Proc. of Int. Conf. on Emerging Trends in Engineering & Technology, IETET

Numerical Investigation of Solar Air Heater with New Design Offset Finned below the Absorber Plate

Shalini Rai[1], Dr.Prabha Chand[2] and Prof.S.P.Sharma[3]
[1] Research scholar, Mechanical Engineering Department, NIT Jamshedpur, Jharkhand (India)
Email: rai.shalin@gmail.com
[2-3] Mechanical Engineering Department, NIT Jamshedpur, Jharkhand (India)

***Abstract*—Energy is never destroyed during a process; it changes from one form to another (First Law of Thermodynamics). In contrast, energy accounts for the irreversibility of a process due to increase in entropy (Second Law of Thermodynamics). Energy is always destroyed when a process involves a temperature change. In this paper the thermal, thermo hydraulic and exergy efficiencies of an offset finned solar air heater have been evaluated theoretically. Parametric study was done to investigate the effect of variation of offset fin parameters i.e. fins spacing and fins height at different mass flow rates on the thermal, thermo hydraulic and energy efficiency. The results indicated that attaching offset finned below the absorber plate at low mass flow rates can lead to noticeable enhancement of exergy efficiency. Decreasing the fins height and fins spacing are effective at low mass flow rates, but at high mass flow rates the inverse trend is observable, such that energy efficiency reduces sharply. The effects of air mass flow rate ranging between 0.01388 to 0.0833 kg/s on the collector efficiency factor, heat removal factor, outlet temperature, thermal, thermo hydraulic (effective) and energy efficiency .The efficiencies of offset finned solar collector were compared with conventional flat-plate.**

***Index Terms*— Thermal efficiency, Thermohydraulic efficiency, Energy efficiency, Parametric study, Offset fins, Plane solar air heater.**

I. Introduction

Solar thermal systems are used to utilize solar energy. The solar air heaters are one of the important device which 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 unfavorable thermo-physical properties of air. Thus, investigators have focused their studies toward diverse performance improvement strategies. Corrugated wall channel have been extensively studies by Piao et.al [1] to enhance the heat transfer rate. Goldstein, L. Sparrow, E.M [2] showed that heat transfer rate for corrugated channels were moderately larger than those for a smooth parallel plate channel in the laminar region. They also reported for turbulent flow, the wall corrugation were responsible for dramatic increase in the heat transfer rate compared with the smooth wall channel.Liu et.al [3] reported that the thermal efficiency of flat plate solar air heater can be increase by pin fin surface attached to the absorber plate in the range of 0.014 to 0.1kg/s mass flow rate and reducing inlet temperature. Paisarn Naphon [4] was found that the thermal

Grenze ID: 02.IETET.2016.5.5

efficiency increases with increase in number of fins. The entropy generation is inversely proportional to the number of fins. Irfan kurtbas &Emre turgut [5] analyzed the free and fixed form of fins absorber plate solar air heater. Results show the reverse relationship between exergy loss ratio and thermal efficiency as well as temperature difference of fluid. Fixed fin collector is more effective than free fin collector.

NOMENCLATURES

h_{vv}	5.67+3.86Vw, convection heat transfer Coefficient	S	absorber solar energy (W/m^2)
h_f	fin convection heat transfer coefficient (W/m^2 K)	U_t	top heat loss coefficient(W/m^2 K)
v_w	wind velocity (m/s)	Q_u	useful energy gain of solar air collector (W)
T_a	ambient temperature (K)	**Greek letters**	
T_{fe}	inlet air temperature of step in the collector (K)	e_{is}	insulation thickness (m)
T_n	mean absorber plate temperature (K)	δ	ratio t/l, dimensionless
C_p	specific heat of air (J/kg K)	d_x	elemental section (m)
C_f	Conversion factor (0.18)	β	collectors tilt angle (degrees)
M	quantities define by eq. (14) (m^{-1})	ρ_f	density of air (kg/m^3)
d_e	hydraulic diameter (m)	η_f	fin efficiency
A_c	dx.lc, elemental collector surface area (m^2)	τ_v	transparent cover transmittance
F'	collector efficiency factor of solar collector	ε_n	emissivity of black plate
G	air mass flow rate (kg/h)	ε_1	emissivity of the inner wall of the absorber plate
I_o	global irradiance incident on solar air heater (W/m^2)	λ_{is}	thermal conductivity of insulator (W/m K)
$\boldsymbol{U_b}$	bottom heat loss coefficient (W/m^2 K)	α	aspect ratio s/h dimensionless
U_L	global heat loss coefficient (W/m^2 K)	γ	ratio t/s, dimensionless
h_{rc}	radiation heat transfer coefficient (W/m^2 K^4)	σ	constant of Stefan Boltzman
h_1	convection heat transfer coefficient (W/m^2 K)	ν_s	dynamic viscosity of air (m^2/s)
v_f	average air velocity in the solar collector (m/s)	μ_f	Kinematic viscosity of air
T_f	air stream temperature of element in the collector (K)	α_n	absorber plate absorption coefficient
T_{fs}	outlet fluid temperature of element in collector (K)	ε_b	wood emissivity
T_2	mean temperature of collector(K)	ε_v	emissivity of glass
T_s	sun temperature(K)	Φ	quantity define by eq. (12)
k_f	thermal conductivity of fin (W/m K)	λ_f	thermal conductivity of air (W/m K)
A_d	cross surface area in channel duct of collector(m^2)	**Dimensionless number**	
A_f	total surface area of fins (m^2)	N_u	Nusselt number
F_R	heat removal factor of solar collector	P_r	Prandtl number
m	air mass flow rate (kg/s)	R_e	Reynolds number
		j	colburn factor

