International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Analysis of Collector Performance Parameters in Three Sides Artificially Roughened and Glass Covered Solar Air Heater

Ashwini Kumar[1], B. N. Prasad[2], K. D. P. Singh[3]
[1]Research Scholar, Mechanical Engineering Department, N.I.T, Jamshedpur, India-831014
[2]Professor, Mechanical Engineering Department, N.I.T, Jamshedpur, India-831014
[3]Associate Professor, Mechanical Engineering Department, N.I.T, Jamshedpur, India-831014
Email address: aknitjsr08[AT]gmail.com

***Abstract*— *Solar air heaters having artificially roughened absorber plate have been found to have higher heat transfer coefficient as compared to that of a solar air heater having a smooth (plane) absorber plate. A novel solar air heater with three artificially roughened absorber plates has been analyzed which result in more increase in heat transfer than that in only one side roughened solar air heaters. Optimal thermo hydraulic performance of one side roughened solar air heaters has been analyzed and investigated for the maximum heat transfer and the minimum pumping power (friction factor). The present paper deals with the results on collector performance parameters in three sides artificially roughened solar air heater with three sides glass covers. Results on the collector performance parameters, F_R (τα) and F_R U_L, have been worked out with the help of the experimental data collected. The values of the collector heat removal factor, F_R and plate efficiency factor, F', obtained, have been found to enhance in the range of 18 to 31 % and 20 to 25% respectively, as compared to one side roughened solar air heater and 51 to 60% and 41 to 49% respectively, as compared to smooth solar air heater, within the range of the parameters investigated.*

***Keywords*— *Collector roughness and flow parameters, collector performance parameters, heat removal factor, plate efficiency factor, collector thermal efficiency*.

***Nomenclature*:-**

- C_p specific heat at constant pressure of air, kJ/kgK
- D hydraulic diameter of solar air heater duct, m
- e artificial roughness height, m
- e/D relative roughness height
- F collector efficiency factor
- F_R collector heat removal factor
- F_0 collector heat removal factor based on outlet temperature, t_0
- G mass flow rate per unit collector area, Kg/sm^2
- L collector length, mm
- $\dot{m}$ mass flow rate of air, Kg/s
- p roughness pitch, mm
- p/e relative roughness pitch
- Re Reynolds number
- t_a ambient air temperature, ^{0}C
- t_i inlet temperature of air, ^{0}C
- t_0 outlet temperature of air, ^{0}C
- $\tau\alpha$ Transmittance-absorptance product
- η_{th} collector thermal efficiency
- W solar air heater duct width, m
- 1r one side roughened collector
- 3r three sides roughened collector

I. Introduction

Plenty of works are available to enhance the heat transfer coefficient in solar air heaters by providing artificial roughness of various geometries on the fluid flow side of the absorber plate. Small diameter wires were used [1-2] to analyze and investigate for the heat transfer coefficient. Transverse ribs have been used [3] to enhance heat transfer coefficient. Inclined rib roughness [4] wire mesh roughness [5], transverse protrusion wire roughness [6], wedge shape ribs [7], V-shape ribs [8], arc shape roughness [9], dimple shape roughness [10], combined inclined and transverse ribs [11], multi V-rib roughness [12], w-shaped ribs [13] are the works on analysis and investigations, where appreciable enhancement in heat transfer coefficient has been found quantitatively and qualitatively both.

The recent analyses [14-15] for three sides artificially roughened solar air heaters with three sides glass covers show even better results with respect to enhancement of heat transfer coefficient as compared to one side roughened solar air heaters. However, investigation on three sides roughened solar air heater with three sides glass covers, (being a novel one) is the most required. Based on the above analyses, the present paper deals with the results on collector performance parameters in three sides artificially roughened solar air heater with three sides glass covers. The enhancement of collector performance parameters with respect to collector heat removal factor, F_R, plate efficiency factor, F', and thermal and performance have been dealt with in detail.

