

# Investigation for Jet Plate Solar Air Heater with Longitudinal Fins

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**Abstract**— The jet impingement concept is an effective method of increasing convective heat transfer in a solar air heater. Jet plate solar air heater is extensively used in the fields of space heating, drying of agriculture crops and supply of hot air in buildings due to its higher convective heat transfer coefficient and collector efficiency. The technologically appropriate solar energy operated systems, for example, the solar air heater which has been discussed in this work is versatile enough to rid these discrepancies. A novel jet plate solar air heater with continuous longitudinal fins underneath the absorber plate is investigated. Performance characteristics with the help of significant parameters are presented. The results are compared with many researches pertaining to other designs of solar air heater like smooth duct, roughened duct and finned duct respectively. An enhancement of 3-14.7% in thermal efficiency is observed for Reynolds number range (3000-15000) in comparison to the other mentioned works. Furthermore, increase in heat transfer enhancement of the order 28%-39% is achieved, which implies higher efficiency of the jet plate solar air heater with continuous longitudinal fins underneath the absorber plate at higher values of Reynolds number. The results are plotted corresponding to Reynolds number ( $Re$ ) = 3000-15000,  $W = 1-5\text{cm}$ , mass flow rate ( $\dot{m}$ ) = 0.0126-0.0675 kg/sec.m<sup>2</sup>.

**Keywords**— Solar drying, global development, reynolds number, effective heat transfer coefficient, thermal efficiency.

## I. INTRODUCTION

Agriculture can play a kingpin role to provide synergy to the Indian economy. Over 70% of the households in India have agriculture as the principal means of livelihood. Agricultural produce constitutes 10% of the country's export being the fourth largest exported commodity of the country. It therefore becomes imperative to produce world class farming products to stay competitive and ahead of others in the world agriculture trade. India must produce state of the art products economically in the environment of high tech processes leaving aside the traditional approaches of open sun drying which is uneconomical and devoid of focus on quality. The need to inspect such methods or systems by which the quality of the agricultural products must be maintained is foremost essential. Crop drying, using methodology of solar energy assisted systems viz. solar air heaters or solar collectors are quite propitious. The sun is a clean, abundant and inexhaustible natural renewable energy resource conveniently available everywhere in the country. These methods are economical, require little maintenance and are very convenient

to operate. Apparently these systems are more efficient hygienic, fast and saves time. These systems have a great impact on techno-economic aspects of society. Hence needless to say, these systems due to their distinct features and utility play an admirable role in global development.

A conventional solar air heater generally consists of a glass cover, an absorber plate with a parallel plate below forming a rectangular duct of high aspect ratio through which air to be heated flows. The air to be heated flows between the glass cover and the absorber plate. The heat transfer coefficient between the absorber plate and air is quite low resulting in low efficiency of the system and high heat losses.

Numerous researches on innovative designs of solar air heaters to improve thermal efficiency and minimize losses have been reported in the literature. (Hottel and Unger, 1959; Close, 1963; Satcunanathan and Deonarane, 1973; Kuzay et al., 1974; Wijesundera et al., 1981) reported investigation of several innovative and energy efficient design of solar air heater in their researches. (K Seluck, 1971), (Buchberg and Lalude, 1971), (Varshney, Saini, 1998 and Prasad et al., 2009), (Thakur et al., 2003) have reported innovative design of the structures of solar air heater realized respectively by introducing overlapped glass plates, honey comb porous bed, application of wire mesh as packing material, packed bed system for low porosity. Literature on solar air heater design is replete with optimization of energy efficiency by applying artificial roughness method while introducing artificial ribs on the absorber plate of solar air heater duct, as presented in the works of (Han et al, 1978), (Chandra et al. 2003), (Lau et al., 1991) who studied the effect of V shaped ribs in square channel by analyzing friction of fully developed flow on turbulent heat transfer. (Prasad and Saini, 1991) reported optimization results for thermo hydraulic performance of artificially roughened solar air heaters and presented the optimal values for the roughness elements yielding maximum thermal efficiency at  $e_{opt}^+ = 24$ . (Hans et al., 2009) investigated the effect of roughness geometries on roughened duct, while using heat transfer and friction factor correlation of previous researches, to compare the thermo-hydraulic performance of roughened duct. The variation of 23 different roughness geometries was investigated to optimise the results. (Singh et al., 2012) investigated v- down rib having gap to improve the thermo-hydraulic performance of the rectangular

solar air heater duct with one side wall roughened and other three sides kept smooth and insulated to improve efficiency. (Sethi et al., 2012) developed heat transfer and friction correlations for dimple shape roughness elements arranged in angular fashion to explain the characteristics of a solar air heated duct. The experiment conducted by (Kumar et al., 2012) investigated performance of rectangular duct providing multi v-shaped ribs with gap in both limbs of roughness element on the absorber plate. (Varun et al., 2007) used correlations developed in previous researches for heat transfer and friction factor to explain the significance of artificial roughness method. In this work several roughness geometries were discussed and optimization results were presented. Jet impingement method is a new technique in this area of research. The mechanism of jet plate in solar air heater duct was introduced by (Kercher & Tabakoff, 1970) they studied the effect of spent air by a square array of round air jets impinging perpendicular to the absorber plate on the heat transfer. The effect of impingement cooling with the help of circular jets on concave surfaces was studied by (Metzger et al., 1971). In another paper (Metzger and Brodersen, 1992) analyzed the effect of resulting flow field by the interaction between impinging jet and rotating disk. (Florscheutz et al., 1979) analyzed a target plate beneath a two-dimensional array of impinging jets and discussed heat transfer characteristics, finally concluded that in-line jet impingement hole patterns is more effective than staggered pattern. (Chaudhary and Garg, 1991) analyzed jet plate solar air heater and presented energy balance equations. Studies by (Garimella and Nenaydykh, 1996) and (Shuja et al., 2005) discussed the significance of nozzle geometry on the efficiency of solar air heater. (Brevet et al., 2002) presented the work in which Nusselt number distribution was studied as a function of impingement distance, Reynolds number, and span-wise hole spacing. (Parsons and Han, 1998) investigated the rotation effect with heated target walls and radially outward cross flow on jet impingement heat transfer in smooth rectangular channels. (Belusko et al., 2008) discussed the application of jet impingement technique in unglazed air collectors and presented the performance results. Analysis by (Katti and Prabhu, 2008), (Goodro et al., 2008), (Zukowski, 2013) emphasized on performance of the solar air heater by analyzing the effect of span wise pitch ratio and slots. Recent studies (Chauhan and Thakur, 2012), (Chauhan and Thakur, 2013) presented their views on the thermo hydraulic performance using jet impingement method, the effect of inline and staggered pattern of holes were discussed. In recent times, the application of continuous longitudinal fins in solar air heater duct has renewed interest. Studies with an aim to determine the optimal fin geometry and shapes were presented by (Wilkins, 1974), (Cobble, 1971). Many researchers contributed experimental and theoretical results while testing fins in rectangular offset plate type heat exchangers (Herold and Hu, 1995), (Dejong et al., 1998), (Manglik and Bergles, 1995). (Garg et al., 1989) presented their work on finned solar air heater and discussed performance of the system. (Moumami et al., 2004) performed energy analysis on solar air heater duct while inserting rows of rectangular plate fins perpendicular to