D.Bhandari & Dr.S.Singh [6] studied the different types of solar air heater (conventional, double glazing single pass and double pass finned solar air heaters) for the same mass flow rate. Results show that the double pass finned solar air heater was having the highest efficiency. Foued Chabane et.al [7] evaluated experimentally the thermal performance of a single pass solar air heater with fins attached, the efficiency increases with increase in solar intensity and take the constant values of a thermal efficiency in during the time of the solar midday to afternoon. K.Mohammadi & M.Sabzpooshani [8] evaluated the Performance of fins with baffles solar air heater .Results indicate that the outlet air temperature, efficiency and effective efficiency is higher.

In this study, a theoretical model has been presented to evaluate the exergetic performance of solar air heater with offset finned attached below the absorber plate. The offset fins parameters, i.e. fins spacing, and fin height as parametric variables as well as mass flow rate, solar radiation intensity have been varied to study their effect on the exergetic performance.

II. THEORETICAL ANALYSIS

Considered a solar air heater consists of a flat glass cover, absorber plate with offset finned attached below the absorber plate. The schematic diagram of offset fins solar air heater illustrated in Fig.1.

Where Lc, lc, s, t, h, D are the length of collector, width of collector, offset fin spacing, fin thickness, fin height and channel duct height, respectively.

The one dimensional mathematical formulation in the flow direction in steady state condition for offset finned absorber solar air heater has been considered as shown in Fig.1The following simplifying assumptions have been made:

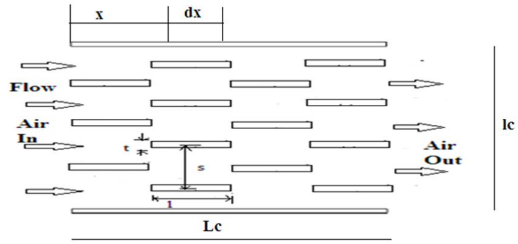

Fig.1.The top view of the absorber plate showing offset finned

- Thermal performance of collector is steady state.
- There is a negligible temperature drop through the glass cover, the absorber plate and the bottom plate.
- There is one-dimensional heat flow through the back insulation which is in the direction perpendicular to the air flow.

A. Energy balance equations

The energy balance equations for offset finned solar air heater absorber plate, glass cover and air stream can be written as follow:

Absorber plate

$$I_o(\tau_v a_n) = U_t.(T_n - T_a) + h_1.(T_n - T_f) + h_f{}^{\phi}(T_n - T_f) + h_r(T_n - T_2). \quad (1)$$

Bottom plate

$$h_r.(T_n - T_2) = h_1.(T_n - T_f) + U_b.(T_2 - T_a) \quad (2)$$

Air stream

$$\left(\frac{\dot{m}C_p.dT_f}{l_c d_x}\right) = h_1.(T_2 - T_f) + h_1.(T_n - T_f) + h_f.{}^{\phi}(T_n - T_f) \quad (3)$$

