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Parametric Effect on Performance Enhancement of Offset Finned Absorber Solar Air Heater

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Abstract: *In this study, A parametric study was done to investigate the effect of variation of system and operating parameters i.e. fin spacing, fin height, fluid mass flow rate and insolation on the performance enhancement (efficiencies) of offset finned absorber solar air heater. Results indicate that the thermal efficiency increases continuously with increase in fluid mass flow rate, whereas thermohydraulic efficiency increases upto a threshold value of fluid mass flow rate, attains a maximum and then decreases sharply for a given fin spacing and fin height. For higher value of the fluid temperature rise parameter, the effective efficiency values closely follow the thermal efficiency values. It is found that attaching offset fins below the absorber plate at lower fluid mass flow rate can lead to appreciable enhancement of the thermal and thermohydraulic efficiencies.*

Keyword: Flat plate collector, offset fins, thermal performance, effective efficiency.

1. INTRODUCTION

Solar air heaters are simple gambits that utilize incident solar radiation to obtain solar energy for wide utilization. Solar air heater are the most frugal and extensively used solar energy accumulation collector employed to distribute heated air at low mitigate temperature for space heating, vegetables and some modern applications. Thus, investigators have focused their research toward diverse performance amelioration methods. The Corrugated wall channel has been extensively studied by [1] to enhance the heat transfer rate. [2] Showed that heat transfer rate for corrugated channels were moderately more astronomically immense than those for a smooth parallel plate channel in the laminar region. Further, reported for turbulent flow, the wall corrugation were responsible for dramatic increase in the heat transfer rate compared with the smooth wall channel. The efficiency of air heating flat plate solar air heater can be increases by decrease in the absorber plate temperature by providing it pin-fin surface reported by [3]. An investigation was done at air mass rate ranging between 0.02 and 0.1 kg/s. The thermal efficiency increases with increase in the number of fins and the entropy generation is inversely proportional to the number of fins [4]. The rectangular forms of fins having two different surface areas were located on absorber surface in free and fixed manners. There was a reverse relationship between exergy loss ratio and collector efficiency as well as temperature difference of fluid. Fixed fin collector is more effective than free fin collector [5]. The thermal and thermohydraulic performance characteristics of wavy finned absorber solar air heater and evaluated the effect of mass flow rate, insolation and fin spacing [6]. The enhancement in collector efficiency is obtained by recycle operation up to 65% [7]. The solar collector with fin and TMS (thin metal sheet) are more effective than other system collector which without TMS at higher Reynolds number and lower duct height/fin height [8].A design criterion for matrix selection by which packing the air flow duct of a solar air heater which gives the best thermal efficiency with minimum pumping power suggested by [9]. The temperature difference between the outlet fluid flows and the ambient was decreased with increasing mass flow rate of air, for the same air mass flow rate the thermal efficiency increased with increasing the number of the fins. If the operation is carried out with an internal recycle to increase the fluid velocity, leading to improve heat transfer coefficient .The enhancement in collector efficiency increase with increasing reflux ratio, especially for operating at lower air mass flow rate with higher inlet air temperature [10]. In the present work, Parametric effect on performance enhancement of offset finned absorber solar air heater is being reported. The effect of system parameters i.e. fin spacing and fin height and operating parameters viz. fluid mass flow rate and insolation on the thermo hydraulic performance are also reported and results are compare with plane solar air heater.

NOMENCLATURE

A_s	$dx.W_s$, elemental surface area of the solar collector (m^2)	E_{fo}	Thermohydraulic percentage enhancement factor
A_c	cross surface area of the solar collector duct (m^2)	h_r	radiation heat transfer coefficient between the absorber plate and bottom plate (W/m^2K^4)
A_t	total surface area of the fins (m^2)	v_a	wind velocity (m/s)
d_e	equivalent hydraulic diameter of solar collector (m)	v_a	average air velocity in the solar collector (m/s)
θ_{fi}	inlet fluid temperature in the solar collector (K)	k_{fi}	thermal conductivity of fin(W/m-K)
		C_f	conversion factor(0.18)
θ_{p}	absorber plate mean temperature in solar collector (K)		**Greek letters**
θ_2	bottom plate mean temperature (K)	dx	elemental section of solar collector length(m)
θ_f	air stream temperature in the solar collector (K)	β_t	solar collector tilt angle (degrees)
U_b	bottom heat loss coefficient of solar collector (W/m^2K)	ρ_a	air density (kg/m^3)
U_{tl}	top loss coefficient through solar collector (W/m^2K)	ε_b	emissivity of bottom plate
U_O	overall heat loss coefficient of solar collector (W/m^2K)	ε_a	emissivity of inner surface of absorber plate
F'_c	collector efficiency factor of solar collector	a	aspect ratio s_f/h_f, dimensionless
F_H	heat removal factor of solar collector	b	ratio t_f/l_f,dimensionless
Q_u	Useful heat gain rate for the solar collector (W)	c	ratio t_f/s_f,dimensionless
h_c	convective heat transfer coefficient (W/m^2K)	σ_s	stefan boltzmann constant
h_{fi}	convective heat transfer coefficient between offset fins and air (W/m^2K)	ν_d	dynamic viscosity of air (m^2/s)
h_a	convective heat transfer coefficient between absorber plate and air (W/m^2K)	ϕ_{fi}	quantity define by eq.(14)
h_r	radiation heat transfer coefficient between the wall(W/m^2K^4)	N_u	Nusselt number
$\Delta\theta$	Rise in temperature $(\theta_{fo} - \theta_{fi})$	P_r	Prandtl number
$E_{t\Delta}$	Temperature rise percentage enhancement factor	R_e	Reynolds number
E_{ft}	Thermal efficiency percentage enhancement factor	j_f	colburn factor

2. THEORETICAL ANALYSIS

A solar air heater having offset finned below the absorber plate as shown in Figs.1-3 has been considered. The energy balance equations are written on the basis of following assumptions [11]:

(1). Steady state performance of solar collector.
(2). There is no absorption of solar energy by glass cover.
(3). One dimensional heat flow through glass cover and back insulation.

2.1 General heat balance equations

Consider elemental view of width ‘W_s ’ and thickness ‘dx’ at a distance x from inlet as shown in Fig.3, then the energy balance equations for the absorber plate, the bottom plate and the air flowing in between can be written respectively as:

Absorber plate

$$I_o(\tau_c\alpha_b) = U_t(\theta_n - \theta_a) + h_a\ (\theta_n - \theta_f) + h_f\ \phi_{fi}\ (\theta_n - \theta_f) + h_r\ (\theta_n - \theta_2) \quad (1)$$

Bottom plate

$$h_r\ (\theta_n - \theta_2) = h_a\ (\theta_n - \theta_f) + U_b\ (\theta_2 - \theta_a) \quad (2)$$

Air stream

$$\frac{C_p d\theta_f \dot{m}}{W_s\ d} = h_a\ (\theta_2 - \theta_f) + h_a\ (\theta_n - \theta_f) + h_f\ \phi_{fi}\ (\theta_n - \theta_f) \quad (3)$$

2.2 Distribution of temperature

The outlet air temperature of the collector can be obtained from an energy balance equation:

$$\frac{\theta_{fi}\ -\theta_a-\left(\frac{S}{U_O}\right)}{\theta_f\ -\theta_a-\left(\frac{S}{U_O}\right)} = \exp\left(-\frac{A_c\ U_O\ F'_c}{\dot{m}C_p}\right) \quad (20)$$

The mean temperature of the absorber plate and the back plate are obtained by solving the energy balance equation given as:

$$\theta_n - \theta_f = \left(\frac{S(U_b\ +h_b\ \phi_{fi}\ +h_r\ )-(\theta_f-\theta_a)(U_b\ U_t+U_b\ h_r\ +U_t h_b\ \phi_{fi}\ +U_t h_r\ )}{(U_t+h_a\ +h_r\ )(U_b\ +h_b\ \phi_{fi}\ +h_r\ )-h_r^2}\right) \quad (21)$$

and

$$\theta_2 - \theta_f = \frac{h_r\ S-(\theta_f-\theta_a)(U_b\ U_t+U_b\ h_r\ +U_t h_r\ +U_b\ h_a\ )}{(U_t+h_a\ +h_r\ )(U_b\ +h_b\ \phi_{fi}\ +h_r\ )-h_r^2} \quad (22)$$

The mean air stream temperature can be expressed as [11]:

$$\theta_f = \theta_{fi} + \left(\frac{\frac{Q_u}{A_s}}{F_H\ U_O}\right)\left(1 - \left(\frac{F_H}{F'_c}\right)\right) \quad (23)$$

The absorbed solar energy is defined by:

$$S = (\tau_c\alpha_a)I_o \quad (24)$$

The useful energy gain is expressed as:

$$Q_u\ = A_s\ F_H\ \left(S - U_O\ (\theta_{fi} - \theta_a)\right) \quad (25)$$

2.3 Thermal efficiency

The thermal efficiency can be expressed as:

$$\eta_t\ = \frac{Q_u\ \text{(useful gain of energy carried away by air)}}{I_o A_s}$$

$$\eta_t\ = \frac{\dot{m}C_p(\theta_f\ -\theta_f)}{I_o A_s} \quad (26)$$

2.4 Thermo hydraulic performance

Thermo hydraulic performance of offset finned solar air heater can be optimized by considering the conversion factor which has been responsible for actual energy gain from conversion of primary energy to mechanical energy, because of losing a considerable part of the energy in conversion and transmission. In order to investigate the thermohydraulic performance of the collector, the following expression for effective efficiency has been used in the present analysis.

$$\eta_e = \frac{Q_u - \frac{P_m}{C_f}}{I_o A_c} \tag{27}$$

Whereas the value of conversion factor, C_f, recommended by [13] is 0.18.