the flow. (Naphon, 2005) discussed entropy generation method to determine the performance of finned solar air heater. Few studies were related to the application of fins in double pass solar air heater (Sebaili et al., 2011) and (Fudholi et al., 2013). (Mohammadi and Sabzpooshani, 2013) presented and discussed the application of fins and baffles on the absorber plate of single pass solar air heater. (Chang et al., 2015) conducted theoretical and experimental research on finned absorber and discussed thermal performance of the duct.

However, in all the above cases, provision of artificial roughness and glass cover has remained limited to only one side (top side) of the solar air heater duct except those of the recent ones (Prasad et al., 2014; Kumar et al., 2016a, Behura et al., 2016; Behura et al., 2017), wherein it has been concluded that three sides roughened and glass covered solar air heaters perform even better than those of one side roughened and glass covered solar air heaters, but friction factor also increases. The effect of glass cover has been shown (Kumar et al., 2016b) by performing an investigation, that has given even better performance for three sides glass covers as compared to that of the one side glass covered one. The authors (Prasad et al., 2015), analysis could reveal that,  $e_{opt}^+ = 23$ , corresponds to the optimal thermo hydraulic performance in three sides artificially roughened and glass covered solar air heaters, which have further been verified by taking an experimental investigation (Kumar et al., 2017)

In spite of the significant innovative researches executed on the various innovative designs and structure of solar air heater, the application of longitudinal fins underneath the absorber plate along with the jet impingement technique is not adequately covered. This paper is a dedicated effort to justify the significance of this novel system in the global development. In the present work the thermal efficiency & performance of novel model of jet plate solar air heater with longitudinal fins attached underneath the absorber is examined. The enhanced thermal efficiency and qualitatively better performance is the prime objective keeping in view the main purpose for these systems.

## II. ANALYSIS AND CALCULATION PROCEDURE

The analysis is accomplished by using the standard assumptions (Duffie and Beckmann, 1980), (Sukhatme, 2001) which are as follows:

- (i) Heat flow is one dimensional.
- (ii) Thermal performance of collector in steady state.
- (iii) The mean temperatures of absorber plate, Jet plate, bottom plate are  $T_{pm}$ ,  $T_j$  &  $T_b$  respectively and their variations are neglected.
- (iv) Side losses are neglected.

Along with these standard assumptions we may also assume, since no recycling of air is done, therefore the inlet air temperature may be approximately equals to the surrounding air temperature and also with the same temperature the air strikes on bottom plate, therefore ( $T_{fi} = T_a = T_b$ ). Since, the jet plate is inserted between absorber and bottom plates, two ducts are formed viz: upper duct between absorber & jet plate

and lower duct between jet plate & bottom plate. In the lower duct the air temperature is 'T<sub>f1</sub>' however in the upper duct the air temperature is maintained at 'T<sub>f2</sub>'. The inlet air having mass flow rate 'm' enters from the lower duct passes through the holes of the jet plate then impinges directly on the fins and finally exits from the exit section of upper duct. The continuous longitudinal fins increase the heat transfer area implying the increased thermal performance of the set up which finally enhances the temperature of the air at outlet section.

**A. Calculation Procedure and Heat Transfer Coefficients**

The calculation procedure to determine the heat transfer coefficient, friction factor and thermal efficiency has been described in details as under:

Values of geometrical parameters (W, L<sub>f</sub>, t<sub>f</sub>) is selected.

Values of fixed system parameters (T<sub>a</sub>, L, W, v<sub>w</sub>, ε<sub>g</sub>, ε<sub>p</sub>, τ<sub>a</sub>, k<sub>i</sub>, δ<sub>i</sub>) is selected.

The first assumption of Mean absorber plate temperature is made (T<sub>pm</sub>)

(Duffie & Beckmann)

$$T_p = T_a + 20^\circ C \tag{1}$$

Overall loss coefficient (U<sub>L</sub>) is calculated

$$U_L = U_t + U_b \tag{2}$$

where, U<sub>t</sub> can be estimated by using equation (Duffie & Beckmann)

$$U_t = \left[ \frac{N}{\left(\frac{C}{T_{pm}}\right) \left(\frac{T_{pm} - T_a}{N + f}\right)^e} + \frac{1}{h_w} \right]^{-1} \tag{3}$$

$$+ \left[ \frac{\sigma(T_{pm}^2 + T_a^2)(T_{pm} + T_a)}{\frac{1}{\varepsilon_p + 0.00591N h_w} + \frac{(2N + f - 1) + 0.133\varepsilon_p - N}{\varepsilon_g}} \right]$$

where

$$f = (1 + 0.089h_w - 0.1166h_w\varepsilon_p) (1 + 0.07866N) = 520(1 - 0.00051\beta^2), N = \text{number of glass covers}$$

Bottom loss 'U<sub>b</sub>' is calculated as

$$U_b = \frac{k_i}{\delta_i} \tag{4}$$

Finally 'U<sub>L</sub>' is calculated with the help of Eq. (2)

