Thermal analysis of parabolic concentrator for finding optical efficiency by different methods with varying parameters.

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Abstract— Parabolic concentrator is used to utilize the solar energy for heating purpose. Thermal tests are performed on concentrator at different time periods and at different masses to find the variation in the optical efficiency and heat loss factor. The results verified by graphical test can be used to design the concentrator for the desired output. It was found that the system gave almost the same values of optical efficiency, for the various masses of water on different days. The value of optical efficiency factor increases slightly by reducing the mass of water. The value of optical efficiency for the parabolic concentrator is obtained as 35%.

Keyword- Focal point, absorber, optical efficiency, heat loss factor.

I. INTRODUCTION

Solar energy is an inexhaustible source having a capacity of meeting a significant portion of the world future energy needs. Sun has produced energy for billions of years. Solar energy can be converted directly or indirectly into other forms of energy, such as heat and electricity [2].Cooking accounted for major portion of the total energy consumed in the rural domestic sector. Various types of solar thermal devices are now available in the country these includes solar flat plate cooker, parabolic concentrator, Sheffler's Disc etc. [3]

In this paper, two thermal performance tests are conducted on different masses of water to compare the results for optical efficiency and heat loss factor. The results plotted are used to design the concentrator and to determine the heat output from the concentrator.

II. EXPERIMENTAL SET UP

Set up consist of 2.2 m diameter concentrator and black coated absorber in the form of cooker. The value of diameter is selected such that heat input available at focal area is in the range of 3000 watts [7].The focal area is a white bright spot measured and found to be almost 0.3 m by 0.3 m and hence absorber in the form of cooker with 0.3 m diameter and 0.3 m height is selected. . Anodized aluminium reflector with reflectivity of 85% is fitted over rings to get the desired shape of parabola.

Fig. 1. Parabolic concentrator with cooker

III. THERMAL PERFORMANCE TESTS

A. Heating and cooling tests

These tests are conducted to evaluate overall heat loss factor ($F'U_L$) optical efficiency Factor ($F' \eta_o$). The testing is done on various quantities of water at different days to find variation in the value of $F'U_L$ and ($F' \eta_o$).The value of the heat loss factor ($F'U_L$) is calculated as,

$$F'U_L = (m \times C_p)/(A \times \tau_o) \qquad (1)$$

Where A = total surface area in m^2, C_p = specific heat in J/kg K, m = mass of water in kg. τ_o = time-constant for cooling. The slope of the line, drawn between [$\ln(T_w-T_a)$] Vs time gives the value of ($-1/\tau_0$).The optical efficiency factor ($F'\eta_o$) is then calculated as,

$$F' \eta_o = \frac{\frac{(F^1 U_L) \times A_{pot}}{A}\left[\left(\frac{T_{wf} - T_a}{(I_b r_b)}\right) - \left(\frac{T_{wi} - T_a}{I_b r_b}\right)\right] e^{-\tau/\tau o}}{1 - e^{-\tau/\tau o}} \qquad (2)$$

Where, T_{wf}= final temperature of water in ^oC, T_{wi}= initial temperature of water in, ^oC, τ = time interval, $I_b r_b$ = irradiance in W/m^2, T_a = ambient air temperature in ^oC [4][5].

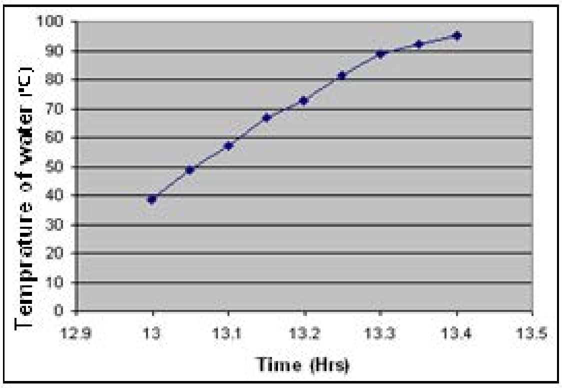
1) Analysis with 8 kg of water

The first test was conducted with 8 kg mass of water using the concentrator. The observations are tabulated below.

