Performance Evaluation of Solar Parabolic Trough Collector with Stainless Steel Sheet as a Reflector

Syed Mohd. Yasir Arsalan[1], Er. Earnest Vinay Prakash[2], Er. Rahul Charles Francis[3]

[1]M.Tech Student, Mechanical Engineering, SSET, Sam Higginbottom Institute of Agriculture Technology and Science, Allahabad, U.P, INDIA
Email: raj_yasir @yahoo.com

[2]Assistant Professor, Department of Mechanical Engineering, SSET, Sam Higginbottom Institute of Agriculture Technology and Science, Allahabad, U.P, INDIA
Email: Earnest.prakash@shiats.edu.in

[3]Assistant Professor, Department of Mechanical Engineering, SSET, Sam Higginbottom Institute of Agriculture Technology and Science, Allahabad, U.P, INDIA
Email: rahul.francis@shiats.edu.in

Abstract— *This paper was concerned with an experimental study of parabolic trough concentrator designed and constructed. A parabolic trough solar collector uses Stainless steel sheet in the shape of parabolic cylinder to reflect and concentrate sun radiations towards an absorber tube made of G.I pipe located at the focus line of the parabolic trough collector. The receiver tube absorbs the incoming radiation and transforms them into thermal energy, the latter being transported and collected by a fluid medium circulating within the absorber tube. This experimental study, includes design, construction and testing the performance of PTC, at various parameters.*

Keywords— Absorber tube, G.I Pipe, Parabolic Trough collector, Reflector, Stainless steel sheet.

I. INTRODUCTION

The Improper use of fossil fuels has led to negative imbalance in the natural environment so need of using both non-renewable and renewable energy resources were taken to be the main aim and the utilization objective outlined the need to use energy efficiently. Solar energy is the primary renewable source of energy for our planet. In the present work, an attempt has been made to design, fabricate, evaluate and the performance of a Parabolic Trough Concentrator (PTC) , to produce hot water, by using stainless steel sheet as a reflector materials. A Parabolic Trough Collector uses reflector in the shape of parabolic cylinder to reflect and concentrate sun radiation towards an absorber tube located at the focus line of the parabolic cylinder. The receiver absorbs the incoming radiation and transforms them into useful energy, and latter being transported and collected by a fluid medium circulating within the absorber tube. The aperture diameter, rim angle, reflector property and absorber size and shape defines the PTC. The absorber tube is made of a G.I pipe for quick heat, low cost and protection from corrosion on outer surface of tube.

II. DESIGN CONSIDERATION

In the present PTC, has following innovative characteristics; easy constructible, strong and stable in structure, light in weight and low in cost. For reflecting mirror Stainless Steel Sheet of the size 2.007 meter long, 1.219 meter wide and 0.318 mm thick has placed longitudinally in the concentrator as a reflecting mirror. A stainless steel mirror sheet is chosen because it reflects 65 % of sunlight. As a part of design of PTC, a stainless steel mirror sheets is installed on the parabolic shape structure of the supporting stand. The size of the stainless steel sheet is exactly same as that of structure size of the supporting stand. The parabolic profile is determined by the shape of the ribs and the width of the sheets. The weight of sheets is rest on said ribs. The supporting stand is made up of cast iron, the receiver material of PTC is G.I. pipes, and rim angle for PTC is 90^0. The aperture area of PTC is 2.131 m^2.The model which is made up of reflector surface, reflector support, absorber pipe and a stand with manual tracking arrangement was fabricated using locally sourced material for rural application point of view.

III. CALCULATION OF PARABOLIC END

In order to determine the dimension of PTC, the following parameters are considered:

Rim angle (ψ) = 90^0 , Width(S) = 1.219 m. or 1219mm.

Width of the aperture (W_a): = 2S tan(ψ/2)/{sec(ψ/2)*tan(ψ/2)+ ln(sec(ψ/2)+tan(ψ/2))} = 1062.25 mm or 1.0622 m.