The mechanical power, P_m, required to blow the air through the duct is given by:

$$P_m = \frac{\dot{m}\Delta p_d}{\rho_a} \tag{28}$$

The pressure drop, Δp_d across the duct of solar air heater of length, L_s, can be determined from the following expression:

$$\Delta p_d = \frac{f_p L_s \rho_a V^2}{2 d_e} \tag{29}$$

The friction factor f_p can be calculated using the correlation reported by [12] as:

$$f_p = 9.6243.\, R_e^{-0.7} \quad a^{-.1} \quad b^{0.3} \quad c^{-0.2} \quad (1 + 7.669 \times 10^{-8}) R_e^{4.4} \quad a^{0.9} \quad b^{3.7} \quad c^{0.2}$$

The effective efficiency has been evaluated using Eq. (27) for various values of system geometrical parameters and operating parameters.

3 CALCULATION PROCEDURE

A proper code in MATLAB 7.8.0 R2009a was developed by considering the following system, system properties and operating conditions as listed in Table 1 for an analytical investigation on thermal and thermohydraulic performance of offset finned absorber solar air heater.

4 RESULTS AND DISCUSSION

In the following section, results of an analytical investigation on thermal and thermohydraulic performance of an offset finned absorber solar air heater are presented.

Fig.4 shows the collector efficiency factor as a function of fluid mass flow rate for different value of fin spacing and insolation Io=950 W/m^2.It is seen from the figure that use of attaching offset finned below the absorber plate, a substantial enhancement of collector efficiency factor as compared to plane solar air heater is achieved. It has been found that the collector efficiency factor moderately increases with increase in mass flow rate and decrease in fin spacing, as from the figure it is seen that collector efficiency factor increases with increase in fluid mass flow rates. This is due to facts that the heat transfer coefficient increases as the fluid velocity increases with increase in fluid mass flow rate and decrease in fin spacing, although the mean plate temperature decreases.

Fig.5 shows the variation of collector efficiency factor as a function of fluid mass flow rate for different fin height and Io=950 W/m^2. From the figure, it is clearly seen that collector efficiency factor increases with increase in fluid mass flow rate for all values of fin height. It is also observed that increase in height of offset fin decreases the collector efficiency factor for all values of fluid mass flow rate. This is because of increasing in offset fin height increases the heat transfer surface area; however it decreases the convective heat transfer coefficient.

Fig.6 shows the effect of fin spacing of offset finned below the absorber plate solar air heater on the collector heat removal factor at various mass flow rate of fluid for Io=950 W/m^{2}From the plots it is seen that collector heat removal factor increases with increase in fluid mass flow rate and decrease in fin spacing. The lower value of fin spacing shows the drastic increase in collector heat removal factor. This is probably because of increase in surface conductance of fins to flowing air.

Fig.7 shows the variation of collector heat removal factor as a function of fluid mass flow rate for different fins height and Io=950 W/m^{2}Result shows that the collector heat removal factor randomly increases with increase in fluid mass flow rate .It is also observed that increase in height of offset fin decreases the collector heat removal factor for different fluid mass flow rate. This is due to facts that increase in fins height (i.e. duct height) decreases the surface conductance of the fins.

The variation of outlet fluid temperature and thermal efficiency with fluid mass flow rate for different fin spacing for Io=750 W/m^{2}and Io=950 W/m^{2}along with plane solar air heater is plotted in Figs.8-9, respectively. From the figures it is found that the trend of variation of outlet fluid temperature and thermal efficiency is reversed with fluid mass flow rate, outlet temperature of fluid decreases, whereas thermal efficiency increases with increase in fluid mass flow rate. Accordingly with increase in fluid mass flow rate, the percentage enhancement of outlet fluid temperature decreases. It is also seen the outlet fluid temperature and thermal efficiency increases for lower value (s_f=1cm) of fin spacing. This is because the heat flow rate increases at lower fin spacing due to increase in heat transfer rate.

Fig. 10 illustrates the variation of the outlet fluid temperature and thermal efficiency with fluid mass flow rate for different fins height and Io=950 W/m^2.It has been seen that the trend of variation of outlet fluid temperature and thermal efficiency with respect to mass flow rate is reverse. It is also found that outlet fluid temperature and thermal efficiency decreases for higher value of fin height (h_f=5.8cm) at different mass flow rate. This effect can be attributed to the facts that increase in fin height decreases the surface conductance of fins.

The variation of the calculated values of the pressure drop vs. fluid mass flow rate for different fin spacing of offset finned absorber solar air heater along with plane solar air heater are presented in Fig.11 for Io=950 W/m^2. It is seen that pressure drop increases with increase in fluid mass flow rate for all value of fin spacing. Also, the pressure drop increases drastically with decrease in fin spacing and increase in mass flow rate. This is because of fact that decreases in fin spacing increases the velocity of flowing air and subsequently increases the pressure drops.

Effect of fin height on pressure drop for different fluid mass flow rate has been represented in Fig.12 for Io=950 W/m^2. From the figure, it is clearly seen that the pressure drop increases randomly with increase in fluid mass flow rate and decrease in fin height/duct height increases the velocity of air and subsequently increases the pressure drop.

Fig.13 shows the variation of friction factor as a function of Reynolds number for different fin spacing along with plane solar air heater for insolation Io=950 W/m^2. From the figure it can be seen that the trend of variation of friction factor with respect to the Reynolds number at lower fluid mass flow rate for different fin spacing, reversed. It is found that the Reynolds number decreases and the friction factor increases at lower fluid mass flow rate for different value of fin spacing; whereas increases in fluid mass flow rate the variations is vice-versa. It is also observed that for higher fin spacing and higher mass flow rate the Reynolds number are higher as compared to fin spacing. Smaller fin spacing reduces the cross section area of flowing fluid, which increase the friction between the air and surface area of offset fins.

Figs.14 and 15 show the effect of fluid mass flow rate on thermal and thermohydraulic efficiencies of offset fins absorber along with plane solar air heater for different value of fin spacing and Io=750 W/m^2;Io=950 W/m^2. From the figures, it has been seen that the fluid mass flow rate increases, the thermal efficiency increases continuously due to increase in convective heat transfer coefficient. However, the thermohydraulic efficiency increases up to a threshold value of fluid mass flow rate(0.028 kg/s), attains a maximum(0.0556kg/s), and then decreases sharply, there exists an optimum value of thermohydraulic efficiency for a given fins spacing. It is found that at lower fins spacing (s_f = 1cm) the thermohydraulic efficiency is almost equal to thermal efficiency in between fluid mass flow rate of 0.020 to0.030 kg/s and there after start decreasing gradually upto 0.062 kg/s and then decreases sharply at higher fluid mass flow rate as compared to thermal efficiency. The effect can be attributed to the fact that the Reynolds number is strong parameter that affects the pumping power and thermal energy gain, thereby affecting the effective efficiency. However for other fin spacing there is slight fall in effective efficiency is observed in the range of mass flow rate investigated.

Fig.16 shows the effect of mass flow rate on thermal and thermohydraulic efficiencies for different fin height and Io=950 W/m^2. It is found that the thermal efficiency increases continuously with increase in fluid mass flow rate for different fin height, whereas the thermohydraulic efficiency increases up to 0.030 kg/s and then decreases for higher fluid mass flow rate. It is also seen that for lower fin height the thermohydraulic efficiency decreases almighty beyond the fluid mass flow rate of 0.030kg/s onwards. This is because increase in friction factor and pressure drop for lower fin height.

5. CONCLUSIONS

Attaching offset finned below the absorber plate is one of the emphatic techniques used to enhance the rate of heat transfer in solar air heaters, due to increase in thermal conductance of the absorber. On the basis of analytical investigations on thermal and thermohydraulic performance of offset finned below the absorber plate solar air heater the following culmination can be drawn:

(1). Theoretical evaluation of thermo hydraulic effect on offset finned absorber solar air heater has been conducted.

(2). Use of offset finned below the absorber plate, a substantial enhancement of collector efficiency factor and heat removal factor as compared to plane solar air heater is achieved.

(3). It is found that the minimum and maximum percentage enhancement in air temperature rise, thermal and thermohydraulic efficiency is found to be 45.17, 33.1, 6.31 and 175.43, 74.57, 72.4 respectively in the range of parameters investigated.

(4). The trend of variation of friction factor and Reynolds number with respect to mass flow rate, reversed. It is also observed that for lower fin spacing and higher mass flow rate the percentage enhancement of Reynolds number are higher as compared to lower mass flow rate.

