

Effect of Parametric Variation on the Offset Finned Absorber Solar air Heater

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Abstract-- In this approach, MATLAB has been used for theoretical investigation on performance of offset finned absorber solar air heater. The evaluation of parametric effect i.e. offset fin spacing 'sf' and offset fin height 'hf' and solar insolation 'Io' at different air mass flow rate on the thermal and exergy performance of solar air heater. Thermal efficiency (the first law of thermodynamic) and exergy efficiency (the efficiency of process taking the second law of thermodynamic in account), the results indicate that the exergy performance is effective at lower air mass flow rate, fin spacing and fin height, whereas the thermal performance at higher air mass flow rate. The exergy efficiency is the main factor for performance evaluation, results show that the trends of variation of the thermal and exergy efficiencies are not the same. The performances of offset finned solar air heater are compared with conventional flat plate solar air heater.

Index Term-- MATLAB, thermal efficiency, exergy efficiency, offset fin, parametric study.

1. INTRODUCTION

Today, solar air heaters are the system which uses the solar energy to fulfill the general requirement in the field of space heating, agricultural and crop drying etc. solar air heaters are widely employed due to simplicity in design, maintenance as well as low cost of materials required for construction. Nevertheless, in spite of these multiple benefits of solar air

heaters, their fundamental deficiency is the low rate of heat transfer between absorber plate and flowing air due to unpropitious thermo-physical properties of air. So that the different researchers [1-6] have centralized their studies toward assorted performances method and used different strategies for increasing the heat-transfer coefficient between the absorber plate and flowing air through the channel include the use of fins, corrugated surface, packed bed and fin with baffles configurations have been investigated.

In order to balance the quality of energy gain and friction losses, the exergy analysis is more appropriate in comparison to the thermal analysis, [7-9] studied the exergetic performance of a solar air heater having discrete V-down rib roughness and compared the obtained results with a conventional flat-plate solar air heater. The exergetic performance evaluation of solar air heater with arc-shaped wire rib roughened absorber plate investigated [10]. Results showed that the exergy analysis is one of the important methods to evaluate the performance of solar air heater. Sahu, M.K., and Prasad, R.K. [11] investigated on exergetic performance evaluation of solar air heater with arc-shaped wire rib roughened absorber plate. Results showed that the exergy analysis is one of the important methods to evaluate the performance of solar air heater.

NOMENCLATURE

L_{sc}	length of the solar collector (m)	E_{Xe}	incoming exergy in the control volume
W_{sc}	width of the solar collector (m)	E_{Xl}	outgoing exergy from the control volume
D_h	duct height of the solar collector (m)	ψ_e	exergy efficiency
l_f	length of the offset fin (m)	E_{Xsr}	exergy of solar radiation falling on glass cover
h_f	height of offset fin (m)	θ_{fi}	inlet fluid temperature in the solar collector (K)
t_f	thickness of offset fin (m)	θ_{fo}	outlet fluid temperature from the solar collector (K)
s_f	fin spacing of offset fin (m)	θ_s	sun temperature (K)
d_e	equivalent hydraulic diameter of solar collector (m)	η_{II}	exergy efficiency or second law efficiency
A_t	total surface area of the fins (m^2)	f_f	friction factor
A_{sc}	$dx.W_{sc}$, elemental surface area of the solar collector (m^2)	P_d	Pressure drop (N/m^2)
A_{cs}	cross surface area of the solar collector duct (m^2)	W_p	required pump work
\dot{m}	air mass flow rate (kg/s)	I_o	global irradiance incident on solar collector (W/m^2)

In the present study, The MATLAB software is used for evaluation of performance of an offset finned absorber solar

air heater on the basis of parameters variation effect has been reported.

2. THEORETICAL ANALYSIS

Considered the offset finned below the absorber plate solar air heater as shown in Fig.1. The channel of width ,duct height, and length of the collector absorber plate ‘W_{sc}’, ‘D_h’ and ‘L_{sc}’ respectively having one glass cover is uniformly heated from

top by solar radiations transmitted through the glass cover. The height ‘h_f’, length ‘l_f’, thickness ‘t_f’ and spacing ‘s_f’ of the offset fin.