The collector efficiency factor F' is calculated as

$$F' = \frac{h_e}{h_e + U_L} \tag{5}$$

Where, h<sub>e</sub> is the effective heat transfer coefficient,

$$h_e = h_{cpa} \left( 1 + \frac{2L_f \phi_f h_{ff}}{W \times h_{cpa}} \right) + \frac{h_r h_{cja}}{h_r + h_{cja}}$$

$$h_e = \frac{Nu \times k_a}{D_h} \tag{6}$$

Hydraulic diameter 'D<sub>h</sub>' is calculated as

$$D_h = \frac{2(W \times H)}{W + H} \tag{7}$$

The collector heat removal factor F<sub>R</sub> is calculated as

$$F_R = \frac{m C_p}{U_L A_c} \left[ 1 - e^{\left( \frac{-A_c U_L F'}{m C_p} \right)} \right] \tag{8}$$

Where, 'm' is the mass flow rate,  $\dot{m} = \frac{R_e \mu A_c}{D_h}$   (9)

A<sub>c</sub> is the collector area, A<sub>c</sub> = L × W  (10)

Useful energy gain by solar air heater is calculated as

$$Q_u = F_R A_c (I_{\tau\alpha} - U_L (T_o - T_i)) \tag{11}$$

With the help of calculated values for U<sub>L</sub>, F', F<sub>R</sub>, and Q<sub>u</sub>, a new value of mean temperature of absorber plate (T<sub>pm</sub>) is determined as,

$$T_{pm} = T_a + \frac{Q_u (1 - F_R)}{A_c U_L F_R} \tag{12}$$

By the help of new calculated value of T<sub>pm</sub> Eq. (12) the top loss coefficient is again calculated with the help of Eq. (3) respectively. This iteration process is repeated in expectation of 0.01% accuracy.

After selecting the final estimated value of mean absorber plate temperature T<sub>pm</sub>, outlet temperature of air T<sub>o</sub> is calculated as

$$\frac{T_o - T_a - I_{\tau\alpha} / U_L}{T_i - T_a - I_{\tau\alpha} / U_L} = \exp\left( \frac{-A_c U_L F'}{m C_p} \right) \tag{13}$$

With the help of T<sub>o</sub>, Thermal efficiency is calculated as,

$$\eta_{th} = \frac{m \times c_p \times \{T_o - T_i\}}{I \times A_c} \tag{14}$$

Step 11. The values of Friction factor may be calculated as:

$$Fr = M \cdot (Re)^{-m} \tag{15}$$

where,  $M = 0.40 \left[ 2.058 - \left\{ \frac{L - L_f}{L_f} \right\}^{0.313} \right]$ ,

$$m = 0.075 \left[ 3.40 - \left\{ \frac{L - L_f}{L_f} \right\}^{0.711} \right]$$

**a. Heat transfer coefficients**

In the analysis of the present model heat transfer coefficients are calculated by the help of following equations:

$$h_w = 5.7 \times 3.8 v_w \tag{16}$$

The convective heat transfer coefficients between air circulating, fins, absorber & jet plates respectively are estimated to be uniformly equal as:

$$h_{ff} = h_{cpa} = h_{cja} = \frac{Nu \cdot k_a}{D_h} \tag{17}$$

Nusselt number for air in upper duct is calculated by the equation (Thombre & Sukhatme)

$$Nu = 0.023 \times (Re)^{0.8} \times (Pr)^{0.4} \tag{18}$$

The radiative heat transfer coefficient 'h<sub>r</sub>' is calculated as:

$$h_r = \sigma \epsilon_p (T_p^2 + T_{sky}^2) (T_p + T_{sky}) \quad (19)$$

Where,  $T_{sky} = 0.0552 T_a^{1.5}$

### III. INVESTIGATION

Fig. 1 shows the sectional view of present model investigated. The absorber plate is a GI sheet 1mm thick underneath which continuous longitudinal fins of 1cm height and pitch of 3 cm and 5 cm are attached respectively. The jet plate with inline holes of diameters (6mm, 8mm, 1cm) respectively is placed just below the absorber plate facing the fins so that the inlet air after passing through the holes of jet plate directly impinges on the fins. Mineral wool of thickness 4mm-8mm is used for bottom and side insulation. The complete assembly is contained in a box of sheet metal and perfectly inclined at a suitable angle. The Detailed layout is shown in Fig. 2

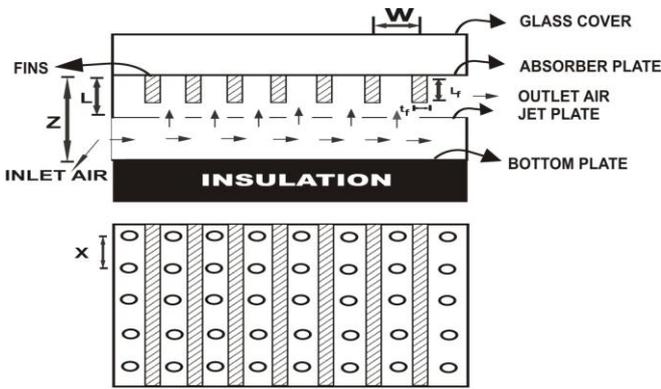


Fig. 1. Sectional view of the present model.

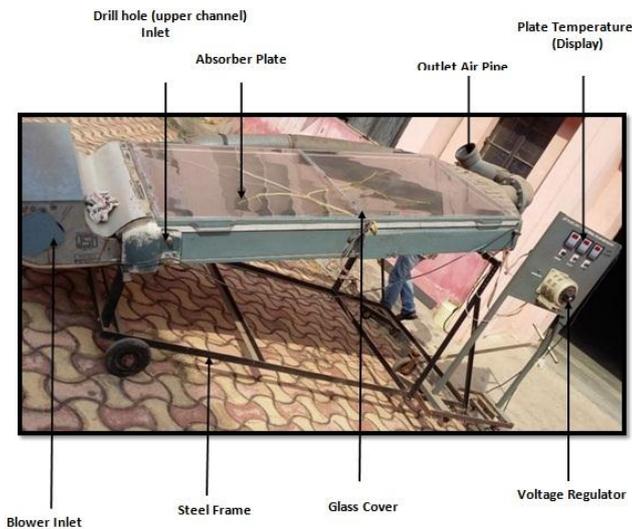


Fig. 2. Detailed layout showing finned jet plate solar air heater.