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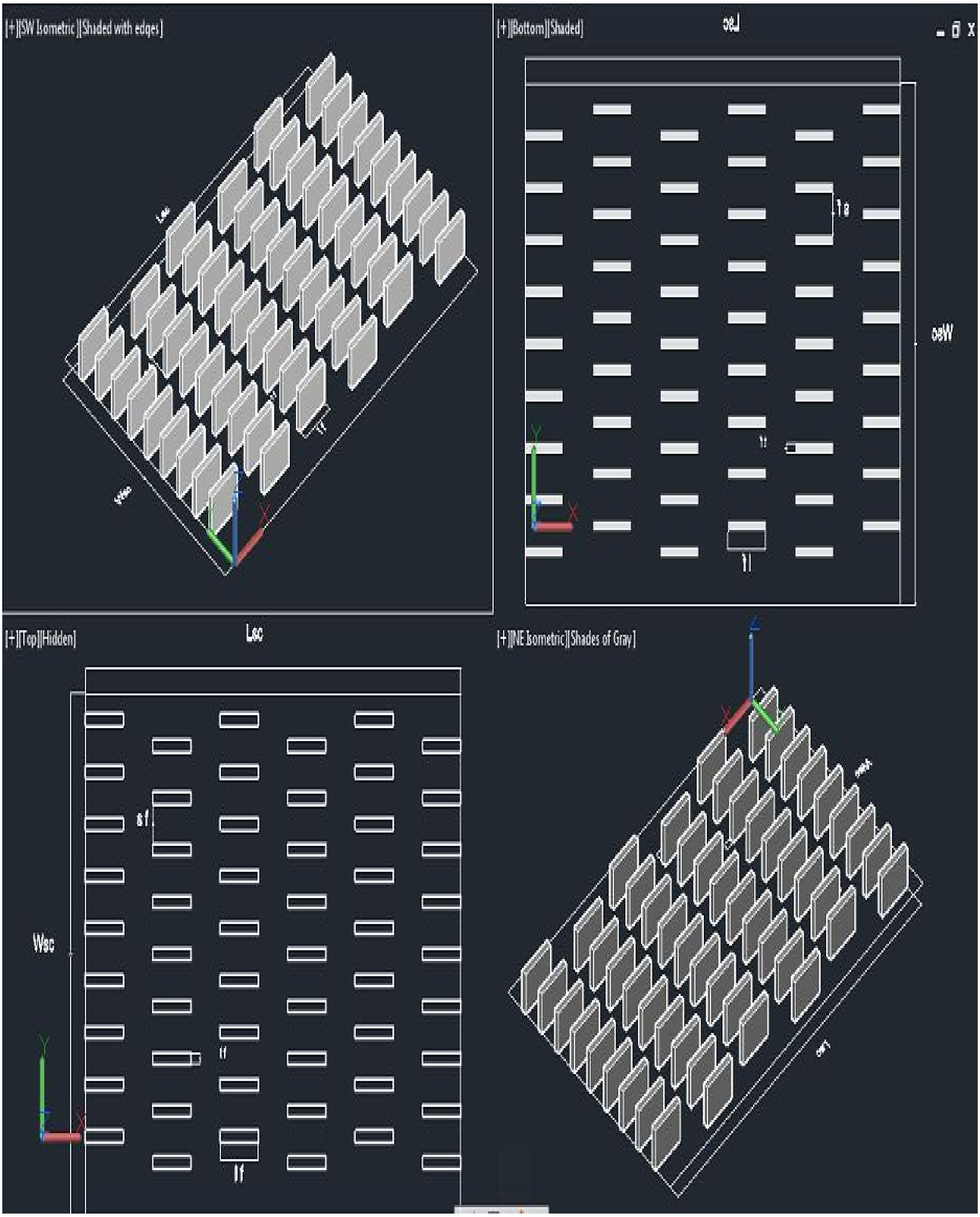

Figure.1 Different views of offset fins absorber plate.

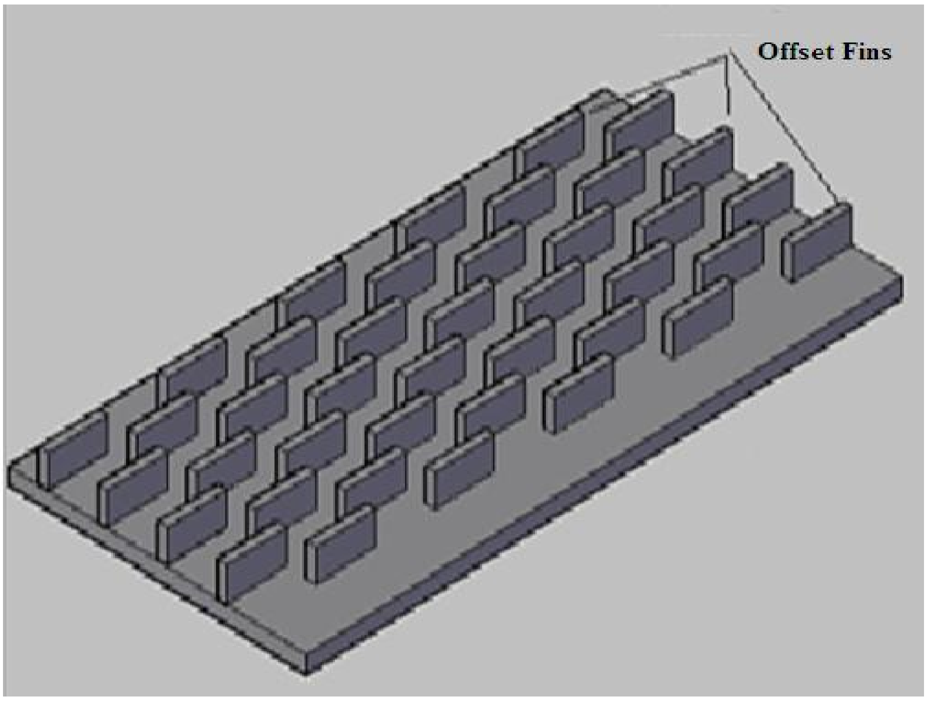

Figure.2 Schematic diagram of bottom view of absorber plate attached with offset fins.

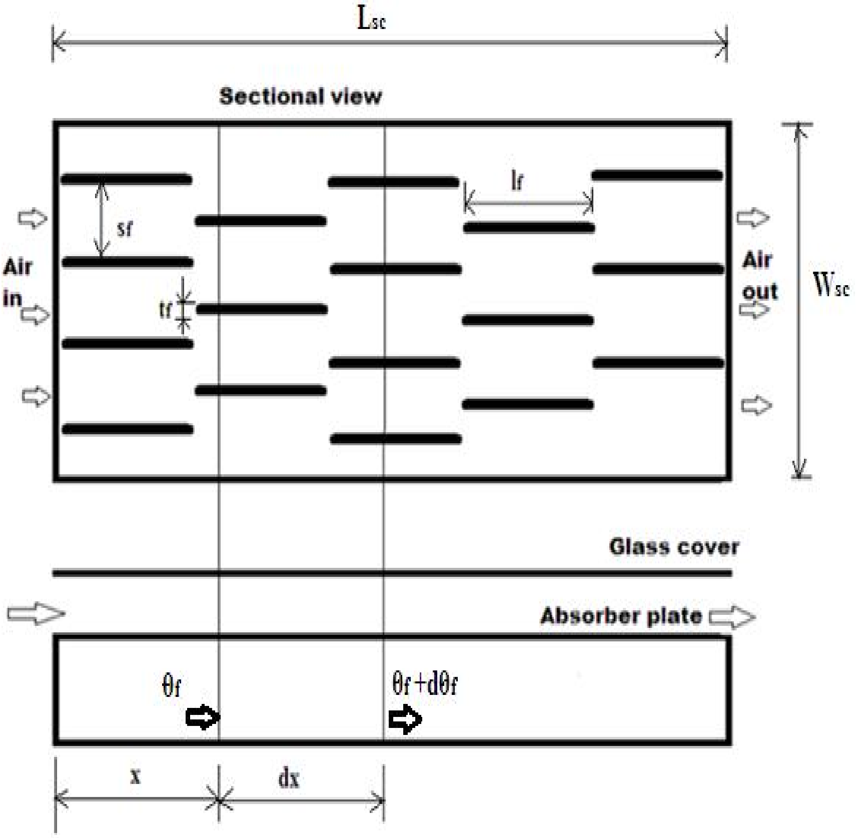

Figure.3 Sectional view of the absorber plate with offset finned.

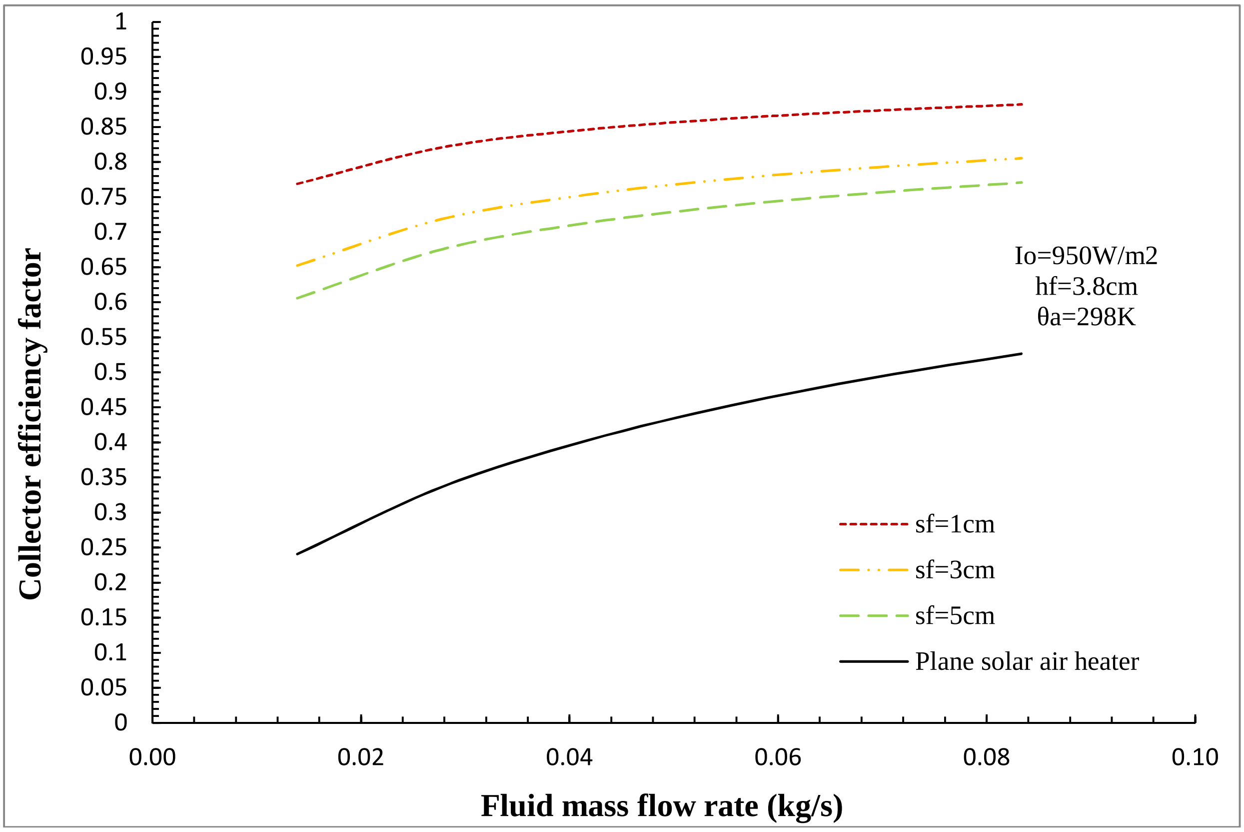

Figure.4 Collector efficiency factor vs. fluid mass flow rate for different fin spacing.

