International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-05, Issue-09, Dec 2019

Effect of Booster Mirror on Inclined Roughened Solar Air Heaters Performance

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Abstract: - Higher value of intensity of radiation on absorber plate of solar air heaters and effective heat removal from the plate by the carrier fluid, air enhances thermal performance of solar air heaters. The paper deals with the experimental result of enhancing the intensity of radiation by means of booster mirrors and that of heat transfer by means of providing artificial roughness on the air flow side of the absorber plate. Heat transfer measurements were conducted for a fully developed turbulent flow in a rectangular plate with its bottom wall blindly holed with circular geometry. The test plate was designed with its bottom wall was made of a rectangular GI plate of length 736 mm , breadth 110 mm and width130 mm. Experiments were carried out based on different geometries. It was found that the enhancement in heat transfer was achieved in rectangular plate with inclined roughened on bottom surface of plate. Inclined roughened on bottom of the GI plate enhance the convective heat transfer rate of the air flowing through it. An enhancement in radiation of about 30% have been found over the normal incident radiation by means of booster mirrors leading to 9% to 17% higher rate of heat collection. Several experimental and numerical investigations, with different roughened geometry and flow conditions, have been carried out. This paper is one such effort of experimental investigations of heat transfer. It presents the effect of booster mirror arrangements on the heat transfer. This paper investigates on the thermal performance of inclined roughened solar air heater with booster mirror.

Keywords: Stanton number, Nusselt number, Friction factor, Thermal performance, Reynolds Number, Angle of Attack.

I. INTRODUCTION

Use of artificial roughness of different configurations has been used in plenty of studies to enhance the heat transfer rate in solar air heaters during the last decades. Varying magnitudes of roughness results in varying values of heat transfer and friction factor enhancement. An enhancement of about double than that of smooth solar air heater with respect to heat transfer coefficient have been reported (Prasad and Saini,1988; Prasad, 2013), while the friction factor quadrupled. Heat transfer and friction factor correlations have been obtained for V-rib roughened solar air heaters (Hans et al., 2010). The effect of different orientation of W-rib roughness has been investigated to enhance heat transfer in solar air heaters (Lanjewar et al., 2011). Review reports on roughness geometries used in solar air heaters are available (Varun et al., 2007; Shakya et al., 2013). CFD based analysis for heat transfer and friction factor has been made for transverse wire roughness in solar air heaters (Yadav and Bhagoria, 2013). Nusselt number and friction factor correlations have been obtained for arc-shaped wire roughness and dimple shaped roughness (Saini and Saini, 2008; Saini and Verma, 2008). Reviews (Chamoli et al., 2012; Gawande et al., 2014) for turbulence promoters and effect of roughness geometries on heat transfer enhancement in solar thermal systems give wide range of data and results on heat transfer and friction factor. Artificial roughness provided on absorber plates invariably enhances heat transfer associated with increase in friction factor. Increase in heat transfer increases the thermal performance but increase in friction factor affects the thermo hydraulic performance. Thermal and thermo hydraulic performance results of roughened solar air heaters have been reported (Bhushan and singh, 2012; Chabane et al., 2014; Saurav and sahu, 2013; Varun et al., 2008). Effect of the roughness parameters (p/e, e/D) and Reynolds number have been represented and discussed in literature to a large extent to arrive at conclusion that increasing values of e/D for a given value of p/e increases heat transfer and friction factor both. This paper is one such effort of experimental investigations of heat transfer. It presents the effect of booster mirror arrangements on the heat transfer. This paper investigates on the thermal performance of inclined roughened solar air heater with booster mirror.

DOI : 10.35291/2454-9150.2019.0571

II. EXPERIMENTAL SET-UP

Table-1

Time	Box	Ta1	Ta2	Ta3	Tp1	Tp2	Tp3
11:00	IR	30	30	31	49	48	47
	IRB	36	37	37	58	57	57
11:30	IR	30	31	31	48	48	47
	IRB	37	37	38	58	57	56
12:00	IR	31	31	32	47	47	46
	IRB	37	38	39	57	56	56
12:30	IR	31	32	33	47	46	45
	IRB	39	39	40	56	55	55
1:00	IR	32	32	34	46	45	45
	IRB	39	40	40	55	55	54
1:30	IR	33	32	35	45	45	44
	IRB	39	40	41	55	54	54
2:00	IR	34	34	35	44	44	43
	IRB	40	41	42	55	54	53
2:30	IR	34	35	36	44	43	42
	IRB	41	42	42	53	53	52
3:00	IR	35	36	37	42	42	41
	IRB	42	43	44	52	52	51