TABLE I
Readings taken for 8 Kg of water during heating test

TIME(sec.)	13.00	13.05	13.10	13.15	13.20	13.25	13.30	13.35	13.40
$I_b r_b$ (W/m^2)	864	861	861	870	877	881	842	821	820
Temp. of water.(^0C)	38.70	48.90	57.00	66.60	72.80	81.50	89.00	92.10	95.10
$\Delta T/ I_b r_b$	-	0.0118	0.009	0.011	0.007	0.011	0.008	0.003	0.003
Efficiency η	-	0.323	0.257	0.303	0.194	0.305	0.238	0.102	0.099

The heating and cooling curves are plotted against time, as shown below.



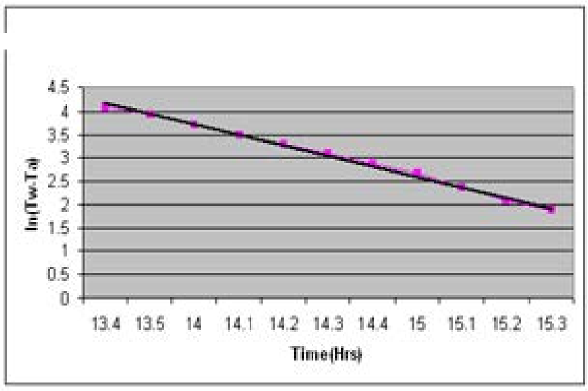


Fig. 1. Heating and cooling curve for 8 kg of water

TABLE III
Readings taken for 8 Kg of water during cooling test

Time(sec.)	13.40	13.50	14.00	14.10	14.20	14.30	14.40	14.50	15.00	15.1	15.2	15.3
Temp.(^0C)	95.10	90.19	87.79	77.96	69.88	63.533	58.49	54.49	51.32	47.796	45.099	43.19
$\ln(T_w-T_a)$	4.048	3.955	3.908	3.688	3.462	3.246	3.020	2.803	2.595	2.282	1.96	1.648

Form the semi-log cooling curve, slope m is calculated as, m= (3.908-3.02)/40 =0.0221.Substituting values obtained from table I and II and from graphs, in equation (1) and (2), the value of $F' \eta_0$ & $F' U_L$ is calculated as follow.

$$F' U_L = \frac{8 \times 4.187 \times 1000}{0.6327(45.04 \times 60)} = 19.87 \text{ W/m}^2 \text{°K}$$

$$F'\,\eta_0 \;=\; \frac{19.87\times 0.6234}{4.15\times 0.1999}\left[\frac{(57-38.7)}{865}-\frac{(38.7-38.7)}{865}\times 0.80\right]=0.314=31.4\ \%$$

Where, τ_o=1/m = 45.04 min, with span of 10 minutes so, τ = 10 min. Similarly the values are calculated for the next spans of 10 minutes and tabulated in table no III.

TABLE IIIII
VALUES OF OPTICAL EFFICIENCY FACTOR FOR 8 KG OF WATER WITH TIME

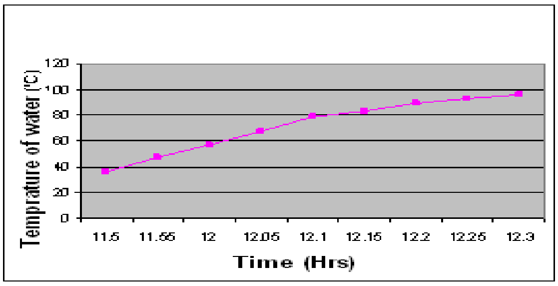
Time(Hrs)	13.10	13.20	13.30	13.40
$F'\eta_o$	0.314	0.3231	0.414	0.327

2) Analysis with 7 kg of water

The second test was conducted with 7 kg mass of water using the concentrator. The observations are tabulated below.