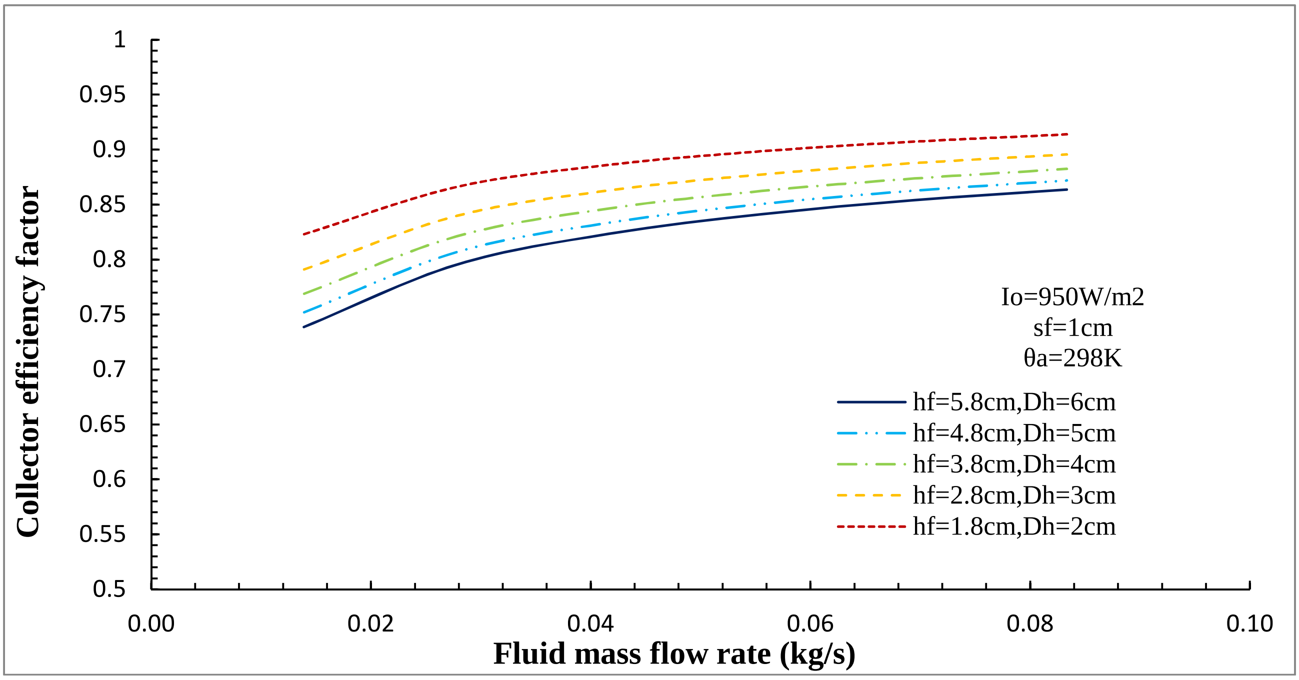

Figure.5 Collector efficiency factor vs. fluid mass flow rate for different fin height.

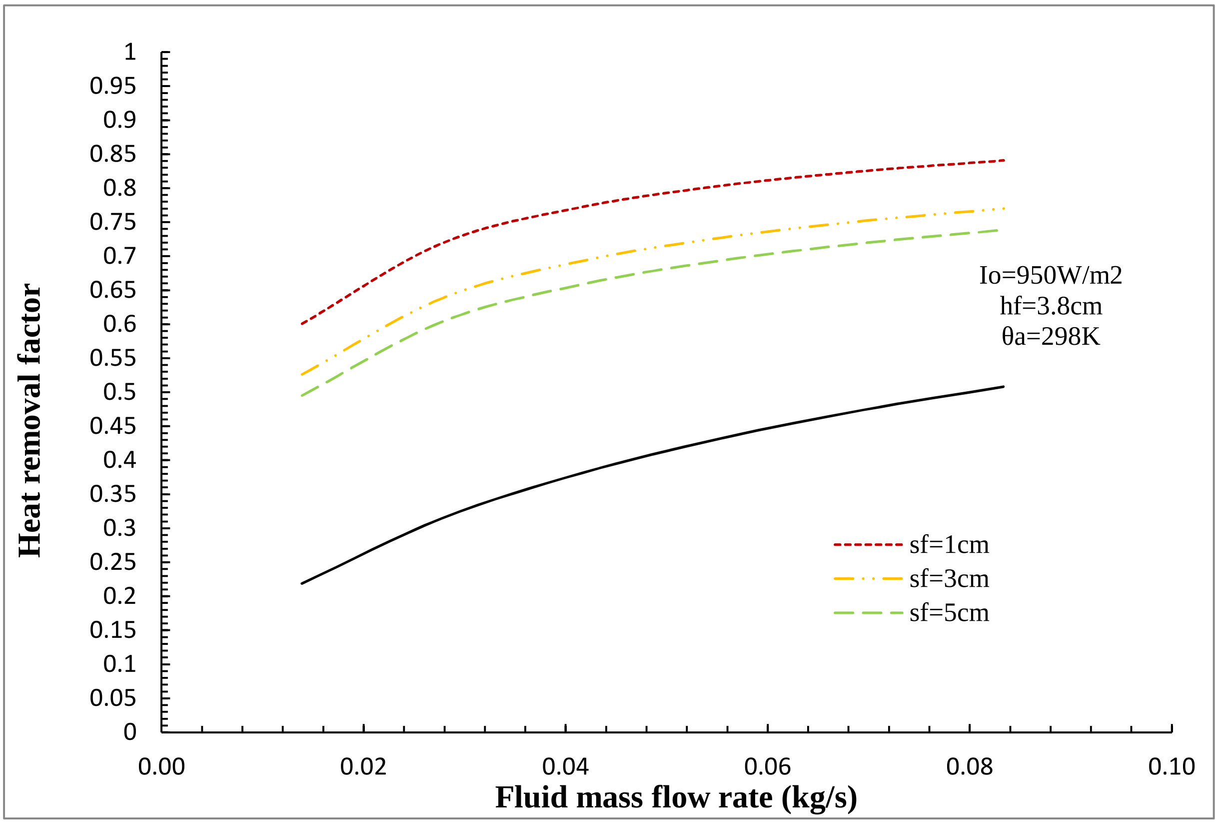

Figure.6 Heat removal factor vs. fluid mass flow rate for different fin spacing.

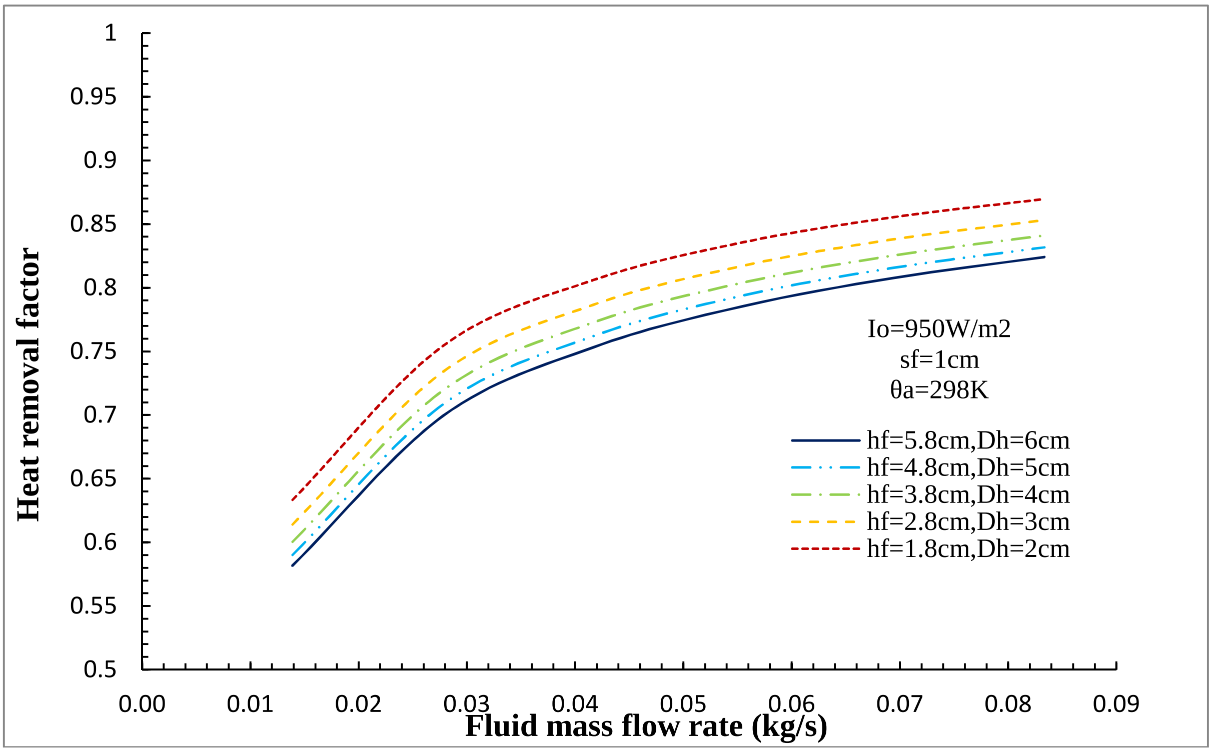

Figure.7 Heat removal factor vs. fluid mass flow rate for different fin height.