The hydraulic diameter is given by the following definition [24]:

$$d_e = \left(\frac{4.s.h.l}{2.(s.l+h.l+t.h)}\right) \quad (4)$$

B. Thermal Efficiency

The thermal efficiency can be expressed as:

$$\eta_{th} = \frac{\dot{m}C_p(T_{fs}-T_{fe})}{I_o A_c} \quad (5)$$

C. Performance optimization

The following expression for effective efficiency has been used in the present analysis.

$$\eta_{eff} = \frac{Q_u - \frac{P_m}{C}}{I_o A_c} \quad (6)$$

D. Exergy analysis

The exergy efficiency, called second law efficiency, of the solar air heater is calculated by dividing the useful exergy gain to the exergy of solar radiation as:

$$\eta_{II} = \frac{E_{Xu.p}}{I_o A_p \psi} = \frac{E_{Xu.p}}{I_O A_p(1-\frac{4}{3}\left(\frac{T_a}{T_s}\right)+\frac{1}{3}(\frac{T_a}{T_s})^4)} \quad (7)$$

III. CALCULATION PROCEDURE

For performing the calculations of this study a proper code in MATLAB 7.8.0 R2009a was developed considering the following configuration, system properties and operating conditions:

L_c = 1.5m, l_c = 1m, l = 0.02m, t = 0.003m, $\tau_v\alpha_n$ = 0.85, e_{is} = 0.04m, λ_{is} = 0.033 W/mK,

$T_s = 5762K, T_a = 298K, \varepsilon_b = 0.93, \varepsilon_v = 0.88, \varepsilon_n = 0.9, \mu_f = 18.97 \times 10^{-6} m^2/s, C_p = 1.005$ kJ/kgK, $\lambda_f = 0.02826\ W/mK, G = 50$ to $300 kg/h, D = 4cm, h = 3.8cm, I_o = 950W/m^2$.

IV. RESULTS AND DISCUSSION

In the following section, results of thermal, thermohydraulic and energetic performance evaluation of an offset finned solar air heater are presented.

The variation of outlet temperature and thermal efficiency with mass flow rate for different fins spacing and fin height at Io=950W/m2 were plotted in Figs.2 and 3.From the figures it is found that the trend of variation of outlet temperature and thermal efficiency reversed with mass flow rate, outlet temperature decreases and thermal efficiency increases with increase in mass flow rate. Accordingly with increase in mass flow rate, the percentage of increment of outlet temperature decreases. It is also seen the outlet temperature and thermal efficiency increases for lower value(s=1cm) of fins spacing. This is because the heat flow rate increases at lower fin spacing due to increase in heat transfer surface. . It is also found that outlet temperature and thermal efficiency decreases for higher value of fin height (h=5.8cm) at different mass flow rate. This effect can be attributed to the facts that increase in fin height decreases the overall heat transfer coefficient.

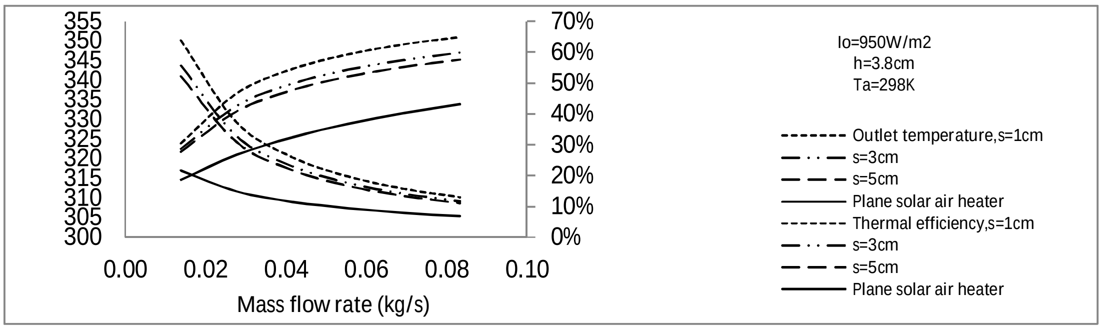

Fig.2.Outlet temperature and thermal efficiency vs. mass flow rate for Io=950W/m2