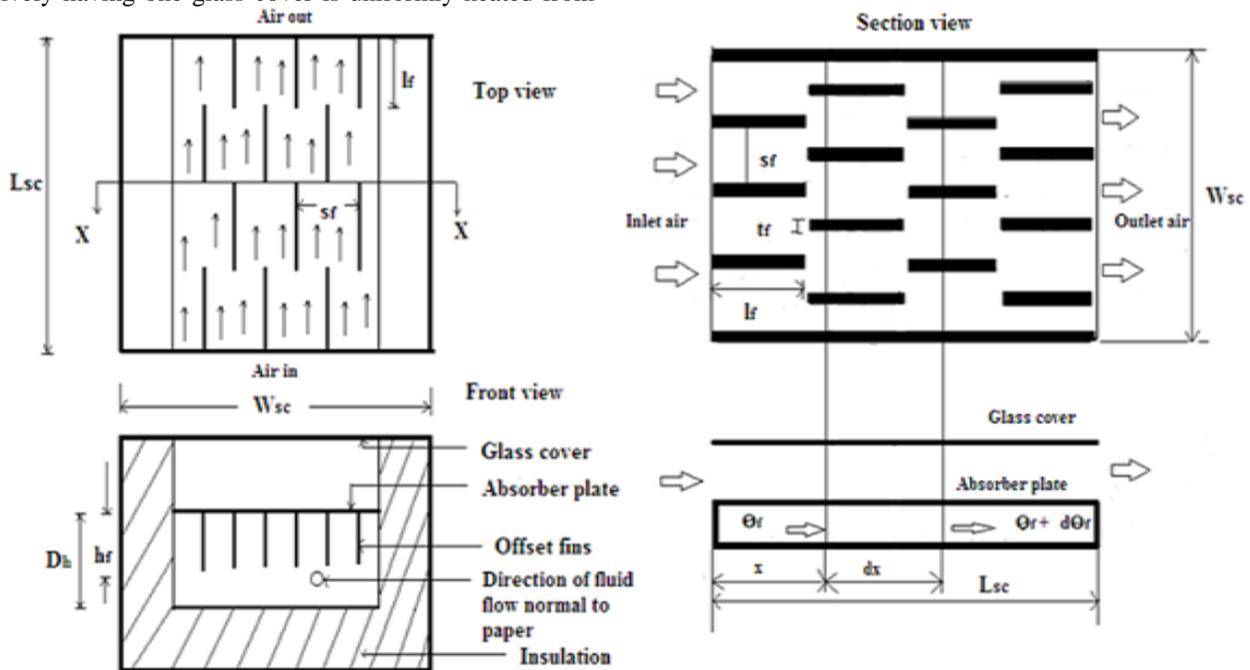


Fig. 1. Sectional view of absorber plate attached with offset fins.

2.1 Thermal efficiency

The thermal efficiency can be expressed as:

$$\eta_{th} = \frac{\dot{m}C_p(\theta_{fo}-\theta_{fi})}{I_o A_{sc}} \quad (1)$$

2.2 Exergy analysis

A fundamental difference between thermal and exergy is that while the former is conserved, the latter is destroyed in all real processes due to irreversibilities. Fig. 2 illustrates that Exergy is lost in two different ways. Internal losses (“destruction”) are caused by irreversibilities in the process (heat transfer,

chemical reaction, mixing, unrestricted expansion, etc.); while external losses (“leakage”) are caused by exergy content in effluent streams that are not utilized (exhaust gases, purge and bleed streams, cooling water, etc.) An efficiency based on total Exergy would only account for internal losses (irreversibilities) in the process.

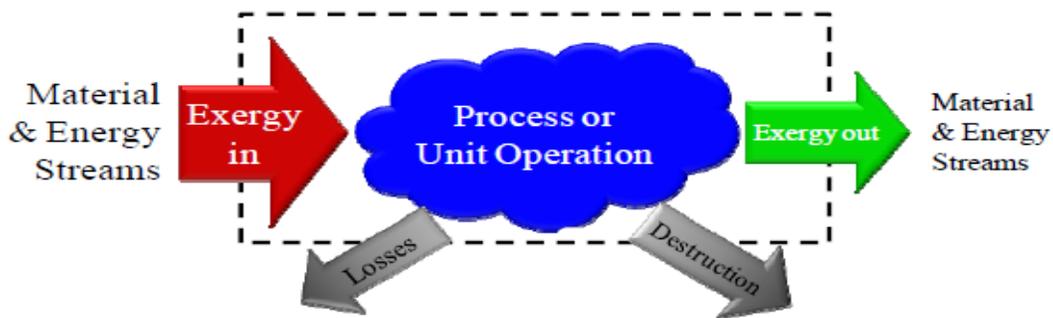


Fig. 2. Exergy Flows entering and exiting a Process.