### IV. VALIDATION

Validation process is accomplished to justify compare the obtained results for heat transfer coefficient, friction factor and thermal efficiency of JPSAHCLF with experimental calculated

values of same parameters for jet plate collector and roughened duct. The correlations for heat transfer coefficient and Friction factor for jet plate solar air heater (Chauhan and Thakur, 2013) and for roughened duct is available in literature given as.

$$h_{jet} = \frac{Nu_{jet} \times k}{D_h} \quad (20)$$

$$Nu_{jet} = 1.658 \times 10^{-3} (Re)^{0.8512} \left(\frac{X}{D_h}\right)^{0.1761} \left(\frac{Y}{D_h}\right)^{0.141} \left(\frac{D_j}{D_h}\right)^{-1.9854} \times \exp[-0.3498(\ln(\frac{D_j}{D_h}))^2] \quad (21)$$

For Friction factor

$$f_{jet} = 0.3475 (Re)^{-0.5244} \left(\frac{X}{D_h}\right)^{0.4169} \left(\frac{Y}{D_h}\right)^{0.5321} \left(\frac{D_j}{D_h}\right)^{-1.4848} \times \exp[-0.2210(\ln(\frac{D_j}{D_h}))^2] \quad (22)$$

$$h_{roughened} = \frac{Nu_{roughened} \times k}{D_h} \quad (23)$$

$$Nu_{roughened} = 0.067 \times (Re)^{0.888} \times (e/D_h)^{0.424} \times (\alpha/60^\circ)^{-0.077} \times e^{-0.782(\ln(\alpha/60^\circ))^2} \quad (24)$$

Fig. 3 and Fig. 4 explains the heat transfer enhancement achieved for JPSAHCLF. The comparison of experimental values of heat transfer coefficient for jet plate and roughened solar air heater has been drawn for stream wise pitch (X=3cm, 6cm), (D<sub>j</sub>=6mm,8mm,1cm) and (e/D<sub>h</sub>=0.043, α=60°) as a function of Reynolds number (Re) respectively. It is seen that application of continuous longitudinal fins in downside of the absorber plate enhances the heat transfer by 1.4-1.5 times over jet plate heat transfer and roughened solar air heater at Reynolds number of 15000, while the corresponding percentage of heat transfer enhancement for a Reynolds number of 15000 are 39% and 28% respectively.

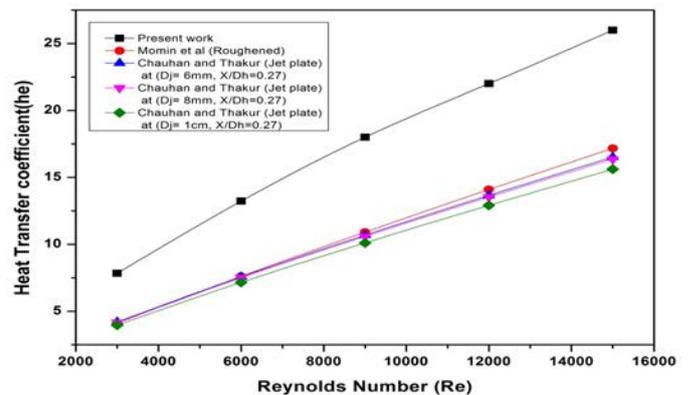


Fig. 3. Heat transfer enhancement for JPSAHCLF with jet plate heat transfer at (X=3cm) and heat transfer for roughened Duct with reference to Reynolds number (Re).

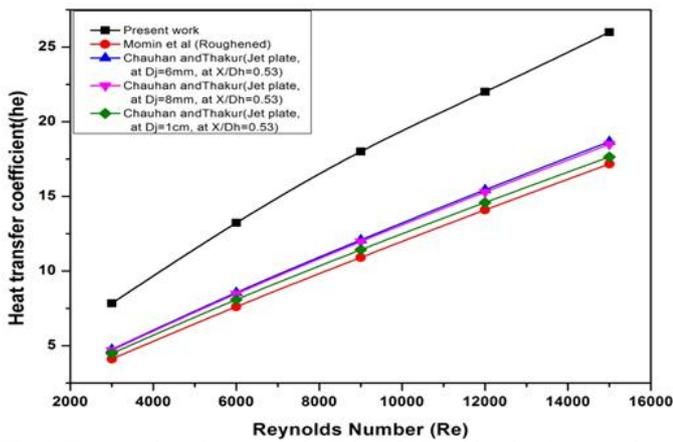


Fig. 4. Heat transfer enhancement for JPSAHCLF and jet plate heat transfer at (X=6cm) and heat transfer for Roughened duct with reference to Reynolds number (Re).

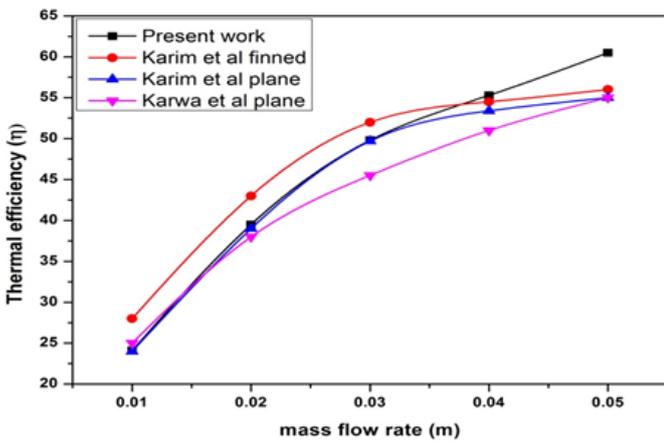


Fig. 5. Thermal efficiency for JPSAHCLF compared with (Karim et al) finned and plane duct, (Karwa et al.) plane duct with reference to Reynolds number (Re).

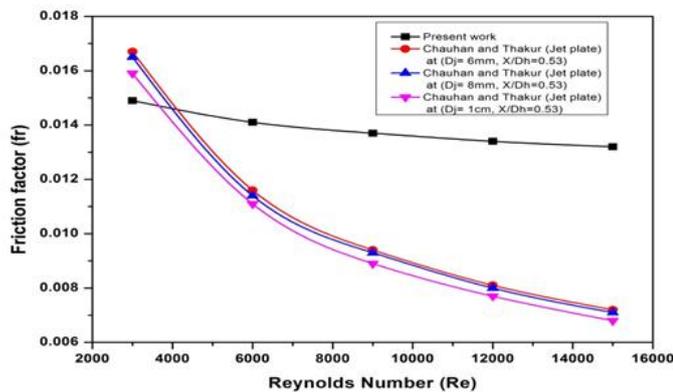


Fig. 6. Comparison of friction factor values for JPSAHCLF with (Chauhan and Thakur) at different hole diameter and X=6cm with reference to Reynolds number (Re).