II. Experimentation

The experimental set-up consists of two rectangular solar air heater ducts of similar size, three sides roughened and the smooth one. Fig. 1(a) shows the four sided smooth duct and Fig. 1(b) shows the present duct model with three roughened sides and one smooth surface. Circular wire of different diameters has been provided on the absorber plate at varying pitches to serve as an artificial roughness element. Fig. 2 (a) shows typically the roughened top absorber plate with provision of artificial roughness elements on it; Fig. 2 (b) shows typically a side absorber plate with artificial roughness elements on it; Fig. 2 (c) shows the top smooth absorber plate and Fig. 2 (d) shows the side absorber plate. The experimental set-up for investigation consists of the two similar size rectangular solar air heater ducts of high aspect ratio (W>>B) as shown in Fig. 3(a). Both the ducts are having three sides glass covers. The total length of the ducts consists of bell-mounted entry sections for flow stabilization and test sections. Mass flow rate was varied by controlling the blower speed by means of a 3-phase auto variac. Flange-tape orifice-meters measured the flow rates in both the solar air heaters (roughened and smooth). Since both the solar air heater ducts are similar in dimensions and are connected to a single blower to run simultaneously, mass flow rate for a particular run for both the solar air heaters measured by means of two separate flange tape orifice-meters happened to be the same. Multi-tube manometers were used to measure the pressure drop, while thermocouples measured the air and plate temperatures. Intensity of solar radiation was measured by a pyranometer. Thermocouple arrangement for the plate and air temperature measurement is shown in Figs.3 (a) and (b).

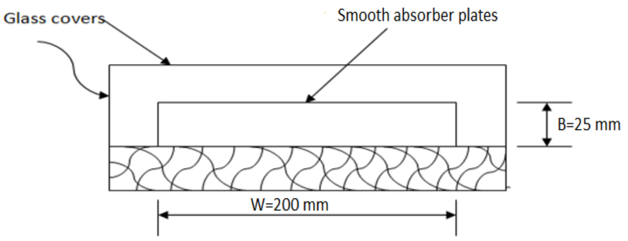

Fig. 1(a) Four sided smooth duct

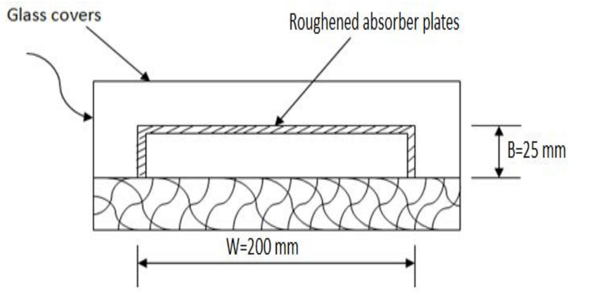

Fig. 1(b) Three sided roughened and one side smooth duct (present duct model)

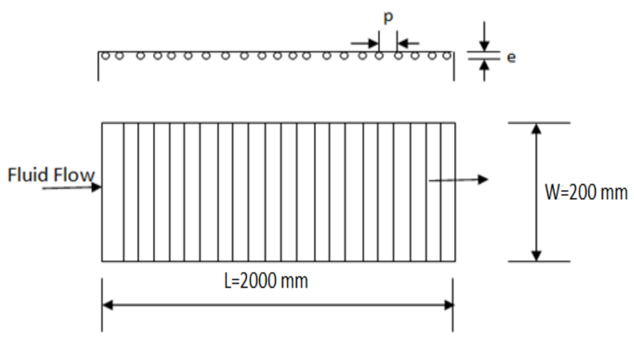

Fig. 2(a) Top absorber plate with artificial roughness

III. Results and Discussions

A wide range of experimental data for roughened absorber plates were collected simultaneously with the smooth ones. Table I shows the range of roughness and flow parameters investigated. The raw experimental data reduced to work out for the results with respect to performance characteristics of three sides solar air heater, have been represented.