Considered the control volume illustrated in Fig.3. The exergy balance equation of solar air heater recommended by M. Sabzpooshani, et al. [12].

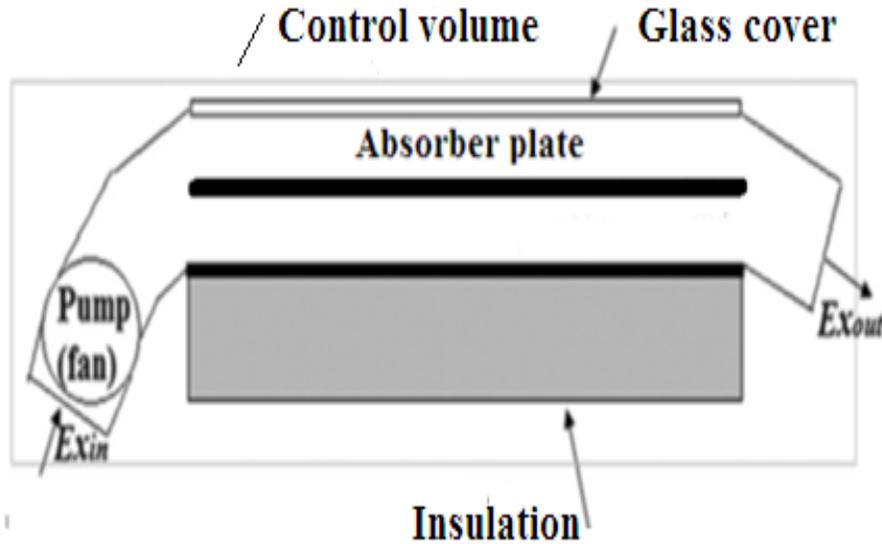


Fig. 3. Considered control volume (CV) for the solar air heater

$$E_{Xin} + E_{Xsr} + E_{Xwp} - E_{Xout} = IR \quad (2)$$

E_{Xin} and E_{Xout} are the exergy associated with the mass flow of flowing air come in and come out the control volume, respectively. The exergy of solar radiation falling on glass cover E_{Xsr} , exergy of the input work required pumping the air through the solar air heater E_{Xwp} and the irreversibility of the air heating process IR . The irreversibility or exergy loss occurs due to the temperature difference between absorber plate surface and sun, heat losses to the ambient and pressure drop in channel.

E_{Xin} and E_{Xout} are:

$$E_{Xin} = (h_e - h_a) - T_a(S_e - S_a) \quad (3)$$

$$E_{Xout} = (h_l - h_a) + T_a(S_l - S_a) \quad (4)$$

The E_{Xs} calculated as [12]:

$$E_{Xsr} = I_o A_{sc} \psi_e = I_o A_{sc} \left(1 - \frac{4}{3} \left(\frac{\theta_a}{\theta_s}\right) + \frac{1}{3} \left(\frac{\theta_a}{\theta_s}\right)^4\right) \quad (5)$$

where exergy efficiency is ψ_e

Considered the pressure drop and assuming air as an incompressible fluid or perfect gas, the useful exergy gain, $E_{Xu,p}$ is expressed as:

$$E_{Xu,p} = E_{Xout} - E_{Xin} - E_{Xwp} = \dot{m} C_p \left[(\theta_{fo} - \theta_{fi}) - T_a \ln \left(\frac{\theta_{fo}}{\theta_{fi}} \right) \right] - \frac{\theta_a}{\theta_{fi}} W_p \quad (6)$$

The term $\left(\frac{\theta_a}{\theta_{fi}}\right) W_p$ is the exergy destruction due to pressure drop. The required pump work is:

$$W_p = \dot{m} \Delta p_d / (\rho_a \eta_{pm}) \quad (7)$$

The following correlation of friction factor is developed for calculating the pressure drop [13]

$$f_f = 9.6243 R_{en}^{-0.7422} a^{-0.1856} b^{0.3053} c^{-0.2659} \times [1 + 7.669 \times 10^{-8} R_{en}^{4.429} a^{0.920} b^{3.767} c^{8.236}]^{0.1} \quad (8)$$

