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Design and Fabrication of Solar Air Heater to Increase Heat Transfer Rate using Artificial Roughness

Anjali Vyas[1], Sanchit Gupta[2], Amankumar Jaiswal[3], Chaitanya Jire[4], Aditya Joshi[5]

[1]Assistant Professor, Mechanical Engineering Department, MCT's Rajiv Gandhi Institute of Technology, Maharashtra, India
[2,3,4,5]Student, Mechanical Engineering Department, MCT's Rajiv Gandhi Institute of Technology, Mumbai, Maharashtra, India

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Abstract - *The solar air heaters, because of their simplicity are cheap and most widely used collection devices of solar energy, has great potential for low temperature applications. To create turbulence near the wall or to break this boundary layer and to improve the thermal performance of air heaters, artificial roughness in the form of wires or ribs of different shapes and in various arrangements have been used. In the present study, Experimentation has been carried out on solar air heater to find out enhancement in heat transfer coefficient due to artificial roughness on absorber plate. Through this study the results obtained had an increment in heat transfer coefficient from 15% to 35%*

Key Words:Solar air heater; Artificial roughness; Reynolds Number: Heat transfer: Experimental setup

1. INTRODUCTION

Solar energy is radiant light and heat from the Sun that is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaics, solar thermal energy, solar architecture, molten salt power plants and artificial photosynthesis. [13]

Solar air heating is a solar thermal technology in which the energy from the sun, insolation, is captured by an absorbing medium and used to heat air. Solar air heating is a renewable energy heating technology used to heat or condition air for buildings or process heat applications. It is typically the most cost-effective out of all the solar technologies, especially in commercial and industrial applications, and it addresses the largest usage of building energy in heating climates, which is space heating and industrial process heating. [2]

A simple solar air collector consists of a flat, dark metal absorber plate encased in an airtight, insulated metal frame with glass over the top. The increase in temperature of air is directly proportional to the flow of air, for which complex designs are used which inhibit roughened surfaces or channels to increase the disturbance of air as it flows through the collector. Commercial manufacturers use black aluminum for the absorber plate. [14]

Concept of artificial roughness on plain surface is an important technique to enhance heat transfer rate of air flowing in solar air heater. The most common types of artificial roughness are fins, perforations, small bumps, wires, ribs, etc.

Applications of artificial roughness on the underside of absorber plate in solar air heater duct have been widely used to improve heat transfer rates. The design of the roughness shape and arrangement is most important 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.

A glazing (a transparent glass) plays a vital role to allow the incident solar radiation for entering the device and substantially restricting infrared energy losses through re-radiation. Reasonable collection of solar radiant energy at moderate temperatures is one of the typical challenges, which is faced by investigators in the field of solar energy utilization. Practically, all absorption collectors proposed to accomplish this function, also depend on the utilization of glazing. A glazing should be used for a high transmissivity to the solar spectrum and extensively opaque to long (or infrared) wavelength solar radiation. A transparent glass is used to transfer the energy from the sun into the solar collector or absorber inside the solar system. The transparent glazing is purposely used to reduce convection losses from the absorber to the environment through the restraint of the stagnant fluid layer in between the absorber and glazing. [2]

An absorber plate is the main component of a SAH and has a momentous effect on thermal performance of a solar thermal system. Many aspects of materials (mainly absorptivity of solar heat) and their properties have a significant effect on the overall performance and the cost of a solar energy device. The major concern will be with different materials as applied to solar collectors, with a reflection to material properties as they affect the overall performance. Basic studies for absorptivity reasons have suggested numerous mechanisms for a selection of energy-absorbing surfaces. [2]

The literature survey of the papers "Thermal Performance of Solar Air Heater Having Absorber Plate with V-Down Discrete Rib Roughness for Space-Heating Applications" by Rajendra Karwaand V. Srivastava and "A review on roughness geometry used in solar air heaters" by Varun, R. P. Saini, S. K. Singal, revealed that use of artificial roughness to increase the rate of heat transfer and turbulence is an effective way to improve the performance of Solar Air Heater if the artificial roughness introduced on the absorber plate is arranged in a V-Down discrete pattern which adds to improvement in the turbulence of the fluid flowing over the absorber plate.