In Fig. 5 results are presented for thermal efficiency of JPSAHCLF and have been compared with the experimental values of thermal efficiency obtained by Karim and Hawalder (2006) for finned, smooth duct & Karwa and Chitoshiya (2013) with respect to mass flow rate. Curve inferred substantial improvement in thermal efficiency values at higher mass flow rate of 0.05 kg/sec.m<sup>2</sup>. Average deviation of

theoretical values for thermal efficiency is found to be ± 4.3 % from the experimental values of the finned duct of Karim and Hawalder (2006) and ±6.7% from the experimental values of smooth duct of Karim and Hawalder (2006), Karwa and Chitoshiya (2013) respectively. Moreover, enhancement in efficiency is found to be 3% - 14.7% over the compared work at the mass flow rate of 0.05 kg/sec.m<sup>2</sup>.

The comparison of Friction factor values obtained for JPSAHCLF with the experimental values of (Chauhan and Thakur, 2013) can be seen in Fig. 6. The theoretical values for JPSAHCLF and experimental values of jet plate solar air heater are plotted with reference to Reynolds number. Quite noticeable point, at lower Reynolds number significant difference between the theoretical calculated friction factor values for JPSAHCLF and the jet plate duct is observed. However at higher values of Reynolds number reverse trend is noticed.

## V. RESULTS AND DISCUSSIONS

The results for various performance indices such as collector efficiency factor (F'), collector heat removal factor (F<sub>R</sub>), effective heat transfer coefficient (h<sub>e</sub>) and thermal efficiency for jet plate solar air heater with longitudinal fins are presented. The following values of system and operating parameters are used.

L=2m, W=1m,H=10cm, N=1, L<sub>f</sub>=1cm,t<sub>f</sub>=1mm, Fin spacing (W=1cm-5cm), K<sub>ins</sub>=0.4 W/m.K, t<sub>ins</sub>=4cm, (τα)<sub>c</sub>=0.85, T<sub>a</sub>=30°C,T<sub>i</sub>=30°C, ε<sub>p</sub>=0.95 ε<sub>g</sub>=0.88, k<sub>a</sub>=0.028 W/m.K, v<sub>w</sub>=1.5m/sec for mass flow range of (0.0125- 0.067 kg/sec.m<sup>2</sup>)

Fig. 7 depicts the variation of collector efficiency factor (F') for different fin spacing with reference to Reynolds number (Re). The values of collector efficiency factor increases as the Reynolds number is increased at all values of fin spacing. It has been observed in the analysis, the maximum value of collector efficiency factor (F') is achieved at least fin spacing of 1cm. The main reason behind this trend is more surface area for heat transfer as the fin spacing is decreased. The percentage enhancement at 1cm fin spacing founds to be 16%.

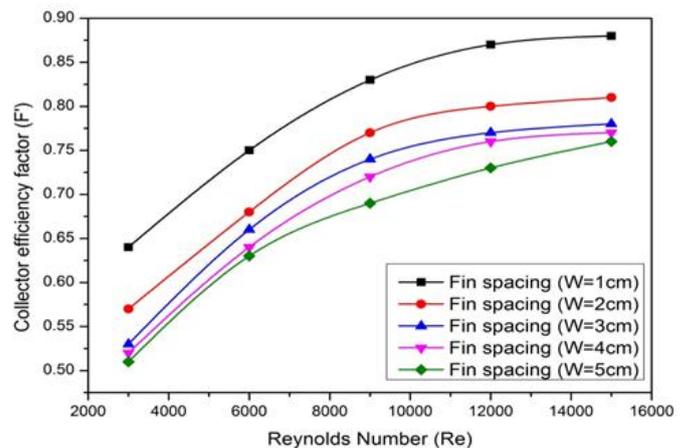


Fig. 7. Variation of collector efficiency factor (F') with reference to Reynolds number for disparate fin spacing.

Fig. 8 illustrates the significance of Reynolds number on effective heat transfer coefficient ( $h_e$ ). It is evident from the curve that with an increase in Reynolds number ( $Re$ ) the effective heat transfer coefficient gradually increases. Higher values of effective heat transfer coefficient are obtained for Reynolds number of 15000 at fin spacing of 1cm while enhancement of 1.98 times is reported in comparison to fin spacing of 5cm.

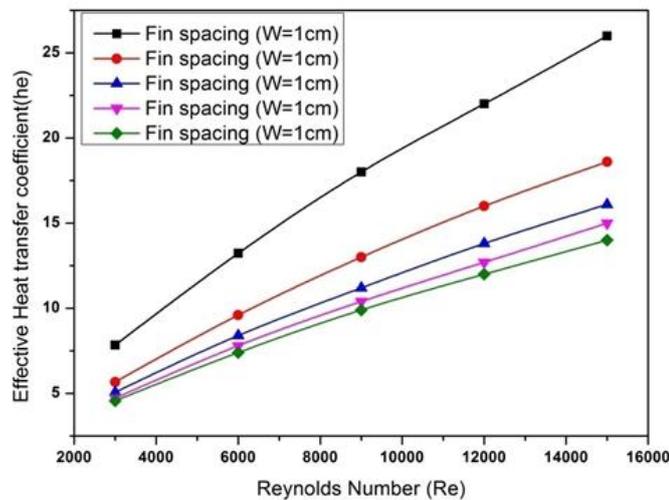


Fig. 8. Effective heat transfer coefficient ( $h_e$ ) with reference to Reynolds number ( $Re$ ) at different fin spacing.

