Analysis of Solar Air Heater with different Shaped Roughened Absorber Plate

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Abstract

In an analytical methodology a trails have been conducted on the heat transfer and friction factor for a solar air heater duct with continuously discrete rib of circular cross-sectional ribs without symmetric gaps. In this experimental investigation, it was assured that the height is 2mm, the pitch (p) of the ribs is 20, the relative roughness pitch (p/e) is 10mm. When the observations were compared between smooth absorber plates. The smooth ribs couldn't transfer the desired heat and so it was not practically prepared. The rough ribs having symmetrical gaps were efficient enough to transfer heat but it is not economical and has a huge complexity in design, whereas the continuous discrete ribs without symmetric gaps overcome this problem. The result of continuous discrete ribs was concluded by comparing Nusselt number and Friction factor with circular ribs having symmetric gaps. The rough ribs were efficient enough to transfer the desired heat, but they are not economical and are very complex in design and construction. Whereas, the Circular ribs gives more area of contact. So, there is enough time to transfer the heat from the ribs to the passing air which touches the ribs and the heat transfer takes place efficiently.

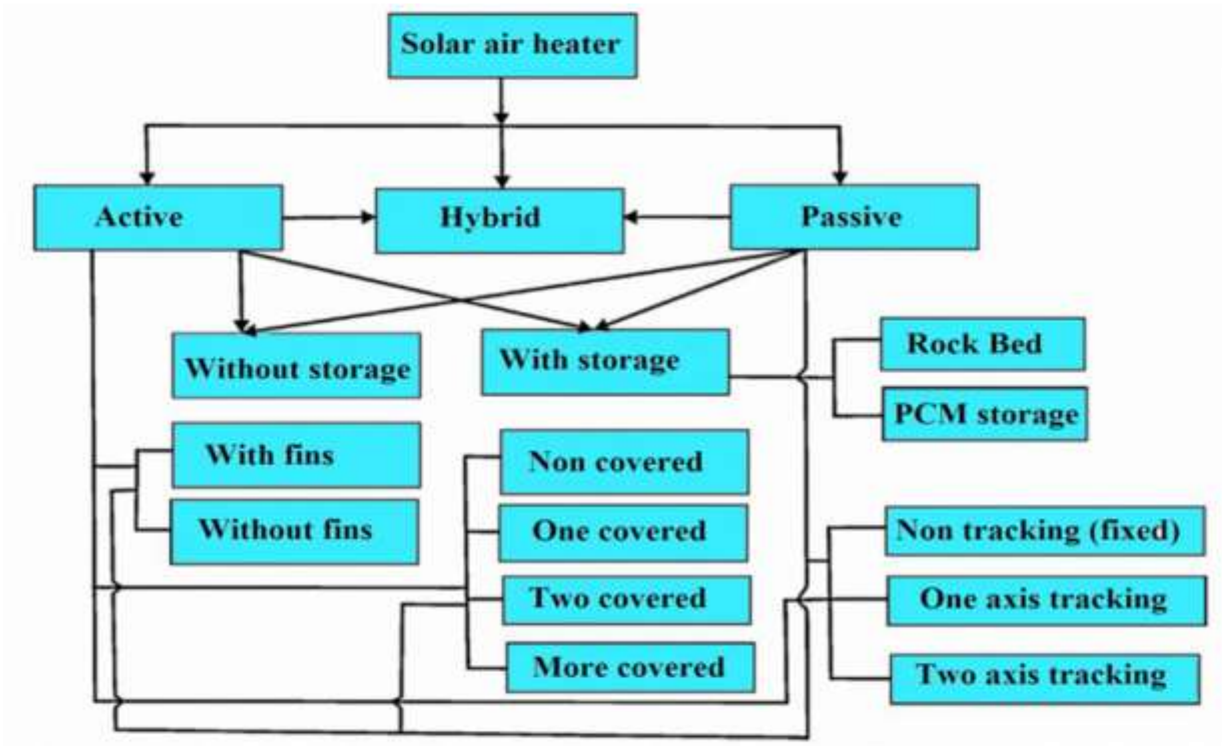
Keywords— *Solar air heater, Artificial roughness, Nusselt Number, Heat Transfer Coefficient, Friction factor.*