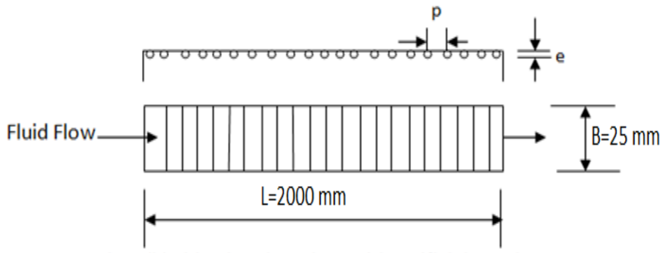

Fig. 2(b) Side absorber plate with artificial roughness

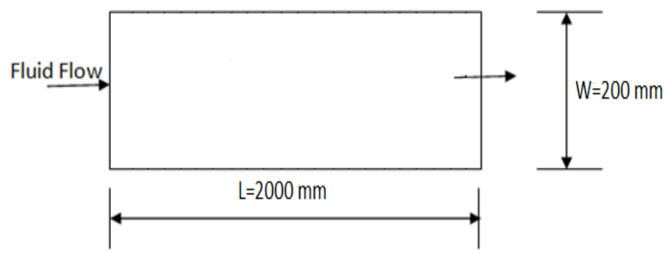

Fig. 2 (c) Top smooth absorber plate

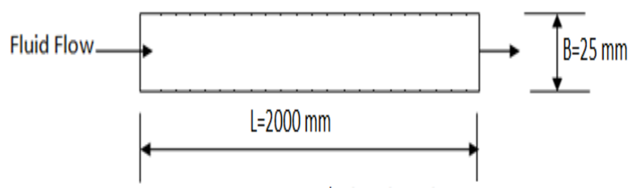

Fig. 2 (d) Side smooth absorber plate

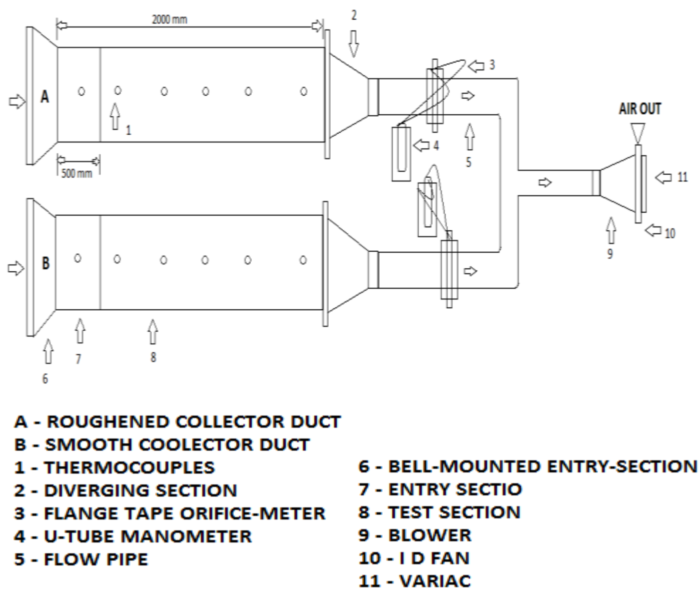

Fig. 3(a). Shematic diagram of experimental set-up.

International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

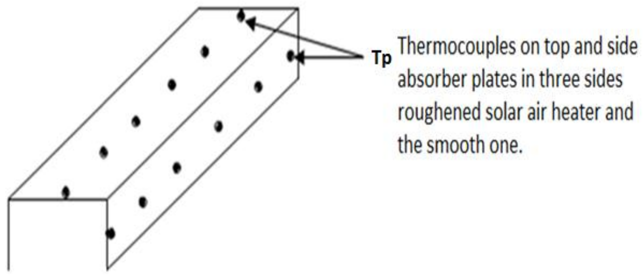

Fig. 3(b.) Thermocouple arrangement on top and sides of three sides roughened and smooth ducts.

TABLE I. Range of parameters investigated.

Sl. No	Parameters	Range of parameters
1.	Mass flow rate (Kg/s)	$8.36 \times 10^{-3} - 3.74 \times 10^{-2}$
2.	Reynolds number, Re	4000 – 20000
3.	Roughness height	0.6 mm – 1.1 mm
4.	Roughness pitch	6 mm – 30 mm
5.	Relative roughness pitch, p/e	10 – 30
6.	Relative roughness height, e/D	0.135 – 0.0247

3.1 Thermal Performance Representation

For both the three sides artificially roughened solar air heater and smooth solar air heater operating without recycling of air, thermal performance has been worked out based on the fluid outlet temperature. Thermal performance of solar collectors given by the conventional equation (1) of Ref. [16], written under could be replaced by equation (2) for solar air heaters without air recycling, based on the fluid outlet temperature. Thermal performance using equation (3) has been represented in Fig. 4.

