Optimization of Single Pass Solar Collector with Fins Absorber Plate

Abhishek Kumar Dey[1], Abhishek Kumar Gupta[2]

[1]M.Tech, Research Scholar, Department of Mechanical Engineering, Shri Shankaracharya Engineering College, Bhilai, Chhattisgarh (India)
[2]Assistant Professor, Department of Mechanical Engineering, Shri Shankaracharya Engineering College, Bhilai, Chhattisgarh (India)

Abstract - *The main objective of the present work is to study effect of height of fin F_H, thickness of the fin Ft, no of fins, n and collector and fin length etc on first and second law performances. These performances have been compared for smooth solar air heater under the same operating parameters. From the study it was found with increasing the number of fins there is enhancement in the both performances parameters while increasing the duct height there is decrement in the both performances of SAHs. Furthermore optimal performance and mass flow rate has been achieved on the basis of second law analysis.*

Key Words: Fin solar air heater, Fin height, Fin thickness, duct height (H), Second law

1. INTRODUCTION AND LITRATURE SURVEY ON APPLICATION OF FINS

Solar collector is a simple system or device which works similar to a heat exchanger which, converts the solar energy which falls on its absorber plate into thermal energy and after that this thermal energy is used to raise the temperature of the fluid (air or water) flowing inside the collector. As per the requirements and temperature ranges the working fluid and its shape and designs may be changed [1-3]. Fig.1.

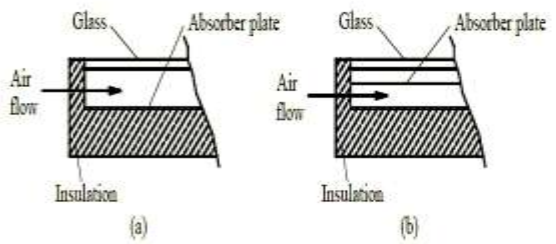

Fig.1. Types of Conventional solar air heater (a) With single glass having absorber plate, single pass (b) With single glass having absorber and bottom plate single pass

Garg and Datta [4] firstly investigated the fin type of solar heater by their experimental work. They have used 3 types of SAHs in the 1st SAH fins were attached in the upper plate with single and double glazing (glass) covers and for the 2nd type SAH corrugated absorber plate was employed.

Furthermore they have compared performances (Fin and corrugated SAHs) with simple smooth plate SAH by encompassing two different mass flow rates. The investigation was based on the effect fin density on the efficiency factor and outlet temperature of SAH.

Garg et al. [11-12] inserted rectangular fins in the air flow path between the absorber plate and rear plate. They have solved analytically the effect of number of fins (n), effect of mass flow rate (m) on energy performance and outlet air temperature. The effect of length of fins (F_L) and depth of the air channel (H) were also investigated on energy, outlet temperature of air and effective heat gain criteria. Finally the performance of finned SAH is compared with the conventional flat plate SAH.

Hachemi [13] carried out his experimental investigation on staggered fin which is soldering underside of the absorber plate. Effect of four different fin length (L) from 2.5 to 20 cm and space between consecutive fin rows (e) 2.5 and 5.0 cm in the staggered fin rows is explored by the author.

He found that efficiency of finned SAH is increases when distance between consecutive row of fin decreases and considerable enhancement in the air temperature as compared to the flat plate solar air heater was achieved.

A. Hachemi [14] carried out his experimental investigation on offset rectangular fin soldering underside of the absorber plate. The fin was placed on the staggered pattern on the absorber plate. The Effect of plate fin length (F_L) and effect of double and triple glass covers on the energy performance of both i.e. fin and flat plate SAH was investigated. The effects of fin length on the electrical power with function of mass flow rate are also investigated and presented by author.

Yeh et al. [15] carried out his experimental and analytical investigation on double flow (air flows on both sides of absorber plate) SAH with fins attached on both upper and lower channels. The air flows simultaneously on upper and lower channel at the same time.