Fig. 1 shows the top view of experimental set-up respectively, combining the two In both the roughened and glass covered solar air heater ducts, the inclined roughness elements have been provided on the flow side of the absorber plate normal to the ambient air flow direction at varying values of relative roughness pitch, p/e equal to 16, relative roughness height, e/D equal to 0.048, flow Reynolds number, Re, in the range of 2000-7000 and mass flow rate, $\dot{m}$, solar air heater ducts with a single blower to run simultaneously with the inclined one. The angle of attack has been taken equal to 60^0. Directions denoted by arrows X and Y represent the ambient air flow in both the inclined roughened ducts. Both the ducts are having one side glass covers. Thermocouples were provided on the collectors to measure temperature distribution, while digital thermometers were used to measure the temperature distribution in the air duct. The output of thermocouple fed to digital voltmeter displays directly the temperature values. Mass flow rate was varied by controlling the blower speed by means of a single phase auto variac. Mass flow rate for a particular run for both the solar air heaters was measured by means of two separate flange tape orifice-meters, provided with U-tube manometers.

Figs. 2 (a) & (b) shows the two solar air heater duct models of similar size having high 1 aspect ratio: (1) inclined roughened with one side glass covers and (2) one sides inclined roughened with booster mirror. Circular wire of different diameters has been provided on the absorber plate at varying pitches to serve as an inclined roughness element. The two ducts have been made similar in all dimensions to achieve direct comparison between the fluid flow as well as the heat transfer characteristics of the two ducts in order to determine the enhancement of thermal performance parameters under similar conditions. Ambient air has been sucked by two separate inlets but, exhausted by means of a single outlet. A common bottom sheet of 840 mm × 140 mm wooden piece with 25 mm thickness has been used for insulation. An air gap of 25 mm has been provided in between the bottom and absorber plate for each duct resulted in a duct cross section of 150 mm × 80 mm each. Out of the total duct length of 850 mm, the last 700 mm portion was utilized for instrumentation and the balance length of 150 mm was served as the entry length for flow stabilization. in the range of $7.32 \times 10^{-3} - 2.71 \times 10^{-2}$. The raw experimental data during experimentation for which included thermocouple readings, ambient temperatures, and temperature of air in the ducts, mass flow rates, pressure drop in ducts, have been tabulated in Table –1.

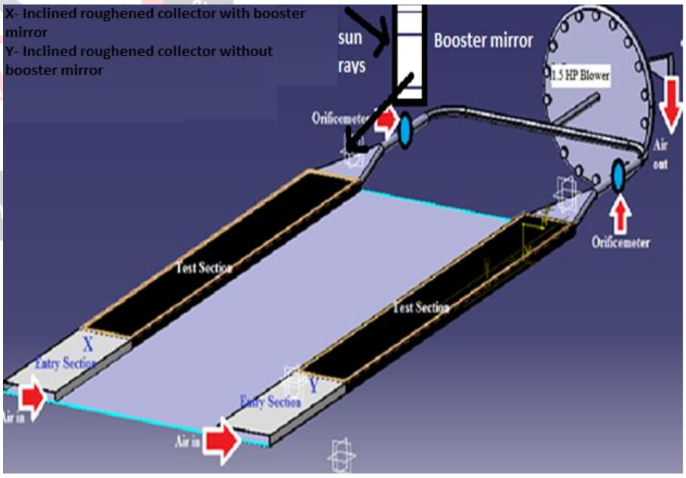
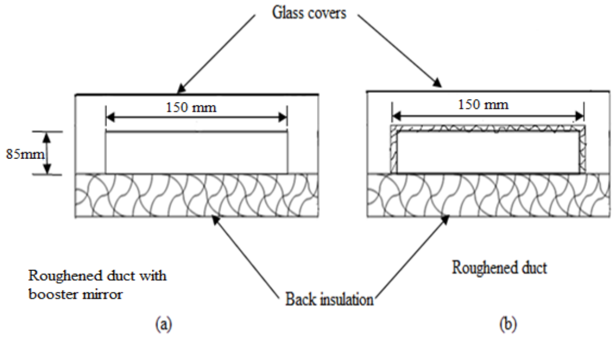