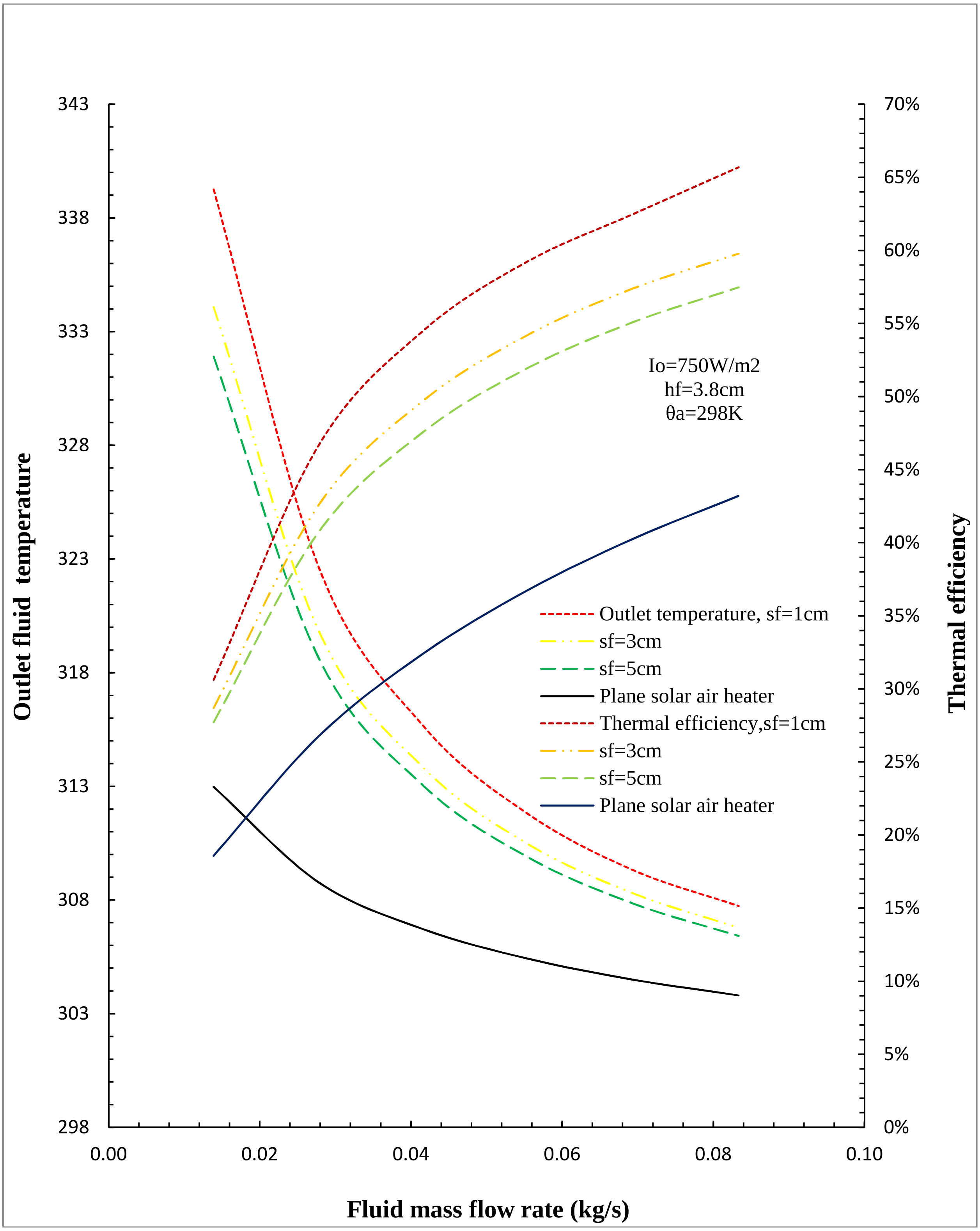

Figure.8 Outlet fluid temperature and thermal efficiency vs. fluid mass flow rate for different fin spacing and Io=750 W/m^2.

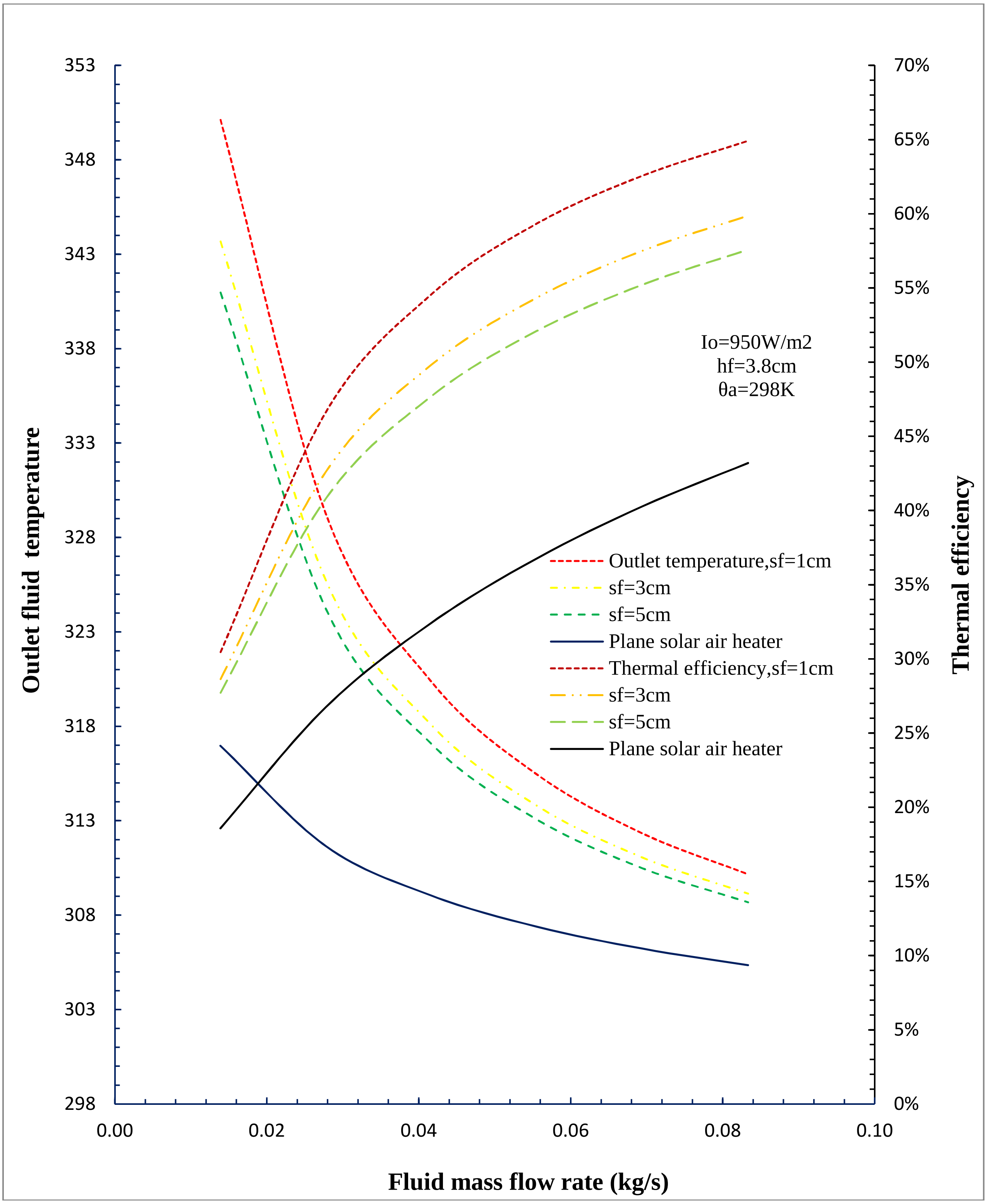

Figure.9 Outlet fluid temperature and thermal efficiency vs. fluid mass flow rate for different fin spacing and Io=950 W/m^2.