The fraction of mass flow rate (r) on the upper and lower channel and energy efficiency of solar air heater is investigated with three different mass flow rate 38-78 kg/hr. They found good agreement between theoretical and experimental work. Double flow performance was higher as compared to the single flow at fraction of airflow rate value of 0.5.

Youcef Ali [16] carried out his experimental investigation by employing offset rectangular plate fins which are used in the heat exchanger. The fins was placed on staggered pattern parallel to the fluid flow and kept underside of the absorber plate. Collector length was taken as 1.6 m and width 0.8 m with single, double and triple glazing. A maximum efficiency of fin solar air heater was found value of 68% for the mass flow rate of 50 kg/h m^2.

Karim and Hawlader [17] carried out there experimental investigation by employing offset rectangular plate fins which are used in the heat exchanger. The fins was placed on staggered pattern parallel to the fluid flow and kept underside of the absorber plate by soldering. Collector length was taken as 1.6 m and width 0.8 m with single, double and triple glazing. A maximum efficiency of fin solar air heater was found value of 68% for the mass flow rate of 50 kg/h m^2.

Chabane et al. [18] carried out there experimental work by using longitudinal fins with Reynolds number (Re) range 965-1301 and mass flow rate (m) 0.012-0.016 kg/s. Authors were investigate and explored the effect of mass flow rate on outlet air temperature of air, Prandtl number (Pr) and effect of length of collector was investigated. The collector area was taken as 2 m^2 with fin in the form of semi-cylindrical, longitudinal along the air flow side.
They have compared smooth SAH under similar conditions. They developed the correlation on the basis of experimental results.

Thermal and thermohydraulic performance of solar air heater having wavy finned absorber plate was investigated by analytically by Priyam and Chand [12]. They investigate effects of fin spacing (e) on thermal performance, collector heat removal factor, pressure drop, air temperature rise parameter and effective efficiency of the solar air heater.

Energy and exergy of SAH having wavy fin absorber plate was investigated by analytically [19]. They investigated effects of mass flow rate and fin spacing on, 2nd law efficiency (exergy efficiency) and exergy destruction.

Furthermore effect of wavelength and amplitude on thermal and thermohydraulic performance of SAH having wavy fin absorber plate explored by [19, 22]. They reported that increasing the wavelength (from 3 cm to 20 cm) and amplitude (from 0.5 cm to 2.5 cm) decreases, thermal efficiency, collector heat removal factor, collector efficiency factor, effective temperature rise and effective efficiency for wavy fin SAH.

2. AIMS OF PRESENT WORK

(1) Analysis for rectangular shape fins placed, longitudinal SAH with single glass cover in order to find the second law of thermodynamic based useful exergy (Ex_{up}), entropy generation (EG), entropy generation number, entropy generation rate (S_{gen}) and other performances.

(2) Comparison of above performances parameters for present fin SAH with conventional SAH under similar operating conditions.

(3) A comparison of present obtained results with available experimental data, reported by other investigators in the literature in order to validate the present work.

(4) To perform detailed parametric analysis and analyze i.e. effect of mass flow rate (m), mass velocity (G), Reynolds number (Re), Solar –radiation intensity (I), fin height (F_H), fin length (F_L), fin thickness (t), duct height (H) etc. on various performances and factors of both SAHs.

By parametric analysis investigate and present those geometric and operating parameters which deliver the maximum desired performance.

Furthermore investigations on the enhancement of different performances parameters of fin SAH as compared to that of conventional or flat plate SAH. Optimum design conditions which deliver maximum performance has also been presented.

Fig. 1 and Fig. 2 show the length and width and other details of the SAH and fins respectively. The various performance calculations and procedures will be done by using following equations.