Focal Length of Parabola: $F = W_a / 4\tan(\psi/2) = 265.56$ mm or .2655 m

Equation of parabola: $X^2 = 4*F*Y$; $X^2 = 4*265.56*Y$; $X^2 = 1062.24Y$

Geometrical concentration ratio: $C = W_a / \pi D_0$; C = 10.91

TABLE 1
SPECIFICATIONS OF PTC

Reflector Material	Stainless Steel
Focal length (F)	0.265m
Rim angle (ψ)	90^0
Aperture width (W_a)	1.0622m
Diameter of receiver tube (D_0)	0.031m
Length of parabola (L)	2.007m
Effective aperture area (A_a)	2.131 m^2
Concentration Ratio(c)	10.91
Reflectivity of collector (ρ)	0.63
Absorptivity of receiver Tube (α)	0.8
Length of receiver tube (L_{abs})	2.13
Receiver material	GI pipe
Thickness of reflector material	0.305mm

IV. EXPERIMENTAL SETUP

The experimental setup consists of a parabolic trough collector. Storage tanks of capacity 25 liters, receiver's pipe of length 2.12 m with two valve both end are used. The reflector material is made by stainless steel. The water supply tank is located above the receiver's pipe level to allow the heating fluid to flow naturally without the pumping system. The storage tank is fill from main water supply. The water inlet and outlet temperature of the absorber tube, the ambient temperature, the reflector temperature, the temperatures at inlet/middle/outlet surface of receiver, the solar radiation intensity and wind velocity are continually measured during the experiment. The experiment is carried out in the month of April and May 2016, SHIATS, Allahabad (UP). The testing system is oriented North-South as shown in figure.

We have fitted the digital thermometers to observe the temperature at point of receiver's in/mid/out points, inlet water storage tank, outlet water storage, reflector sheet's front sides and ambient temperature pick. We have used solarimeter to measure the solar radiation intensity on mirror sheet and receiver tube. For measuring wind velocity we used anemometer.

FIG 1: EXPERIMENTAL SETUP OF PTC

V. TESTING

Testing was started at the local time 10 A.M. Water was inserted into receiver tube 30 minutes before the actual reading is started. Temperature of water is measured after every 30 minutes. To ensure that the incoming beam radiation should always remain normal to the reflecting surface, parabola trough was manually rotated after 15 minutes along with the sun about the focal line of the parabola and it was held at that position for 15 minutes by using strings.

TABLE 2
OBSERVATION TABLE RECORDED ON 26/04/2016

S.No.	Time	INLET Temp. (T_1)	Outlet Temp. (T_6)	S.I. (H_b)	Wind Speed (W_v)	Ambient Tem. (T_a)
1	10:00	35.1	42.7	800	0.3	39.1
2	10:30	36.3	47.5	900	0.6	39.9
3	11:00	36.9	48.8	1100	1.1	40.3
4	11:30	37.4	49.6	700	1.9	40.8
5	12:00	38.6	52.2	1200	0.9	41.3
6	12:30	38.6	55.3	1200	1.2	43.6
7	01:00	39	55	1200	1.3	43.5
8	01:30	39.2	53.2	1200	0.8	43.3
9	02:00	39.2	49.8	800	2.1	42.2
10	02:30	39.2	49	900	1.5	41.5
11	03:00	39.5	50.6	1000	0.8	40.1
12	03:30	38.5	45	700	1.4	39.8
13	04:00	36.9	43.2	400	1.6	38.3
14	04:30	36.7	43.1	400	1.8	38.1