TABLE IVV
READINGS TAKEN FOR 7 KG OF WATER DURING HEATING TEST

Time(sec.)	11.50	11.55	12.00	12.05	12.10	12.15	12.20	12.25	12.30
$I_b r_b$ (W/m^2)	842	865	853	845	845	865	875	882	871
Temp of water.(^{0}C)	36.2	47	56.90	67.50	78.40	83.00	89.10	92.70	95.64
$\Delta T/ I_b r_b$	-	0.012	0.011	0.012	0.012	0.005	0.007	0.004	0.003
Efficiency η	-	0.302	0.275	0.298	0.308	0.128	0.167	0.098	0.803



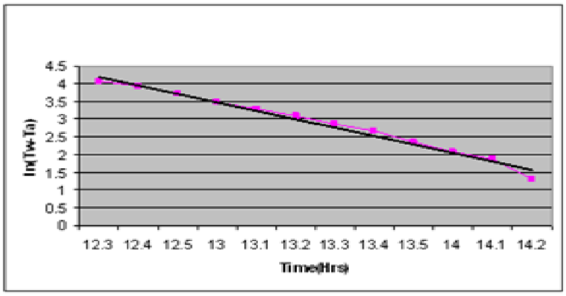


Fig. 3. Heating and cooling curve for 7 kg of water

TABLE V
Readings taken for 7 Kg of water during cooling test

Time(sec.)	12.30	12.40	12.50	13.00	13.10	13.20	13.30	13.40	13.50	14.00	14.10	14.20
Temp.(^{0}C)	95.64	88.50	78.50	70.60	64.60	59.00	55.10	52.00	48.50	46.00	43.50	40.00
$\ln(T_w-T_a)$	4.085	3.945	3.7813	3.5243	3.3809	3.091	2.767	2.5672	2.3513	2.0794	1.8718	1.332

Similar to 8 kg of water, the values obtained from tables and graphs are substituted in equation (1) and (2), the value of $F'\,\eta_0$ & $F'\,U_L$ is calculated as,

$$F'\,U_L=\frac{7\times 4.187\times 1000}{0.6234\times 41.089\times 60}=19.07\ \text{W/m}^{2\circ}\text{K}$$

$$F'\,\eta_0 \;=\frac{19.07\times 0.6234}{4.15\times 0.216}\left[\frac{(56.9-36.2)}{853}-0\right]=0.318=31.8\%$$

Similarly the values are calculated for the span of 10 minutes and tabulated in table no.VI

TABLE VI
Values of optical efficiency factor for 7 kg of water with time

Time(Hrs)	12.00	12.10	12.20	12.30
$F'\eta_o$	0.318	0.3392	0.4102	0.327

3) Analysis with 5 kg of water

The third test was conducted with 5 kg mass of water using the concentrator. The observations are tabulated below.

TABLE VII
Readings taken for 5 Kg of water during heating test

Time(sec.)	12.00	12.05	12.10	12.15	12.20
$I_b r_b$ (W/m^2)	871	864	876	870	862
Temp of water.(^{0}c)	37.01	52.22	68.12	82.24	96.32
$\Delta T/ I_b r_b$	-	0.017	0.018	0.016	0.016
Efficiency η	-	0.294	0.312	0.276	0.277

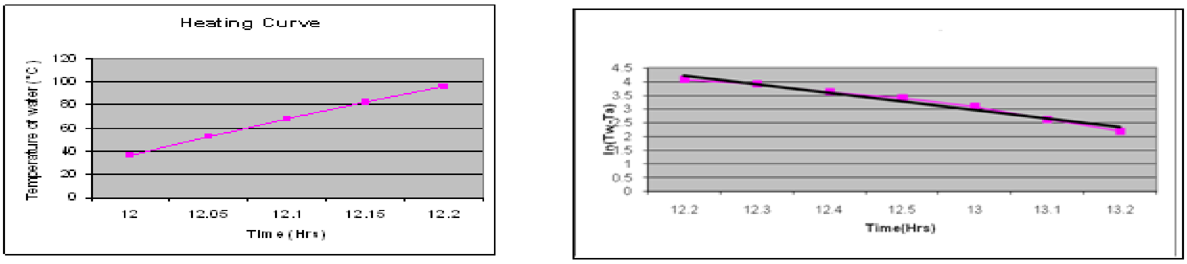


Fig. 4. Heating and cooling curve for5 kg of water

TABLE VIII
Readings taken for 5 Kg of water during cooling test

Time(sec.)	12.20	12.30	12.40	12.50	13.00	13.10	13.20
Temp.(^{0}c)	96.32	87.29	74.77	70.60	67.36	50.58	44.45
$\ln(T_w\text{-}T_a)$	4.080	3.916	3.6293	3.4167	3.0964	2.631	2.2012