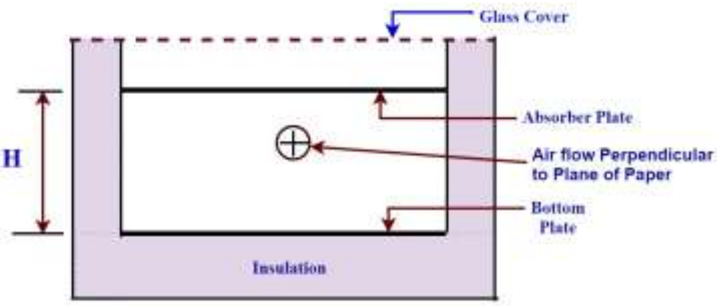

Figure 1 Conventional smooth absorber plate SAH (Front view)

3. THERMAL AND EFFECTIVE EFFICIENCY CALCULATION

The thermal energy efficiency of SAH is calculated as:

$$\eta_{th} = \frac{Q_u}{IA_c} \qquad (1.1)$$

Where
$Q_u = m.Cp. (T_{fo}-T_{fi})$

The effective efficiency is defined as ratio of net thermal energy gain of solar air heater to the falling incident solar radiation on the absorber plate.

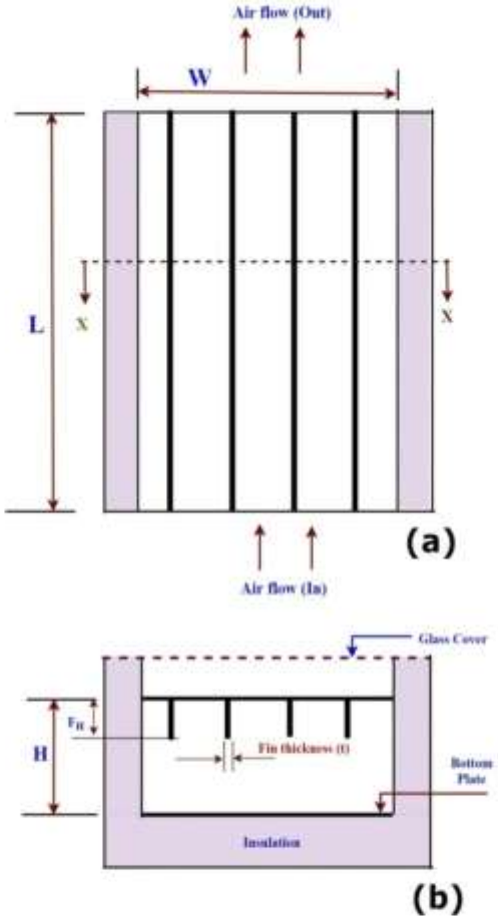

Figure 2 Rectangular shape longitudinal fins attachment on SAH for present analysis (a). Top view (b). Front view

The effective efficiency takes in account the fan mechanical work (Wp) by subtracting the equivalent thermal energy from useful output power (Q_u) by air heater to obtain net thermal energy gain.

$$\eta_{eff} = \frac{Q_u - \left(Wp / C_{fan} \right)}{I \times A_c} \quad (1.2)$$

$$W_P = V A_c \Delta P \quad (1.3)$$

The Value of pressure drop (ΔP) in the duct is calculated as:

$$\Delta P = \frac{2 f L V^2 \rho}{D} \quad (1.4)$$

The values of heat transfer coefficient, (h) and friction factor, (f) for smooth solar air heaters have been evaluated by [1-2, 12];

$$Nu = 0.0158 \,\mathrm{Re}^{0.8} \quad (1.5)$$

Friction factor, (f_s) for smooth solar air heaters is calculated by;

$$f_s = 0.050 \,\mathrm{Re}^{-0.25} \quad (1.6)$$

The effectiveness of fin (ϕ) is given by

$$\phi = 1 + \left[\frac{A_f}{A_c} \right] \eta_f \quad (1.7)$$

Where surface area of fin (A_f) is evaluated as calculated as;

$$A_f = 2.\mathrm{n}.\mathrm{H}_F \times L_F \quad (1.8)$$

Fin efficiency of solar air heater with rectangular longitudinal fin is given by;

$$\eta_f = \left[\frac{\tanh.(M.\mathrm{H}_F)}{(M.\mathrm{H}_F)} \right] \quad (1.9)$$