$$\eta_{th} = F_R(\tau\alpha) - F_R U_L (t_i - t_a)/IA \quad (1)$$

$$\eta_{th} = F_0(\tau\alpha) - F_0 U_L (t_0 - t_i)/IA \quad (2)$$

$$\eta_{th} = \dot{m} C_p (t_0 - t_i)/IA \quad (3)$$

The thermal efficiency data points of Ref. [2] for one side artificially roughened solar air heaters, together with the present case of three sides artificially roughened solar air heaters, along with the smooth solar air heaters, are shown in Fig. 4 for varying values of mass flow rate. The respective efficiency data points have been further represented by the respective best fit lines, A_{1r}-B_{1r}, A_{3r}-B_{3r} and A_S-B_S for one side roughened collector [2], three sides roughened collector & the smooth one. Fig. 4 also represents the performance characteristics of the present solar air heaters for relative roughness pitch, p/e, equal to 10 and relative roughness height, e/D, equal to 0.0247 at various mass flow rates. The upper data points correspond to the three sides artificially roughened solar air heater, middle data points correspond to the one side artificially roughened solar air heater, whereas, the lower data points corresponds to smooth solar air heater.

TABLE II. Values of intercept and slope for solar air heaters.

	S	1r, [2]	3r
Intercept, $F_0(\tau\alpha)$	0.521	0.536	0.697
Slope, $F_0 U_L$ (W/m^{2}K)	6.014	6.50	8.881

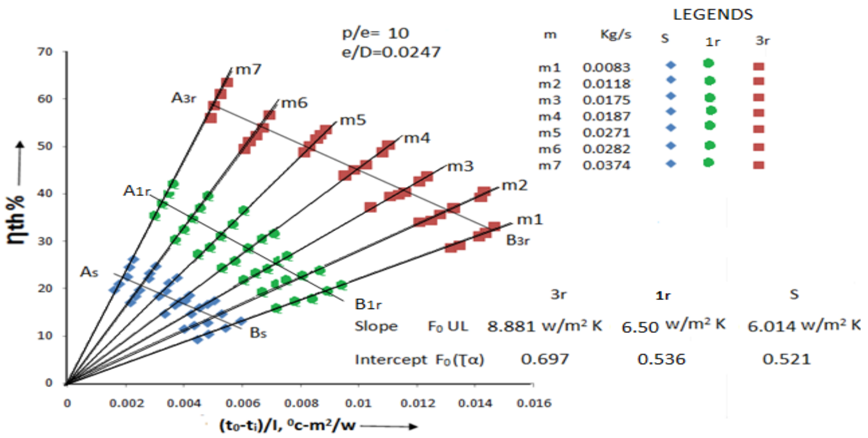

Fig.4. Performance characteristic of solar air heaters

The best fit lines A_{1r}-B_{1r}, A_{3r}-B_{3r} and A_S-B_S , plotted with efficiency data points represent the thermal performance curves for the top side artificially roughened solar air heater, three sides artificially roughened solar air heater and smooth solar air heater, respectively. The values of the slope, $F_0 U_L$, and the intercept, $F_0(\tau\alpha)$, of the curves have been found out and written in Fig. 4 and Table II. Higher value of the intercept corresponds to higher value of thermal performance for three sides roughened solar air heaters.

3.2 Collector Heat Removal Factor (F_R) *and Collector Efficiency Factor* (F ′)

The values of the slope and the intercept, $F_0 U_L$ and $F_0(\tau\alpha)$ respectively have been utilized to find out for the values of the performance parameters, $F_R U_L$ and $F_R(\tau\alpha)$, which have been further used to work out for the values of F_R and F' for an assumed value of $(\tau\alpha)$ equal to 0.84, from the following equations (4-6) of (Ref. [17] :

Ashwini Kumar, B. N. Prasad, and K. D. P. Singh, “Analysis of collector performance parameters in three sides artificially roughened and glass covered solar air heater,” *International Research Journal of Advanced Engineering and Science*, Volume 2, Issue 3, pp. 224-229, 2017.