Nomenclature

A	area of absorber plate, m2	Q	useful heat gain, W
Cp	specific heat of air, J/kgK	T_i	inlet temperature of air, K
h	heat transfer coefficient, W/m^{2}K	T_o	outlet temperature of air, K
L	length of test section of duct, m	T_p	mean plate temperature, K
ṁ	mass flow rate, kg/s	T_m	mean fluid (air) temperature, K
R_e	Reynolds Number	ρ	Density of air, kg/m^3
ΔP_0	Pressure drop in orifice	v	velocity of air, m/s
μ	viscosity of air, N-m/s	D_e	effective diameter of pipe, m

2. EXPERIMENTAL SETUP

An experimental setup has been fabricated to study the effect of artificial roughness on heat transfer coefficient.

Table 1: Dimensions of Test Section

Upper Wooden Box:
Length = 1200 mm
Breadth = 600 mm
Height = 50 mm

Lower Wooden Box:
Length = 1200 mm
Breadth = 600 mm
Height = 20 mm

Collector Plate:
Length = 1150 mm
Breadth = 550 mm
Height = 2 mm

Test Section:
Length = 1.18 m
Breadth = 0.57 m
Square hole area = 0.07*0.07 m^2
S-Pattern area = 2*(0.035*0.48) m^2
Area = 0.66 m^2

During the first pass, air is moved through and s-pattern which gives more time for the air to exchange heat with the absorber plate. This also leads to increase in turbulence which in turn helps to increase the heat transfer rate.

During the second pass air is made to flow through a duct below the absorber plate. Artificial roughness i.e. fins have been introduced on the bottom surface of the absorber plate. They are arranged in a v-down discrete pattern and as seen from the literature review, this pattern gives the most increase in the heat transfer rate. The fin geometry is selected as trapezoidal. This happens because the artificial roughness introduces turbulence to the flowing air resulting in an increase in flow time which benefits the heat transfer from the absorber plate to the flowing air. Thermocouples are used at regular intervals at both first and second pass to measure the temperature rise of the flowing air. Various Thermocouples are to be attached at inlet, outlet and test section of absorber plate.

Then, the air is passed through an exit port and into a pipe. Along this pipe, and orifice meter and a pressure gauge are fixed to measure the flow rate and output pressure. A blower is also fitted at the end of the exit pipe so that a uniform air flow can be maintained through the heater.

By measuring the temperature and pressure difference finally heat transfer coefficient is determined which is further used to find heat transfer rate.

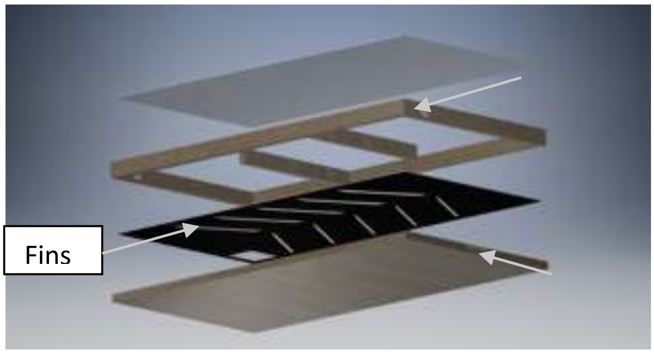

Fig -1: Layout of Geometry

The layout of geometry is shown in fig-1. After the assembly of the heater and its final inspection, the experimental setup was done on the balcony of the college. The blower was turned on an hour prior to taking the temperature readings every time so as to obtain accurate results. Temperature readings of inlet, plate and outlet we taken for three consecutive days at peak hours.The blower attached was used to create suction in the solar air heater. The air is first passed through the S-Pattern on top of the Solar Air Heater. Then it enters the 2nd pass from the hole cutout into the absorber plate and then navigates itself via the fins and to the outlet. The arrangement of fins on absorber plate in v-down discrete pattern is as shown in fig-2

Fig -2: Arrangement of fins in V-Down Discrete Pattern

An orifice meter is also attached to get the pressure difference of the air coming out of the outlet. An anemometer was also used to measure the velocity of the outlet air. Experimental setup is as shown in fig-3.