Where (M) is the dimensionless term and it is the function of fin thickness (t), thermal conductivity of fin (K_f) and heat transfer coefficient between flowing fluid and fin absorber plate.

$$M = \sqrt{2h_{c-ab-f} / K_f.t} \quad 1.10$$

Friction factor for fin SAH is calculated by [1-2, 12];

$$f = 0.079 \,\mathrm{Re}^{-0.25} \quad 1.11$$

The values of heat transfer coefficient, (h) for longitudinal fin absorber plate solar air heaters have been determined by the correlations developed for heat transfer by[14-15] which is given by;

$$Nu = 0.0293 \,\mathrm{Re}^{0.98} \quad (1.12)$$

4. SECOND LAW ANALYSIS

Where, $EX_{u,p}$ is the useful exergy gain including the blower work by air flowing through the SAH duct, and is given by

$$EX_{u,p} = EX_o - EX_i - EX_w$$

$$= \dot{m}.C_p(T_{fo} - T_{fi}) - \dot{m}.C_p T_a.\ln\left(\frac{T_{fo}}{T_{fi}}\right) - \frac{T_{fo}}{T_{fi}}\dot{W}_p \quad (1.13)$$

The entropy created (S_{gen}) owing to heating of air and the blower work is

$$S_{gen} = \dot{m}.\mathrm{C_p}\ln\left(\frac{T_{fo}}{T_{fi}}\right) + \frac{\dot{W}_p}{T_{fi}} \quad (1.14)$$

Total entropy generated $(S_{gen})_{Total}$ is given by [28-31]

$$(S_{gen})_{\mathrm{Total}} = T_a.S_{gen} \quad (1.15)$$

The exergy collection efficiency (η_{Ex}) based on second law of thermodynamics by taking exergy of solar radiation can be written as [7, 8]

$$\eta_{Ex} = \frac{EX_{u,p}}{EX_i} = \frac{EX_{u,p}}{A_c.I.\xi} \quad (1.16)$$

Table 1 THE VALUES OF PARAMETERS CONSIDERED FOR THE PRESENT INVESTIGATION:

Parameters	Symbol	Value and Range	Unit
System parameters			
Collector length	L	2.0	m
Collector width	W	1.0	m
Height of Duct	H	0.030	m
Thickness of insulation		0.05	m
Thermal conductivity of insulation	Ki	0.037	W/m K
Number of glass covers	N	1	W/m K
Emissivity of absorber plate	ε_p	0.90	
Emissivity of glass cover	ε_g	0.85	
Transmittance-absorptance product	$\tau\alpha$	0.85	
Fin height Fin thickness	F_H t	0.020 - 0.050 0.001-0.003	m m
Number of fins	n	20-50	
Overall heat loss coefficient	U_l	4-10	W/m² K
Operating parameters **Fixed**			
Ambient air temperature	T_a	300	K
Intensity of solar radiations	I	700-1000	W/m²
Variable parameters			
Mass flow rate		0.0207 to 0.2171	kg/s-m²
Reynolds number Re		2048-22740	

Where, ξ is the exergy efficiency of incident solar energy and is given by [24]

$$\xi = 1 - \frac{4}{3}\left(\frac{T_a}{T_s}\right) + \frac{1}{3}\left(\frac{T_a}{T_s}\right)^4 \quad (1.17)$$

And the sky temperature T_s is given by

$$T_s = 0.0552 T_a^{1.5} \quad (1.18)$$

5. RESULT AND DISCUSSION

5.1. Effect of fin density

Fig.3 has been plotted between mass flow rate (m) and thermal efficiency (η_{th}) in order to understand the effect of fin density (no of fins) on efficiency of fin SAH.

The values of (n) have been taken as 20 and 50 for the purpose of comparison. The other specific parameters have been shown in the fig.