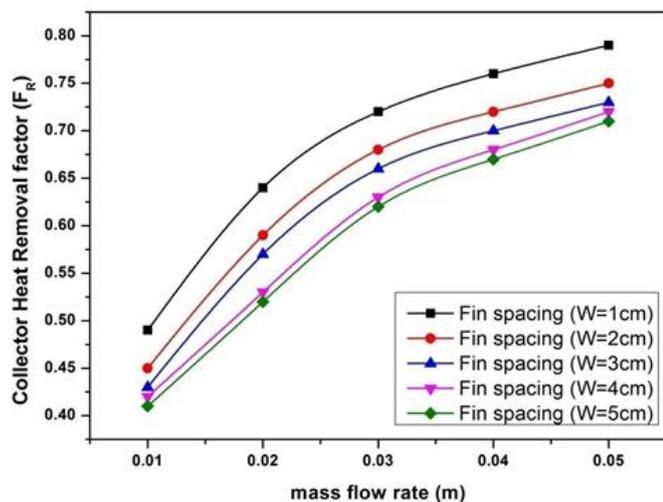


Fig. 9. Variation of collector heat removal factor ( $F_R$ ) with reference to Reynolds number at different fin spacing.

Variation of collector heat removal factor ( $F_R$ ) with reference to mass flow rate at disparate fin spacing is articulated in fig. 9. It is clear from plots, as the mass flow rate is increased in collector heat removal factor for all fin spacing also significantly increased. Again it is found that the minimum value of fin spacing corresponds to maximum value of collector heat removal factor. The value of collector heat removal factor ( $F_R$ ) at fin spacing of 1cm is 11.5% higher in reference to the value obtained at fin spacing of 5cm.

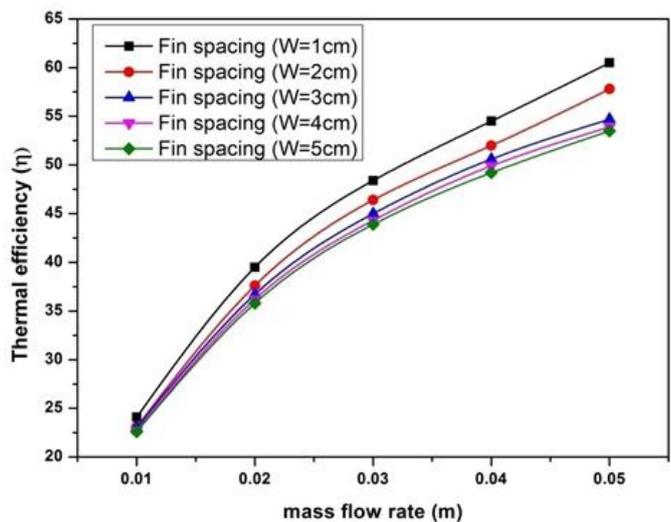


Fig. 10. Thermal efficiency ( $\eta_{th}$ ) trend with reference of mass flow rate at different fin spacing.

Fig. 10 represents variation of thermal efficiency at different fin spacing. It is quite evident from the curve that with increase in mass flow rate values for all fin spacing, in general thermal efficiency increases gradually. The maximum efficiency of 61% can be seen at fin spacing 1cm respectively.

## VI. POLICY IMPLICATION

It is quite clear fact that these technologically operated solar air heater will be more beneficial for the small scale farmers since due to their very low budget they cannot afford other resources for crop drying purpose. These systems are more convenient with respect to the other conventional energy sources such as oil, coal and natural gas. As the use of these sources not only pollutes the environment but also put an economic burden on the society. The key aspects of global development are social development, economical development and environment cleanliness. Solar energy operated systems such as solar air heaters due to their distinguished characteristics justify each one of them.

Major social benefits are (i) more hygienic (ii) greater reliability (iii) technologically advanced (iv) more user friendly (v) increased work opportunity.

Outlined economic benefits are (i) ample job opportunities (ii) cost-effective systems (iii) multi skill development. Moreover the use of solar energy as a fuel is off course the cleanest source. As we are aware that heavy use of fossil fuels leads to emissions of sulphur dioxide, nitrogen oxide and other harmful gases in the environment which excessively pollutes air. Water pollution is also a significant drawback of using fossil fuels.

## VII. CONCLUSIONS

The extensive analysis reaches the noteworthy conclusions are as under:

1. The thermal performance of JPSAHCLF is evaluated in terms of important performance parameters like heat transfer enhancement, collector efficiency factor, and heat removal factor.

- The maximum enhancement obtained in the value of collector efficiency factor at fin spacing of 1cm is 16%. Similarly for collector heat removal factor ( $F_R$ ) percentage enhancement is found to be 11.5% at fin spacing of 1cm.
- The heat transfer enhancement in the present analysis is found to be 1.98 times for fin spacing of 1cm at Reynolds number of 15000 with maximum thermal efficiency of 61% which is a remarkable value.
- The calculated data for heat transfer enhancement and thermal efficiency is compared well with those found in the literature for jet plate solar air heater & roughened duct. It is seen that application of continuous longitudinal fins in downside of the absorber plate enhances heat transfer by 1.4-1.5 times over jet plate heat transfer and roughened duct at Reynolds number of 15000, while corresponding percentage of enhancement in heat transfer for Reynolds number value of 15000 are 39% and 28% respectively.
- Results inferred substantial improvement in thermal efficiency values at higher mass flow rate of 0.05 kg/sec.m<sup>2</sup>. The average deviation of theoretical values for thermal efficiency is found to be  $\pm 4.3\%$  -  $\pm 6.7\%$  from the compared experimental values of the finned duct and smooth duct respectively. Moreover, enhancement in efficiency is found to be 3% - 14.7% over the compared work at the mass flow rate of 0.05 kg/sec.m<sup>2</sup>.
- It is concluded, the least fin spacing (W) is the optimal design parameter for heat transfer enhancement in the finned duct.
- Undoubtedly, these technologically appropriate systems are conducive. The use of these systems must be promoted as these systems will certainly strengthen the global development initiatives.