Hence, Pressure drop

$$\Delta p_d = \frac{4 f_f \rho_a L_{sc} V^2}{2 d_e}$$

η_{pm} , the pump motor efficiency and is taken to be 0.85 [12]. The exergy efficiency, called second law efficiency, of the solar air heater is calculated by dividing the useful exergy gain to the exergy solar radiation as:

$$\eta_{II} = \frac{E_{Xu,p}}{I_o A_p \psi_e} = \frac{E_{Xu,p}}{I_o A_p \left(1 - \frac{4}{3} \left(\frac{\theta_a}{\theta_s}\right) + \frac{1}{3} \left(\frac{\theta_a}{\theta_s}\right)^4\right)} \quad (9)$$

3. CALCULATION PROCEDURE

Procedures followed for determination of the thermal and exergy performance evaluation of offset finned absorber solar air heater listed in Table I.

Step-1	Assumed initial value of absorber mean temperature θ_n , air stream temperature θ_f and bottom mean temperature θ_2 .
Step-2	Find out convective heat transfer coefficient by using Eqs. (9) and (10) Shalini rai et al [14]
Step-3	θ_f , θ_n and θ_2 were checked using Eqs. (4), (5) and (6) from [14] and the calculated values of temperature were compared with the initial assumptions of temperature. If difference between calculated values and initial guess values were less than 0.001, assumed temperature values were considered correct; otherwise, the procedure was repeated until the values reached to a convergence.
Step-4	Upon completion of step (3), the values of mean temperatures were calculated and the exergy efficiency was calculated via Eq. (9).

4. RESULTS AND DISCUSSION

Results of the thermal and exergy analysis of an offset finned attached absorber solar air heater are presented.

Figs.4 (a) and (b) show the variation of thermal efficiency with mass flow rate of air for different fin spacing and insolation for $I_o=750W/m^2$ and $I_o=950W/m^2$.

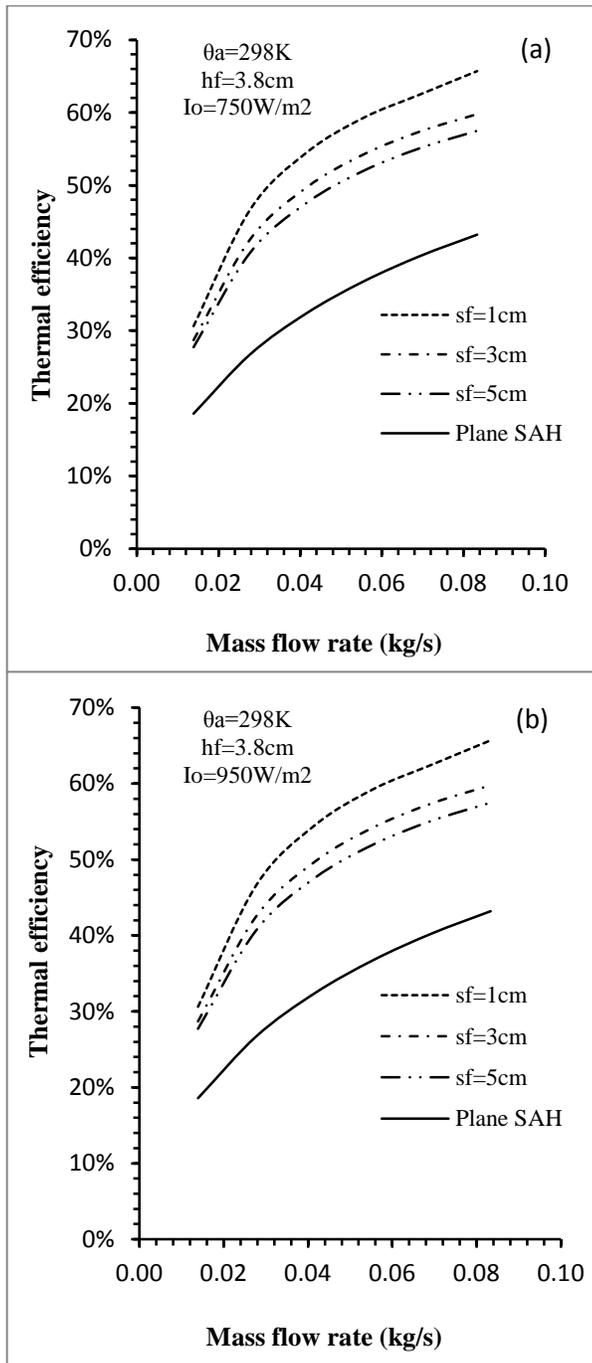


Fig. 4. Thermal efficiency vs. mass flow rate for various fin spacing (a) $I_o = 750\text{W/m}^2$, (b) $I_o = 950\text{W/m}^2$.