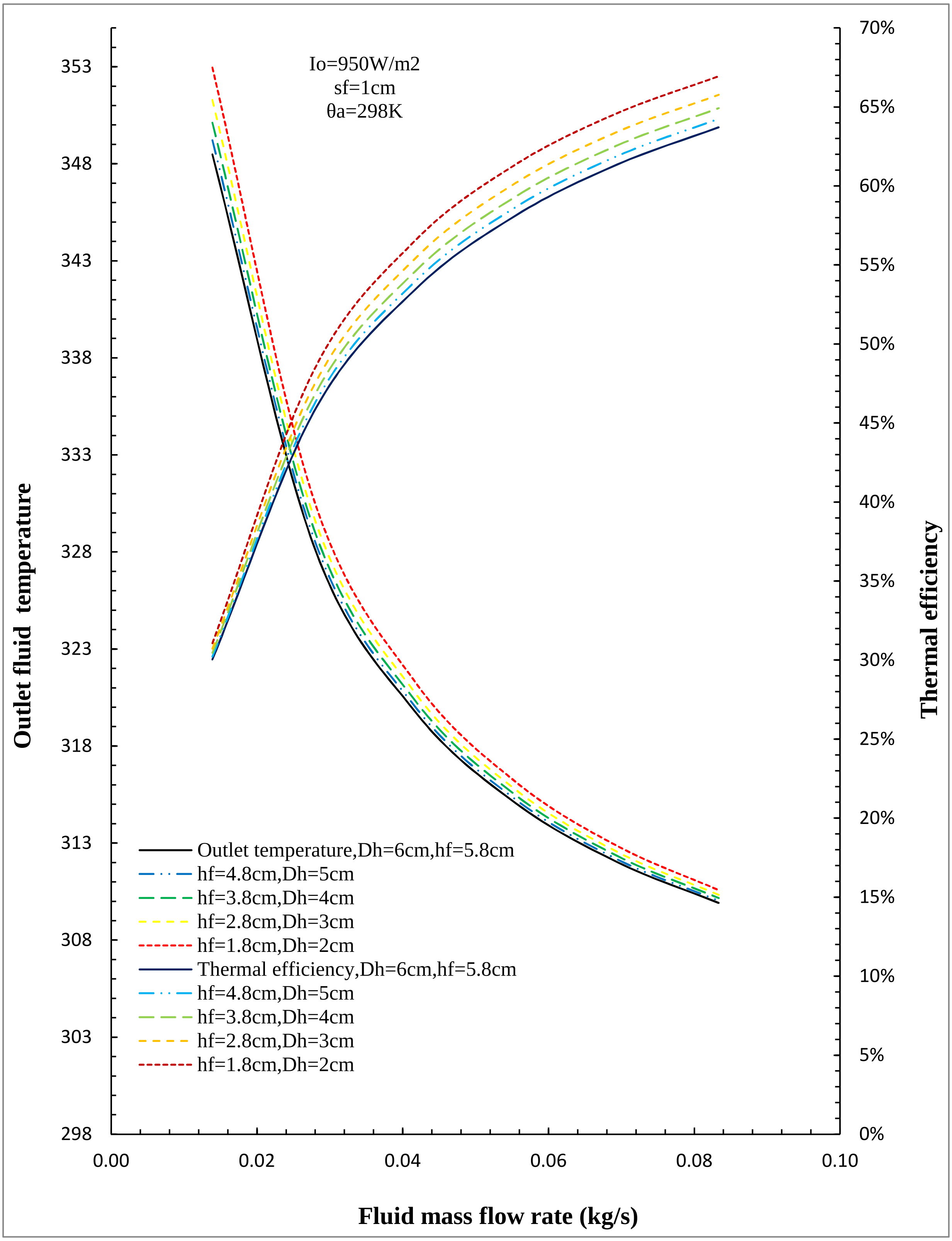

Figure.10 Outlet fluid temperature and thermal efficiency vs. fluid mass flow rate for different fin height and Io=950 W/m^2.

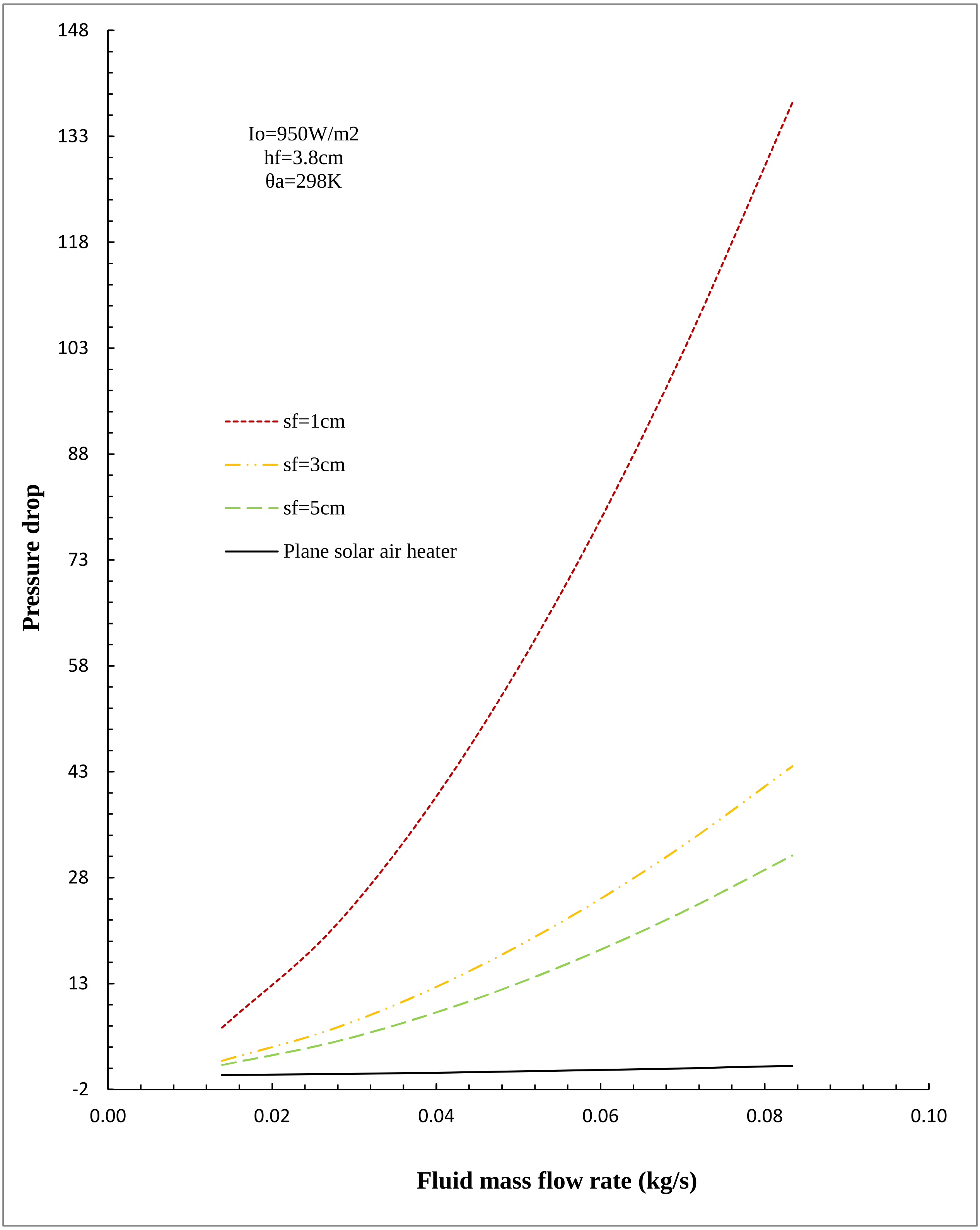

Figure.11 Pressure drop vs. fluid mass flow rate for different fin spacing.

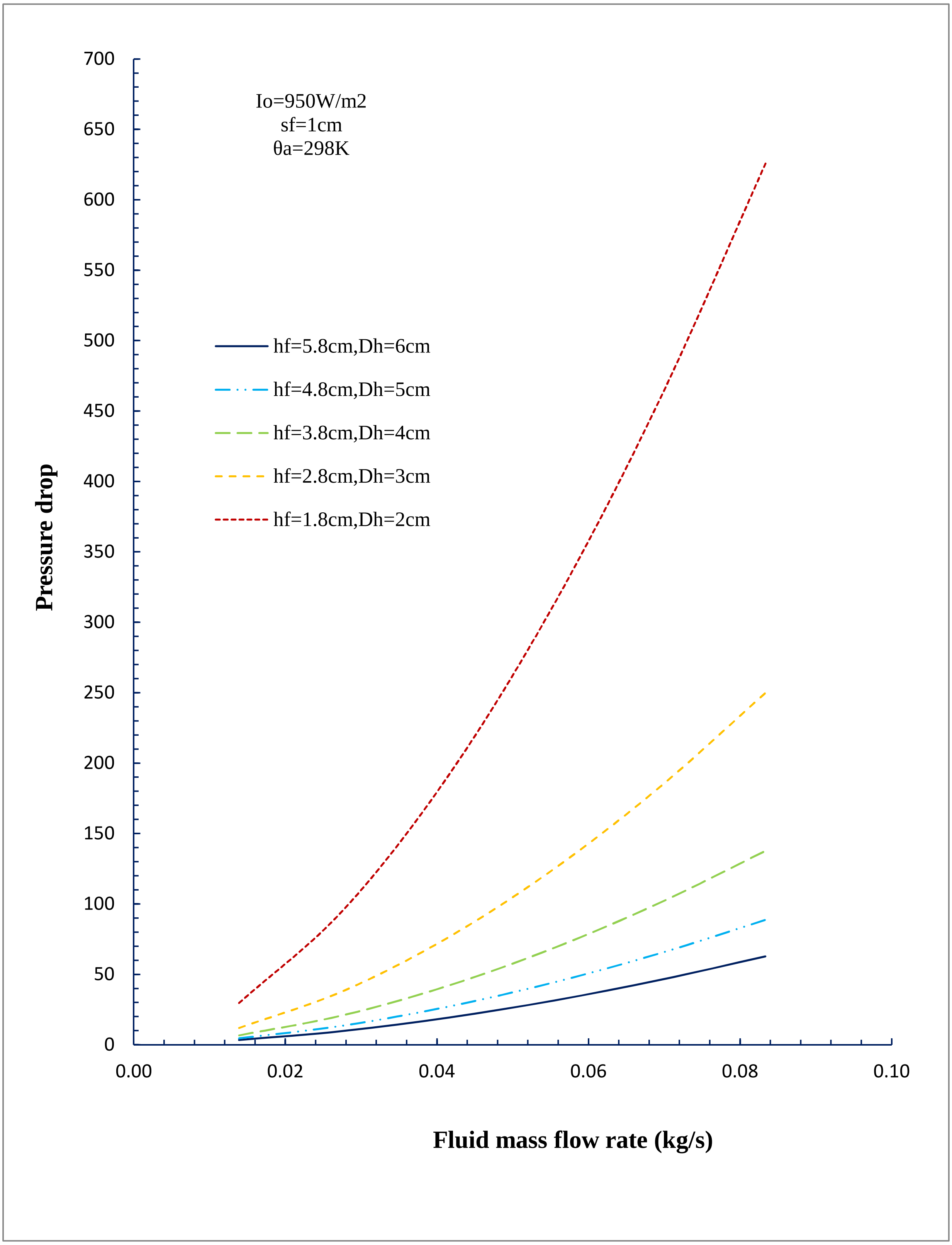

Figure.12 Pressure drop vs. fluid mass flow rate for different fin height.

