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To Analyze the Performance of Solar Parabolic Trough Concentrator with Two Different Reflector Materials

Syed Mohd. Yasir Arsalan[1], Earnest Vinay Prakash[2], Dr. Ajeet Kumar Rai[3]

[1]M.Tech Student, Mechanical Engineering, SSET,
Sam Higginbottom Institute of Agriculture Technology and Sciences, Allahabad (U.P), India

[2]Assistant Professor, Department of Mechanical Engineering, SSET, Sam Higginbottom Institute of Agriculture Technology and Sciences, Allahabad (U.P), India

[3]Assistant Professor, Sr.Grade, Department of Mechanical Engineering, SSET, Sam Higginbottom Institute of Agriculture Technology and Sciences, Allahabad (U.P), India

Abstract: ***In the present work, an attempt has been made to design, fabricate, evaluate and compare the performance of two different PTCs, to produce hot water, by using two different reflector materials. In PTC-1, reflector material is made by acrylic mirror sheet, and in PTC-2 reflector material is made of by stainless steel sheet. For both the PTCs the rest of the materials used are same. The supporting stand is made up of cast iron, the receiver material for both the PTC is G.I. pipes, and rim angle for both the concentrator is 90^0. The aperture area of both the concentrators is 2.131 m^2. And concentration ratios of both the concentrators are 10.91. The maximum instantaneous thermal efficiency obtained by the concentrator having acrylic mirror sheet is 13.67 %, and concentrator having stainless steel material is 15.85 %.***

Keywords: Solar Parabolic Trough Collector (PTC), Reflector, Receiver, Maximum Temperature, Thermal Efficiency

1. Introduction

The current industrial growth and environmental impacts shows that solar energy for solar thermal power plant is the most promising of the unconventional energy sources. Solar energy is an exhaustible source of energy potentially capable of meeting a significant portion of all nations. The most common commercially available solar power plants use parabolic trough concentrators.

Parabolic trough concentrator is a solar concentrator technology that converts solar beam radiation into thermal energy. It consists of a cylindrical parabolic reflector and a metal tube receiver at its focal plane. . The heat transfer fluid flows through the absorber tube, gets heated and thus carries heat. Such concentrators have been in use for many years. The aperture diameter, rim angle and absorber size and shape may be used to define the concentrator. The absorber tube may be made of by G.I. pipes or copper. Selective coatings may be used for better performance. Depending on the temperature requirement different heat transfer liquids may be used. Reflectors may be of anodized, aluminium Mylar or curved silvered glass. Since it is difficult to curve a very large, mirror strips are sometimes used in the shape of parabolic cylinder. The reflecting part is fixed on a light weight structure. A cylindrical parabolic trough may be oriented in any of the three directions: East-west, north-south or polar. The first two orientations although simple to assemble, have higher incidence angle cosine losses. The polar configuration intercepts more solar radiation per unit area as compared to other modes and thus gives the best performance.

2. 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 three Acrylic Mirror Sheets of the size 0.92 meter long, 1.219 meter wide and 1.35 mm thick has placed longitudinally in one concentrator. And for another concentrator stainless steel sheet of 2.007 meter long, 1.219 meter wide and 0.318 mm thick has placed as a reflecting mirror. They were placed longitudinally; this in turn determined the size of the PTC. An acrylic mirror sheet is chosen because it reflects 80% of sunlight. The reflectivity of stainless steel mirror is 65% of sunlight. As a part of design of PTC, both mirror sheets are 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. But the acrylic mirror sheet is installed with little modification on its length. 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.

2.1 Calculation for 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):
$W_a = 2S \tan(\psi/2)/\{\sec(\psi/2)*\tan(\psi/2) + \ln(\sec(\psi/2)+\tan(\psi/2))\}$
W_a = 1062.25 mm or 1.0622 m.