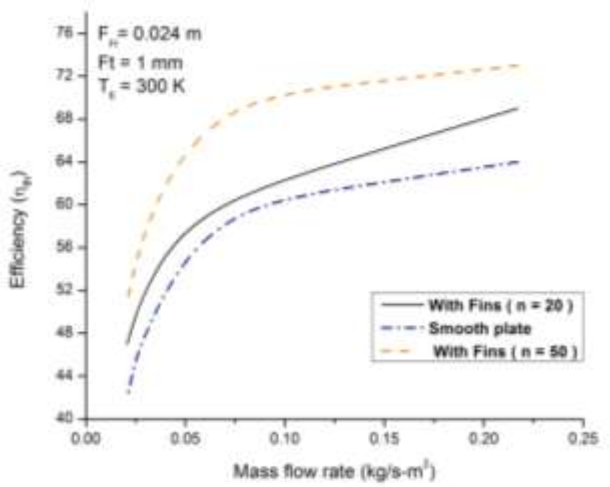

Figure 3 Thermal efficiency variation for fin density as function of mass flow rate for both SAHs

5.2. Effect of fin height

Fig.4 shows the effect of different fin height values (F_H) on useful heat gain of fin SAH with change in the values of m. The fixed parameter was taken as, fin thickness t = 0.001 m, fin length F_L = 1.99 m, I = 800 W/m^2, n =50, T_{fi} = 300 K.

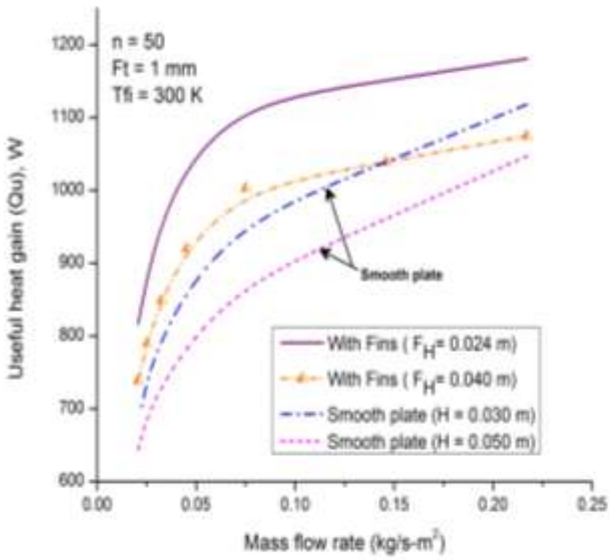

Figure 4 Comparison of energy efficiency of fin and smooth plate SAHs with different fin height values as function of m

Fig.5 shows energy efficiency performance analysis for varying F_H for fin SAHs and comparison have been made with flat plate SAH. It is clearly visible that by SAH having less F_H having more energy efficiency as compared to higher one. This phenomenon is also followed by smooth absorber SAH.

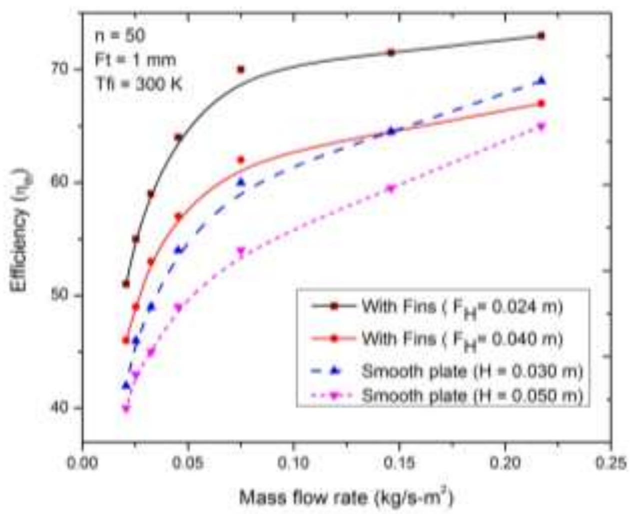

Figure 5 Comparison of energy efficiency of fin and smooth plate SAHs with different fin height values as function of m.

Fig.6 shows the comparison for useful exergy output for smooth plate and fin SAHs. The all fixed parameters like F_H , n, Tfi etc have been already given in the fig.