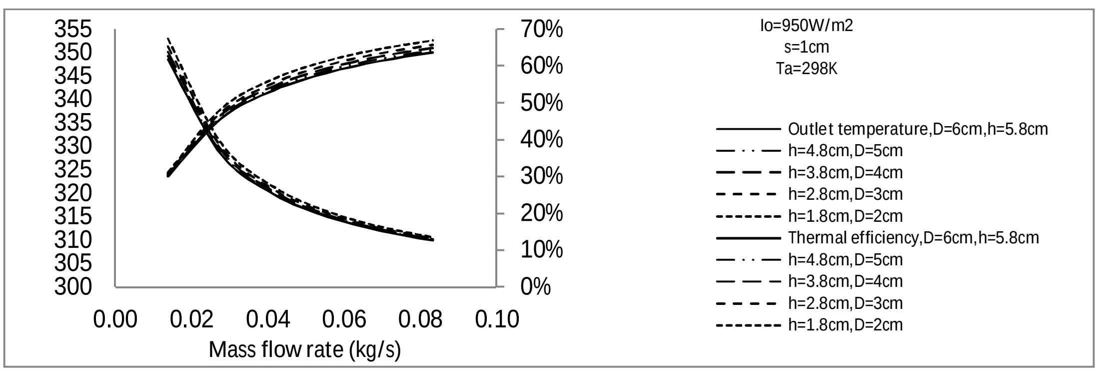

Fig.3.Outlet temperature and thermal efficiency vs. mass flow rate for Io=950W/m2

Figs.4-5 show the effect of mass flow rate on thermal and effective (thermohydraulic) efficiency for different value of fin spacing and fin height, respectively. It is seen that as the air mass flow rate increases, the thermal efficiency increases continuously and effective efficiency increases up to a threshold value of mass flow rate, attains a maximum, and then reduces sharply, there exists an optimum value of thermohydraulic efficiency for a given fins spacing. It is also found that for lower fins spacing the thermohydraulic efficiency is higher in between 0.020 to 0.040kg/s mass flow rate. This effect can be attributed to the fact that Reynolds number is strong parameter that affects the pumping power and thermal energy gain, thereby affecting the effective efficiency and the friction factor increases for higher mass flow rate and lower fin height, due to this the pressure drop increases.

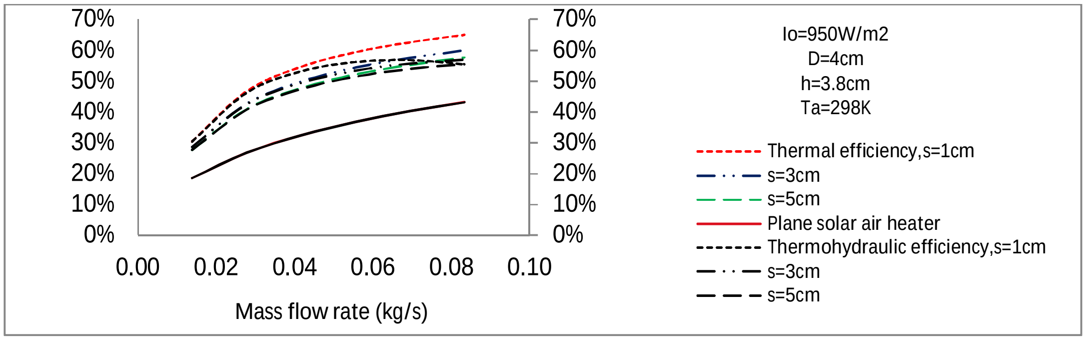

Fig.4.Thermal efficiency and effective efficiency vs. mass flow rate for Io=950W/m2

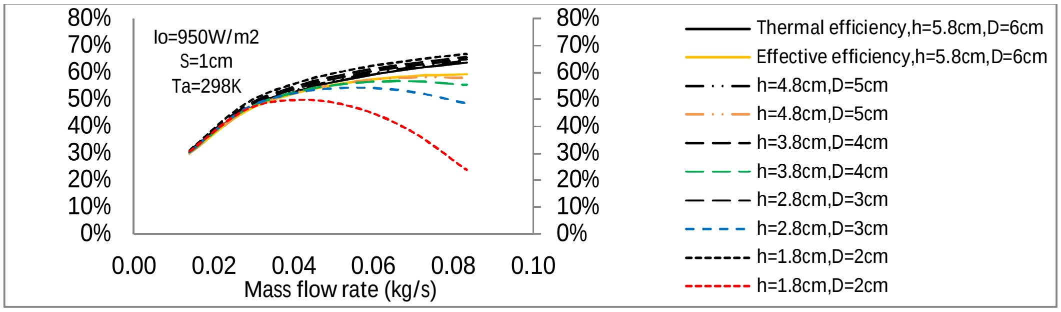

Fig.5.Thermal efficiency and effective efficiency vs. mass flow rate for Io=950W/m2

Figs.6-7 show variation of energy efficiency with mass flow rate for different fin spacing and fin height, respectively .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 energy efficiency at lower mass flow rate for Io=950W/m2; 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 energy efficiency decreases rapidly with increase in fin spacing. This is due to increased exergy destruction due to higher pressure drop in the channel. It is noticed that lower fin height (1.8cm) maintains the higher energy efficiency at lower mass flow rate, whereas for higher fin height (5.8cm) the reverse trend is observed.