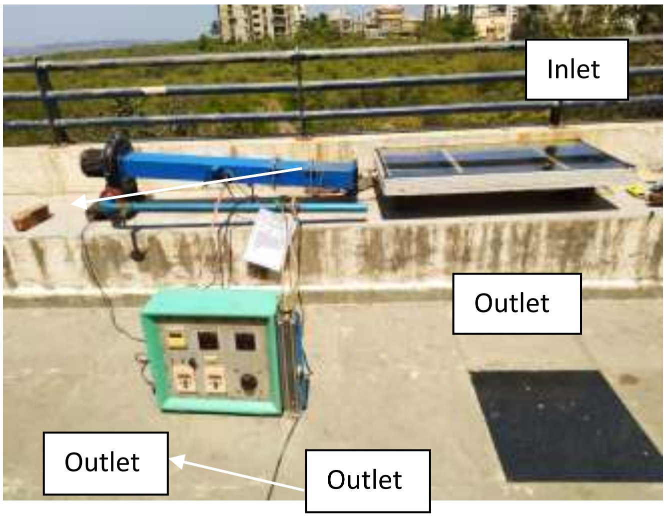

Fig -3: Experimental Setup

2.1 Data Reduction

Steady state values of temperature of air at various locations where measured. Let outlet pressure drop across the duct was measured by U-Tube Manometer. Mass flow rate was calculated from the pressure difference.

$\dot{m} = C_d A \sqrt{2g\rho o \Delta Po}$

Reynolds Number can be calculated as follows:

$R_e = \frac{\rho v De}{\mu}$

The useful heat gain Q can be calculated form first law as

$Q = mc_p\,(T_o - T_i)$

Where m = mass flow rate, kg/sec

T_i= inlet temperature of air

T_o= outlet temperature of air

The useful gain can also be obtained from heat transfer consideration, i.e.

$Q = hA_c\,(T_{pm} - T_m)$

Where h= is convective heat transfer coefficient form plate to the air T_{pm}= is the mean plate temperature,

$T_m = (T_i + T_o)/2$ is the mean fluid (air) temperature in the air heater duct,

A_c= is the area of heat transferring surface.

The top loss Q is the significant loss from an air heater. It is function of the wind velocity, emissivity of the plate, air gap between the absorber plate and the glass cover, collector inclination, atmospheric temperature, and the plate temperature.

If temperature depression of the absorber plate is reduced, the top loss can be reduced to enhance the heat transfer coefficient from the absorber plate to the air flowing through collector duct.

Thermal optimization of Roughened Solar Air Heater:

Since the enhancement in heat transfer coefficient is strong function of roughness parameters, it is essential that optimum values of the parameters are found that result i.e.

result in maximum possible enhancement in heat transfer rate.

A version of Solar Air Heater has been fabricated. Then, the entire apparatus was kept in the college balcony and temperature readings were taken at regular intervals for peak hours of the day. Calculations have been done as given earlier in this chapter.
Results were obtained from experimenting once without fins and once with fins.
The maximum increase obtained in the heat transfer coefficient is 34.09%
The range of increase in temperature difference between inlet and outlet is obtained between 10 to 16 °C throughout the day.

