Performance Analysis of Parabolic Solar Collector at Various Operating Conditions

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ABSTRACT

Nowadays days, many researchers are concern about solar energy systems and they are continuously working on these systems to improve the performance. And they are more concern about solar power plants. In this performance analysis work, cylindrical parabolic solar collector has been chosen. Then useful heat gain rates, fluid outlet temperatures, absorbed fluxes, overall heat loss coefficients, collector efficiency factors, heat removal factors and exergy analyses have been done at different operating conditions. For calculations, different conditions are - instantaneous efficiencies, instantaneous beam radiations, mass flow rates, absorptivity, reflectivity, transmissivity and intercept factor have been taken. Work has been concluded as when instantaneous efficiency increases then heat gain rate, fluid outlet temperature, collector efficiency factor and heat removal factor increase but overall heat loss coefficient decreases whereas when instantaneous beam radiation increases then only heat gain rate, fluid outlet temperature and absorbed flux increase.

KEYWORDS – *Parabolic solar collector, exergy analysis, overall heat loss coefficient, collector efficiency factor and heat removal factor.*

LIST OF NOMENCLATURE AND SYMBOLS

A_s = *Inner surface area of pipe in* m^2,

C = Concentration ratio,

C_p = *Specific heat of fluid in J/kgK,*

h_f = *Convective heat transfer coefficient for fluid in* W/m^2K,

I_bR_b = *Instantaneous beam radiation on per unit area of the surface in* W/m^2,

L = Effective length of the pipe in meters,

m = Mass flow rate of fluid which is flowing in the pipe in kg/sec,

Q_u = *Rate of heat transfer in Watts,*

S = Absorbed flux,

T_{fo} *and* T_{fi} *= Fluid temperatures at inlet and outlet respectively in Kelvin,*

T_p *and* T_{fo} *= Temperatures of pipe and outlet fluid respectively in Kelvin,*

U_l *= Overall heat loss coefficient in* W/m^2K*,*

W = Aperture width in meters,

ρ *= Reflectivity,*

γ *= Intercept factor,*

τ *= Transmissivity,*

α *= Absorptivity,*

Ψ_{in} *= Amount of exergy input in Watt,*

Ψ_{out} *= Amount of exergy output in Watt,*

η_{Ψ} *= Exergy efficiency in %,*

η_{ib} *= Instantaneous efficiency in %.*

1. INTRODUCTION

Energy is a property of the object which can be transferred from one form to another form or it can also be defined as ability to do the work. There are many types of energies – kinetic energy, potential energy, mechanical energy, chemical energy, electrical energy, magnetic energy, radiant energy nuclear energy and heat energy. Mainly energy is classified into two forms – renewable energy and nonrenewable energy. Renewable energy is also called non consumable energy because this energy is collected from those sources which are naturally available; like sun (solar) energy, wind energy, tidal energy, geothermal energy etc. In all renewable energy sources, solar energy is most important source of energy. Concentrator collector type solar power plants are most common type of the plant. Layout of the solar thermal power plant is as shown in figure 1.