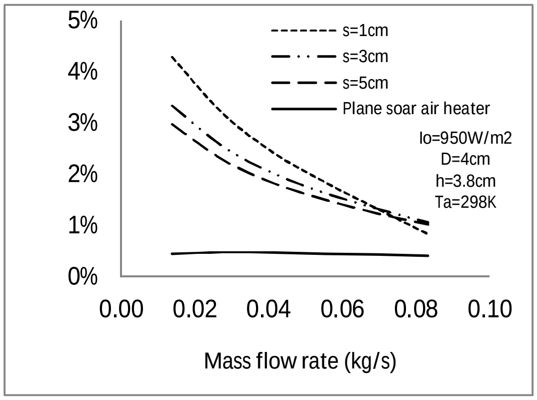

Fig.6. Energy efficiency vs. mass flow rate

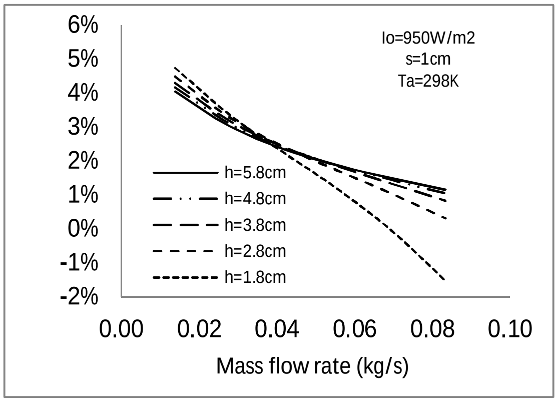

Fig.7. Energy efficiency vs. mass flow rate

V. CONCLUSIONS

- It is found that for higher value of the temperature rise parameter, the thermo hydraulic efficiency values closely follow the thermal efficiency values, whereas there is an appreciable difference in the lower range of temperature rise parameter values.
- The exergy analysis shows that the trend for the exergy efficiency is not the same.
- Comparison between the energy and exergy based analyses reveals that the exergy efficiency is a more accurate criterion for performance evaluation.
- According to the parametric study performed, the energetic performance is very sensitive to the variation of fins spacing.
- Attachment of the offset finned below the absorber plate at lower mass flow rates enhances the energy efficiency remarkably, however in higher mass flow rates; it does not result in significant improvement.

REFERENCES

[1] Piao.Y. Hauptmann E.G &Iqbal, M; Forced convective heat transfer in cross-corrugated solar air heater, Solar Energy, Engineering 1994; 116: 212-214.

[2] Goldstein,L.Sparrow,E.M;Heat/mass transfer characteristics for flow in a corrugated wall channel, ASME J.of heat transfer 1977; 99:187-195.

[3] Liu,Ye-Di,Diaz,L.A.and & Suryanarayana, N.V ;Heat transfer enhancement in air heating flat plate solar collectots,ASME Trans.1984;106:358-368.

[4] Paisarn Naphon; On the performance and entropy generation of the double-pass solar air heater with longitudinal fins, sciencedirect.com-renewable energy (Elsevier) 2004 30, 1345-1357.

[5] Irfan kurtbas &Emre turgut; Experimental Investigation of solar air heater with free and fixed fins: Efficiency and exergy loss, International journal of science & Technology, 2006, Vol 1, no, 75-82.

[6] D.Bhandari & Dr.S.Singh; Performance analysis of flat plate solar air collector with and without fins, International journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181 Vol.1 issue 6 August-2012.

[7] Foued Chabane, Noureddine Moummi &Said Benramache; Experimental performance of solar air heater with internal fins inferior an absorber plate: In the region of Biskra, International Journal of Energy &Technology 4 (33) (2012) 1-6, ISSN 2035-911X.

[8] K.Mohammadi & M.Sabzpooshani Comprehensive performance evaluation and parametric studies of single pass solar air heater with fins and baffles attached over the absorber plate. (Elsevier) Energy 57 (2013) 741-750.