I. INTRODUCTION

Solar air heaters form the major component of solar energy utilization system which absorbs the incoming solar radiation, converting it into thermal energy at the absorbing surface, and transferring the energy to a fluid flowing through the collector. Solar air heaters because of their inherent simplicity are cheap and most widely used collection devices. These have found several applications including space heating and crop drying. The efficiency of flat plate solar air heater has been found to be low because of low convective heat transfer coefficient between absorber plate and the flowing air which increases the absorber plate temperature, leading to higher heat losses to the environment resulting in low thermal efficiency of such collectors. Several methods, including the use of fins, artificial roughness and packed beds in the ducts, have been proposed for the enhancement of thermal performance. Use of artificial roughness in the form of repeated ribs has been found to be a convenient method. Ribs of various shapes and orientations have been employed and the performance of such systems has been investigated. The use of artificial roughness in solar air heaters owes its origin to several investigations carried out in connection with the enhancement of heat transfer in nuclear reactors and turbine blades. In the era of energy exploration it has shown the great interest in the alternate source of energy. Since, solar energy is one of them which never end. Only thing is that, how to utilize this energy in an effective way to overcome the energy losses. Various methods are used to convert solar energy into useful form of energy. Like conversion of solar energy into electrical energy by using photovoltaic cell, and to collect this solar energy from collector which is used for heating the water or other sources. In the present study, solar duct is used in order to collect the solar energy used for heating the air, since the amount of heat transferred from solar energy into air is small and the reason for this is the thermal conductivity of air is low so air absorbs less heat from solar energy in solar duct. Our effort is to achieve high amount of heat absorbed by air from solar energy in solar duct. As we know that, the thermal conductivity of air is low but we cannot use other gases instead of air for collecting the solar energy, because air is freely and easily available as compare to other gases. However heat transfer in air increases by increasing the time of contact between air and solar duct, so this require the reduction in flow velocity of air in the solar duct. Thus, reduction in the flow velocity of air is achieved by providing artificial roughness in the solar duct.

II. ABOUT THE SOLAR DUCT

Solar air heating is a solar thermal technology in which the energy from the sun is absorbed by air and is used to heat the spaces in building or process heat application such as drying crops (that is tea, corn, coffee) and other drying applications. In solar duct the flow of air inside the duct is due to blower or fan installed on one end of the duct which sucks the air from the other end of the duct. In the duct, solar collectors are provided which collects the solar energy and transfers it to air as the air becomes dry. Solar Duct is based on the highly efficient and award-winning Solar Wall system. The technology has been specifically engineered for roof settings and for applications in which a traditional wall mounted system is not feasible. Like the original Solar Wall technology, SolarDuct is a solar heating system that heats ventilation air before it enters the air handling units. The patented system uses an all-metal collector panel (transpired solar collector) and is suitable for commercial, industrial, and institutional facilities. Perforations in the panels allow the heat that normally collects on a dark surface to be uniformly drawn through the Solar Duct panel and then ducted into the conventional HVAC system. The Solar Duct system is optimized to meet site conditions in terms of orientation towards the sun and proximity to rooftop air handling units. The modular arrays are sized according to the energy requirements of the building.



Features & Advantages of Solar Duct

- Heats ventilation air using the highest performing and lowest cost solar collector on the market
- Collector efficiency up to 80%
- Easy to install modular rooftop units
- Optimized to meet site conditions
- Internally ballasted or fastened system which is quick to assemble and simple to integrate into existing air intake system
- Individual units are 6’ by 4’ and each produces 1000 watts of thermal energy
- Typical string length is 48 feet long (8 units) with no limit to array size, and will deliver up to 2000 CFM of heated ventilation air and 8kW of heating
- Substantial CO_2 displacement

Objective

- To predict nusselt no. and friction factor for roughened solar duct.
- To analyze the continuous discrete circular rib with different relative gap width roughened solar duct of the different roughened profile.

- To define average heat transfer coefficient, Nusselt number and friction factor for the continuous discrete roughened solar duct.
- Predict temperature distribution along the Duct.

III. RESULTS

EXPERIMENTAL SET-UP

An experimental set-up to study the effects of Continuous discrete ribs with symmetrical gaps on heat transfer and fluid flow characteristics in a rectangular duct has been designed and fabricated as per the ASHRAE standard recommendation. The schematic diagram of the experimental set-up and test plate is shown in Fig. The rectangular duct is 2395 mm long with a flow cross section area of 300 mm×25 mm, fabricated from ply board. The duct has an inlet, test and exit section of 740 mm, 1100 mm and 555 mm length respectively; equivalent to 16 D, 24 D and 12 D respectively. The duct is insulated with 50 mm thick polystyrene insulation of 0.037W/mK thermal conductivity. An aluminum test plate of dimension 300 mm×1100 mm provided with a roughness is placed on the top of the test section to form a roughened wall of the duct. A uniform heat flux of 1000 W/m2 was supplied to the roughened plate by an electric heater. Air was circulated in the duct by a 2 HP centrifugal blower. The mass flow rate of air was calculated by measuring the pressure drop across the orifice meter employed in the circulation pipeline and the pressure drop across the test section was measured with the aid of digital micro-manometer, Having least count of 0.01 Pa. The temperature of heated plate at 21 locations was measured under the steady state condition by calibrated J-type copper constantan thermocouples connected to digital temperature display via selector switch. The exit temperature of the air was recorded at three different locations in the Transverse direction to get the mean air temperature at the outlet and; inlet air temperature was measured by placing a thermocouple at the inlet section.