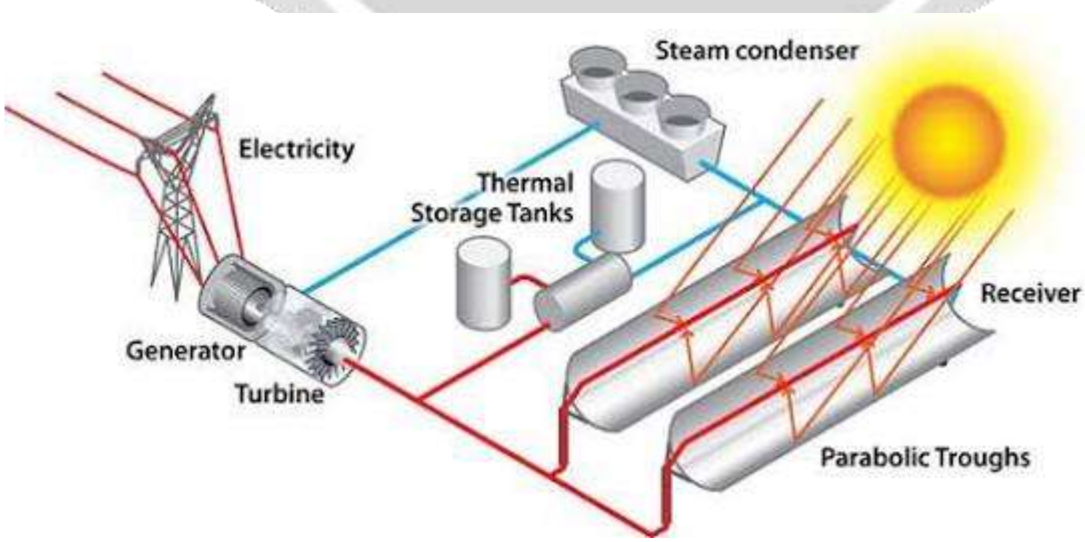

Figure 1 – Schematic layout of the solar power plant

In all the parts of a solar system, solar collectors are the most important part. Solar collectors collect heat energy from sun and give this heat energy to flowing fluid. Solar collectors capture all the solar radiation which incident on the collector area in the form of electromagnetic waves. In this research work, cylindrical parabolic solar collector is selected for analysis. All analyses are done for solar collector at various operating conditions. Important terminologies which are used during the work; (1) instantaneous efficiency (η_{ib}) for a parabolic solar collector can be defined as amount of heat energy which is delivered to the flowing fluid in the pipe to the amount of solar energy which is incident on the aperture area. (2) Instantaneous beam radiation (I_bR_b) is amount of solar energy which is incident on per unit surface area of the object. (3) Useful heat gain rate (Q_u) is the rate of heat energy which is absorbed by flowing fluid in the pipe. (4) Concentration ratio (C) for parabolic solar collector can be expressed as the ratio of total aperture area of the collector to the total outer surface area of the receiver (pipe). For higher temperature of the flowing fluid, concentration ratio should be high. (5) Overall heat loss coefficient (U_l) is the summation of convective heat transfer coefficient and radiation heat transfer coefficient between receiver pipe - atmospheric air. (6) Collector efficiency factor (F') is the ratio of actual useful heat gain rate per tube per unit length to the heat gain rate which is found if the collector absorber is at the temperature T_f. Here T_f is local fluid temperature. (7) Heat removal factor (F_r) is the ratio of actual useful heat gain rate to the heat gain which is achieved if the collector absorber is at the temperature T_{fi} everywhere. It is a measure of thermal resistance encountered by the absorbed solar radiation in reaching the collector fluid [1-9]. In this research work heat gain rates, temperatures, overall heat loss coefficients, collector efficiency factors and heat removal factors are calculated. A schematic diagram of absorber tube is as shown in figure 2. In this research work exergy analysis is also done for solar collector.

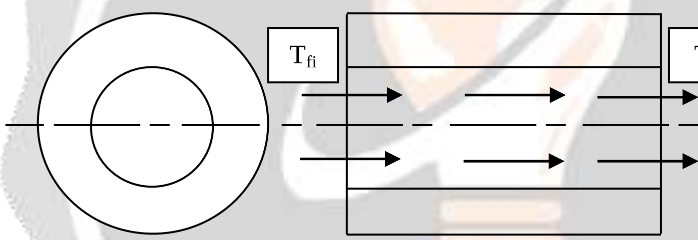

Figure 2 – Parabolic solar collector pipe with various temperatures

Mustapha D. [2] et al have analysed on parabolic solar collector which is working at high temperature greater than 250°C in the Adrar area. They have introduced mathematical model for various elements of the parabolic solar collector. Kumar K. V. P. [3] et al have designed and fabricated parabolic solar collector. Then numbers of experiments have been performed to find best operating conditions for collector. Tzivanidis C. [4] et al have designed solar collector model and then simulated for various working conditions. This model has been used to predict efficiency and heat transfer rate for solar system. Wang F. [5] et al have worked on performance investigation of heat pump assessed solar system. They have simulated this analysis by TRNSYS and experimental analyses are also done. Almasabi A. [6] et al have developed a distributed transient optical-thermal-fluid model for parabolic solar collector and compared all the results with field results. They have suggested different ways to improve solar collector efficiency under variable operating conditions. Liu Xiaoyan [7] et al have focused on thermal efficiency of parabolic solar collector and they have found effects of climate on the thermal efficiency of solar plant. Mohamad A. [8] et al have advised that the rate of heat loss increased when the length of the collector increased or flow rate of the fluid decreased. Tadahmun A. Y. [9] has done experimental and theoretical study to determine thermal efficiency of the parabolic solar collector . Padilla R. V. [10] have analysed effects of operational and environmental parameters on the performance of parabolic solar collector. For that exergy analyses have been done for solar collector. Kalogirou S. A. [11] has reviewed research paper which was based on exergy analysis for solar systems. For the analysis, they have considered different types of solar collectors and different types of solar thermal systems. After these literature reviews, objectives of the research work have been decided. Main objectives of the research work are to find out - useful heat gain rate, fluid outlet temperature, absorbed flux, overall heat loss coefficient, collector efficiency factor and heat removal factor. All these analyses are done at different operating conditions. And finally exergy analyses are also done in this research work.