It can be seen from fig that useful exergy output for both SAHs increases up to certain value of mass flow rate (also called critical or optimum m) after that it starts decreases with further increase in the values of m.

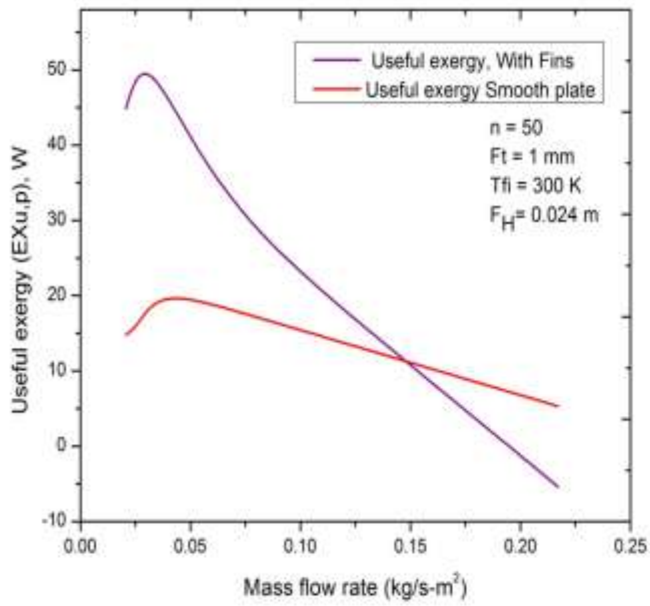

Figure 6 Variation of useful exergy output for fin and smooth absorber SAHs.

It is clearly visible that by inserting fin in SAH having advantages Exup up to m < 0.15 kg/s-m^2.

Fig.7 shows the comparison for entropy generation rate for both SAHs as function of m. The all fixed parameters like F_H , n, T_{fi} etc have been already given in the fig.

It can be seen from fig that entropy generation rate for both SAHs increases for all values of mass flow rate. It can be seen that SAH having more number of fins (n = 50) is having low values of S_{gen} as compared to SAH having n =20.

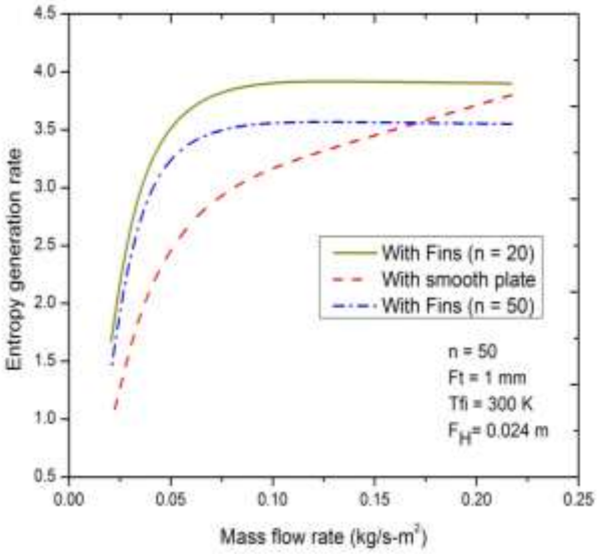

Figure 7 Variation of entropy generation rate as function of mass flow rate for varying number of fins for fin and smooth absorber SAHs.

Furthermore (from fig 7) smooth absorber SAH having higher values of S_{gen} after m > 0.15 kg/s-m², however S_{gen} values is less than for fin SAH having n = 20 for all values of m.

Fig.8 shows the comparison for Irreversibility for both SAHs as function of m. The all fixed parameters like F_H , n, T_{fi} etc have been already presented in the fig.

It can be seen from fig that Irreversibility for all have been SAHs as increases in the values of mass flow rate. It can be seen that SAH having more number of fins (n = 50) is having low values of Irreversibility as compared to SAH having n =20.