TABLE 3
OBSERVATION TABLE RECORDED ON 27/04/2016

S.No.	Time	INLET Temp. (T_1)	Outlet Temp. (T_6)	S.I. (H_b)	Wind Speed (W_v)	Ambient Tem. (T_a)
1	10:00	35.4	42.8	800	2.2	36
2	10:30	38.1	48.2	1200	2.5	38.3
3	11:00	39.8	48.8	1000	1.5	41
4	11:30	39.6	48.7	1100	1.3	41.1
5	12:00	40.6	53.3	1200	1.6	43
6	12:30	40.6	53.3	1100	2.7	43.1
7	01:00	40	47	800	2.1	43
8	01:30	39.9	46.9	800	0.9	43
9	02:00	39.8	47	600	0.5	42
10	02:30	38.2	45.9	500	1.7	39.5
11	03:00	38.1	45.8	450	1.3	39
12	03:30	37	43.9	400	2.7	39.9
13	04:00	36.5	43.6	350	1.1	38.3
14	04:30	35.8	45	300	1.8	38

TABLE 4
OBSERVATION TABLE RECORDED ON 28/04/2016

S.No	Time	INLET Temp. (T_1)	Outlet Temp. (T_6)	S.I. (H_b)	Wind Speed (W_v)	Ambient Tem. (T_a)
1	10:00	36	48.1	1200	0.9	39.8
2	10:30	36.3	50.3	1200	0.8	40
3	11:00	39.3	50.1	1200	1.5	40.4
4	11:30	39.8	50.2	1200	1.7	42.2
5	12:00	40	50.4	1200	2.1	42.5
6	12:30	41.6	56.6	1200	1.1	44.4
7	01:00	41.5	54.2	1200	0.6	44.3
8	01:30	41.2	50	1100	1.9	43.1
9	02:00	41	48	1000	0.8	43
10	02:30	40.5	49.1	900	1.5	42.9
11	03:00	40.1	51.9	850	1.1	42.9
12	03:30	39	50.1	700	0.3	42
13	04:00	38	48.8	600	0.5	41.8
14	04:30	35.8	47.3	400	0.9	40.3

TABLE 5
OBSERVATION TABLE RECORDED ON 02/05/2016

S.No.	Time	INLET Temp. (T_1)	Outlet Temp. (T_6)	S.I. (H_b)	Wind Speed (W_v)	Ambient Tem. (T_a)
1	10:00	34.9	49.8	750	1.5	40.2
2	10:30	35.3	52.3	1200	1.7	41.3
3	11:00	35.6	52.9	1200	1.1	41.4
4	11:30	37.5	50.7	1200	1.9	42.2
5	12:00	38.7	50.7	1200	2.1	41.6
6	12:30	39.5	51.1	1200	2.2	42.2
7	01:00	39.8	50.9	1200	2.8	41.9
8	01:30	39.1	51.1	1200	2.9	42.1
9	02:00	39.5	51	1200	2.1	42.9
10	02:30	38.8	49.4	1170	1.7	41.9
11	03:00	38.1	48.9	920	1.3	41.6
12	03:30	37.9	48.5	710	0.9	41.4
13	04:00	37.7	48.2	620	1.1	41.1
14	04:30	36.3	45.5	260	0.8	40.8

TABLE 6
OBSERVATION TABLE RECORDED ON 03/05/2016

S.No	Time	INLET Temp. (T_1)	Outlet Temp. (T_6)	S.I. (H_b)	Wind Speed (W_v)	Ambient Tem. (T_a)
1	10:00	30.2	43.6	320	3.8	31.1
2	10:30	30.8	44.1	420	3.5	31.6
3	11:00	33.6	46.1	560	2.5	33.2
4	11:30	34.6	47.5	880	2.6	34.4
5	12:00	35.8	56	980	2.4	36.6
6	12:30	37.8	57.2	860	3.6	37.5
7	01:00	38.1	57.8	960	3.8	38.3
8	01:30	38.3	57.6	880	1.7	38.1
9	02:00	38.6	55	720	2.1	38.6
10	02:30	38	54.2	620	2.7	41.8
11	03:00	38.2	52.4	550	1.3	41.5
12	03:30	37.8	50.6	490	1.5	41.3
13	04:00	36.5	48.2	200	2.1	39.9
14	04:30	36.2	48.9	100	1.1	39.2