#### REFERENCES

- H. C. Hotel and T. A. Unger, "The properties of a copper oxide – aluminium selective black surface absorber of solar energy," *Solar Energy*, vol. 3, issue 3, pp. 10-15, 1959.
- D. J. Close, "Solar air heaters for low and moderate temperature applications," *Solar Energy*, vol. 7, issue 3, pp. 85-156, 1963.
- S. Satcunanathan and S. Deonarine, "A two-pass solar air heater," *Solar Energy*, vol. 15, issue 1, pp. 41-49, 1973.
- T. M. Kuzay, M. A. S. Malik, and K. W. Boer, "Solar collectors of solar one," *Proceedings Workshop Solar Collectors Heating Cooling Buildings*, 99, 1974.
- N. E. Wijesundera, A. H. Lee, and L. E. Tjioe, "Thermal performance study of two-pass solar air heaters," *Solar Energy*, vol. 28, issue 5, pp. 363-370, 1981.
- K. Seluck, "Thermal & economic analysis of the overlapped glass plate solar air heater," *Solar Energy*, vol. 13, issue 12, pp. 165-191, 1971.
- H. Buchberg, O. Lalude, and D. K. Edwards, "Performance characteristics of rectangular honey comb Solar – Thermal converters," *Solar Energy*, vol. 13, issue 2, pp. 193-221, 1971.
- L. Varshney and J. S. Saini, "Heat transfer and friction factor correlations for rectangular solar air heater duct packed with wire screen matrices," *Solar Energy*, vol. 62, issue 4, pp. 255-262, 1998.
- N. S. Thakur, J. S. Saini, and S. C. Solanki, "Heat transfer and friction factor correlations for packed bed solar air heater for a low porosity system," *Solar Energy*, vol. 74, issue 4, pp. 319-329, 2003.
- S. B. Prasad, J. S. Saini, and Krishan M. Singh, "Investigation of heat transfer and friction characteristics of packed bed solar air heater using wire mesh as packing material," *Solar Energy*, vol. 83, issue 5, pp. 773-783, 2009.
- J. C. Han, L. R. Glicksman, and W. M. Rohsenow, "An investigation of heat transfer & friction for rib roughened surfaces," *International Journal of Heat & Mass Transfer*, vol. 21, issue 8, pp. 1143-1156, 1978.
- P. R. Chandra, C. R. Alexander, and J. C. Han, "Heat transfer & friction behaviours in rectangular channel with varying number of ribbed walls," *International Journal of Heat and Mass Transfer*, vol. 46, issue 3, pp. 481-495, 2003.
- S.C Lau, R.T Kukreja R.D McMillin, "Effect of V shaped rib arrays on turbulent heat transfer and friction of fully developed flow in square channel," *International Journal of Heat & Mass Transfer*, vol. 34, issue 7, pp. 1605-1616, 1991.
- B. N. Prasad and J. S. Saini, "Optimal thermohydraulic performance of artificially roughened solar air heaters," *Solar Energy*, vol. 47, issue 2, pp. 91-96, 1991.
- V. S. Hans, R. P. Saini, and J. S. Saini, "Performance of artificially roughened solar air heaters- A review," *Renewable and Sustainable Energy Reviews*, vol. 13, issue 8, pp. 1854-1859, 2009.
- S. Singh, S. Chander, and J. S. Saini, "Investigations on thermohydraulic performance due to flow attack angle in V-down rib with gap in a rectangular duct of solar air heater," *Applied Energy*, vol. 97, pp. 907-912, 2012.
- M. Sethi, Varun, and N. S. Thakur, "Correlations for solar air heater duct with dimple shaped roughness elements on absorber plate," *Solar Energy*, vol. 86, issue 9, pp. 2852-2861, 2012.
- A. Kumar, R. P. Saini, and J. S. Saini, "Experimental investigation on heat transfer and fluid flow in a rectangular duct with multi v- shaped rib with gap roughness on the heated plate," *Solar Energy*, vol. 86, issue 6, pp. 1733-1749, 2012.
- Varun, R. P. Saini, and S. K. Singhal, "A review on roughness geometry used in solar air heaters," *Solar Energy*, vol. 81, issue 11, pp. 1340-1350, 2007.
- D. M. Kercher and W. Tabakoff, "Heat transfer by a square array of round air jets impinging perpendicular to a flat surface including the effect of spent air," *ASME Trans. Journal of Engineering for Power*, vol. 92, issue 2, pp. 73-82, 1970.
- D. E. Metzger, T. Yamashita, and C. Jenkins, "Impingement cooling of concave surfaces with lines of circular jets," *ASME Trans. Journal of Engineering for Power*, vol. 91, issue 3, pp. 149-158, 1971.
- S. Brodersen, and D. Metzger, "Experimental investigation of the flow field resulting from the interaction between an impinging jet and rotating disk," *Experimental Thermal and Fluid Science*, vol. 5, issue 3, pp. 351-358, 1992.
- D. E. Metzger, L. W. Florschuetz, D. I. Takeuchi, R. D. Behee, and R. A. Berry, "Heat transfer characteristics for inline and staggered arrays of circular jets with crossflow of spent air," *ASME Trans. Journal of Heat Transfer*, vol. 101, issue 3, pp. 526-531, 1979.
- C. Chaudhary and H. P. Garg, "Evaluation of Jet plate solar air heater," *Solar Energy*, vol. 46, issue 4, pp. 199-209, 1991.
- S. V. Garimella and B. Nenaydykh, "Nozzle-geometry effects in liquid jet impingement heat transfer," *International Journal of Heat and Mass Transfer*, vol. 39, issue 14, pp. 2915-2923, 1996.
- S. Z. Shuja, B. S. Yilbas, and S. Khan, "Jet impingement onto a conical cavity: Effects of annular nozzle outer angle and jet velocity on heat transfer and skin friction," *International Journal of Thermal Sciences*, vol. 48, pp. 985-997, 2009.
- P. Brevet, C. Dejeu, E. Dorignac, M. Jolly, and J. J. Vullierme, "Heat transfer to a row of impinging jets in consideration of optimization," *International Journal of Heat and Mass Transfer*, vol. 45, issue 20, pp. 4191-4200, 2002.
- J. A. Parsons and J. C. Han, "Rotation effect on jet impingement heat transfer in smooth rectangular channels with heated target walls and radially outward cross flow," *International Journal of Heat and Mass Transfer*, vol. 41, issue 13, pp. 2059-2071, 1998.
- M. Belusko, W. Saman, and F. Bruno, "Performance of jet impingement in Unglazed air collectors," *Solar Energy*, vol. 82, issue 5, pp. 389-398, 2008.
- V. Katti and S.V. Prabhu, "Influence of spanwise pitch on local heat transfer distribution for in-line arrays of circular jets with spent air flow in two opposite directions," *Experimental Thermal and Fluid Science*, vol. 33, pp. 84-95, 2008.
- M. Goodro, J. Park, P. Ligrani, M. Fox, and H. K. Moon, "Effect of hole spacing on spatially resolved jet array impingement heat transfer,"

