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PERFORMANCE OPTIMIZATION OF SOLAR PARABOLIC TROUGH CONCENTRATOR USING BLACK PAINT COATING ON THE ABSORBER

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ABSTRACT

This paper is based upon an experimental study of two different parabolic trough collectors which have been designed, fabricated and evaluated to derive a comparison between their performances, in producing hot water, by using a black coated receiver tube and an uncoated receiver tube. The Parabolic Trough Solar Collectors uses Stainless steel sheet in the shape of a parabolic cylinder to concentrate and reflect the radiations from the Sun towards an absorbing receiver tube made of Galvanized Iron (G.I), located at the focus line of the PTC. The receiver tube in the first PTC is uncoated whereas the second PTC consists of a black enameled receiver tube. The receiver tube assimilates the incoming radiations leading to their transformation into thermal energy which is further transported and collected by a fluid medium circulating within the receiver tube.

KEYWORDS: Solar Parabolic Trough Collector (PTC), Reflector, Receiver Tube, Thermal Efficiency, Ambient Temperature, Wind Velocity.

I. INTRODUCTION

Parabolic Trough Collector is the most mature technology for large scale exploitation of solar energy. Several power plants based on this technology have been operational for years, and more are being built. However, the current technology suffers from a too high installation cost. This high cost makes it very hard to compete economically with fossil energy, compromising the perspective of using this technology to solve the problem of Carbon Dioxide emissions.

Parabolic trough collector 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 fluid flowing through the absorbing receiver tube gets heated and thus carries the 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 G.I. pipes orcopper. Selective coatings may be used for better a performance.

Solar parabolic trough collectors have been used togenerate power by converting water to steam in much the same way that a conventional thermal power plants work with the exception being that instead of utilizing thermal energy released by the burning of fossil fuels, solar power is utilized to obtain thermal energy. The current industrial growth and environmental impacts show that solar energy for solar thermal power plants is the most promising of the unconventional energy sources. The mostcommon commercially available solar power plants use parabolic trough concentrators parabolic trough is a type of solar thermal energy collector.

II. DESIGN CONSIDERATION

The present PTC has following experimental characteristics; easy constructible, strong and stable structure, light weight and low cost. For each concentrator a stainless steel sheet of 2.007 meter long, 1.219 meter wide and

0.318 mm thick has been placed longitudinally as a reflecting mirror. The reflectivity of stainless steel mirror is supposed to be 65% of the sunlight. As a part of the design of the PTCs, both mirror sheets are installed on the parabolic shaped supporting structure. The size of the stainless steel sheet is exactly same as that of the size of the supporting structure. The total aperturearea is for both the 90° included collector's shadow is 2.131 m² , but the reflector's total area is equal for both the systems.

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(ψ/2)/{sec(ψ/2)*tan(ψ/2)+ ln(sec(ψ/2)+tan(ψ/2))}

W_a= 1062.25 mm or 1.0622 m.

Focal Length of Parabola: F = W_a/ 4tan(ψ/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/ D_0

C = 10.91

Table 1: Specifications of PTCs

P.T.C. Name	**PTC (1)**	**PTC-(2)**
Receiver Type	Uncoated	Black Coated
Focal length (F)	0.265 m	0.265 m
Rim angle (ψ)	90 degrees	90 degrees
Aperture width (Wa)	1.0622 m	1.0622 m
Diameter of receiver tube (D0)	0.031 m	0.031 m
Length of parabola (L)	2.007 m	2.007 m
Effective aperture area (Aa)	2.131 m2	2.131 m2
Concentration Ratio(c)	10.91	10.91
Reflectivity of collector (ρ)	0.63	0.63
Absorptivity of receiver Tube (α)	0.8	0.8
Length of receiver tube (Labs)	2.13 m	2.13 m
Receiver material	GI pipe	GI pipe
Thickness of reflector material	1.35 m	1.31 mm

III. 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:

Collector support structure

For the collector`s precision and stability, a rigid and robust supporting structure is designed using firm iron strips. The frame of the structure is made up of mild steel Iron that has been assembled with the use of arc welding, drilling and nut-bolt joint which further supports the rotation axis of the parabolic reflecting surface. It is used for the rotation of the horizontal axis for daily tracking of the sun. The reflector supporting frame portion was adjustable to horizontal axis for automatic or manual sun tracking.