$$F_R(\tau\alpha) = F_0(\tau\alpha)\left[\frac{\dot{m}C_p / A_c}{\frac{\dot{m}C_p}{A_c} + F_0 U_L}\right] \quad (4)$$

$$F_R U_L = F_0 U_L\left[\frac{\dot{m}C_p / A_c}{\frac{\dot{m}C_p}{A_c} + F_0 U_L}\right] \quad (5)$$

$$F' = GC_p\left[\ln\left(\frac{F_0 U_L}{F_R U_L}\right) / U_L\right] \quad (6)$$

From Fig. 4, at p/e, equal to 10 and e/D, equal to 0.0247, the value of F_0U_L is equal to 8.881 W/m^{2}K and that of $F_0(\tau\alpha)$ is equal to 0.697 for three sides artificially roughened solar air heater. Now, for mass flow rate, $\dot{m}$, equal to 0.0374 Kg/s and C_p equal to 1005 J/Kg K, the value of F_RU_L and $F_R(\tau\alpha)$, worked out from Eqs. (4) and (5), comes out equal to 8.803 W/m^{2}K and 0.691 respectively. For $(\tau\alpha)$ equal to 0.84, the value of F_R equal to 0.8226, when substituted, gives the value of U_L equal to 10.701 W/m^{2}K and that of F' equal to 0.891. Similarly, the respective values of F_R and F' have been worked out for the one side artificially roughened solar air heater, three sides artificially roughened solar air heater and the smooth solar air heater for the range of parameters investigated to obtain Figs. 5 and 6. Fig. 5 shows the comparison of the values of collector heat removal factor, (F_R) for three sides roughened collector over one side roughened collector [2] and consequently over the smooth ones for a given value of p/e, equal to 10 and e/D equal to 0.0247. Fig. 6 shows the comparison of the values of collector efficiency factor,(F') for three sides roughened collector over one side roughened collector [2] and consequently over the smooth ones for a given value of p/e, equal to 10 and e/D equal to 0.0247. It could be seen that the values of collector heat removal factor, F_R, and collector efficiency factor, F', increases in three sides roughened collector as compared to one side roughened collector and the smooth ones. The values of the collector heat removal factor, F_R and plate efficiency factor, F', have been found to be enhanced in the range of 18 to 31 % and 20 to 25% respectively, as compared to one side roughened solar air heater and 51 to 60% and 41 to 49% respectively, as compared to smooth solar air heater, within the range of the parameters investigated.

3.3 Thermal Efficiency Curves

The respective thermal performance equations (7-9) have been derived by substituting the respective values of the performance parameters, F_RU_L and $F_R(\tau\alpha)$ based on the conventional equation (1) of Ref. [16]. Fig. 7 shows the thermal efficiency curves for three cases: (i) one side artificially roughened solar air heater, (Prasad, 2013) (ii) three sides artificially roughened solar air heater and (iii) smooth solar air heater.

