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Effect of artificial roughness on Thermal and Thermohydraulic efficiency in Rectangular Duct of a Double pass solar Air Heater by using transverse ribs on the absorber plate

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ABSTRACT: *This paper represents the effect of artificial roughness on the absorber plate in the form of transverse ribs of a double pass solar air heater. An experimental study has been carried out to see the effect of transverse ribs(α=90°) attached on both sides to the absorber plate of a Double pass solar air heater on the Thermal and Thermohydraulic efficiency in a rectangular Duct. The aspect ratio of the Duct (W/H) is 10. The range of Reynolds number varies from 4900 to 12000. The relative roughness pitch (p/e) is between 5-20 and fixed relative roughness height (e/Dh) 0.044 and fixed angle of attack (α) 90°. It has been observed that the maximum thermal and thermohydraulic efficiency of transverse ribs comes at relative roughness pitch (p/e) of 10.*

KEYWORDS: *Absorber Plate, Double pass solar air heater, Thermal efficiency, Thermohydraulic efficiency, Nusselt Number, Reynolds number.*

I. INTRODUCTION

Solar air heater is the simplest device which is used to convert the solar energy into heat energy. In solar air heater heat generated by solar energy is collected over a collector and that heat is then taken away by the fluid flowing i.e. air in the duct of solar air heater. The heat carried away by air is then used for various purposes and in many applications such as crop drying, space heating [1].

The efficiency of solar air heater is low due to low convective heat transfer between the absorber plate and the fluid flowing inside the duct. So to increase the thermal efficiency of solar air heater many investigators put forth their views.

Several methods have been used by various investigators to increase efficiency. Some of these are Use of artificial roughness on absorber plate, use of fins, electro hydrodynamic method, packed bed etc. Out of these the easiest and most acceptable method to enhance the thermal and thermo hydraulic efficiency is the creation of artificial roughness on the absorber plate of solar air heater.

Dhiman et al. [2] performed an analytical study to predict the thermal performance of a novel parallel flow packed bed solar air heater. They found that parallel flow solar air heater with packed bed material give a higher heat flux as compared to the conventional non-porous bed double flow system. Momin et al. [3] carried out an experimental investigation to show the effect of geometrical parameters of V-shaped ribs on heat transfer and fluid flow characteristics of rectangular duct of a solar air heater. They observed that using V- shaped ribs maximum heat transfer occurred at relative roughness height of 0.034 and at an angle of attack of 60°.

El-Sebaii et al. [4] carried out an experimental as well as analytical study for the thermal performance of a double pass flat and V-corrugated plate solar air heater. They found that double pass V-corrugated plate solar air heater is more efficient than double pass flat plate solar air heater by 11-14% and the maximum value of the thermo hydraulic efficiency of V as well as flat plate solar air heater occur at mass flow rate 0.02kg/s. Sudhanshu et al. [5] shows the effect of artificial roughness on heat transfer and friction factor characteristics on double pass solar air heater using transverse ribs. They found that by providing the artificial roughness on both sides of the absorber plate the heat transfer and friction factor gets improved with maximum heat transfer and friction factor occur at relative roughness pitch of 10. This study also shows that the Nusselt number increase by 1.06 times as that of the smooth one.

El-khawaja et al. [6] carried out an experimental study to show the thermal performance and the effect of using transverse fins on a double pass solar air heater using wire mesh as an absorber plate. He found that the thermal efficiency increases with the increase in mass flow rate and is highest in 0.042kg/s. Sahu and Bhagoria [7] experimentally studied the thermal performance of a solar air heater and show the variation in the thermal performance by using 90° broken ribs on the absorber plate and found that the thermal performance lie in the range of 51 to 83.5% with 90° broken ribs.

Aldabbagh [8] calculated the thermal performance of a single and double pass solar air heaters with steel wire mesh layer instead of a flat absorber plate and the results indicate that the efficiency increases with increasing the mass flow rate within the range of 0.012 to 0.038kg/s. Efficiency is more for double pass than single pass solar air heater by 34-45% for the same mass flow rate. Prasad and Saini[9] experimentally studied the effect of roughness and flow parameters on heat transfer and friction factor of a solar air heater. They observed that the maximum thermo hydraulic performance is achieved at relative roughness height of 0.033 and relative roughness pitch of 10. They also found that Nusselt number varies 2.38 times and friction factor varies 4.25 times as that of smooth one.