It is seen that use of attaching offset finned below the absorber plate lead to higher thermal efficiency as compared to a conventional (plane) solar air heater. It has been found that the thermal efficiency monotonically increases with an increase in mass flow rate apparently because of an increase in the convective heat transfer coefficient. The lowest fin spacing (1cm) maintains the highest efficiency value throughout the range of mass flow rate investigated. Furthermore, a slightly fall is observed in the rate of increase of efficiency as mass flow rate increases apparently due to relatively lower percentage increase in surface conductance as mass flow rate increases as also due to relatively higher heat flow rate. Also increase in fin spacing decreases the thermal efficiency of solar air heater. This is due to facts that increase in fin spacing resulted in decrease in heat transfer surface area and hence heat transfer rate.

Figs.5 (a) and (b) show variation of thermal efficiency as a function of mass flow rate for different fin height and insolation for $I_o = 750\text{W/m}^2$ and $I_o = 950\text{W/m}^2$. From the figure it is seen that thermal efficiency increases with increase in mass flow rate. It is also observed that increase in height of offset fin slightly decreases the thermal efficiency of solar air heater. This is because of increase in offset fin height increase the heat transfer surface area; however it decreases the convective heat transfer coefficient.

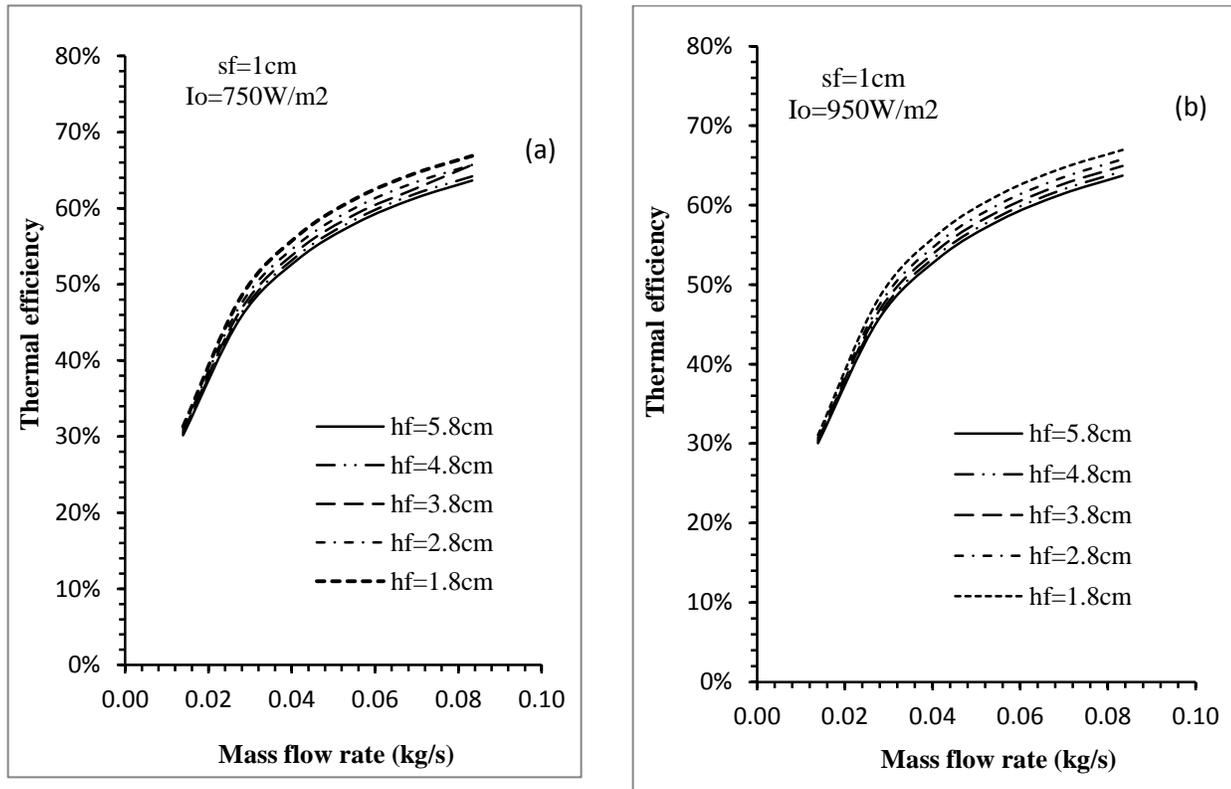
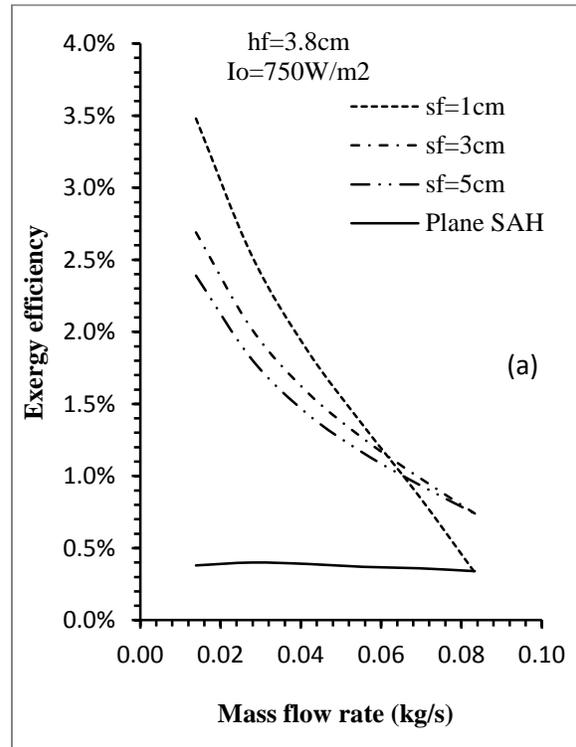