Case1-Calculation of Thermal efficiency
Date: 03/05/2016
Weather condition: Hot weather
Minimum ambient temperature: 31.1^0C.at 10 A.M.
Maximum ambient temperature: 41.8 ^{0}C.at 02: 30 P.M
Thermal Efficiency: $\eta = Q * 100 / (A_a * H_b * \rho * R_b)$
Where, Q = Net useful heat gained by the fluid(watt) = $m\ C_p(T_6 - T_1)$
m = mass flow rate of fluid (Kg/sec); C_p= specific heat of fluid = 4180 J/Kg K for water
T_6= Maximum temperature attained by fluid (^{0}C); T_1= Initial temperature of fluid (^{0}C)
A_a= Aperture area (m^2); H_b= Solar Intensity (W/m^2); ρ = Reflectivity of collector materials
R_b= Tilt Factor for beam radiation (assuming collector is always normal to radiation) =1
Mass flow rate (m) = 3.16 kg / hrs = .000878 kg / sec
For, Initial Temperature (T_1) = 36.2 ^{0}C at 04:30 P.M
Maximum Temperature (T_6) = 48.9 ^{0}C at 04:30 P.M
$Q = m\ C_p(T_6 - T_1)$ = 46.6095 W
Efficiency (η) = $Q * 100 / (A_a * H_b * \rho * R_b)$
= 34.71 %

VI. RESULTS AND DISCUSSIONS

Numbers of observations were taken on the system in the Month of April & May 2016 in the campus of SHIATS, Allahabad, Uttar Pradesh, India. Data are plotted for a particular day (03/05/2016)

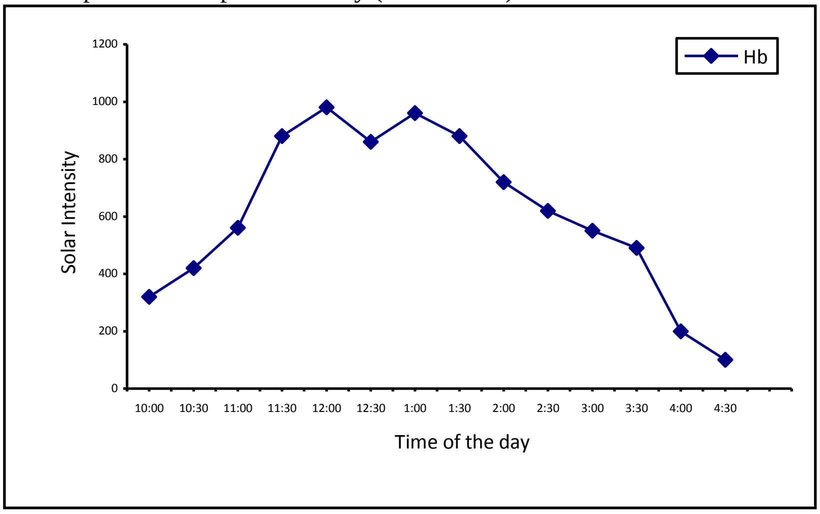

FIG 2: VARIATION OF SOLAR INTENSITY WITH TIME

Fig.2 shows the variation of solar intensity with time. As it is expected, the maximum intensity of 980W/m^2 is obtained at around 12:00 PM