Nephon [10] performed a numerical study on the performance and entropy generation of a double pass solar air heater having longitudinal fins and mathematical model was developed for heat transfer characteristics for the mass flow rate of 0.02-0.1kg/s. He found that the thermal efficiency increases with increase in the number of fins and increase in their height

whereas entropy generation decreases with b the increase in the number of fins and their height. Suppramaniam and Satcunanathan [11] concluded that a simple two glass cover solar air heater can be operated as a two pass solar air heater by passing the air between glass panes before passing it through the blackened area which results in increase in the performance of collector with no further increase in cost.
The aim of this study is to show the effect of using transverse ribs on the absorber plate (upper side and lower side) on heat transfer and friction factor characteristics.

I.1 ARTIFICIAL ROUGHNESS

Thermal performance of solar air heater can be increased by using artificial roughness on the absorber plate to make it rough to increase the heat transfer rate and friction factor characteristics.

Due to this roughness, turbulent boundary layer with small laminar sub-layer is formed on the absorber plate. This laminar sub-layer offer very high resistance to the heat flow. So by breaking this layer to create turbulence the heat transfer rate and friction factor characteristics can be increased which further increases the thermal efficiency and thermo hydraulic performance of a solar air heater [12].

Hence, it is necessary that the turbulence must be created in the vicinity of heat transfer surface i.e. laminar sub layer only where the heat exchange takes place and the flow should not be unduly disturbed so as to avoid excessive friction losses. This can be done by keeping the height of the roughness element to be small in comparison with the duct dimensions. Although there are several parameters that characterize the arrangement and shape of the roughness, the roughness element height (e) and pitch (p) are the most important. These parameters are usually specified in terms of dimensionless parameters, namely, relative roughness height (e/D_h) and the relative roughness pitch (p/e). The roughness elements can be two dimensional ribs or three dimensional discrete elements, transverse or angled ribs or V-shaped continuous or broken ribs.

II. EXPERIMENTAL SET-UP

A Schematic view of double pass solar air heater is shown in fig 1. The rectangular duct of double pass solar air heater consists of two consecutive sections that is entry section and the test section. The size of the entire duct is 2070mm*250mm*25mm. Length of test section is 1600mm and entry length is 400mm. A space of 70mm is to be left out at the end for the movement of air towards upper duct. The entry length is considered on the basis of the American society heating refrigeration and air conditioning engineers (ASHRAE) std [13].

A heating source is provided so that we get required amount of intensity equivalent to that of 900W/m^2 which is equal to the intensity of sun. Halogen lights of 500W each is used as a heating source. These halogen lights are fixed on a flat board at a height of 1m above the duct. The intensity of radiations is measured with the help of pyranometer. A glass sheet of thickness 4mm is placed over the duct to make passage of air to make it double pass and also it makes the intensity comes from halogen lights to get directly falls over the absorber plate.

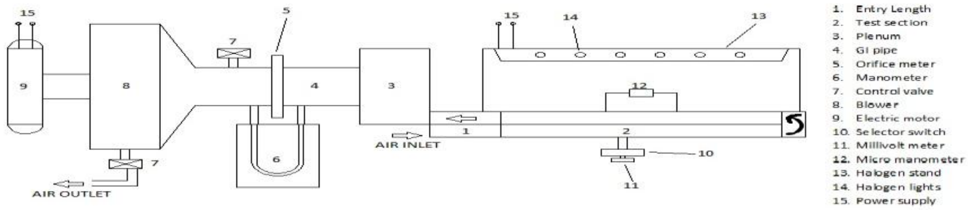

Fig 1. Schematic view of experimental set up

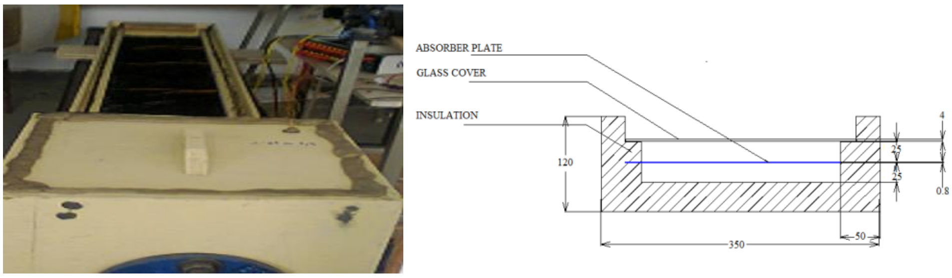

Fig 2. Pictorial and sectional view of Duct

The absorber plate is of galvanized iron (GI) having thickness of 0.8mm. Ribs are attached to the upper and lower side of the absorber plate with the help of glue. The material for ribs is aluminum wires of diameter 2mm. The schematic view of the absorber plate is given in fig 3.