- International Journal of Heat and Mass Transfer*, vol. 51, pp. 6243-6253, 2008.
- [32] M. Zukowski, "Heat transfer performance of a confined single slot jet of air impinging on a flat surface," *International Journal of Heat and Mass Transfer*, vol. 57, issue 2, pp. 484-490, 2013.
- [33] R. Chauhan and N. S Thakur, "Heat Transfer and friction factor correlations for impinging jet solar air heater," *Experimental thermal & Fluid Science*, vol. 44, issue 6, pp. 760-769, 2012.
- [34] R. Chauhan and N. S Thakur, "Investigation of Thermo-hydraulic efficiency of impinging jet solar air heater," *Experimental Thermal & Fluid Science*, vol. 44, issue 6, pp. 760-769, 2013.
- [35] J. E. Wilkins, "Optimum Shapes for Fin Rejecting Heat by Convection and Radiation," *Journal of the Franklin Institute*, vol. 297, issue 1, pp. 1-6, 1974.
- [36] M. H. Cobble, "Optimum fin shape," *Journal of the Franklin Institute*, vol. 291, pp. 283-292, 1971.
- [37] S. Hu and K. E. Herold, "Prandtl number effect on offset fin heat exchanger performance: experimental results," *International Journal of Heat & Mass Transfer*, vol. 38, issue 6, pp. 1053-1061, 1995.
- [38] N. C. Dejong, L. W. Zhang, A. M. Jacobi, S. Balachandar, D. K. Tafti, "A complementary experimental and numerical study of the flow and heat transfer in offset strip-fin heat exchangers," *Journal of Heat Transfer ASME*, vol. 120, issue 3, pp. 690-708, 1998.
- [39] R. M. Manglik and A. E. Bergles "Heat transfer and pressure drop correlations for the rectangular offset strip fin compact heat exchanger," *Experimental Thermal & Fluid Science*, vol. 10, issue 2, pp. 171-180, 1995.
- [40] H. P. Garg, G. Datta, and A. K. Bhargava, "Performance studies on a finned-air heater," *Energy*, vol. 14, issue 2, pp. 87-92, 1989.
- [41] N. Moumni, S. Y. Ali, A. Moumni, and J. Y. Desmons "Energy analysis of a solar air collector with rows of fins," *Renewable Energy*, vol. 29, issue 13, pp. 2053-2064, 2004.
- [42] P. Naphon "On the performance and entropy generation of the double-pass solar air heater with longitudinal fins," *Renewable Energy*, vol. 30, issue 9, pp. 1345-1357, 2005.
- [43] A. A. El-Sebaei, S. Aboul-Enein, M. R. I. Ramadan, S. M. Shalaby, B. M. Moharram, "Thermal performance investigation of double pass finned plate solar air heater," *Applied Energy*, vol. 88, issue 5, pp. 1727-1739, 2011.
- [44] A. Fudholi, K. Sopian, M. H. Ruslan, and M. Y. Othman, "Performance and cost benefit analysis of double pass collector with and without fins," *Energy Conversion and Management*, vol. 76, pp. 8-19, 2013.
- [45] K. Mohammadi and M. Sabzpooshani, "Comprehensive performance evaluation and parametric studies of single pass solar air heater with fins and baffles attached over the absorber plate," *Energy*, vol. 57, pp. 741-750, 2013.
- [46] W. Chang, Y. Wang, M. Li, X. Luo, Y. Ruan, Y. Hong, and S. Zhang, "The theoretical and experimental research on thermal performance of solar air collector with finned absorber," *Energy Procedia*, vol. 70, pp. 13-22, 2015.
- [47] M. N. Ozisik, *Heat Transfer: A Basic Approach*, McGraw Hill Book Company, New York, 1985.
- [48] J. A. Duffie and W. A. Beckman, *Solar Engineering of Thermal Processes*, Wiley, New York, 1980.
- [49] S. P. Sukhatme, *Solar Energy Principles of Thermal collection and Storage*, Tata McGraw Hill, New Delhi, 2000.
- [50] S. B. Thombre and S. P. Sukhatme, "Turbulent flow heat transfer and friction factor characteristics of shrouded fin arrays with uninterrupted fins," *Experimental Thermal and Fluid Science*, vol. 10, issue 3, pp. 388-396, 1995.
- [51] Md. A. Karim and M. N. A. Hawalder, "Performance investigation of flat plate, V- corrugated and finned air collectors," *Energy*, vol. 31, issue 4, pp. 452-470, 2006.
- [52] R. Karwa and G. Chitoshiya, "Performance study of solar air heater having v-down discrete ribs on absorber plate," *Energy*, vol. 55, pp. 939-955, 2013.
- [53] A. K. Behura, B. N. Prasad, and L. Prasad, "Heat transfer, friction factor and thermal performance of three sides artificially roughened solar air heaters," *Solar Energy*, vol. 130, pp. 46-59, 2016.
- [54] A. K. Behura, S. K. Rout, H. Pandya, A. Kumar, "Thermal analysis of three sides artificially roughened solar air heaters," *Energy Procedia*, vol. 109, pp. 279-285, 2017.
- [55] A. Kumar, B. N. Prasad, and K. D. P. Singh, "Thermal and thermo hydraulic performance of three sides artificially roughened solar air heaters," *International Research Journal of Advanced Engineering and Science*, vol. 2, issue 2, pp. 215-231, 2017.
- [56] A. Kumar, B. N. Prasad, and K. D. P. Singh, "Enhancement of collector performance parameters in three sides artificially roughened solar air heater," *Proceedings of the 2<sup>nd</sup> International Conference on advances in Steel, Power and Construction Technology*, 4-6 March, 2016.
- [57] A. Kumar, B. N. Prasad, and K. D. P. Singh, "Performance characteristics of three sides glass covered smooth solar air heaters," *Transylvanian Review*, vol. 24, issue 11, pp. 3247-3256, 2016.
- [58] 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.
- [59] 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.