Fig. 1 Top view of the experimental set-up



Figs. 2 (a) and (b) Solar air heater duct models

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III. DATA REDUCTION

The experimental data with respect to the relative roughness height, relative roughness pitch, flow Reynolds number, intensity of solar radiation, plate and air temperatures, pressure drops along the duct length and orifice-meter have been reduced to obtain the results, using the relevant expressions. The experimental values of heat transfer coefficient have been obtained using the following Eq. (1), given under as:

$$\dot{m}C_P(T_0 - T_i) = hA_C(\overline{T_P} - \overline{T_f}) \qquad (1)$$

The values of heat transfer coefficient, h, have been further used to calculate the values of Nusselt number by the following Eq. (2):

$$Nu = \frac{hD}{K} \qquad (2)$$

The values of Nusselt number have been further used to obtain the values of Stanton number by Eq. (3) written under:

$$S_t = \frac{Nu}{Re\ P_r} \qquad (3)$$

The values of Nu and f obtained from experimental data for smooth solar air heater have been compared to the values obtained from Dittus-Boelter equation for Nu and modified Blasius equation for f,which are reproduced below, written under as the following Eqs.(4) and (5):

$$Nu = 0.023Re^{0.8}{P_r}^{0.4} \qquad (4)$$

$$f = 0.085Re^{-0.25} \qquad (5)$$

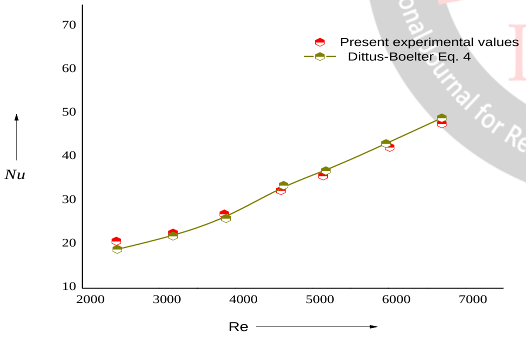

Fig. 3 Validity curve for experimental values of Nusselt number

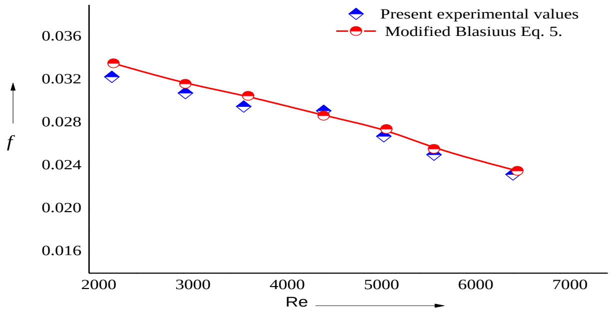

Fig. 4 Validity curve for experimental values of friction factor

Comparison of the referred and present experimental values of Nusselt number and friction factor has been shown in Figs. 3 and 4, respectively. The average deviations between experimental values of Nu &f, and the values predicted by Eqs. (4) and (5), have been found to be ±2.7 and ±2.5, respectively, that shows a good agreement between the two sets of values, ensuring the accuracy of the present data collected with the experimental set-up.

IV. RESULTS AND DISCUSSIONS

Fig. 5 shows the effect of the roughness and flow parameters p/e, e/D and Re on Stanton number in one sides inclined roughened and roughened with booster mirror one. It could be seen from these figures that the values of Stanton number in one sides inclined roughened collector with and without booster mirrors decrease with increasing values of relative roughness pitch, p/e, for a given value of relative roughness height, e/D and decreasing values of relative roughness height, e/D, for a given value of relative roughness pitch, p/e. The values of Stanton number are found to decrease with increasing values of flow Reynolds number. It could be worked out from Fig. 5 that the values of Stanton number are more in one sides inclined roughened with booster one in the range of 31% to 39%, as compared to without booster mirror ones. Fig. 6 shows the effect of p/e on friction factor for a given value of e/D. It could be seen from the figure that the values of friction factor increase with decrease in the value of the relative roughness pitch,p/e, and decrease with increasing values of the flow Reynolds number, Re. The values of friction factor in are more in one sides inclined roughened with booster one in the range of 23% to 29%, as compared to without booster mirror ones**.** Fig. 6 shows the effect of p/e on friction factor for a given value of e/D. It could be seen from the figure that the values of Nusselt number increase with increase in the value of the relative roughness pitch,p/e, and increase with increasing values of the flow Reynolds number, Re. The values of Nusselt number in are more in one sides inclined roughened with booster one in the range of 31% to 43%, as compared to without booster mirror ones**.**

