. To increase the thermal performance of the conventional solar air heater there is a need to break this laminar sub layer. Laminar sub layer can be break by different methods by using artificial ribs on the underside of the absorber plate, by using packed bed, by using fins, or any other method which breaks the laminar sub layer.

There is a limitation in artificial roughness technique for performance improvement that it increases the friction in the solar air heater which needs more pumping power. For lower pumping power need the roughness created is in laminar sub layer region only.

There are different methods for producing artificial roughness some of them are mentioned below:

1. Casting
2. Sand blasting
3. Forming
4. Machining
5. Welding
6. Pasting ribs with the help of glue

Pasting ribs with help of glue is an easy and economical method for making roughness absorber plates but it is constrained to some shapes only.

There are different types of parameters which are used in artificial roughness ribs, the roughness element height (e) and roughness element pitch(p). the other parameters are relative roughness height (e/D), relative roughness pitch (p/e), aspect ratio(W/H), angle of attack (α), relative gap position (d/W), relative gap width (g/e), groove position (g/p) etc. roughness elements are of different shapes and different orientations it can be two dimensional or three dimensional elements. Some of the shapes used by different researchers are transverse shape rib roughness, inclined, combination of inclined and transverse, w-shaped, v-shaped, rib groove etc.

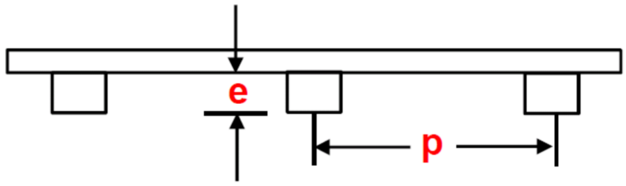

Fig.2. Rib's cross section (Magnified view)

2 DIFFERENT TYPES OF ROUGHNESS GEOMETRIES USED BY RESEARCHERS IN SOLAR AIR HEATERS

A lot of research work has done in this field by different researchers by which there is a increase in thermal performance of the conventional solar air heater. Different types of shapes and orientations are used by researchers which are given below:

2.1 Transverse rib

Prasad and Saini[10] experimentally shows the effect of relative roughness pitch and relative roughness height on the heat transfer and friction factor of a solar air heater duct. The roughness created is in the shape of transverse shape which is made with the help of small diameter wires pasted on the absorber plate. Fig.3. shows the transverse type rib roughness.

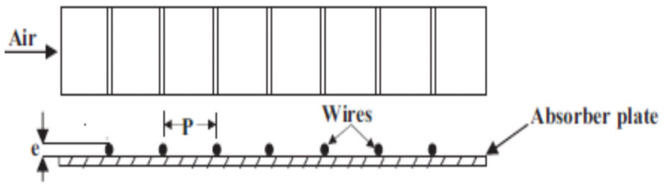

Fig.3.Transverse continuous ribs[10]

2.1 Inclined continuous ribs

Gupta et *al.* [11]studied the enhancement of heat transfer coefficient having inclined ribs. The enhancement has been obtained with the help of this type of rib roughness. Fig.4. shows inclined continuous ribs.

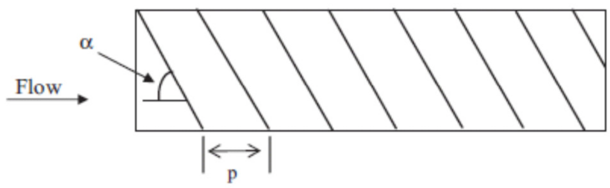

Fig.4. Inclined continuous ribs[11]

2.2 Combination of inclined and transverse ribs

Varun et *al.* [12]investigated the heat transfer and friction factor characteristics of combination of inclined and transverse ribs and predicts a correlation for Nusselt number and friction factor from the experimental results. Fig.5. shows the combination of transverse and inclined continuous ribs.

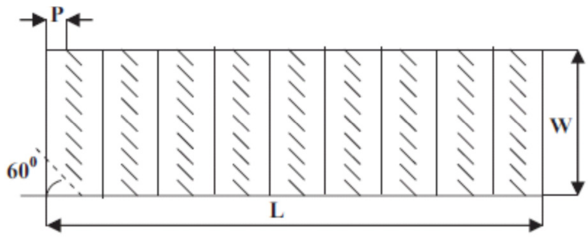

Fig.5. combination of inclined and transverse ribs[12]

2.3 V-shaped rib roughness

Momin et *al.* [13]experimentally investigated the effect of different parameters of V-shaped rib roughness on heat transfer and friction factor of the rectangular duct of solar air heater. He also developed correlations for heat transfer coefficient and for friction factor of the roughened duct.
Fig.6. shows the V-shaped rib roughness.