Fig. 5. Thermal efficiency vs. mass flow rate for various fin height (a) $Io=750\text{W/m}^2$, (b) $Io=950\text{W/m}^2$.

Figs.6 (a) and (b) show variation of exergy efficiency with mass flow rate for different fin spacing and for insolation $Io=750\text{W/m}^2$ and $Io=950\text{W/m}^2$. It is clearly seen that attaching offset fins below the absorber plate, lead to exergy efficiency increase compared to a plane solar air heater. From the figure it is also observed that decrease in fin spacing gives higher exergy efficiency at lower mass flow rate for $Io=750\text{W/m}^2$ and $Io=950\text{W/m}^2$; the improvement in exergy efficiency is due to enhanced heat transfer area and also creation of more turbulence which results in higher heat energy gain. Also result reveals that at higher mass flow rate exergy efficiency decreases rapidly with increase in fin spacing. This is due to increased exergy destruction due to higher pressure drop in the channel.



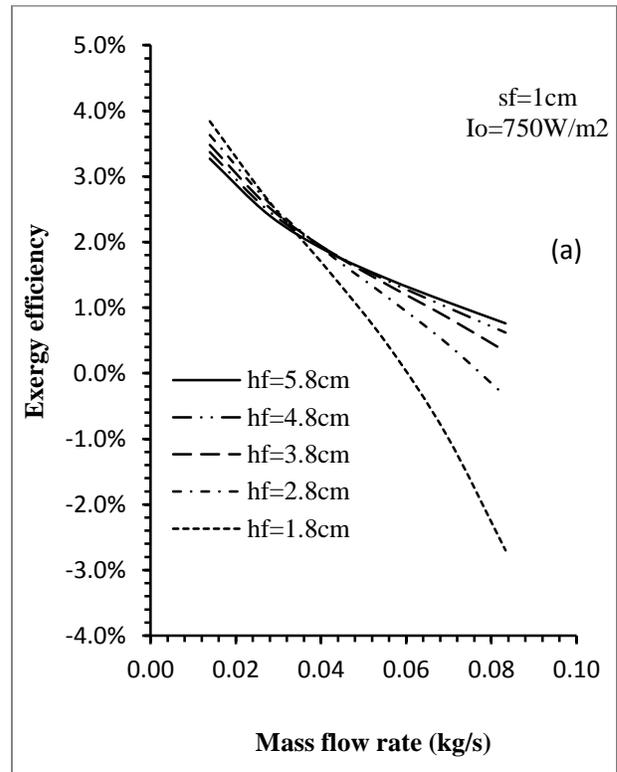
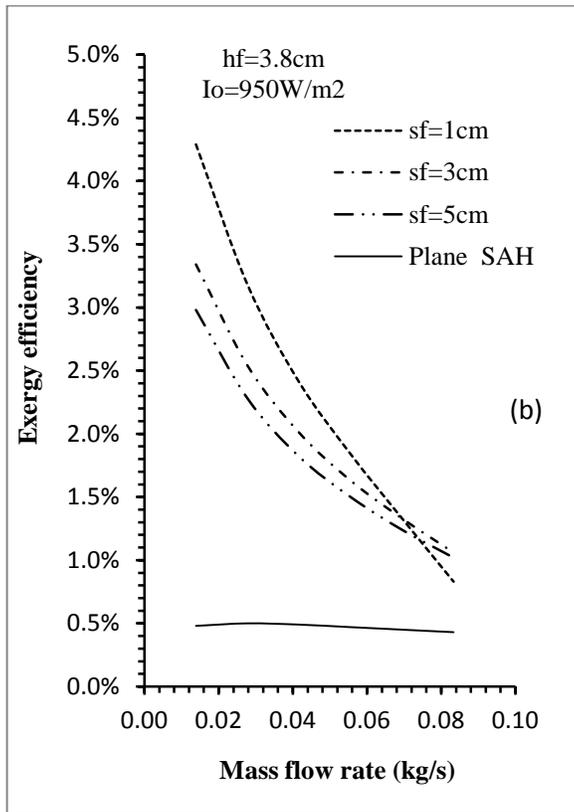