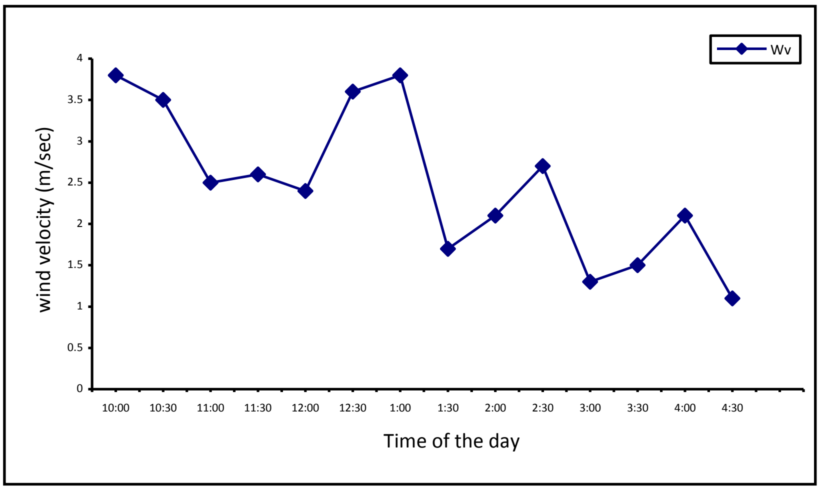

FIG 3: VARIATION OF WIND VELOCITY WITH TIME

Fig.3 shows the variation of wind speed with time, which is moderate.

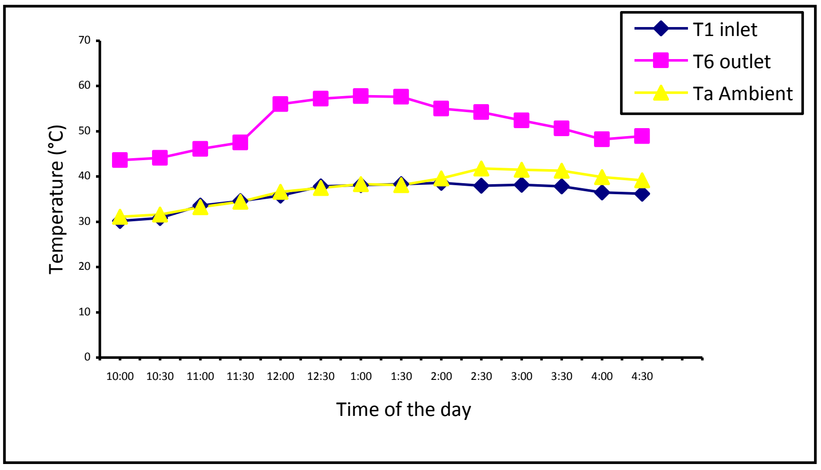

FIG 4: VARIATION OF INLET, OUTLET & AMBIENT TEMPERATURES WITH TIME

Fig.4 shows the variation of inlet water, outlet water and ambient temperature of the PTC with time of the day. It is clear from fig 3 and fig 4 that, due to better solar intensity of 960 W/m^2 at 01:00 PM, water outlet temperature from the receiver pipe is 57.8 ^{0}C in the afternoon. The red line shows water outlet temperature of PTC, blue line shows water inlet temperature of PTC, and yellow line shows the ambient temperature with time of the day. For PTC, maximum outlet temp of 57.8^{0}C is obtained at around 01:00 PM.