2. METHODOLOGY

Research analysis are done for parabolic solar collector. Method which is adopted for this work is described in this section. For numerical calculations different formulas are used. Step by step formulas used for calculations are as follow [1];

Instantaneous efficiency, $\eta_{ib} = (Q_u) / (I_b R_b\, W\, L)$ *Eq. (1)*

Here Q_u is rate of heat transfer in Watts, I_bR_b is instantaneous beam radiation on per unit area of the surface in W/m^2, W is aperture width in meters and L is effective length of the pipe in meters.

Useful heat gain rate, $Q_u = m\, C_p\, (T_{fo} - T_{fi})$ *Eq. (2)*

Here Q_u is useful heat gain in Watts, m is mass flow rate of fluid which is flowing in the pipe in kg/sec, C_p is specific heat of fluid in J/kgK, T_{fo} and T_{fi} are fluid temperatures at inlet and outlet respectively in Kelvin.

Convective heat transfer, $Q_u = h_f\, A_s\, (T_p - T_{fo})$ *Eq. (3)*

Here h_f is convective heat transfer coefficient for fluid in W/m^2K, A_s is inner surface area of pipe in m^2, T_p and T_{fo} are temperatures of pipe and outlet fluid respectively in Kelvin.

Concentration ratio is the ratio of effective aperture area to pipe surface area. It is represented by C. Here W is aperture width in meters and D_o is pipe outer diameter in meter [1],

Concentration ratio, $C = \{(W - D_o)\, L\} / \{\pi\, D_o\, L\}$ *Eq. (4)*

Absorbed flux, $S = \{I_bR_b\, \rho\, \gamma\, (\tau\, \alpha)_b + I_bR_b\, (\tau\, \alpha)_b\, [D_o / (W - D_o)]\}$ *Eq. (5)*

Here ρ is reflectivity of the collector surface, some amount of reflected radiation is intercepted by the pipe which is known as intercept factor and it is denoted by γ, τ is transmissivity and α is absorptivity.

Conductive heat transfer through the pipe, $Q_u = \{[2\, \pi\, K\, L\, (T_c - T_p)] / [\ln (D_o/D_i)]$ *Eq. (6)*

Here K is thermal conductivity of the pipe material in W/mK, T_c are T_p are pipe surface temperature at outlet and inlet respectively in Kelvin. Amount of heat transfer (Q_u) can also be written with overall heat loss coefficient (U_l), concentration ratio (C) and absorbed flux (S) as [1],

$Q_u = [\, S - (U_l / C)\, (T_p - T_a)]\, (W - D_o)\, L$ *Eq. (7)*

Collector efficiency factor, $F' = [U_l \{(1 / U_l) + [D_o / (D_i\, h_f)]\}]^{-1}$ *Eq. (8)*

Heat removal factor, $F_r = (m\, C_p) / (\pi\, D_o\, L\, U_l)\, [1 - \exp \{(- F'\, \pi\, D_o\, U_l\, L) / (m\, C_p)\}]$ *Eq. (9)*

Focus point for cylindrical parabolic collector can be found by mathematical relation between focus point, aperture width and concentration ratio [1].

$F = (W^2) / (16\, C)$ *Eq.(10)*

Exergy analysis for the solar collector is done by using following equations [11].