Focal Length of Parabola: $F = W_a / 4\tan(\psi/2)$

F = 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

P.T.C. Name	PTC (1)	PTC-(2)
Reflector Material	Acrylic mirror	Stainless Steel
Focal length (F)	0.265m	0.265m
Rim angle (ψ)	90^0	90^0
Aperture width (W_a)	1.0622m	1.0622m
Diameter of receiver tube (D_0)	0.031m	0.031m
Length of parabola (L)	2.007m	2.007m
Effective aperture area (A_a)	2.131 m^2	2.131 m^2
Concentration Ratio(c)	10.91	10.91
Reflectivity of collector (ρ)	0.8	0.63
Absorptivity of receiver Tube (α)	0.8	0.8
Length of receiver tube (L_{abs})	2.13m	2.13
Receiver material	GI pipe	GI pipe
Thickness of reflector material	1.35mm	0.305mm

3. Fabrication of PTC

The parabolic trough collector is constructed in very simple manner. It consists of a parabolic trough collector, a receiver and a support structure. The detail description is given below:

3.1 Collector support structure

For collector`s stability and accuracy, a rigid supporting structure is designed and made with rigid iron strips. The structure frame is supported to the rotation axis of the parabolic reflecting surface. It is used for the rotation of the horizontal axis for daily tracking of the sun. For test purpose and cost reduction, the unit is designed for easy manual tracking.

3.2 Parabolic trough

The proposed trough collectors consists of acrylic mirror sheet of 1.35 mm thickness, and stainless steel sheet of 0.318 mm thickness, which has undergo a careful deformation process that was necessary to bring it into parabola shape. The material is easily available and can be given requisite shape. For the easy manoeuvrability of the collector system, the aperture width of trough is taken as 1.062 m and focal length is 0.265 m. The aperture area of reflecting surface is 2.131 m^2.

3.3 Receiver

The purpose of designed parabolic trough collector was to heat water at atmospheric temperature and pressure. The desired process is carried out in the receiver placed concentrically along the focal line of collector. Out of many shapes thought of, from circular to square, circular section was finalized .The reason being easy availability and less area coverage to avoid shading of reflector. The circular pipe made of Galvanized iron (GI) pipes is used for both the PTCs for the receiver purpose. The size of receiver was decided based on two factors viz. (1) Local availability of channel section, and (2) Concentration ratio desired. The final receiver dimensions are taken as outer diameter 0.03m and length 2.12 m.

4. Experimental Setup

The experimental setup consists of two parabolic trough collectors. For each PTC, a storage tank of capacity 25 liters, receiver's pipe of length 2.12 m with two valve both end are used. In PTC-1, reflector material is acrylic mirror sheet, and in PTC-2 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 to capture maximum insulation as shown in figure.

Figure 1: Experimental setup of PTC

5. 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.

Case 1 - For PTC-1 having Acrylic Mirror sheet reflector

Date: 25/04/2016

Weather condition: Hot weather

Minimum ambient temperature: 36.6^0C.at 10 A.M.

Maximum ambient temperature: 43.4^0C.at 12: 30 P.M.

Table 2: Observation Table for PTC 1

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	35.6	46.3	600	2.1	36.6
2	10:30	38.4	52.2	900	1.8	38.5
3	11:00	38.7	52.6	800	1.9	41.1
4	11:30	38.8	54.7	950	0.6	42.2
5	12:00	39.4	57.4	1000	0.9	43.1
6	12:30	39.8	59.3	1020	1.6	43.4
7	01:00	39.1	58.8	820	1.3	42.3
8	01:30	38.8	57.1	780	0.8	42.1
9	02:00	38.3	55.3	660	1.9	41.9
10	02:30	37.8	54.2	560	2.1	39.4
11	03:00	37.4	52.9	420	1.5	39.1
12	03:30	37.1	51.5	400	1.4	38.8
13	04:00	36.4	49	300	1.3	38.5
14	04:30	36.1	48.8	200	0.4	38.1

Calculation for 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) = 36.1 ^{0}C at 04:30 P.M
Maximum Temperature (T_6) = 48.8^{0}C at 04:30 P.M
Q = m $C_p(T_6 - T_1)$ = 46.6095 W
Efficiency (η) = $Q * 100 / (A_a * H_b * \rho * R_b)$
= 13.67 %

Case 2 - For PTC-2 having Stainless steel reflector

Date: 25/04/2016
Weather condition: Hot weather
Minimum ambient temperature: 36.6^{0}C.at 10 A.M.
Maximum ambient temperature: 43.4^{0}C.at 12: 30 P.M.