Parabolic trough

The proposed trough collectors consists of stainless steel sheets each of thickness 0.318 mm , which has to undergo a careful deformation process that was necessary to bring it into the parabolic shape. The material is easily available and can be given the required shape. For the easy maneuverability 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 m2.

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 pipes made of Galvanized Iron (GI) are used for both the PTCs for the receiver purpose. The size of receiver was decided based upon two factors viz. (1) Local availability of channel section, and (2) Concentrationratio desired. The final receiver dimensions are taken as outer diameter 0.03m and length 2.12 m.

Sun Tracking

Manual sun-tracking was done during the experimentation period. The system was adjusted into the north-south direction, so as to obtain the maximum available solar radiations. The tracking was done to rotate the collector about east-west axis. The horizontal axis tracking was simply obtained through a manual observation of reflection of the sun rays on the reflective surface at the duration of every half an hour.

IV. 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 valves atboth the ends are used. In both the PTCs, reflector material is a stainless steel sheet. The water supply tank is located above the receiver’s pipe level to allow the heating fluid to flow spontaneously without the pumping system. The storage tank is filled from the 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 surfaces of the receiver, the solar radiation intensity and wind velocity are continuously measured during the experimental period. The experiment is carried out in the month of April and May, 2017 at the Solar Lab in the Mechanical Engg. Dept., SIET, SHUATS, Allahabad (UP). The testing system is oriented North-South to capture maximum insulation as shown in figure.

Figure 1: Experimental Setup of the PTC

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V. TESTING

Testing was started at the local time 10 A.M. Water was inserted into receiver tube 30 minutes before theactual 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 uncoated receiver tube.
Date: 20/05/2017
Weather condition: Hot weather
Minimum ambient temperature: 37.0 $_0$C.at 4 P.M.
Maximum ambient temperature: 46.1 $_0$C.at 1: 00 P.M.

Table 2: Observation Table for PTC-2

S. No.	Time	Inlet Temp. (T1)	Outlet Temp. (T2)	S.I. (Hb)	Wind Velocity (Wv)	Ambient Temp. (Ta)
1	10:00	34	48.5	500	2.1	40.8
2	10:30	34.5	49.2	571	1.9	41.0
3	11:00	35.1	52.3	600	1.8	41.2
4	11:30	36.2	54.1	690	0.9	43.8
5	12:00	36.8	58.1	680	0.6	44.6
6	12.30	36.5	58.7	700	1.3	44.8
7	1:00	34.3	60.4	780	1.6	46.1
8	1:30	35.1	59.2	800	1.9	46.0
9	2:00	34.5	57.1	795	0.8	44.0
10	2:30	34.4	53.9	720	2.1	42.6
11	3:00	34.7	48.8	670	1.5	40.1
12	3:30	34.1	43.8	600	1.4	39.9
13	4:00	34.8	42.3	550	1.2	37.0

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 $C_p(T_2 - T_1)$
m = mass flow rate of fluid (Kg/sec)
C_p= specific heat of fluid = 4180 J/Kg K for water
T_2= 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) = 2.5 lit./hrs
= .00013888 kg / sec
For,
Initial Temperature (T_1) = 34.3 $_0$C at 01:00 P.M
Maximum Temperature (T_2) = 60.4$_0$C at 01:00 P.M
Q = m $C_p(T_2 - T_1)$ = 151.428 W
Efficiency (η) = $Q * 100 / (A_a * H_b * \rho * R_b)$
= 14.46 %

Case 2 - For PTC-2 having coated receiver tube.
Date: 20/05/2017
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 2: Observation Table for PTC-2

S. No.	Time	Inlet Temp. (T1)	Outlet Temp. (T2)	S.I. (Hb)	Wind Velocity (Wv)	Ambient Temp. (Ta)
1	10:00	34.2	50.9	500	2.1	40.8
2	10:30	34.7	53.8	571	1.9	41.0
3	11:00	35.1	56.7	600	1.8	41.2
4	11:30	34.8	57.7	690	0.9	43.8
5	12:00	34.3	59.8	680	0.6	44.6
6	12.30	34.4	61.8	700	1.3	44.8
7	1:00	34.5	66.9	780	1.6	46.1
8	1:30	35.2	60.8	800	1.9	46.0
9	2:00	35.1	58.2	795	0.8	44.0
10	2:30	35.1	56.2	720	2.1	42.6
11	3:00	35.3	52.1	670	1.5	40.1
12	3:30	35.1	47.5	600	1.4	39.9
13	4:00	35.2	44.2	550	1.2	37.0