Fig. 6. Exergy efficiency vs. mass flow rate for various fin spacing (a) $I_o=750W/m^2$, (b) $I_o=950W/m^2$.

The variation of exergy efficiency with mass flow rate for different fin height is plotted in Figs.7 (a) and (b) for $I_o=750W/m^2$ and $I_o=950W/m^2$ respectively. It is observed that the exergy efficiency decreases with increase in mass flow rate. From the figure it is clearly seen that there is drastic fall in exergy efficiency as mass flow rate increases for lower fin height of 1.8cm, whereas the exergy efficiency slightly decreases with increase in mass flow rate for higher fin height of 5.8cm. This trend continues for other heights of fin also. Further, it is noticed that lower fin height (1.8cm) maintains the higher exergy efficiency at lower mass flow rate, whereas for higher fin height (5.8cm) the reverse trend is observed.

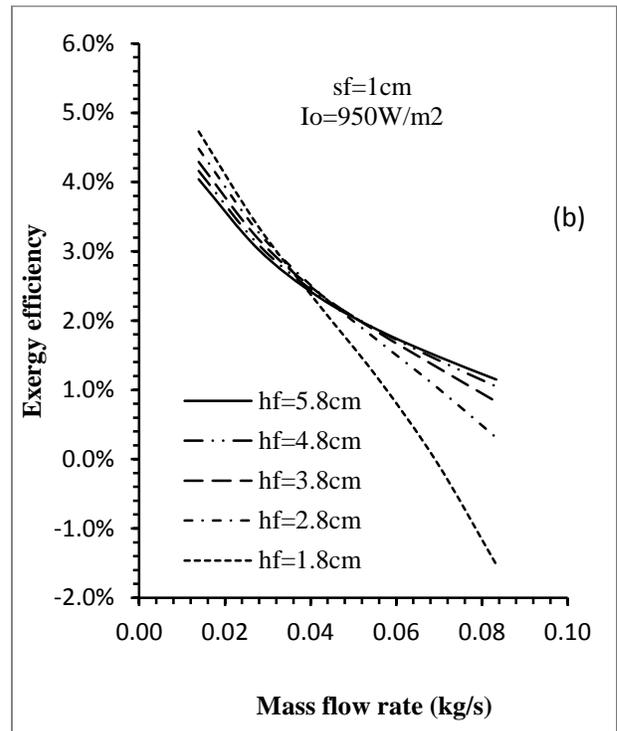


Fig. 7. Exergy efficiency vs. mass flow rate for various fin height (a) $I_o=750W/m^2$, (b) $I_o=950W/m^2$.