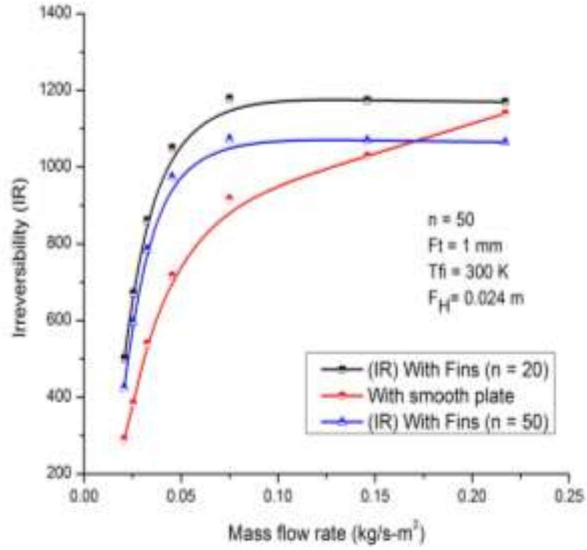

Figure 8 Irreversibility comparison for varying number of fins for fin and smooth absorber SAHs.

Fig.9 shows the comparison for useful exergy output and entropy generation rate for both SAHs as function of m.

The all fixed parameters like F_H , n, T_{fi} etc have been already given in the fig. It can be seen from fig that entropy generation rate for both SAHs increases for all values of mass flow rate.

It can be also seen that for both SAHs useful exergy output increases up to certain value of mass flow rate after that its trend is starts decreases with further increase in the values of m.

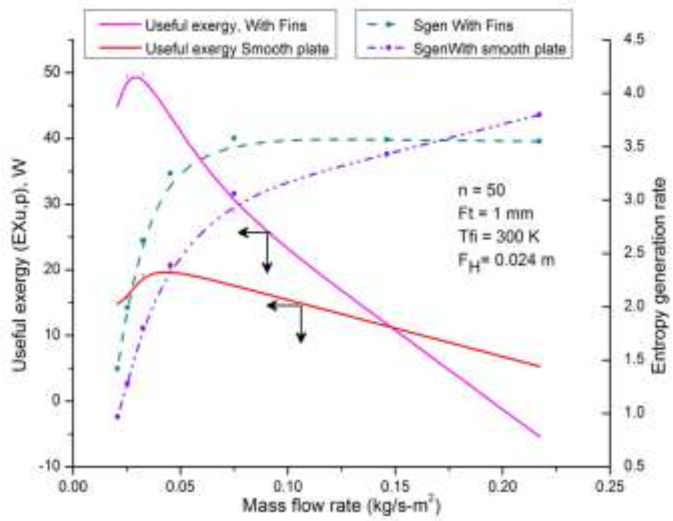

Figure 9 Variation of useful exergy output and entropy generation rate comparison for fin and smooth absorber SAHs as function of mass flow rate.

5. CONCLUSIONS

1. With increasing the fin height form 0.024 to 0.040 m there is decrement in the thermal performance of fin solar air heater. i.e. thermal performance is higher for the low value of fin height for present analysis.
2. With increasing the duct depth there is decrement in the values of useful heat gain and also thermal performance for both SAHs.
3. Increasing the fin density there enhancement in the values of useful heat gain and also thermal performance for fin SAH.
4. It can be seen from that useful exergy output for both fin and smooth SAHs increases up to certain value of mass flow rate after that it starts decreases with further increase in the values of m. So there is an optimum value of m for each values of geometrical and operating parameters n, for fin along with smooth SAHs.