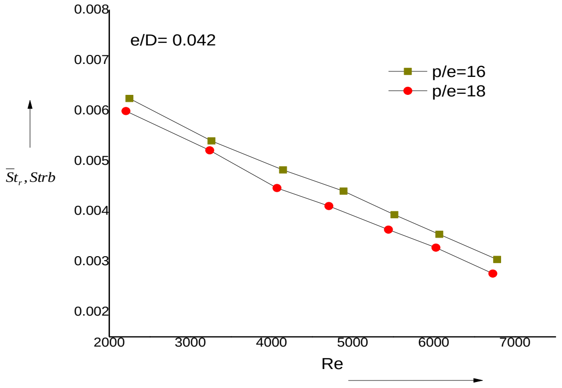

Fig.5 Effect of p/e on Stanton number in one sides inclined roughened solar air heater with and without booster mirror

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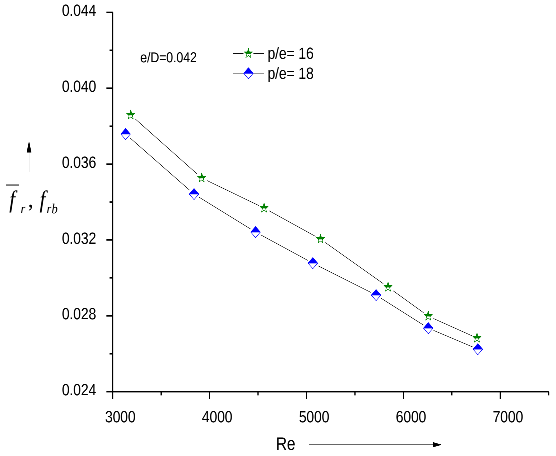

Fig. 6 Effect of p/e on friction factor in one sides inclined roughened solar air heater with and without booster mirror

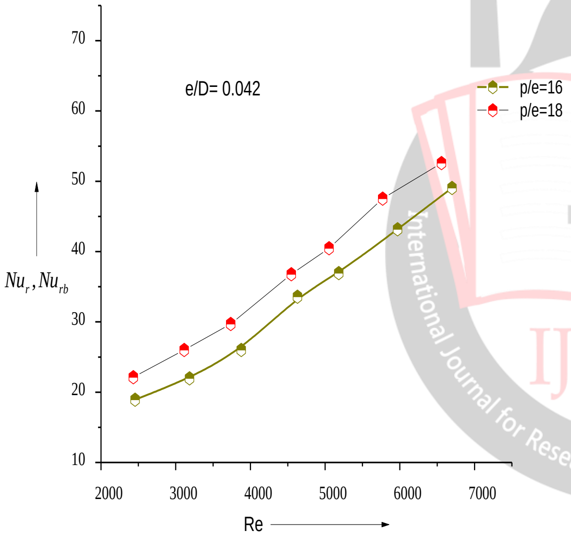

Fig. 7 Effect of p/e on Nusselt number in one sides inclined roughened solar air heater with and without booster mirror

V. CONCLUSIONS

1. The values of Stanton number would be more in one side inclined roughened with booster one in the range of 31% to 39%, as compared to without booster mirror ones.
2. The values of friction factor in would be more in one side inclined roughened with booster one in the range of 23% to 29%, as compared to without booster mirror ones.
3. The values of Nusselt number in would be more in one side inclined roughened with booster one in the range of 29% to 38%, as compared to without booster mirror ones.
4. The top side inclined roughened and glass covered solar air heater with the provision of booster mirror will be 35% to 41% more efficient than that of without booster mirror one.

ACKNOWLEDGMENT

We acknowledge the help of Mechanical Engineering Department, BITS Bhopal. We also acknowledge our deep sense of humor to Dr. Ashwini Kumar for his valuable and proper guidance of project completion, as the current work has been emphasized on the basic idea of artificial roughness by the application of booster mirror, which has been done earlier by Dr. Ashwini Sir.

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DOI : 10.35291/2454-9150.2019.0571