$\Psi_{in} = m\, \{\int_{T0}^{Tfi} Cp\, (T)\, dT + v\, (P_{fi} - P_0) - T_0 \int_{T0}^{Tfi} Cp\, (T) dT/T + V_{fi}^{\,2}/2\, \} + I_bR_b\Psi$ *Eq. (11)*

Here Ψ_{in} is the amount of exergy input, m is mass flow rate of the flowing fluid in kg/sec, T_{fi} and T_0 are temperature of the fluid at inlet and atmosphere temperature in K. P_{fi} and P_0 are the pressure of fluid at inlet and atmospheric pressure in bar. V_{fi} is the velocity of the fluid at inlet in m/sec and Ψ is maximum useful work energy which can be achieved by solar radiation.

$$\Psi_{out} = m\{\int_{T0}^{Tf0} Cp(T)dT + v(P_{f0} - P_0) - T_0\int_{T0}^{Tf0} Cp(T)dT/T + V_{f0}^2/2\} + I_bR_bA_c\Psi \quad Eq.(12)$$

Here Ψ_{out} is the amount of exergy output, m is mass flow rate of the flowing fluid in kg/sec, T_{f0} and T_0 are temperature of the fluid at outlet and atmosphere temperature in K. P_{f0} and P_0 are the pressure of fluid at outlet and atmospheric pressure in bar. V_{f0} is the velocity of the fluid at outlet in m/sec and A_c is the solar radiative area that incident on the surface in m^2.

$$\Psi = 1 - \frac{4}{3}(T_0/T_s) + \frac{1}{3}(T_0/T_s)^4 \quad Eq. (13)$$

$$\Psi_{gain} = m\{\int_{Tfi}^{Tf0} Cp(T)dT - T_0\int_{Tfi}^{Tf0} Cp\ (T)\ dT/T - v\ dP\} \quad Eq. (14)$$

Here Ψ_{gain} is the heat energy which is gained by working fluid due to solar radiation. For the above equations kinetic energy and pressure energy are negligible. Exergy efficiency is calculated by the following equation.

$$\eta_{\Psi} = \Psi_{gain} / (I_bR_bA_c\Psi) \quad Eq. (15)$$

Overall heat loss factor is the ratio of overall heat loss coefficient at variable conditions to the overall heat loss coefficient at designed condition. Important dimensions are; (a) aperture width (W) of the collector is 1.25 m, (b) length of collector and absorber pipe is 2.5 m, (c) inner diameter (D_i) of hollow tube is 0.025 m, (d) outer diameter (D_o) of hollow tube is 0.038 m and concentration ratio (C) is 10.1. Following operating conditions are vary – instantaneous efficiency, instantaneous beam radiation, mass flow rate of fluid, specific heat of fluid and absorptivity/reflectivity/transmissivity/intercept factor.

3. RESULTS

For solar collector analysis, calculations are done in this research work and all the calculations are completed according to the steps which are mentioned in the methodology. For calculations instantaneous efficiencies (30%, 35% and 40%), instantaneous beam radiations per unit surface area (06.30AM - 360.4W/m^2, 8.30AM - 489W/m^2 and 14.30PM - 537.2W/m^2), mass flow rates (0.02kg/sec, 0.05kg/sec and 0.08kg/sec), absorptivity (0.7, 0.75 and 0.8), reflectivity (0.85, 0.9 and 0.95), transmissivity (0.7, 0.75 and 0.8) and intercept factor (0.85, 0.9 and 0.95) are assumed. All results are shown in tables 1-3 for various arrangements.

Table 1 – Thermodynamic properties at different instantaneous η and at different I_bR_b

Efficiencies	**Thermal Properties at 360.4 W/m^2 I_bR_b**					
η (%)	**Q_u (W)**	**T_{fo} (ºC)**	**S**	**U_l (W/m^2K)**	**F'**	**Fr**
30	337.88	26.61	164.91	36.74	0.7	0.69
35	394.19	26.88	164.91	20.54	0.81	0.80
40	450.50	27.15	164.91	8.38	0.91	0.91
Efficiencies	**Thermal Properties at 489.0 W/m^2 I_bR_b**					
η (%)	**Q_u (W)**	**T_{fo} (ºC)**	**S**	**U_l (W/m^2K)**	**F'**	**Fr**
30	458.44	27.19	223.76	36.74	0.7	0.69