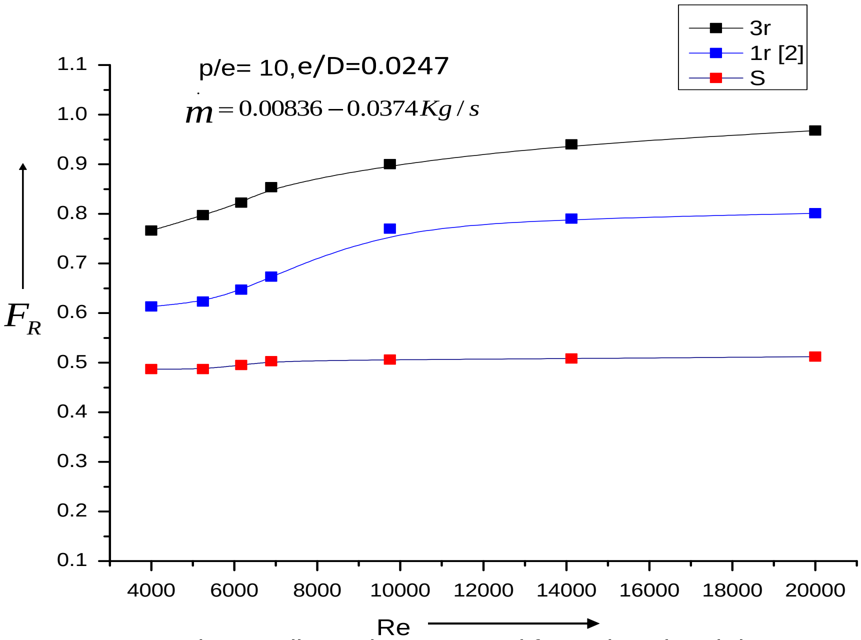

Fig. 5 Collector heat removal factor in solar air heaters

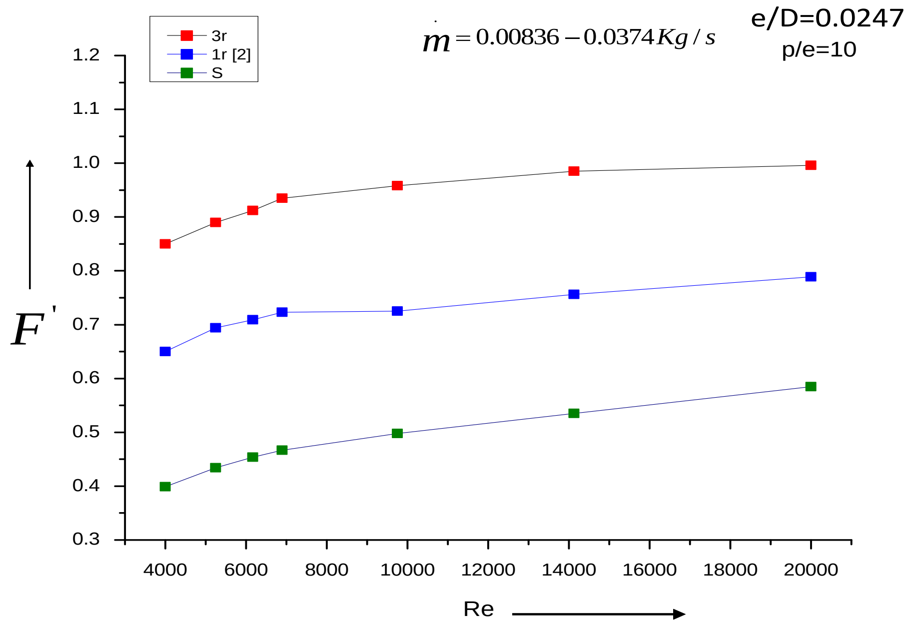

Fig. 6 Plate efficiency factor in solar air heaters

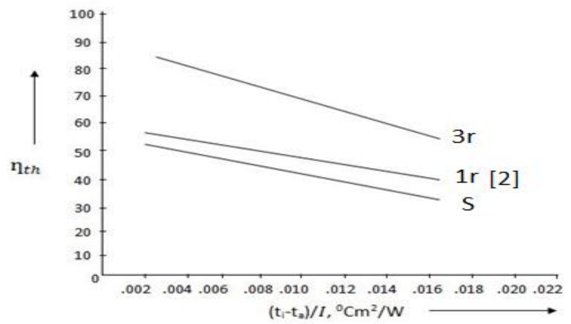

Fig. 7 Thermal efficiency curves for solar air heaters

From Fig. 7, it could be worked out by utilizing the thermal performance equations (7-9) to see that three sides roughened solar air heater is about 40-48% and 47-56% more efficient than one side roughened solar air heater and smooth solar air heater, respectively.

$$\eta_{th(1r)} = 0.502(\tau\alpha) - 6.104\left(\frac{t_i - t_a}{IA}\right) \quad (7)$$

$$\eta_{th(3r)} = 0.691(\tau\alpha) - 8.803\left(\frac{t_i - t_a}{IA}\right) \quad (8)$$

$$\eta_{th(S)} = 0.492(\tau\alpha) - 5.673\left(\frac{t_i - t_a}{IA}\right) \quad (9)$$

IV. CONCLUSIONS

(A) Collector heat removal factor, F_R, and collector efficiency factor, F', in three sides artificially roughened solar air heater have been found to enhance by about 18 to 31 % and 20 to 25% respectively over the one side artificially roughened solar air heater.