5. With increasing the fin density there is decrement in the values of entropy generation rate and Irreversibility.

6. REFERENCE

1. Duffie JA, Beckman WA. Solar engineering of thermal processes. New York: Wiley; 1991.
2. Garg HP, Prakash J. Solar energy fundamentals and applications. New Delhi: Tata McGraw-Hill; 1997.
3. Incropera FP, De Witt D P, editors. Fundamentals of heat and mass transfer. 5th ed. New York: John Wiley & Sons; 2006.
4. Md. Azharul Karim, M.N.A. 2006, Hawlader. Performance evaluation of a v-groove solar air collector for drying applications.Applied Thermal Engineering,26 :121–130.
5. Tabish Alam , R.P. Saini , J.S. Saini,2014, Heat and flow characteristics of air heater ducts provided with turbulators—A review, Renewable and Sustainable Energy Reviews ,31: 289–304.
6. Ho-Ming Yeh, Chii-Dong Ho, Chi-Yen Lin,2000, Effect of collector aspect ratio on the collector efficiency of upward type baffled solar air heaters. Energy Conversion &Management, 41: 971-981.
7. S. Jaisankar,J. Ananth ,S. Thulasi , S.T. Jayasuthakar , K.N. Sheeba,2011, A comprehensive review on solar water heaters,Renewable and Sustainable Energy Reviews,15 3045–3050.
8. M.S. Hossain , R. Saidur, H. Fayaz , N.A. Rahim, M.R. Islam , J.U. Ahamed, M.M. Rahman, 2011, Review on solar water heater collector and thermal energy performance of circulating pipe,Renewable and Sustainable Energy Reviews , 15: 3801–3812.
9. Satyender Singh , Prashant Dhiman,2016, Thermal performance of double pass packed bed solar air heaters – A comprehensive review, Renewable and Sustainable Energy Reviews, 53, 1010–1031.
10. Adnane Labed, Noureddine Moummi, Adel Benchabane, Kamel Aoues, Abdelhafid Moummi, 2012,Performance investigation of single- and double-pass solar airheaters through the use of various fin geometries. International Journal of Sustainable Energy, 423–434.
11. H. P. Garg, G. Datta.Performance Studies on a Finned Air Heater. Energy 1989; 14, 87-92.
12. H.P. Garg, Ranjana Jha, C. Choudhury, Gouri Datta,1991,Theoretical Analysis on a New Finned Type Solar Air HeaterEnergy, 16: 1231-1238.
13. A. Hachemi,1995,Thermal Performance Enhancement of SolarAir Heaters, by a Fan-Blown Absorber Plate with Rectangular Fins, 19: 567-578.
14. A. Hachemi, 1999, Experimental study of thermal performance of offset rectangular plate fin absorberplates.Renewable Energy, 17; 371-384.
15. H.-M. Yeh, C.-D. Ho, J.-Z. Hou,2002, Collector efficiency of double-flow solar air heaters with fins attached, Energy, 27 :715–727
16. S. Youcef-Ali,2005,Study and optimization of the thermal performances of the offset rectangular plate fin absorber plates, withvarious glazing. Renewable Energy,30: 271–280.
17. Md. Azharul Karim, M.N.A Hawlader, 2006, Performance investigation of flat plate, v-corrugatedand finned air collectors,Energy, 31; 452–470.
18. Foued Chabane, Noureddine Moummi, Djamel Bensahal, Abdelhafid Brima,2014,Heat Transfer Coefficient and Thermal Losses of Solar Collector and Nusselt Number Correlation for Rectangular Solar Air Heater Duct with Longitudinal Fins Hold under the Absorber Plate.Applied Solar Energy ,50: 19–26.
19. Abhishek Priyam, Prabha Chand, Suresh Prasad Sharma, Energy and Exergy Analysis of Wavy Finned Absorber Solar Air Heater. International Energy Journal ,16, 2016, 119-130..
20. Cortes A, Piacentini R, 1990, Improvement of efficiency of a bare solar collector by means of turbulence promoters. Appl Energy, 36:253–61.
21. El- Sebaii, A.A. Aboul-Enein, S.Ramadan, M.R.I. Shalaby, S.M. Moharram, B.M.,2011, Thermal performance investigation of double pass-finned plate solar air heater. Appl. Energy, 88: 1727–1739
22. Paisarn Naphon, 2005, Effect of porous media on the performance of the double-pass flat plate solar air heater, International Communications in Heat and Mass Transfer,, 32, 140–150.