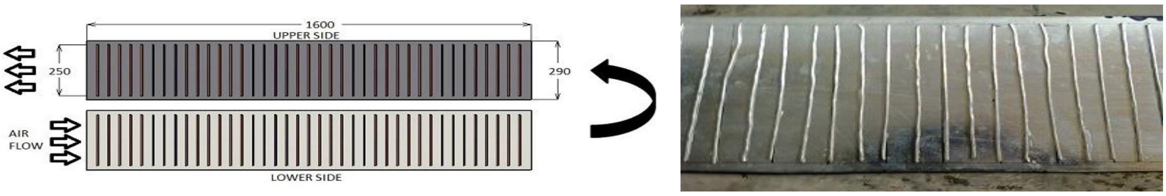

Fig 3. Schematic view of absorber plate

The mass flow rate of air through the duct is measured by means of a calibrated orifice meter which is inserted in the circular pipe and the flow is controlled by means of a control valve provided in blower which is attached to the circular pipe at the end. The copper-constantan thermocouple wire (T-type) was used to measure the air and absorber plate temperature at different locations. The pressure across the test section is measured with the help of micro manometer.

2.1 INSTRUMENTATION

A. Measurement of Air flow

The air flow rate through the duct was measured by using concentric orifice plate with 45° bevelled edges. It was designed, fabricated and fitted in the 80 mm pipe which carries the air from plenum to the blower. The orifice plate was calibrated against Pitot tube and the value of coefficient of discharge (C_d) was determined as 0.612. The pressure drop across the orifice meter was measured by means of a U-tube manometer.

B. Temperature Measurement

For measuring the temperatures of air and absorber plate Calibrated copper-constant (T type), thermocouples were used. Twelve Thermocouples were mounted on the upper side of the absorber plate to measure its mean temperature. For measuring the temperature of air two thermocouples were inserted at inlet and outlet section of the duct.

C. Pressure Drop Measurement

The pressure drop across the test section of the duct was measured with the help of a micro-manometer. It is having a least count of 0.01 mm. The movable reservoir is mounted using a lead screw having a pitch of 1.0 mm with a graduated dial having a 100 division. The meniscus is maintained at a fixed point by moving the reservoir up and down. Then the movement is noted, which gives the pressure difference across the two tapings.

2.2 DATA REDUCTION

The values of all the important parameters like temperature of absorber plate, air inlet and outlet temperature and pressure drop are required to calculate mass flow rate ‘m’, velocity of air, heat supplied to the air and heat transfer coefficient ‘h’ were calculated by using the following expressions.

Mass flow rate, $$m = C_d A_o \sqrt{\frac{2\rho(\Delta P_o)}{1-\beta^4}} \quad (1)$$

The heat transfer coefficient,

$$h = \frac{Q_u}{A_p\left(T_{pm} - T_{fm}\right)} \quad (2)$$

Where heat transfer rate (Q_u) to the air is given by

$$Q_u = mC_p\left(T_o - T_i\right) \quad (3)$$

The heat transfer coefficient calculated is then used to determine the Nusselt number as given below;

$$Nu = \frac{hD_h}{k} \quad (4)$$

Where D_h is the hydraulic diameter of the duct.

The Darcy Wiesbach equation is then used to determine the friction factor by measured value of pressure drop $(\Delta P)_d$ across the test section length as below,

$$f = \frac{2(\Delta P)_d D_h}{4\rho L V^2} \quad (5)$$

III. RESULTS AND DISCUSSION

In this section of paper the effect of relative roughness pitch on thermal and thermohydraulic performance is given and discussed. Fig. 4(a) shows the variation of thermal efficiency as a function of Reynolds number for different values of Relative roughness pitch(p/e) 5-20 and fixed value of angle of attack 90° with a fixed value of relative roughness height (e/Dh) 0.044.

Fig. 4(a) shows that the maximum efficiency occurs at relative roughness pitch of (p/e) 10. This is due to the reason that at p/e = 10 maximum number of reattachment points are found and hence thermal efficiency get increased.Hence the maximum thermal efficiency occurs at relative roughness pitch (p/e) of 10.

Also at relative roughness pitch (p/e) of 5 thermal efficiency is more or less same as that of smooth plate, this is due to the reason that as the gap between the ribs is very less at this juncture hence the flow does not get separated and very less or no reattachment points has been formed.