(B) Collector heat removal factor, F_R, and collector efficiency factor, F', in three sides artificially roughened solar air heater have been found to enhance by about 51 to 60% and 41 to 49% respectively over the smooth solar air heater.

(C) Three sides artificially roughened solar air heaters are superior to those of the one side artificially roughened solar air heaters and the smooth ones, qualitatively and quantitatively both.

(D) Three sides roughened solar air heaters are thermally 40-48% more efficient than those of one side roughened solar air heaters.

(E) Three sides roughened solar air heaters are thermally 47-56% more efficient than those of smooth solar air heaters.

REFERENCES

[1] 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, issue 6, pp. 555-560, 1988.

[2] B. N. Prasad, "Thermal performance of artificially roughened solar air heaters," *Solar Energy*, vol. 91, pp. 59-67, 2013.

[3] D. Gupta, S. C. Solanki, and J. S. Saini, "Heat and fluid flow in rectangular solar air heater ducts having transverse rib roughness on absorber plate," *Solar Energy*, vol. 51, issue 1, pp. 31-37, 1993.

[4] D. Gupta, S. C. Solanki, and J. S. Saini, "Thermo-hydraulic performance of solar air heaters with roughened absorber plates," *Solar Energy*, vol. 61, issue 1, pp. 33–42, 1997.

[5] R. P. Saini and J. S. Saini, "Heat transfer and friction factor correlations for artificially roughened duct with expanded metal mesh as roughness element," *International Journal of Heat and Mass Transfer*, vol. 40, issue 4, pp. 973-986, 1997.

[6] S. K. Verma and B. N. Prasad, "Investigation for the optimal thermo hydraulic performance of artificially roughened solar air heaters," *Renewable Energy*, vol. 20, issue 1, pp. 19–36, 2000.

[7] J. L. Bhagoria, J. S. Saini, and S. C. Solanki, "Heat transfer coefficient and friction factor correlation for rectangular solar air heater duct having

transverse wedge shaped rib roughness on the absorber plate," *Renewable Energy*, vol. 25, issue 3, pp. 341-369, 2002.

[8] A. M. E. Momin, J. S. Saini, and 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*, vol. 45, issue 16, pp. 3383–3396, 2002.

[9] S. K. Saini and 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*, vol. 82, issue 12, pp. 1118-1130, 2008.

[10] R. P. Saini and J. Verma, "Heat transfer and friction correlations for a duct having dimple shape artificial roughness for solar air heater," *Energy*, vol. 33, issue 8, pp. 1277-1287, 2008.

[11] Varun, R. P. Saini, and S. K. Singal, "Investigation on thermal performance of solar air heaters having roughness elements as a combination of inclined and transverse ribs on the absorber plate," *Renewable Energy*, vol. 33, issue 6, pp. 1398-1405, 2008.

[12] V. S. Hans, R. P. Saini, and J. S. Saini, "Heat transfer and friction factor correlations for a solar air heater duct roughened artificially with multiple V-ribs," *Solar Energy*, vol. 84, issue 6, pp. 898-911, 2010.

[13] A. M. Lanjewar, J. L. Bhagoria, and R. M. Sarviya, "Experimental study of augmented heat transfer and friction in solar air heater with different orientations of W-Rib roughness," *Experimental Thermal and Fluid Science*, vol. 35, issue 6, pp. 986-995, 2011.

[14] B. N. Prasad, A. K. Behura, and L. Prasad, "Fluid flow and heat transfer analysis for heat transfer enhancement in three sided artificially roughened solar air heater," *Solar Energy*, vol. 105, pp. 27-35, 2014.

[15] B. N. Prasad, A. Kumar, and K. D. P. Singh, "Optimization of thermo hydraulic performance in three sides artificially roughened solar air heaters," *Solar Energy*, vol. 111, pp. 313-319, 2015.

[16] R. W. Bliss, "The derivation of several plate efficiency factor useful in the design of flat plate solar heat collectors," *Solar Energy*, vol. 3, issue 4, pp. 55-64, 1959.

[17] J. A. Duffie and W. A. Beckman, *Solar Engineering of Thermal Processes*, Third ed. Wiley Interscience, New York. 2006.