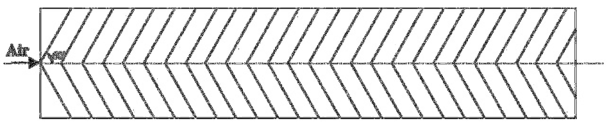

Fig.6. V-shaped rib roughness[13]

2.4 Dimple shape artificial roughness

Saini and Verma [14] carried an experiment to study the effect of roughness and operating parametrs on heat transfer and friction factor in a roughened duct provided with dimple–shape roughness geometry. He also developed correlation for Nusselt number and friction factor for such artificial roughness. Fig.7. shows the dimple shape artificial roughness.

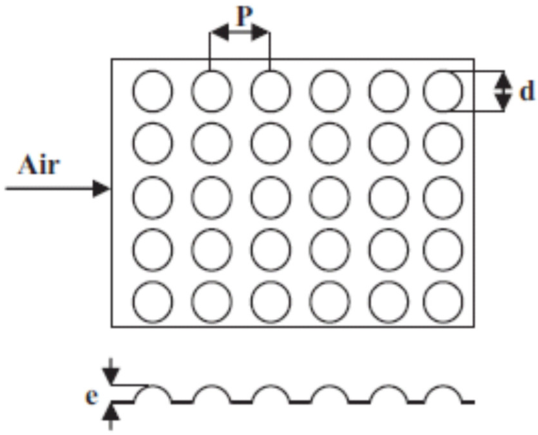

Fig.7. Dimple shaped artificial roughness geometry[14]

2.5 Arc shaped rib roughness

Saini and Saini [15] experimentally investigated the heat transfer and friction factor of a solar air heater having roughened air duct provide with artificial roughness in the form of arc-shape parallel wire. He also gave correlations for Nusselt number and friction factor for such solar air heaters. Fig.8. shows arc-shaped rib roughness.

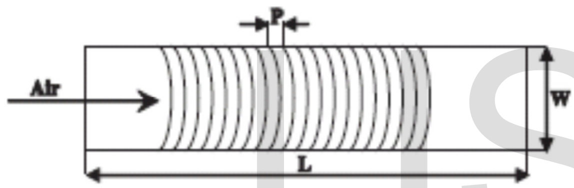

Fig.8. Arc shaped rib roughness[15]

2.6 W-shaped rib roughness

Lanjewar et al. [16] studied the heat transfer and friction factor of a rectangular solar air heater duct roughened with W-shaped ribs on the underside of the absorber plate. He compares the results obtained with those of smooth solar air heater under similar flow and thermal boundary conditions to determine the thermo hydraulic performance. Fig.9. shows the diagram of W-shaped rib roughness.

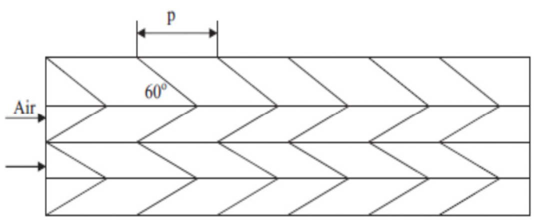

Fig.9. W-shape rib roughness[16]

3 EXPERIMENTAL SETUP

Most of the researchers who done experiment for performance prediction of a solar air heater made an experiment setup according to ASHRAE 93-77 [5] standards. According to which set up consists of different parts which are shown in the diagram given below:

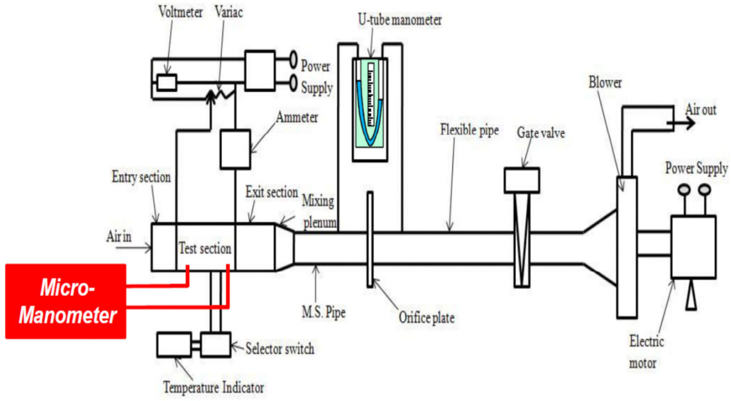

Fig.10.(a) Schematic diagram of experimental setup

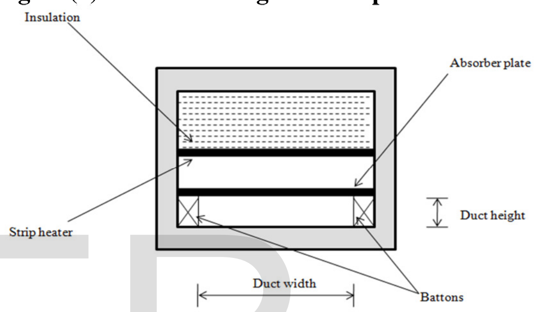

Fig.10. (b) Cross Sectional View of Test Duct

The experimental duct is made of soft wood which is of rectangular type. The rectangular duct consists of entry section, test section, exit section and a mixing plenum. In mixing plenum there are baffles placed for proper mixing of air in this section. Mixing plenum is attached with mild steel pipes which holds the orifice plates and then to flexible pipes. Flexible pipes are attached to gate valve and gate valve is attached to a blower. Blower is attached to electric motor which rotates it. Electric motor is connected to the power supply. Absorber plate is made of aluminum, G.I. sheet etc. U-tube manometer measure the pressure drop across the orifice plate which measure the mass flow rate of the air. Selector switch selects the thermocouple locations of different places and temperature indicator indicates the temperature of the absorber plates at different locations. Micro-manometer measures pressure drop across the test section. Ammeter and voltmeter are used to measure the current and voltage supplied to the heater which heats the absorber plate. Variac is used to control the voltage supplied to the heater. Thermocouples are used for temperature measurement at different locations. Gate valve is used to control the mass flow rates inside the duct. Insulation is done with the help of glass wool.

4 EXPERIMENTAL PROCEDURE

After assembling the whole experimental setup, the measuring instruments were installed in proper position and electric connections of the following namely Variac, ammeter, voltmeter, temperature indicator and heater were made. Air is sucked through the blower, driven by motor from the duct.
Before heating the duct all thermocouples were checked by adjusting the corresponding selector switch position. Before starting the experiment all the joints are sealed with the help NC putty, so that no leakage occurs from the duct. After that Variac should be adjusted to the proper voltage and this voltage is supplied to the strip heater. The steady state condition occurs after 1-2 hours after starting the heater and blower. When steady state condition occurs the temperature of different thermocouples should be noted. Then the mass flow rate can be changed with the help of gate valve attached to the blower and thus by changing the different plates the process should be repeated until all the readings are achieved.

4.1 Parameter Measurement

The following parameters are to be measured for performance analysis of roughened solar air heater.

- Temperature of heated absorber plate at different locations.
- Temperature of air at inlet and outlet section.
- Ambient Temperature.
- Pressure drop across the orifice meter and test section.
- Heating Energy.

4.2 Validity test

For the validation of the experimental setup Nusselt number and friction factor for smooth duct were experimentally determined. Experimentally determined values for smooth solar air heater are compared with Dittus-Boelter[] and Modified Blasius equation[] for Nusselt number and friction factor respectively.
Dittus-Boelter and Modified Blasius equation is given below:

$$Nu_s = 0.023Re^{0.8}Pr^{0.4} \quad (1)$$

$$f_s = 0.085Re^{-0.25} \quad (2)$$

Above equations shows the values of a smooth plate solar air heater and the experimentally values are compared with those to check the accuracy of the setup.

Table.1.
Values of relative roughness height at which maximum value of heat transfer rate for different artificial roughness geometries used in solar heater duct.

Investigators	Rib geometry	Optimum (e/D)
Prasad and Saini	Transverse ribs	0.033
Gupta et al.	Inclined ribs	0.023
Varun et al.	Combination of transverse and inclined	0.030
Momin et al.	V-shaped rib	0.034
Saini and Verma	Dimple–shape geometry	0.0379
Saini and Saini	Arc shaped ribs	0.0422
Lanjewar et al.	W-shaped ribs	0.03375

Table.2.
Values of relative roughness pitch at which maximum value of heat transfer rate for different artificial roughness geometries used in solar heater duct.

Investigators	Rib geometry	Optimum (p/e)
Prasad and Saini	Transverse ribs	10
Gupta et al.	Inclined ribs	10
Varun et al.	Combination of transverse and inclined	8
Momin et al.	V-shaped rib	10
Saini and Verma	Dimple–shape geometry	10
Saini and Saini	Arc shaped ribs	10
Lanjewar et al.	W-shaped ribs	10

5 CONCLUSION

After doing a lot of review it has been found that roughness geometries being used in solar air heater are of different types depending upon the shapes, sizes, orientations of the roughness elements on the absorber plate. Artificial roughness in the form of repeated ribs is an important easy method for the performance enhancement of the conventional solar air heater. There is a need to work on different roughness geometries which are not made by investigators till today.

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