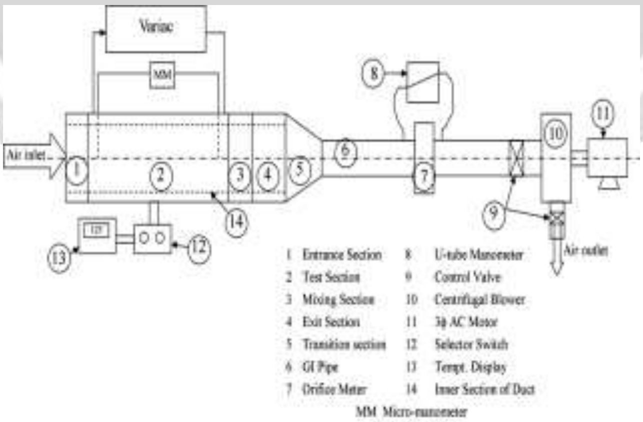


Figure: Schematic diagram of the experimental set-up.

RESULT OBTAINED FROM EXPERIMENTALY SOLAR DUCT WITH ROUGHENED ABSORBER PLATE WITH SMOOTH PLATE

The experimental data for plate and air at various locations in the duct were recorded under steady state conditions for given heat flux and mass flow rate of air. The data was used to compute the heat transfer rate of air flowing in the duct. Following equations have been used to determine heat transfer coefficient ‘h’, Nusselt number ‘Nu’, Reynolds number ‘Re’, friction factor ‘f’.

$$\frac{Q_u}{A_p}(T_p - T_a)$$

Where, the rate of heat gained by the air ‘Qu’ is given by,

$$Q_u = m \times C_p \times (T_o - T_i)$$

M=Mass flow rate.

Heat transfer coefficient has been used to determine the Nusselt Number using the equation:

$$Nu = h\frac{D_h}{k}$$

Friction factor was determined from the flow velocity ‘V’ and the Pressure drop (ΔP) measured across the test section length of 1.1 m using the Darcy–Wiesbach equation as,

$$f = \frac{(2 \times \Delta P \times D_h)}{(4 \times \rho \times L \times V^2)}$$

The same formula is also used for obtaining the result but data require for the given formula is calculated from the contours of pressure & temperature. In order to calculate the Nusselt no. for different Reynolds number, temperature contour of air at outlet of duct and contour of plate temperature at Reynolds number 4000 is used.

Calculation of Nusselt at Reynolds No. 4000 for smooth plate

From the air outlet & plate temperature contour following calculations were done

Temperature of plate= 558 k

Temperature of outlet air=360 k (it is the average of temperature range from 421 to 300)

$$\boldsymbol{Q = M \times C_p \times (T_o - T_i)}$$

$\boldsymbol{T_o}$=outlet temperature of Air

$\boldsymbol{T_i}$=inlet temperature of Air, T_i=300 k

M=mass flow rate of air, M=density×Area×Velocity

Density of air = 1.225kg/m^3,

C_p= specific heat of air (1005J/kg-k),

Cross section area of duct = (0.3×0.025) = 0.0075 m^2

Velocity of air at Reynolds number 4000 when used

We know that, $\boldsymbol{Re = \rho \times v \times \frac{D}{\mu}}$

Where,

ρ= density of fluid (1.225 kg/m^3)

v=velocity of fluid (to be determined)

D=hydraulic diameter $\frac{(2\times W\times H)}{(W+H)}=\frac{(2\times 0.3\times 0.025)}{(0.3+0.025)}$=0.046154 m

μ= dynamic viscosity of air = 0.00001983

Putting the value in Reynolds number formula for Re=4000 we get the value of velocity & it is 1.3 m/s.