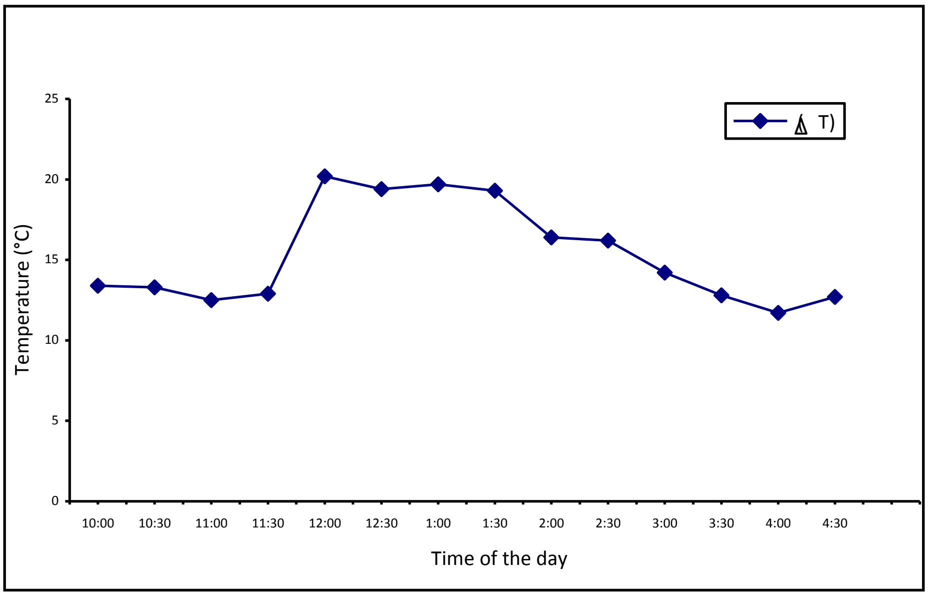

FIG 5: VARIATION OF TEMPERATURE DIFFERENCE WITH TIME

Fig 5 shows the variation of temperature difference between inlet and outlet temperatures with time of the day. As it is clear from the figure the maximum temperature difference is 20.2^{0}C, and it is obtained at 12:00 PM.

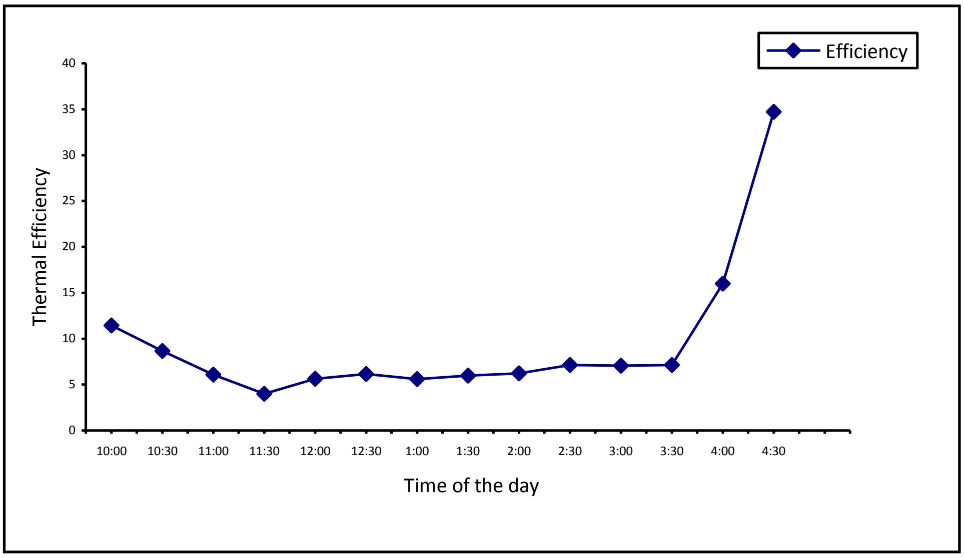

FIG 6: VARIATION OF INSTANTANEOUS THERMAL EFFICIENCY WITH TIME

Fig.2 shows the variation of instantaneous thermal efficiency of PTC with time of the day. As it is clear from the figure, a maximum instantaneous thermal efficiency of PTC having stainless steel reflector is 34.71 %, and it is obtained at around 04:30 hrs.

VII. CONCLUSION

In the present work, the performance of a new parabolic trough collector for hot water generation system is investigated through experiments over one full day in the month of May 2016. The maximum value of each of those parameters is observed around noon, when the incident beam radiation is at its peak. The fabrication and design of a solar parabolic trough collector using locally available materials is possible hence low temperature trough will be a better solar thermal device for the rural and remote area. From the result it has been seen that the parabolic trough is better option to reduce the water heating cost. This research has its own special features, maintenance cost is minimum and hence economical, running cost is nil, the labour cost is minimized on account of its simple design. As other forms of energy are fast depleting and polluting the atmosphere, non-conventional energy resources like solar energy are best suited to use. The solar parabolic trough is among the best way to use solar energy efficiently due to its advantages to convert abundantly available solar energy into effective and convenient form of heat energy which can be use for various purposes.

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