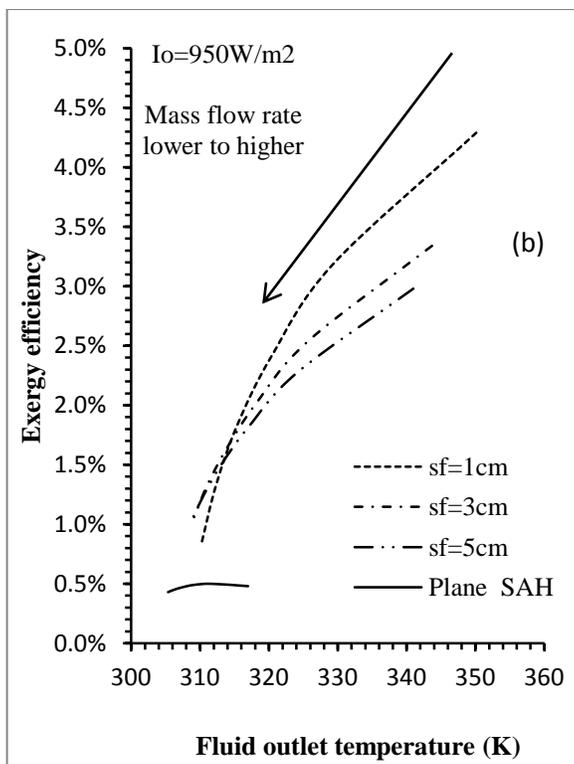
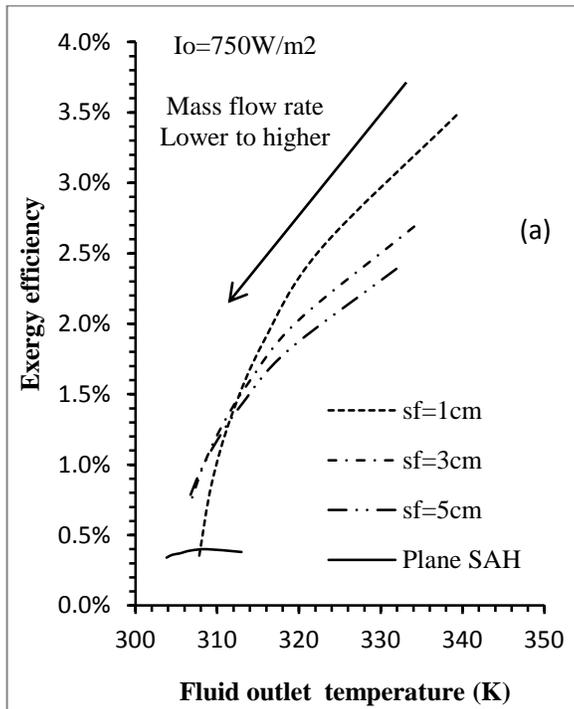


Fig. 8. Exergy efficiency vs. Fluid outlet temperature at different mass flow rate for various fin spacing (a) $I_o=750\text{W/m}^2$, (b) $I_o=950\text{W/m}^2$.

Figs.8 (a) and (b) show effect of offset fin spacing on the exergy efficiency and outlet temperature at different mass flow rate along with conventional solar air heater for $I_o=750\text{W/m}^2$ and $I_o=950\text{W/m}^2$ respectively. From the figure it is clearly seen that increase in mass flow rate decreases the exergy efficiency for all values of fin spacing. The lower fin

spacing (1cm) at lower mass flow rate of 0.01388 kg/s maintains the higher exergy efficiency and outlet temperature of flowing fluid. It is found that at lower mass flow rate of 0.01388 kg/s the variation of exergy for different fin spacing is higher and at higher mass flow rate of 0.0833 kg/s, the trend of variation is reversed. Further it is seen that the outlet temperature is almost same for all fins spacing at higher mass flow rate of air.

5. Conclusions

An analytical approach for thermal and exergy performances of offset finned solar air heater has been carried out. The most important findings of this study are summarized in the following:

- 1) The thermal efficiency increases with increase in mass flow rate and decrease in fin spacing, fin height, whereas the trend of exergy efficiency is reversed. The trend of variation of thermal and exergy efficiency is not the same.
- 2) The percentage enhancement in thermal efficiency increases with increase in mass flow rate whereas the exergy efficiency decreases.
- 3) At lower mass flow rate of 0.01388 kg/s the variation of exergy for different fin spacing is higher whereas at higher mass flow rate of 0.0833 kg/s, the trend of variation is reversed.
- 4) The outlet temperature is almost same for all fins spacing at higher mass flow rate of air.
- 5) Attaching offset fins below the absorber plate, lead to exergy efficiency increase compared to a plane solar air heater. The improvement in exergy efficiency is due to enhanced heat transfer area and also creation of more turbulence which results in higher heat energy gain. Also result reveals that at higher mass flow rate exergy efficiency decreases rapidly with increase in fin spacing.

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