2.2 Results

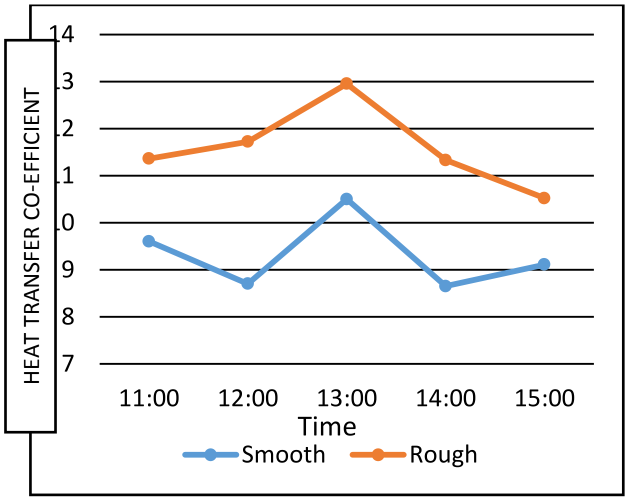

Fig -4: Heat transfer coefficients obtained at different times for actual experiment and referred paper

In this fig-4, obtained value of 'h' for rough plate is plotted against value of h for smooth plate against different times of experimentation.

Table -1:Results obtained with experimental setup

Time	T_i	T_o	v m/s	h_{smooth}	h_{rough}	% Increase in h
11:00	27	39	3.8	9.6	11.36	18.33
12:00	28	42	4.1	8.70	11.72	34.71
13:00	29	45	4.4	10.50	12.95	23.33
14:00	30	44	4.7	8.65	11.33	30.98
15:00	31	44	4.8	9.11	10.52	15.47

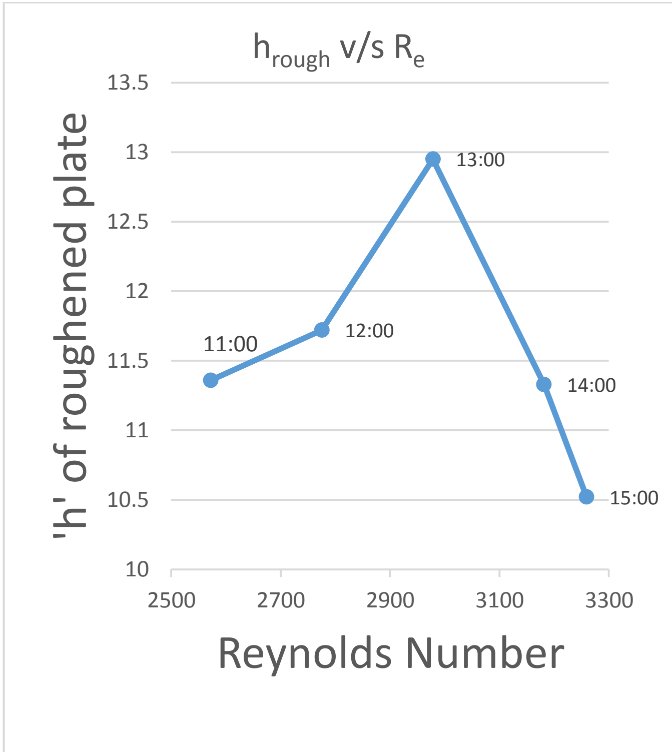

Fig -5: Values of heat transfer coefficient and Reynolds Number obtained at various times