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) = 2.5 lit./hrs

= 0.00013888 lit./ sec

Initial Temperature (T_1) = 34.5^{0}C at 01:00 P.M

Maximum Temperature (T_6) = 66.9^{0}C at 01:00 P.M

$Q = m\ C_p(T_2 - T_1)$ = 187.9796 W

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

= 17.95 %

VI. RESULTS AND DISCUSSION

Numbers of observations were taken on the system in the month of April & May 2017 in the Solar Lab of the Department of Mechanical Engg., SIET at the campus of SHUATS, Allahabad,Uttar Pradesh, India. The obtained data has been plotted on graphs for a particular day.

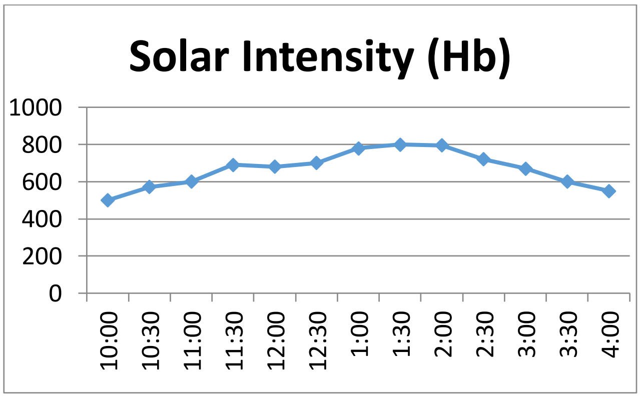

Figure 2: Variation of solar intensity with time

Figure 2 shows the variation of solar intensity with time. As it is expected, the maximum intensity of 800 W/m2 is obtained at around 1:30 PM.

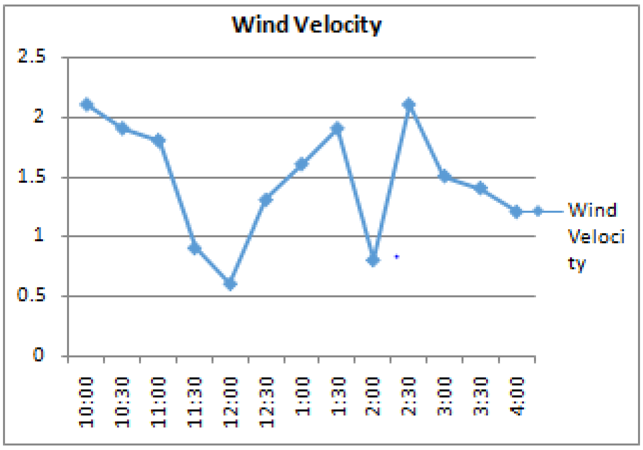

Figure 3: Variation of wind velocity with time

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

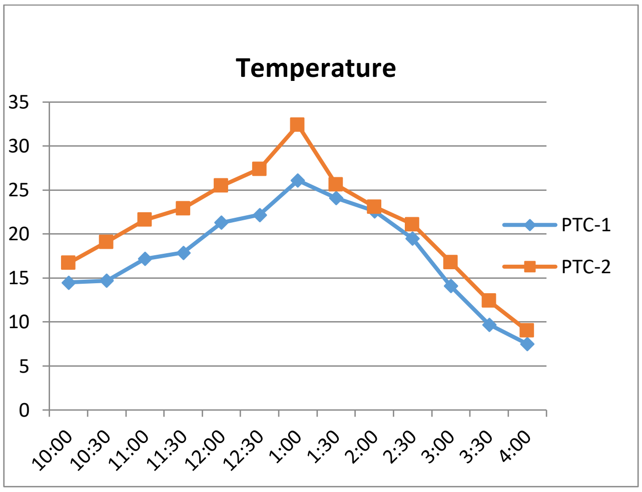

Figure 4: Variation in temperature difference with time

Figure 4 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 an uncoated receiver tube),the red line shows temperature difference of PTC-2 (having a black coated receiver tube). The maximum temperature difference of 26.1$_0$C is obtained at around 01:00 PM for PTC-1. And theAs it is expected, the maximum intensity of 800 W/m2 is obtained at around 1:30 PM.