Putting the value of velocity in mass flow rate equation i.e., M=1.225×0.0075×1.3

M=0.01194375 kg/s

Putting the value of M in Q= M×C_p× (T_o-T_i)

Therefore, Q=0.01194375×1005× (360-300)

Q =720.2081 watt

$$\boldsymbol{Q = h \times A \times (T_p - T_i)}$$

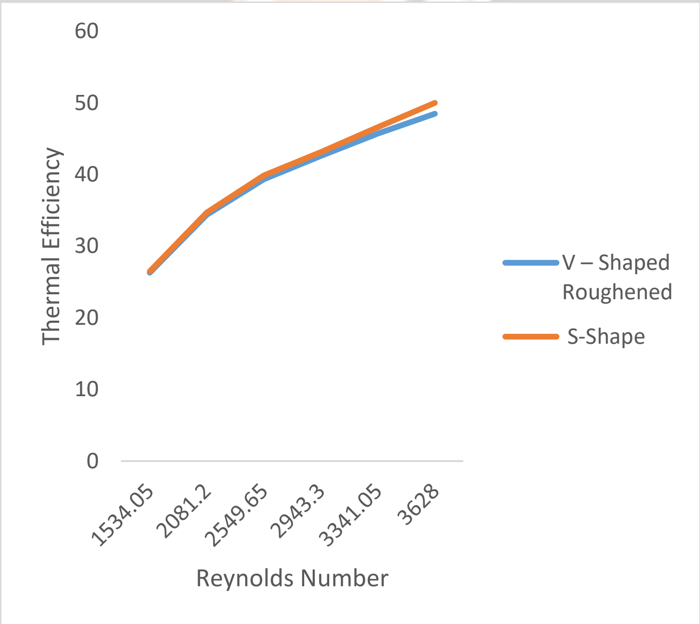
Where, h convective heat transfer coefficient

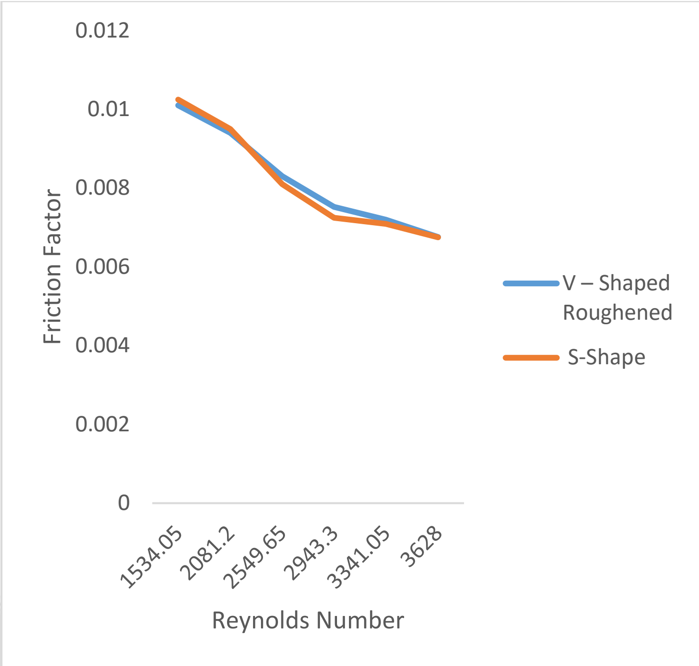
T_p =temperature of plate

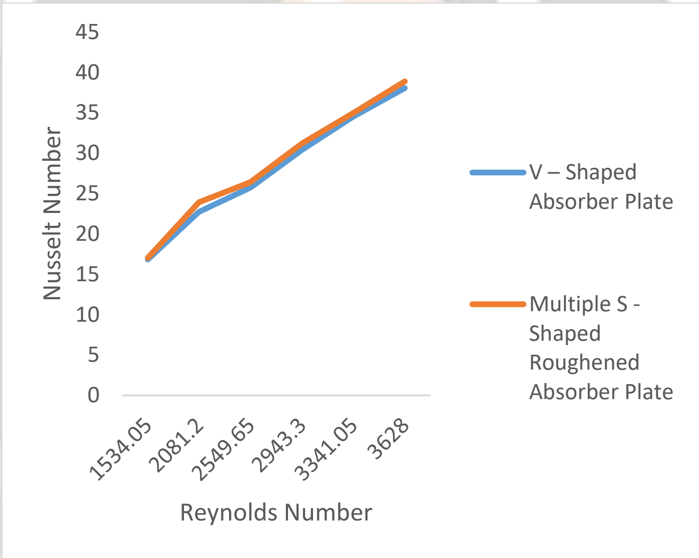
T_i = inlet temperature of air
h=720.2081/(.0075× (360-300))
h=8.459104 W/(m^2k)

$$NU = \frac{hD_h}{k}$$

Where, K= thermal conductivity of air (0.0242 W/m-k)
Hydraulic Diameter = 0.046154, putting the value of D_h&k in Nusselt No. equation we get,
Nu=16.13307 (NU obtained from experimental)