35	534.84	27.56	223.76	20.53	0.81	0.80
40	611.25	27.92	223.76	8.38	0.91	0.91
Efficiencies	**Thermal Properties at 537.2 W/m^2 I_bR_b**					
η (%)	**Q_u (W)**	**T_{fo} (ºC)**	**S**	**U_l (W/m^{2}K)**	**F'**	**Fr**
30	503.63	27.41	245.82	36.73	0.7	0.69
35	587.56	27.81	245.82	20.53	0.81	0.80
40	671.50	28.21	245.82	8.38	0.91	0.91

Table 2 – Thermodynamic properties at different mass flow rates, at different instantaneous η and at different I_bR_b

Efficiencies	**Mass Flow Rates of Flowing Fluid**	**Thermal Properties at 360.4 W/m^2 I_bR_b**					
η (%)	**m (kg/sec)**	**Q_u (W)**	**T_{fo} (ºC)**	**S**	**U_l (W/m^{2}K)**	**F'**	**Fr**
30	**0.02**	337.88	29.04	164.91	31.52	0.73	0.70
35	**0.05**	394.19	26.88	164.91	20.54	0.81	0.80
40	**0.08**	450.50	26.35	164.91	8.73	0.91	0.91
Efficiencies	**Mass Flow Rates of Flowing Fluid**	**Thermal Properties at 489.0 W/m^2 I_bR_b**					
η (%)	**m (kg/sec)**	**Q_u (W)**	**T_{fo} (ºC)**	**S**	**U_l (W/m^{2}K)**	**F'**	**Fr**
30	**0.02**	458.44	30.48	223.76	31.53	0.73	0.70
35	**0.05**	534.84	27.56	223.76	20.53	0.81	0.80
40	**0.08**	611.25	26.83	223.76	8.73	0.91	0.91
Efficiencies	**Mass Flow Rates of Flowing Fluid**	**Thermal Properties at 537.2 W/m^2 I_bR_b**					
η (%)	**m (kg/sec)**	**Q_u (W)**	**T_{fo} (ºC)**	**S**	**U_l (W/m^{2}K)**	**F'**	**Fr**
30	**0.02**	503.63	31.02	245.82	31.53	0.73	0.70
35	**0.05**	587.56	27.81	245.82	20.53	0.81	0.80
40	**0.08**	671.50	27.01	245.82	8.74	0.91	0.91

Table 3 – Thermodynamic properties at different absorptivity/ reflectivity/ transmissivity/ intercept factor, at different instantaneous η and at different I_bR_b

Efficiencies	**Material Properties**	**Thermal Properties at 360.4 W/m^2 I_bR_b**					
η (%)	**Absorptivity/ Reflectivity/ Transmissivity/ Intercept Factor**	**Q_u (W)**	**T_{fo} (ºC)**	**S**	**U_l (W/m^{2}K)**	**F'**	**Fr**
30	**0.7/0.85/0.7/0.85**	337.88	26.61	133.13	14.87	0.85	0.84
35	**0.75/0.9/0.75/0.9**	394.19	26.88	170.56	23.87	0.78	0.77
40	**0.8/0.95/0.8/0.95**	450.50	27.15	215.4	34.43	0.71	0.70
Efficiencies	**Material Properties**	**Thermal Properties at 489.0 W/m^2 I_bR_b**					
η (%)	**Absorptivity/ Reflectivity/ Transmissivity/**	**Q_u (W)**	**T_{fo} (ºC)**	**S**	**U_l (W/m^{2}K)**	**F'**	**Fr**

	Intercept Factor						
30	**0.7/0.85/0.7/0.85**	458.44	27.19	180.63	14.87	0.85	0.84
35	**0.75/0.9/0.75/0.9**	534.84	27.56	231.42	23.86	0.78	0.77
40	**0.8/0.95/0.8/0.95**	611.25	27.92	292.26	34.42	0.71	0.70
Efficiencies	**Material Properties**	**Thermal Properties at 537.2 W/m^2 I_bR_b**					
η (%)	**Absorptivity/ Reflectivity/ Transmissivity/ Intercept Factor**	**Q_u (W)**	**T_{fo} (ºC)**	**S**	**U_l (W/m^{2}K)**	**F'**	**Fr**
30	**0.7/0.85/0.7/0.85**	503.63	27.41	198.44	14.87	0.85	0.84
35	**0.75/0.9/0.75/0.9**	587.56	27.81	254.24	23.87	0.78	0.77
40	**0.8/0.95/0.8/0.95**	671.50	28.21	321.07	34.42	0.71	0.71

Exergy analyses are done for solar collector at different operating conditions. After analysis results are shown in tabulated form. Table 4, table 5 and table 6 are exergy outputs at different instantaneous efficiencies and at different instantaneous beam radiations per unit surface area.