Like previous cases, the values obtained from tables and graphs are substituted in equation (1) and (2), and the value of $F' \eta_0$ & $F' U_L$ is calculated as below.

$$F' U_L = \frac{5 \times 4.187 \times 1000}{0.6324 \times 31.13 \times 60} = 17.97 \ W/m^{2\circ}K$$

$$F' \eta_0 = \frac{17.97 \times 0.6234}{4.15 \times 0.2747}\left[\frac{(68.12 - 37.11)}{868} - 0\right] = 0.35268 = 35.26\%$$

Similarly the values are calculated for the span of 10 minutes and tabulated in table no. IX

TABLE IX
VALUES OF OPTICAL EFFICIENCY FACTOR FOR 5 KG OF WATER WITH TIME

Time(Hrs)	12.10	12.20	12.30
$F'\eta_o$	0.354	0.423	0.349

Fig. 5 shows the variation of optical efficiency factor for different mass of water at different times. The graphs drawn from table no III, XI and IX shows almost similar curve with value average value of $F' \eta_0$ equal to 0.354.

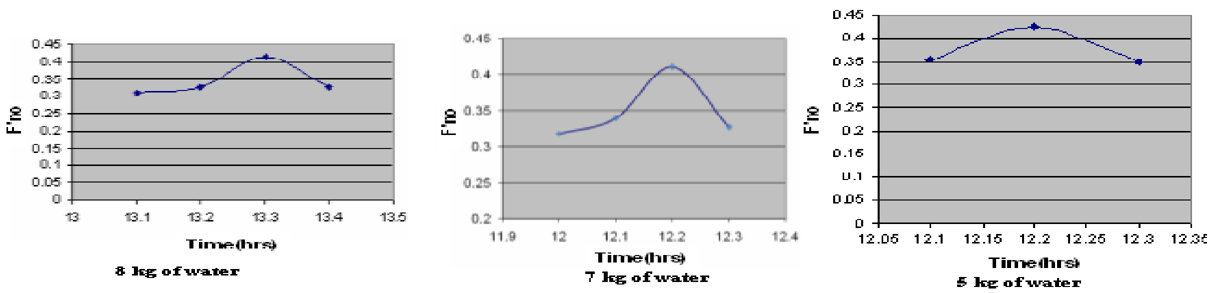


Fig. 5. Variation of Optical Efficiency factor with respect to times for 3 cases

B. Graphical Method

The optical efficiency obtained in the previous section can be analysed in another way. The difference between water temperature and ambient temperature is determined (ΔT), over a period of 5 minutes .The value of the instantaneous efficiency is then calculated as,

$$\eta_i = \frac{m_w C p_w \Delta T_w}{t \times A_c \times I_b r_b}$$

. The factor $\Delta T/I_b r_b$ is determined and plotted against the instantaneous efficiency. A least square regression straight line is fitted through these data points, and this equation is compared with the equation,

$\eta_i = \eta_o - (U_L)_c\ (\Delta T/I_b\ r_b)$.

Slope of the line is the heat loss factor of concentrator and y-intercept is the optical efficiency of the system [3].This analysis is applied for 2 cases and taking values from Table I and IV for 8 kg and 7 kg of water respectively. The graphs are plotted as shown below in Fig. 6.