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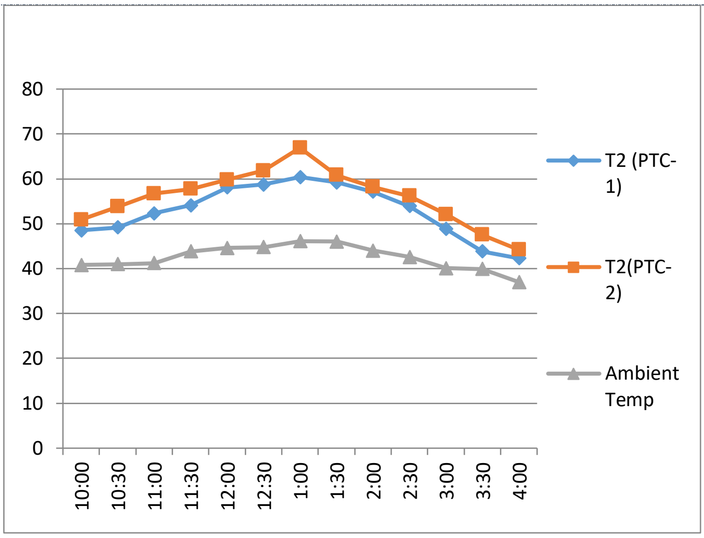

Figure 5: Variation of outlet temp & ambient temp with time

Figure 5 shows the variation of water outlet from the receiver pipe and ambient temperature for both systems with the various time of the day. It is clear from Figure 3 and Figure 4 that, due to better solar intensity in the 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 60.4 Degree Celsius is obtained at around 12:30 PM and for PTC-2 max. temperature of 66.6 Degree Celsius is also obtained at around 1:00 PM.

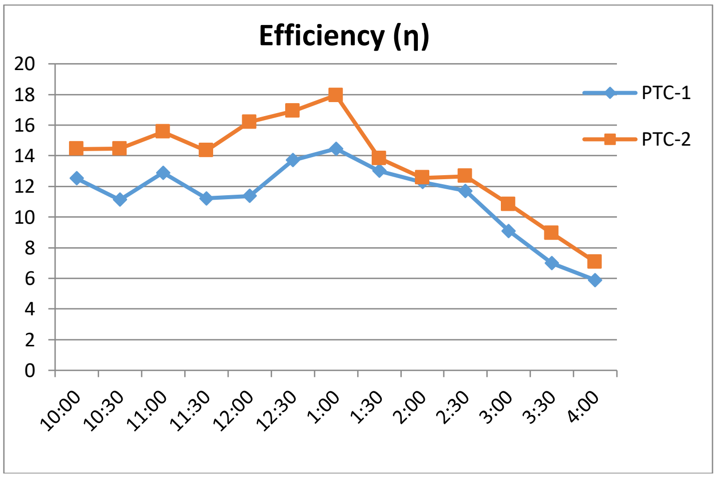

Figure 6: Variation of thermal efficiency with time

Figure 6 shows the variation of instantaneous thermal efficiency of both the systems with various time of the day. As it is clear from the figure, a maximum instantaneous thermal efficiency of PTC-2 having black coated receiver tube is 17.95%, and for PTC-1 having uncoated receiver tube is 14.46%, and both are obtained at around 01:00 P.M.

VII. CONCLUSION

From the collected data, figures, graphs and tables, in relation to the analysis and discussions, this research can conclude 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 uncoated receiver tube) was 60.4 °C and of PTC -2 (having black-coated receiver tube) was 66.90 °C, a maximum temperature difference from the inlet for PTC-1 was 26.1 °C and for PTC-2 it was 32.40°C. Due to its low cost and simple technology, it is affordable for every class of people in India.

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From the observations, the research investigations can be calculated that the PTC-2 has the maximum thermal efficiency of 17.95% for the receiver having a black coat and 14.46% for the receiver being uncoated. The result concludes that at 90° rim angle PTC-2 having a black-coated receiver tube is more efficient in comparison to PTC-1 having a non-coated receiver tube.

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