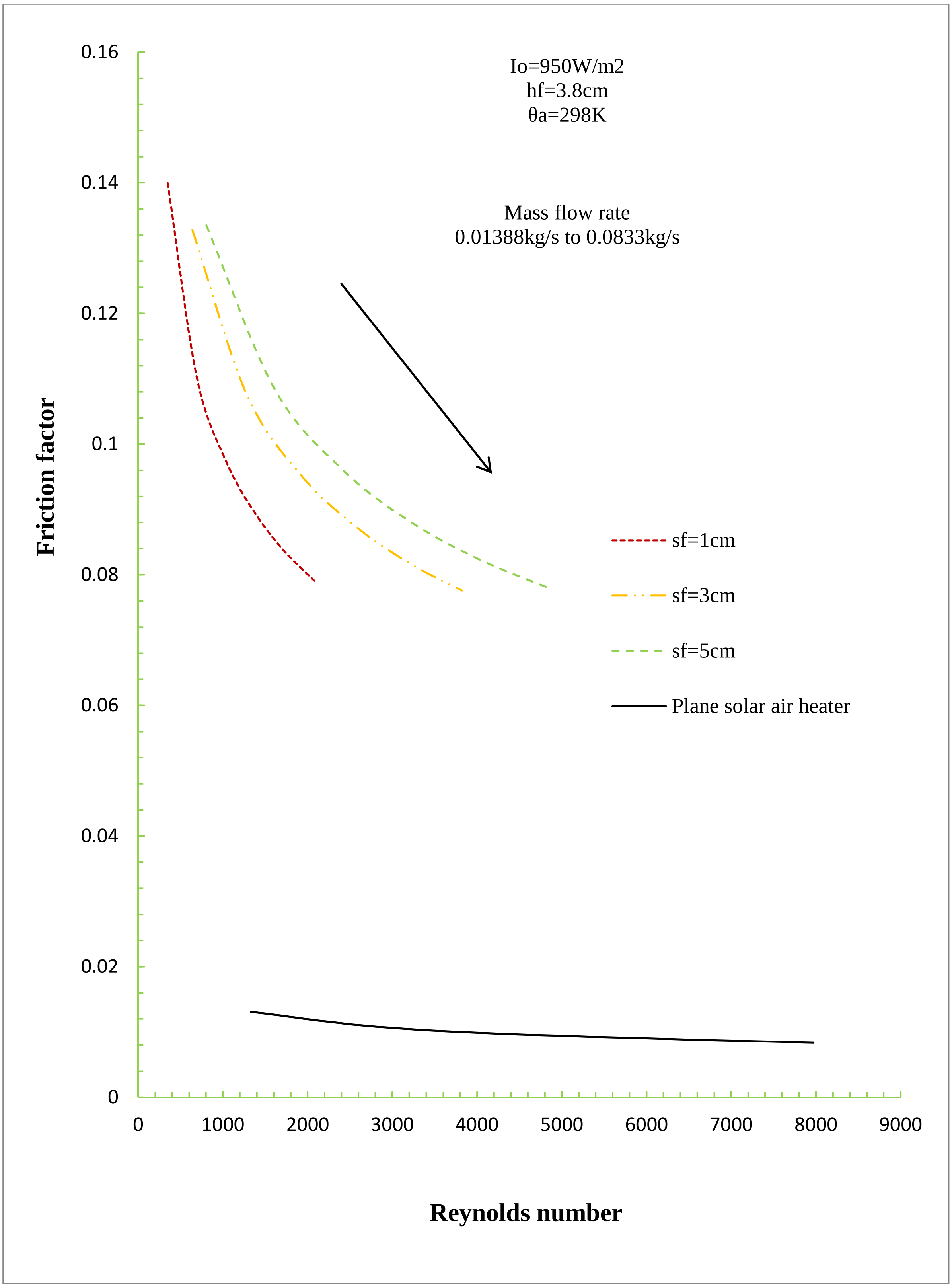

Figure.13 Friction factor vs. Reynolds number for different fin spacing.

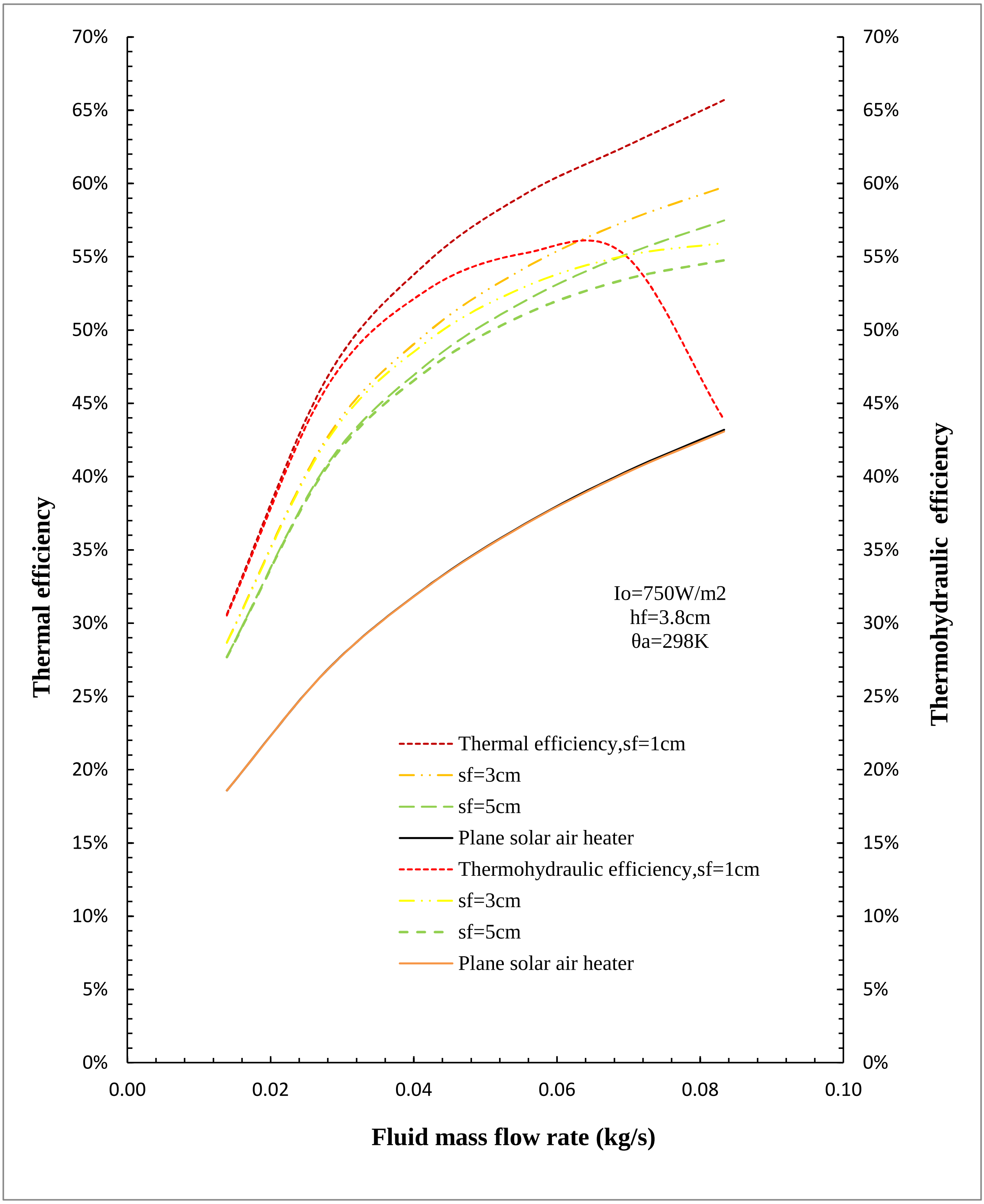

Fig.14 Thermal and thermohydraulic efficiencies vs. fluid mass flow rate for different fin spacing and Io=750 W/m^2.