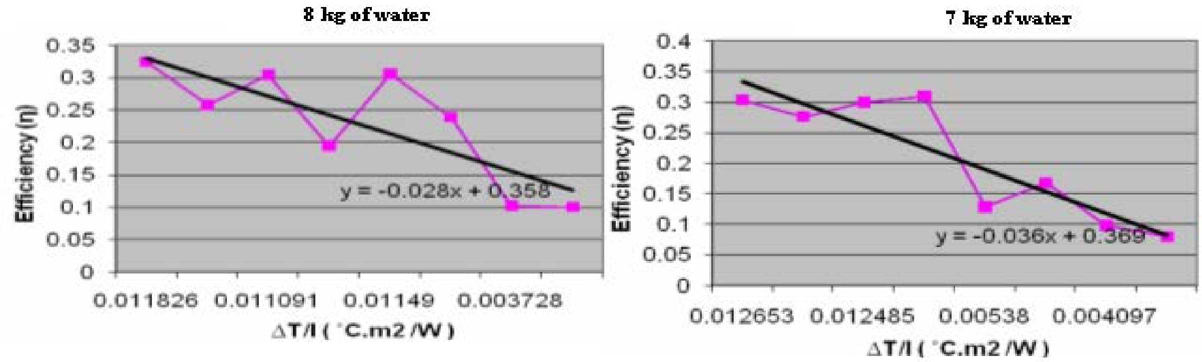


Fig. 5. Variation of Optical Efficiency factor with respect to time for 3 cases

The equation of line y= 0.358 -0.028 x is compared with the equation, $\eta_i = \eta_o - (U_L)_c\ (\Delta T/\ I_b\ r_b)$ and the value of optical efficiency obtained is 0.358, for 8 kg of water, similarly, y= 0.369 -0.036 x is compared with the equation and the value of optical efficiency obtained is 0.369, for 7 kg of water.

IV. CONCLUSION

The value of overall heat loss factor and optical efficiency factor are calculated and verified by two methods and it has been observed that the value of $F' U_L$ is found to be 17 to 20 $W/m^2\ {}^0K$.The theoretical value for U for air is in the range of 10 to 100 $W/m^2\ {}^0K$ [8]. The value of overall heat loss factor increases and hence the value of optical efficiency factor decreases with increase in the mass of water. The value of overall heat loss factor is least and the value of optical efficiency factor is highest for 5 kg of water. It was found that the system gave almost the same values of optical efficiency, for the various masses of water on different days. It was observed that optical efficiency of the system increases when the bright spot moves towards the centre of the cooker. This is possible by keeping the axis of the concentrator parallel to the sun rays. From both the analysis, value of optical efficiency obtained is 35%.Thus analysis helps to design the concentrator for the desired output at the absorber. Considering 65% loss and the solar radiation available at a particular area, the output at the absorber can be calculated.

REFERENCES

[1] Goswami D. Yogi, Frank Kreith, Jan F. Kreider *"Principal of solar energy"* 2nd Edition 2000 published by Taylor & Francis pp[1-2].
[2] Yu.M.lytvynenko and Schur D.V. *" Utilization the concentrated solar energy "* Renewable energy 16(1999)pp[753-756]
[3] Sukatme S.P. "*Solar Energy*"2nd edition Tata McGraw-Hill Publishing Company Ltd. pp[62-66].
[4] C Z M Kimambo" *Development and performance testing of solar cookers* "Journal of Energy in Southern Africa • Vol 18 No 3 , August 2007.
[5] M. Ouannene, B. Chaouachi, S.Gabsi" *Design and realisation of a parabolic solar cooker* "National School of Engineers of Gabes (E.N.I.G) - Omar Ibn ElKhattab Street -6029 Gabes-Tunisia.
[6] Yogesh R. Suple 1 Dr. S.B. Thombre" *Performance Evaluation of Parabolic Solar Disc for Indoor*" IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)ISSN: 2278-1684 Volume 4, Issue 6 (Jan. - Feb. 2013), PP 42-47
[7] A.B.Auti" *Domestic solar water Desalination* "*Energy Procedia*, ELSVIER,Volume 14, 2012, pp[1774-1779]
[8] http://www.engineeringtoolbox.com/overall-heat-transfer-coefficient-d_434.html.