Table 3: Observation Table for PTC 2

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	35.3	45.2	600	2.1	36.6
2	10:30	38.2	48.8	900	1.8	38.5
3	11:00	38.5	50.3	800	1.9	41.1
4	11:30	38.8	52.6	950	0.6	42.2
5	12:00	38.8	55.9	1000	0.9	43.1
6	12:30	39.1	56.9	1020	1.6	43.4
7	01:00	39.8	56.3	820	1.3	42.3
8	01:30	39.1	54.6	780	0.8	42.1
9	02:00	38.5	53.8	660	1.9	41.9
10	02:30	38.3	52.1	560	2.1	39.4
11	03:00	37.1	51.4	420	1.5	39.1
12	03:30	36.8	49.1	400	1.4	38.8
13	04:00	36.1	47.8	300	1.3	38.5
14	04:30	35.9	47.5	200	0.4	38.1

Calculation for Thermal Efficiency:

$\eta = Q * 100 / (A_a * H_b * \rho * R_b)$

Where,
Q = Net useful heat gained by the fluid (watt)= m $C_p(T_6 - T_1)$
Mass flow rate (m) = 3.16 kg / hrs
= .000878 kg / sec
Initial Temperature (T_1) = 35.9 ^{0}C at 04:30 P.M
Maximum Temperature (T_6) = 47.5 ^{0}C at 04:30 P.M
Q = m $C_p(T_6 - T_1)$ = 46.6095 W
Efficiency (η) = $Q * 100 / (A_a * H_b * \rho * R_b)$
= 15.85 %

6. Results and Discussion

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.

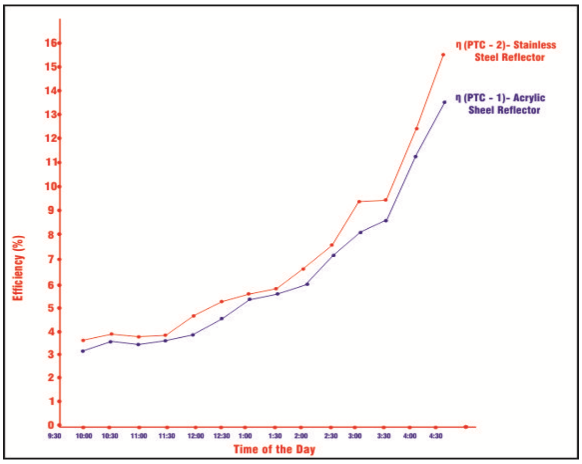

Figure 2: Variation of thermal efficiency with time

Figure 2 shows the variation of instantaneous thermal efficiency of both the systems with time of the day. As it is clear from the figure, a maximum instantaneous thermal efficiency of PTC-2 having stainless steel reflector is 15.85%, and for PTC-1 having acrylic mirror sheet reflector is 13.67%, and both are obtained at around 04:30 hrs.

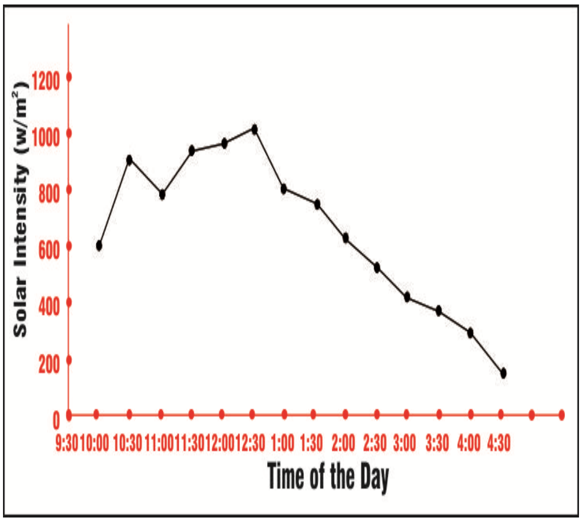

Figure 3: Variation of solar intensity with time

Figure 3 shows the variation of solar intensity with time. As it is expected, the maximum intensity of $1020 W/m^2$ is obtained at around 12:30 PM.