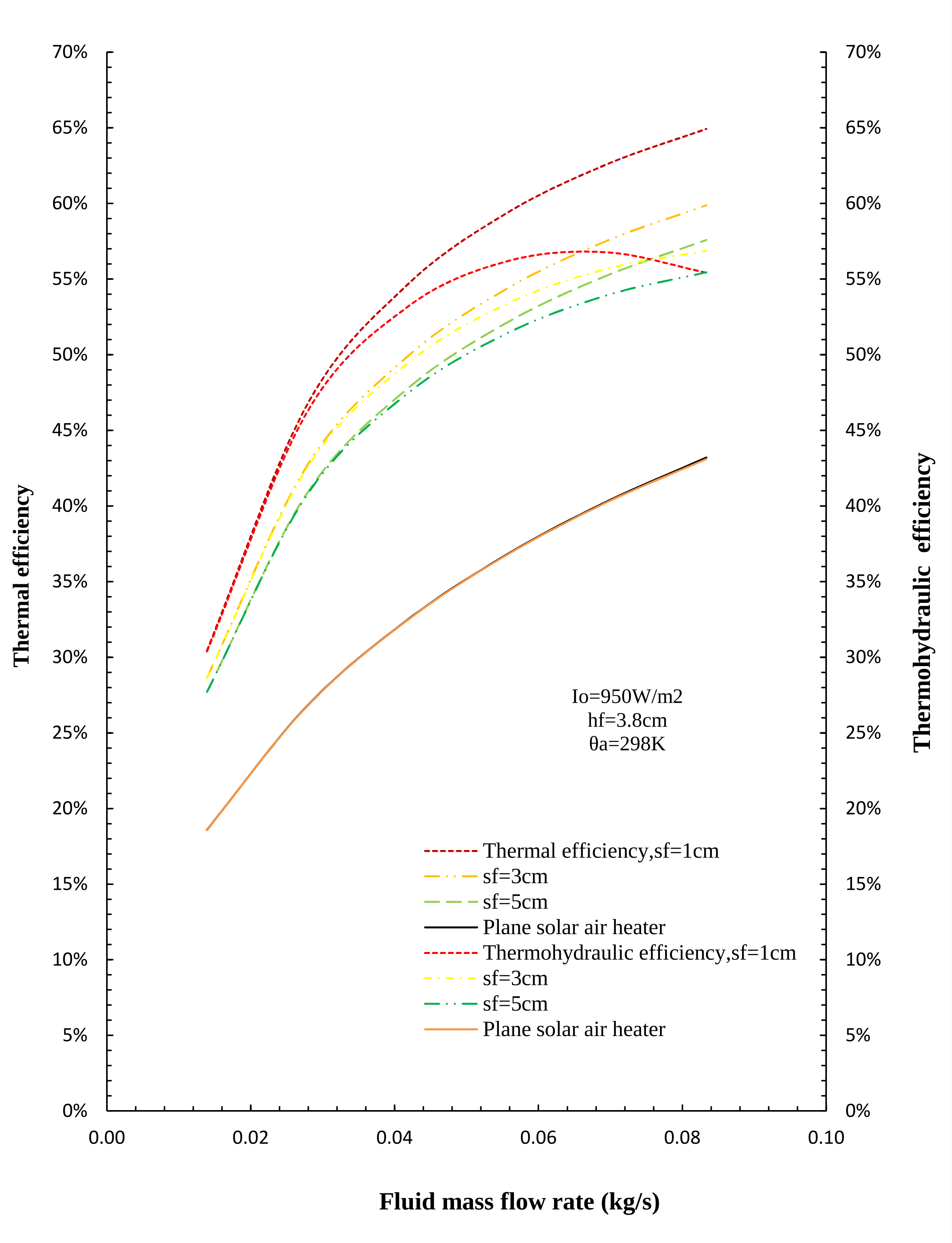

Figure.15 Thermal and thermohydraulic efficiencies vs. fluid mass flow rate for different fin spacing and Io=950 W/m^2.

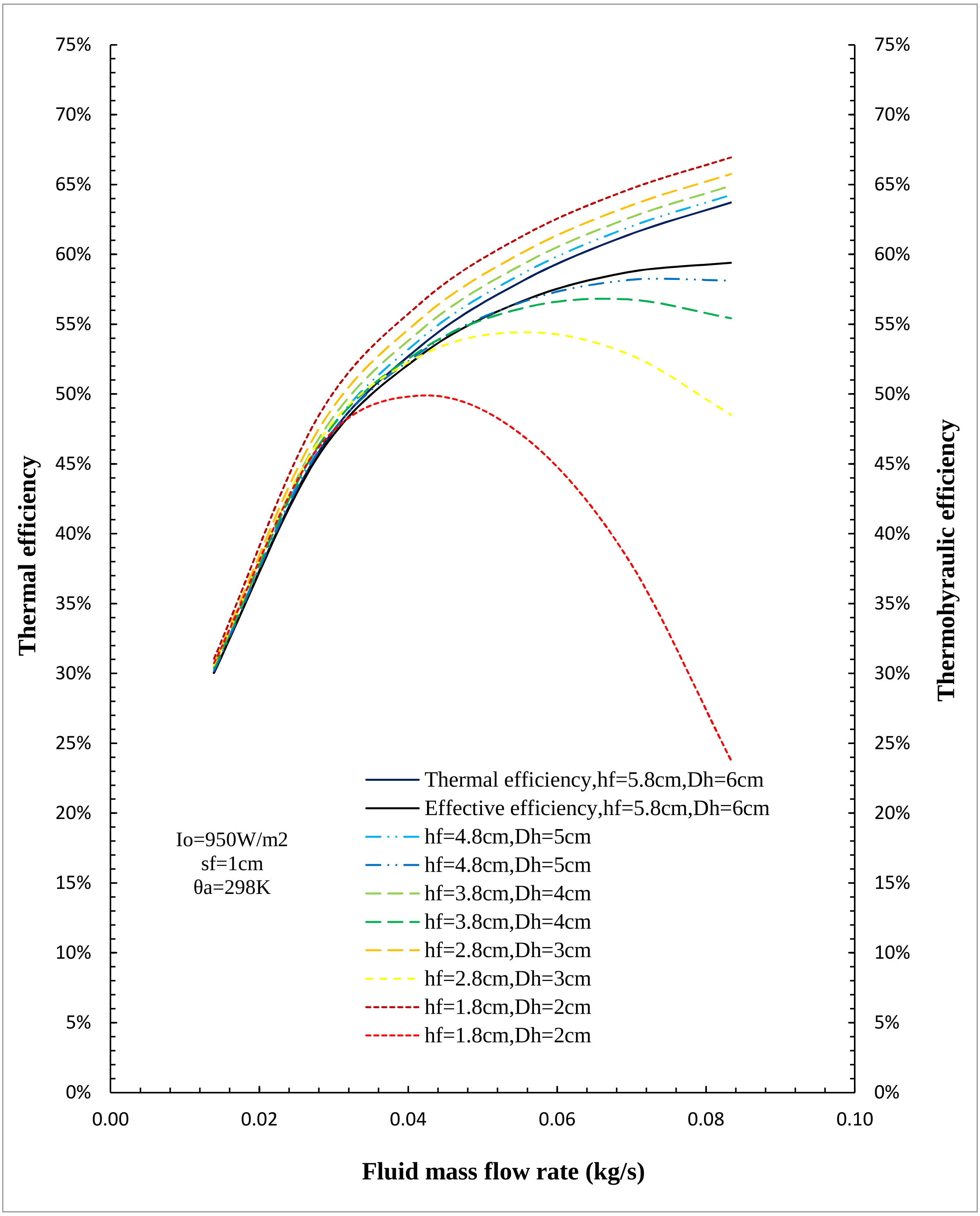

Figure.16 Thermal efficiency and effective efficiency vs. mass flow rate for different fin height and Io=950 W/m^2.

Table 1 Numerical values of system and operating parameters used in an analytical investigation of offset finned absorber solar air heater.

Input data	Numerical value
Length of collector,L_s	1.5 m
Width of collector,W_s	1 m
Channel duct height,D_h	2 cm to 6 cm
Offset fin height,h_f	1.8 cm to 5.8 cm
Offset fin spacing,s_f	1 cm to 5 cm
Offset fin length,l_f	2 cm
Offset fin thickness,t_f	3 mm
Fluid mass flow rate in kg/s,$\dot{m}$	0.0139 kg/s to 0.083 kg/s
Fluid m ass flow rate in kg/h,G_a	50 kg/h to 300 kg/h
Product of transmissivity and absorptivity,$\tau_c\alpha_a$	0.85
Solar insolation,I_o	750 W/m^2 and 950 W/m^2
Insulation thickness,t_{i}	4 cm
Insulation thermal conductivity,k_{i}	0.033 W/m-K
Ambient temperature,θ_a	298 K
Specific heat of air,C_p	1.005 kJ/kg-K
Thermal conductivity of air,k_a	0.02826 W/m-K
Kinematic viscosity of air,μ_k	$18.97\times10^{-6}\ m^2/s$
Emissivity of wood,ε_w	o.93
Emissivity of glass,ε_g	0.88
Emissivity of back plate ,ε_w	0.9

Table 2 Enhancement in fluid temperature rise ,thermal and thermohydraulic efficiencies of offset finned absorber solar air heater at different fin spacing for different mass flow rates and insolation Io=750 W/m^2,h_f = 3.8cm.

		Plane solar air heater				Offset finned absorber solar air heater				Percentage enhancement		
s_f (cm)	$\dot{m}$ (kg/s)	θ_{f} (K)	$\Delta\theta$ (K)	η_{tl} (%)	η_e (%)	θ_{f} (K)	$\Delta\theta$ (K)	η_{tl} (%)	η_e (%)	$E_{t\Delta}$	E_{ft}	E_{fe}
1	0.0139	312.98	14.98	18.58	18.58	339.26	41.26	30.6	30.5	175.43	64.7	64.2
	0.0278	308.78	10.78	26.75	26.74	322.65	24.65	46.7	46.1	128.66	74.57	72.4
	0.0417	306.72	8.72	32.43	32.41	315.64	17.64	54.5	52.7	102.29	68.1	62.6
	0.0556	305.41	7.41	36.78	36.74	311.77	13.77	59.3	55.3	85.82	61.22	50.51
	0.0694	304.49	6.49	40.28	40.21	309.30	11.3	62.5	55.2	74.11	55.16	37.28
	0.0833	303.80	5.80	43.20	43.08	307.74	9.74	65.9	45.8	67.93	52.5	6.31

3	0.0139	312.98	14.98	18.58	18.58	334.09	36.09	28.7	28.7	140.92	54.5	54.5
	0.0278	308.78	10.78	26.75	26.74	319.85	21.85	42.6	42.4	102.69	59.25	58.56
	0.0417	306.72	8.72	32.43	32.41	313.82	15.82	49.7	49.2	81.42	53.3	51.8
	0.0556	305.41	7.41	36.78	36.74	310.45	12.45	54.3	53.0	68.02	47.63	44.26
	0.0694	304.49	6.49	40.28	40.21	308.29	10.29	57.4	55.1	58.55	42.50	37.03
	0.0833	303.80	5.80	43.20	43.08	306.79	8.79	59.8	56.0	51.55	38.4	29.99
5	0.0139	312.98	14.98	18.58	18.58	331.92	33.92	27.7	27.7	126.44	49.1	49.1
	0.0278	308.78	10.78	26.75	26.74	318.65	20.65	40.7	40.6	91.56	52.15	51.83
	0.0417	306.72	8.72	32.43	32.41	313.02	15.02	47.6	47.2	72.25	46.8	45.6
	0.0556	305.41	7.41	36.78	36.74	309.87	11.87	52.0	51.1	60.19	41.38	39.09
	0.0694	304.49	6.49	40.28	40.21	307.84	9.84	55.1	53.5	51.62	36.79	33.05
	0.0833	303.80	5.80	43.20	43.08	306.42	8.42	57.5	54.8	45.17	33.1	27.2

*Inlet temperature θ_{fi}=298K **enhancement factor $E_f = \left(\frac{O \quad fi \quad -P}{p}\right) \times 100$