CONCLUSIONS

- Average deviation of result obtained from experimental for smooth & Continuous discrete ribs plate for Nu number & Friction factor lies within the range, average Nu Number is deviate 3.76% for smooth plate and Average Friction factor is deviate 3.91% for smooth plate.
- Average deviation of results obtained for continuous discrete ribs from experimental in Nu Number is deviated by 17.01 % i.e., Nu Number increases for Continuous discrete ribs plate at each Reynolds number taken for experimentally.
- Average deviation of result obtained for continuous discrete ribs from experimental in Friction factor is deviated by 20.15% i.e., Friction factor increases for Continuous discrete ribs plate at each Reynolds number taken for experimentally.

REFERENCES

[1] Rajesh Maithani , J.S. Saini “Heat transfer and friction factor correlations for a solar air heater duct roughened artificially with V-ribs with symmetrical gap” Experimental Thermal and Fluid Science 70 (2016) 220–227.

[2] Sukhmeet Singh , SubhashChandera, J.S. “Saini Heat transfer and friction factor correlations of solar air heater ducts artificially roughened with discrete V-down ribs” Energy 36 (2011) 5053-5064.

[3] Arvind Kumar, J.L. Bhagoria, R.M. Sarviya “Heat transfer and friction correlations for artificially roughened solar air heater duct with discrete W-shaped ribs” Energy Conversion and Management 50 (2009) 2106–2117.

[4] S.K. Saini a, R.P. Saini “Development of correlations for Nusselt number and friction factor for solar air heater with roughened duct having arc-shaped wire as artificial roughness” Solar Energy 82 (2008) 1118–1130.

[5] S.V. Karmare, A.N. Tikekar “Heat transfer and friction factor correlation for artificially roughened duct with metal grit ribs” International Journal of Heat and Mass Transfer 50 (2007) 4342–4351

[6] R.P. Saini, JitendraVerma “Heat transfer and friction factor correlations for a duct having dimple-shape artificial roughness for solar air heaters” Energy 33 (2008) 1277– 1287.

[7] S.C. Lau, R.T. Kukreja, R.D. Mcmillin, “Effects of V-shaped rib arrays on turbulent heat transfer and friction of fully developed flow in a continuous discrete channel” Int. J.Heat Mass Transfer. Vol. 34, No. 7 .pp 1605-1616, 1 991

[8] J.C. Han and Y.M Zhang “High performance heat transfer ducts with parallel broken and V-shaped broken ribs” Int. J.Heat Mass Transfer. Vol. 35, No. 2 .pp 513-523, 1992

[9] TabishAlam, R.P.Saini, J.S.Saini “Effect of circularity of perforation holes in V-shaped blockages on heat transfer and friction characteristics of rectangular solar air heater duct” Energy Conversion and Management 86 (2014) 952–963

[10] RajendraKarwa “Experimentally investigated that heat transfer and friction factor in rectangular duct with rectangular cross-section rib on one broad wall in transverse inclined V-continues and V-discrete pattern” Int. Comm. Heat Mass Transfer Vo.30,No.2,pp.241-250,2003

[11] Dhanjay Gupta, S.C. Solanki, J.S. Saini “Thermo hydraulic Performance On Solar air Heater With Roughened Absorber Plates” Solar Energy Vol. 61, No. 1, pp. 33-42, 1997

[12] R. Karwa, S.C Solanki ,J.S Saini “Heat transfer coefficient and friction factor correlations for the transitional flow regime in rib roughened rectangular ducts” International Journal of Heat and Mass Transfer 42 (1999) 1597-1615

[13] P.R. Chandra, C.R Alexandra, J.C. Han “Heat transfer and friction behaviors in rectangular channels with varying number of ribbed walls” International Journal of Heat and Mass Transfer 46 (2003) 481–495

[14] J.L. Bhagoria, J.S. Saini, S.C. Solanki “Heat transfer coefficient and friction fact correlations for rectangular solar air heater duct having transverse wedge shaped rib roughness on the absorber plate Renewable Energy 25 (2002) 341–369

[15] Abdul-Malik EbrahimMomin, J.S. Saini S.C. Solanki “Heat transfer and friction in solar air heater duct with V-shaped rib roughness on absorber plate” International Journal of Heat and Mass Transfer 45 (2002) 3383–3396.