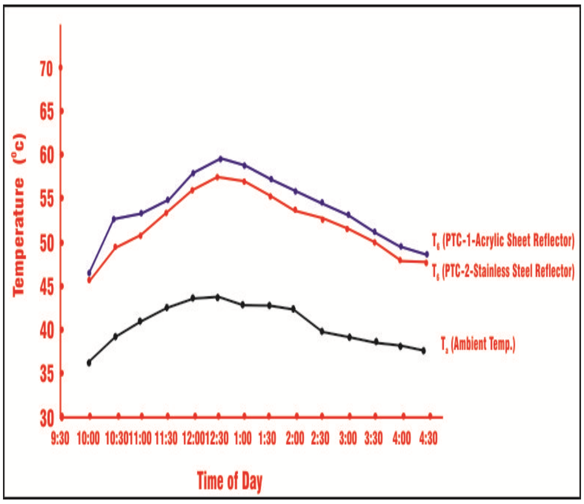

Figure 4: Variation of outlet temp & ambient temp with time

Figure 4 shows the variation of water outlet from the receiver pipe and ambient temperature for both systems with time of the day. It is clear from Figure 3 and Figure 4 that, due to better solar intensity in forenoon, water outlet temperature from the receiver pipe is higher in the afternoon. The blue line shows water outlet temperature of PTC-1(having acrylic Mirror sheet), red line shows water outlet temperature of PTC-2 (having stainless steel) and black line shows the ambient temperature with time of the day. For PTC-1, maximum temp of 59.3^0C is obtained at around 12:30 PM and for PTC-2 max. temp of 56.9^0C is also obtained at around 12:30 PM.

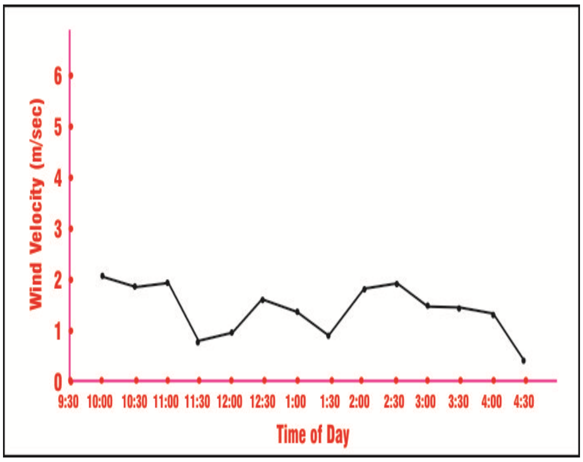

Figure 5: Variation of wind velocity with time

Figure 5 shows the variation of wind speed with time, which is moderate.

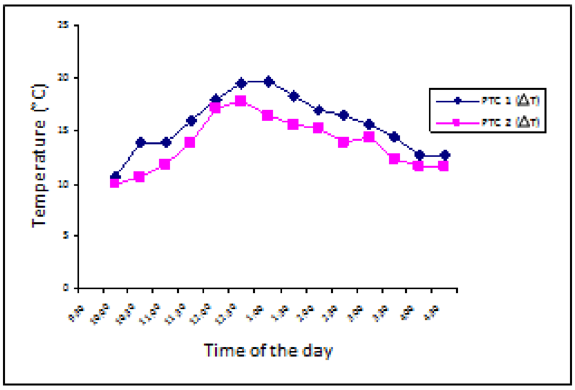

Figure 6: Variation temperature difference with time

Figure 6 shows the variation of temperature difference between inlet and outlet temperature with the time of the day. The blue line shows temperature difference of PTC-1 (having acrylic Mirror sheet), red line shows temperature difference of PTC-2 (having stainless steel). The maximum temperature difference of 19.7^0C is obtained at around 01:00 PM for PTC-1. And the maximum temperature difference of 17.8^0C is obtained at around 12:30 PM for PTC-2.

7. Conclusion

From the collected data, figures, graphs and tables, in relation with the analysis and discussions, this research investigation can be concluded that, the fabricated PTC is quite efficient. As the construction is very simple with locally available low cost materials, it could be manufactured in any workshop. The maximum water temperature obtained from the PTC-1(having acrylic Mirror sheet) was 59.3°C and of PTC-2 (having stainless steel sheet) was 56.9^0C, a maximum temperature difference from the inlet for PTC-1 was 19.7°C & for PTC-2 was 17.8^0C. Due to its low cost and simple technology, it is affordable by the middle and lower middle class people of India.

From the observations, the research investigation can be calculated that fabricated PTC-2 has maximum thermal efficiency of 15.85 % for reflector having stainless steel sheet and 13.67% for reflector having acrylic mirror sheet. The result concludes that 90° rim angle PTC-2 having stainless steel reflector is more efficient in compare to 90^0 rim angle PTC-1 having acrylic mirror sheet.

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Author Profile

Syed Mohd Yasir Arsalan received the Bachelor of Technology degrees in Mechanical Engineering from Uma Nath Singh Institute of Engineering and Technology, V.B.S Purvanchal University, Jaunpur, UP, India. In present he is final semester student of Master of Technology in Mechanical Engineering (specialization in Production & Industrial Engineering) from Shepherd School of Engineering & Technology, Sam Higginbottom Institute of Agriculture Technology and Sciences, Allahabad (U.P), India.