Table 4 – Exergy Outlets at different instantaneous η and at different I_bR_b

Efficiencies	**Thermal Properties at 360.4 W/m^2 I_bR_b**			
η (%)	**Exergy In (W)**	**Exergy Out (W)**	**Exergy Gain (W)**	**Exergy Efficiency (%)**
30	1047.41	358.61	688.80	65.76
35	1047.41	414.62	632.79	60.41
40	1047.41	469.50	577.91	55.18
Efficiencies	**Thermal Properties at 489.0 W/m^2 I_bR_b**			
η (%)	**Exergy In (W)**	**Exergy Out (W)**	**Exergy Gain (W)**	**Exergy Efficiency (%)**
30	1421.16	477.54	943.62	66.40
35	1421.16	550.74	870.42	61.25
40	1421.16	620.03	801.13	56.37
Efficiencies	**Thermal Properties at 537.2 W/m^2 I_bR_b**			
η (%)	**Exergy In (W)**	**Exergy Out (W)**	**Exergy Gain (W)**	**Exergy Efficiency (%)**
30	1561.24	521.31	1039.93	66.61
35	1561.24	599.05	962.19	61.63
40	1561.24	674.5	886.74	56.8

Table 5 – Exergy Outlets at different mass flow rates, at different instantaneous η and at different I_bR_b

Efficiencies	**Mass Flow Rates of Flowing Fluid**	**Thermal Properties at 360.4 W/m^2 I_bR_b**			
η (%)	**m (kg/sec)**	**Exergy In (W)**	**Exergy Out (W)**	**Exergy Gain (W)**	**Exergy Efficiency (%)**
30	**0.02**	1047.41	329.59	717.82	68.53
35	**0.05**	1047.41	414.62	632.79	60.41
40	**0.08**	1047.41	485.76	561.65	53.62

Efficiencies	**Mass Flow Rates of Flowing Fluid**	**Thermal Properties at 489.0 W/m^2 I_bR_b**			
η (%)	**m (kg/sec)**	**Exergy In (W)**	**Exergy Out (W)**	**Exergy Gain (W)**	**Exergy Efficiency (%)**
30	**0.02**	1421.16	424.79	996.37	70.11
35	**0.05**	1421.16	550.74	870.42	61.25
40	**0.08**	1421.16	646.93	774.23	54.48
Efficiencies	**Mass Flow Rates of Flowing Fluid**	**Thermal Properties at 537.2 W/m^2 I_bR_b**			
η (%)	**m (kg/sec)**	**Exergy In (W)**	**Exergy Out (W)**	**Exergy Gain (W)**	**Exergy Efficiency (%)**
30	**0.02**	1561.24	457.87	1103.37	70.67
35	**0.05**	1561.24	599.05	962.19	61.63
40	**0.08**	1561.24	705.89	855.35	54.79

Table 6 – Exergy Outlets at different absorptivity/ reflectivity/ transmissivity/ intercept factor, at different instantaneous η and at different I_bR_b