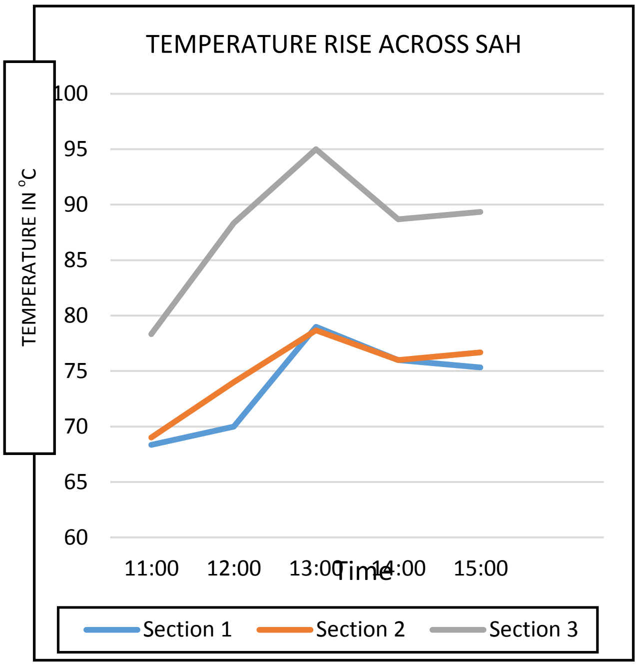

Fig -6: Temperature rise across the various sections of the solar air heater

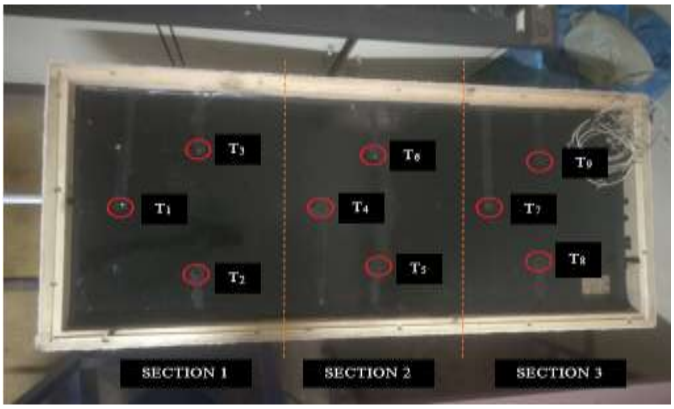

Fig -7: Position of thermocouples

3. CONCLUSIONS

Artificial roughness in the form of trapezoidal shaped fins helped to increase the heat transfer coefficient of air up to 34.09% which is a significant rise in the value of h as compared to the value of h as obtained in free-flowing air. Multiple other factors contribute towards the increase in temperature of air obtained at the outlet;

1. Solar air Heater having artificial roughened absorber Plate have high rate of heat transfer than that of smooth solar air heater
2. The aluminium sheet coated with black paint allows for more absorptivity of sunlight that falls on the absorber plate which increases the overall temperature of the plate to values as high as 100°C.
3. The double pass provision allows more time for the air flowing around the absorber plate to heat up and to obtain significant rise in temperature.
4. The wooden blocks placed on the upper side of the aluminium sheet also provide more time for the flowing air to get heated up by radiation from the aluminium sheet.
5. Greater volume on the upper side of the absorber plate between the aluminium sheet and glass panel allow for a large quantity of air to enter through the inlet duct as compared to the low volume between the under-side of the absorber plate and wooden base where the volume is significantly reduced to allow a rise in the heat transfer coefficient with the provision of artificial roughness.
6. The use of asbestos sheet along the periphery of the Solar Air Heater helps to significantly reduce the losses obtained due to absence of an insulator.

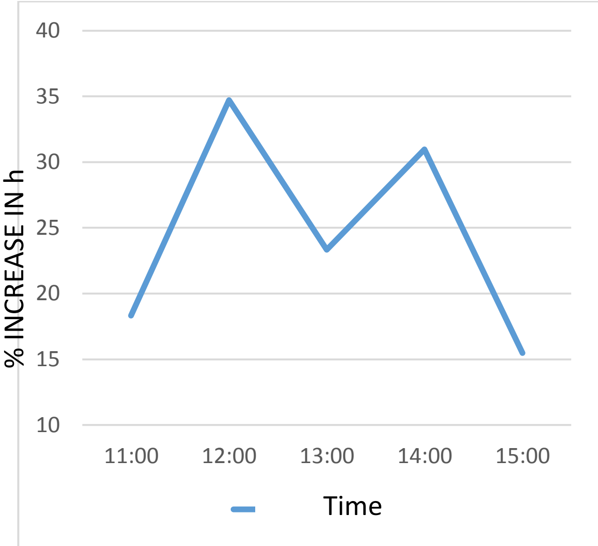

Fig-8: Percentage increase in heat transfer rate due to artificial roughness

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