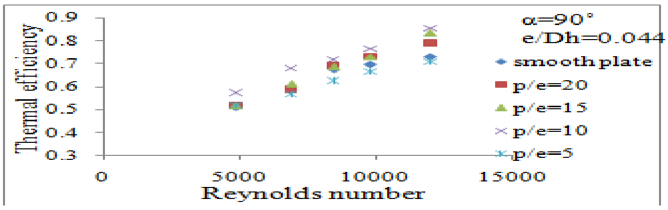

Fig 4(a). Variation of thermal efficiency with the Reynolds number for different values of relative roughness pitch and for fixed value of angle of attack 90° and relative roughness height

Fig 4(b) shows that the variation of thermo hydraulic efficiency as a function of Reynolds number for different values of relative roughness pitch (p/e) 5-20 and for a fixed value of angle of attack 90° with relative roughness height (e/Dh) 0.044. It can be seen from the figure that effective efficiency increases with the increase in Reynolds number and after a certain value it starts decreasing. This is due to the reason that the quality of collected heat decreases and pump work increases.

The maximum value of effective efficiency occurs at relative roughness height of 0.044 and relative roughness pitch of 10.

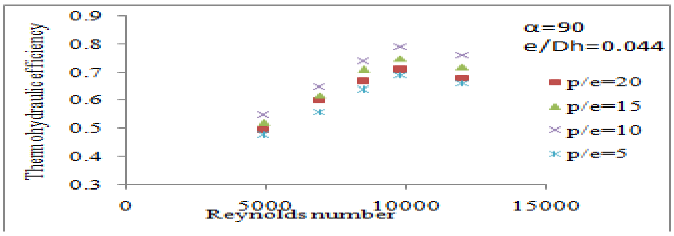

Figure 4(b). Variation of the thermohydraulic efficiency with the Reynolds number for different values of relative roughness pitch and for fixed value of angle of attack 90° and relative roughness height

REFERENCES

[1]. N.K.Bansal, "Solar air heater applications in India" 1998 published by Elsevier Science Ltd. PII: S0960-1481(98)00237-7.
[2]. Prashant Dhiman , N.S.Thakur, Anoopkumar, Satyendersingh, "An analytical model to predict the thermal performance of a novel parallel flow packed bed solar air heater," Applied energy 88(2011) 2157-2167.
[3]. Abdul- Malik Ebrahim Momin, J.S.Soni, S.C.Solanki, "Heat transfer and Friction factor in solar air heater duct with V-shaped rib roughness on absorber plate," Internantional journal of heat and mass transfer 45(2002) 3383-3396.
[4]. A.A.ElSebii, S.AboulEnein, M.R.I.Ramadan, S.M.Shalaby, B.M.Moharram, "Investigation of thermal performance of double pass flat and V-corrugated plate solar airheaters," Energy 36(2011) 1076-1086.
[5]. Sudhanshu Dogra, Nitin Chauhan, Gaurav Bhardwaj, "Effect of artificial roughness on heat transfer and friction factor characteristics in rectangular duct in double pass solar air heater" International Journal of Mechanical Engineering and Technology (IJMET), ISSN 0976 – 6340(Print), ISSN 0976 – 6359(Online) Volume 4, Issue 3, May - June (2013) © IAEME.
[6]. M.F.ElKhawajah, L.B.Y.Aldabbagh, F.Egelioglu, "The effect of using transverse fins on a double pass solar air heater using wire mesh as an absorber," Solar energy 86(2011) 1479-1487.
[7]. MM Sahu and JL Bhagoria, "Augumentation of heat transfer coefficient by using 90° broken transverse ribs on absorber plate," Renewal energy 2005; 30:2057-2063.
[8]. A.P.Omojaro, Aldabbagh, "Experimental performance of a single and double pass solar air heater with fins and steel wire mesh as an absorber," Applied energy 87(2010) 3759-3765.
[9]. B.N.Prasad and J.S.Saini, " Effect of artificial roughness on heat transfer and friction factor in a solar air heater," Solar energy vol.41, No. 6. Pp. 555-560, 1988.
[10]. PaisarnNaphon, " Perfrmance and entropy generation of the double pass solar air heater with longitudinal fins," Renewable energy 30(2005) 1345-1357.
[11]. Suppramaniam Satcunanathan and Stanley Deonarine, " A two pass solar air heater,"Solar energy 1973 , vol.15, pp.41-49.
[12]. Vikrant Katekar, AnkurVithalkar, Bhojraj Kale, "Enhancement of convective heat transfer coefficient in solar air heater of roughened absorber plate," ICETET' 09 Proceedings, IEEE comp. society, Washington DC, USA 2009, doi>10.11.09/ICETET-2009.
[13]. ASHARAE Standard 93–77. Method of testing to determine the thermal performance of Solar Air Heater, New York 1997; 1–34.