Efficiencies	**Material Properties**	**Thermal Properties at 360.4 W/m^2 I_bR_b**			
η (%)	**Absorptivity/ Reflectivity/ Transmissivity/ Intercept Factor**	**Exergy In (W)**	**Exergy Out (W)**	**Exergy Gain (W)**	**Exergy Efficiency (%)**
30	**0.7/0.85/0.7/0.85**	1047.41	358.61	688.80	65.76
35	**0.75/0.9/0.75/0.9**	1047.41	414.62	632.79	60.41
40	**0.8/0.95/0.8/0.95**	1047.41	469.50	577.91	55.18
Efficiencies	**Material Properties**	**Thermal Properties at 489.0 W/m^2 I_bR_b**			
η (%)	**Absorptivity/ Reflectivity/ Transmissivity/ Intercept Factor**	**Exergy In (W)**	**Exergy Out (W)**	**Exergy Gain (W)**	**Exergy Efficiency (%)**
30	**0.7/0.85/0.7/0.85**	1421.16	477.54	943.62	66.40
35	**0.75/0.9/0.75/0.9**	1421.16	550.74	870.42	61.25
40	**0.8/0.95/0.8/0.95**	1421.16	620.03	801.13	56.37
Efficiencies	**Material Properties**	**Thermal Properties at 537.2 W/m^2 I_bR_b**			
η (%)	**Absorptivity/ Reflectivity/ Transmissivity/ Intercept Factor**	**Exergy In (W)**	**Exergy Out (W)**	**Exergy Gain (W)**	**Exergy Efficiency (%)**
30	**0.7/0.85/0.7/0.85**	1561.24	521.31	1039.93	66.61
35	**0.75/0.9/0.75/0.9**	1561.24	599.05	962.19	61.63
40	**0.8/0.95/0.8/0.95**	1561.24	674.5	886.74	56.8

4. CONCLUSION

Conclusion gives the overall results of the research work. After finding out results from thermodynamic analyses, main conclusions are given as under with different conditions – It has been observed that at constant solar radiation when instantaneous efficiency increases then heat gain rate, fluid outlet temperature, collector efficiency factor and heat removal factor increase but overall heat loss coefficient decreases. It has been found that at fix instantaneous efficiency when instantaneous beam radiation per unit surface area increases then heat gain rate, fluid outlet temperature and absorbed flux increase but overall heat loss coefficient, collector efficiency factor and heat removal factor remain unchanged. It has been concluded that at constant solar radiation when instantaneous efficiency and mass flow rate of the fluid increase then heat gain rate, collector efficiency factor and heat removal factor increase but outlet temperature and overall heat loss coefficient decrease. But absorbed flux remains unchanged. It has been found that at fix instantaneous efficiency and mass flow rate when instantaneous beam radiation per unit surface area increases then heat gain rate, fluid outlet temperature and absorbed flux increase but overall heat loss coefficient, collector efficiency factor and heat removal factor again remain unchanged. It has been observed that at constant solar radiation when instantaneous efficiency, absorptivity, reflectivity, transmissivity and intercept factor increase then heat gain rate, fluid outlet temperature, absorbed flux and overall heat loss coefficient increase but collector efficiency factor and heat removal factor decrease. It has been observed that at constant instantaneous efficiency, absorptivity, reflectivity, transmissivity and intercept factor when solar radiation increases then heat gain rate, fluid outlet temperature and absorbed flux increase but overall heat loss coefficient, collector efficiency factor and heat removal factor again remain unchanged. It has been found that when absorptivity increases then overall heat loss factor increases but collector efficiency factor and heat removal factor decrease. When reflectivity increases then overall heat loss factor increases but collector efficiency factor and heat removal factor decrease. When transmissivity increases then overall heat loss factor increases but collector efficiency factor and heat removal factor decrease. And when intercept factor increases then overall heat loss factor increases but collector efficiency factor and heat removal factor decrease. This conclusion is for all conditions. It has been observed that at constant solar radiation when instantaneous efficiency increases then exergy out increases but exergy gain and exergy efficiency decrease. And exergy in remains unchanged. It has been found that at fix instantaneous efficiency when instantaneous beam radiation per unit surface area increases then exergy in, exergy out, exergy gain and exergy efficiency increase. It has been observed that at constant solar radiation when instantaneous efficiency and mass flow rate of the fluid increase then exergy in remain unchanged, exergy out increases but exergy gain and exergy efficiency decrease. It has been found that at fix instantaneous efficiency and mass flow rate when instantaneous beam radiation per unit surface area increases then exergy in, exergy out, exergy gain and exergy efficiency increase.It has been observed that at constant solar radiation when instantaneous efficiency, absorptivity, reflectivity, transmissivity and intercept factor increase then exergy gain and exergy efficiency decrease but exergy out increases. And exergy in remains unchanged. It has been observed that at constant instantaneous efficiency, absorptivity, reflectivity, transmissivity and intercept factor when solar radiation increases then exergy in, exergy out, exergy gain and exergy efficiency increase. It has been found that when collector aperture area and absorber pipe length increase then exergy in, exergy out, exergy gain and exergy efficiency increase.

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