Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 11, November-2019

Performance Optimization of Solar PTC System using two Different Receiver Tube Materials

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Abstract- **When it comes of solar energy, solar PTC technology is the most significant technology that transforms the radiation coming from sun into heat. In this technology the energy costs reduces as compared to fossil fuels/electricity that is used for traditional working fluid heating. This technology is used for hot working fluid production, process steam requirement power generation and many more. This technology is also used to produce electricity in thermal power plants based on solar. In this research, optimization of performance of two different SPTC systems has been done to derive the comparison between their thermal performances. In this study stainless steel sheet of 1.678 m long, 1.22 m wide, and 0.318 m thick has been taken as the reflector material for each collector to concentrate solar radiation towards an absorber tube located at the focal line of the parabolic trough. Copper tube and Galvanized Iron tube is taken as the absorber tube for each collector. Rest of the materials used for both the PTCs are same. Rim angles for the collectors are 90 degree. The aperture area for both the collectors is 2.047 square-meters.**

Keywords- Ambient Temperature, PTC, Receiver Tube, Reflector, Solar Intensity, Thermal efficiency.

I. INTRODUCTION

Owing to the energy crisis and scarcity in conventional energy resources and the subsequent increase in oil prices, the awareness to use alternate energy sources, including solar energy, has gained momentum both in industrialized and developing countries. Intensified research and development on renewable energy sources, which followed the energy crisis, resulted in demonstration of the technical feasibility of many alternate energy options which shows solar energy is the most encouraging unconventional energy sources. Solar collectors are uncommon kind of warmth exchangers that changes solar energy to inner energy of the transport medium in the cylinders to be carried as usable energy. The most widely recognized utilizations of solar collectors are mostly found in solar working fluid heating and space heating, industrial processes. Therefore, due to their wide range of applications it is necessary for the engineers or designers to determine the thermal execution of solar collectors. One of the most significant components of PTC system is the optically selective coating of solar absorber, which should ideally behave as a black body, engrossing a limit of the approaching sun oriented radiation, while limiting energy losses by infrared radiation. Another important element of PTC system is the reflector; reflectors may be of anodized, aluminum Mylar or curved silvered glass. The polar configuration intercepts more solar radiation per unit area as compared to east-west, north-south orientation and thus gives the best performance.

II. DESIGN CONSIDERATION

The present PTC system has following experimental characteristics; easy constructible, strong and stable in structure, light in weight and low cost. For each PTC system a stainless steel sheet of 1.678 meter long, 1.22 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 sheet is exactly same as the size of the supporting structure. The total aperture area for 90 degree rim angle is 2.047 square-meters.

III. SPECIFICATIONS OF PTCs

Specifications of the both PTC system is listed in Table 1.

Table 1 Specification of both PTCs

Components	**PTC – 1**	**PTC – 2**
Reflector Material	Stainless steel	Stainless steel
Focal Length (F)	0.265 m	0.265 m
Rim Angle (ψ)	90º	90º
Aperture width (W_a)	1.22 m	1.22 m
Diameter of Receiver Tube (D_o)	0.031 m	0.031 m
Length of parabola (L)	1.678 m	1.678 m
Effective Aperture Area (A_a)	2.047 m²	2.047 m²
Concentration Ratio (c)	10.91	10.91
Reflectivity of collector (ρ)	0.63	0.63
Absorptivity of Receiver Tube (α)	0.9	0.8
Length of receiver Tube (L_{abs})	2.13 m	2.13 m
Receiver Material	Copper Pipe	GI Pipe
Thickness of Reflector Material	0.318 mm	0.318

IV. EXPERIMENTAL ARRANGEMENT

The set up comprises of two parabolic trough collectors. For each PTC, a storage tank of capacity 15 liters, receiver's pipe of length 2.13 m with two valves at the both ends are used. In these two PTCs, reflector material is of stainless steel sheet. The working fluid supply tank had been placed above the receiver tube's level to permit the heating working fluid to flow impulsively without the pumping system. The storage tank was filled by the main working fluid supply. The flowing working fluid inlet and outlet temperature of the absorber tube, the ambient temperature, the reflector temperature, and the temperatures at surfaces of the receiver, the solar radiation intensity and wind velocity are continuously observed throughout the experiment. The experiment was done in 2019, at the Solar Lab in the Department of Mechanical Engineering, Vaugh Institute of Agricultural Engineering & Technology, SHUATS, Allahabad (UP). The testing system was oriented North-South to capture maximum insulation. The system was enabled accurately for manual tracking. I have installed the digital thermometers to observe the temperature of receiver, source storage tank, collector storage, reflector sheet's front/back sides and ambient temperature are chosen. Use of solar meter is to determine the solar radiation intensity on mirror sheet and receiver tube. For measuring wind velocity anemometer is used.

V. TESTING

The testing was carried out from 9:30 am to 4:00 pm with a solar intensity in the range of 190-850 W/m^2. Inlet working fluid was taken from a tank at a height of 2 m from the base of PTC. The use of Plastic pipe was to connect the working fluid tank and the inlet of the receiver of the PTC system, for scheming the flow of working fluid a tab was used. At the outlet of receiver, a beaker was used to measure the mass flow rate of the working fluid. Temperature of working fluid was measured after every 30 minutes of interval at the inlet and outlet of receiver. To make sure that the incoming beam radiations should always remain normal to the reflector of PTC, parabolic trough was manually rotated after every 30 minutes along with the sun about the focal line of the parabola and it was held in that position for the next 30 minutes with the help of iron supporting strings.

Case 1 – For PTC-1 having copper tube as receiver

Minimum ambient temperature: 32.8 °C at 4:00 PM

Maximum ambient temperature: 38 °C at 11:30 AM

Table 2: Experimental Data recorded for PTC-1

Time	**Inlet Temp (°C) (T_i)**	**Outlet Temp (°C) (T_o)**	**Ambient Temp (°C) (T_a)**	**Solar Intensity (S.I.) (w/m²)**	**Wind Velocity (W_v) (m/s)**
9:30	**29.8**	**46.1**	**33.6**	**705**	**0.9**
10:00	**31.1**	**50.3**	**34.3**	**760**	**1.3**
10:30	**32.1**	**54.4**	**35.5**	**800**	**1.7**
11:00	**33.2**	**58.8**	**36.8**	**820**	**2.1**
11:30	**33.8**	**61.5**	**38**	**825**	**1.5**
12:00	**34.2**	**63.4**	**37.5**	**805**	**2.7**
12:30	**34.6**	**61.0**	**37.1**	**775**	**2.9**
1:00	**35.1**	**59.0**	**36.6**	**720**	**2.3**
1:30	**34.8**	**55.6**	**35.8**	**670**	**1.7**
2:00	**33.6**	**51.0**	**35.2**	**590**	**2.2**
2:30	**32.8**	**46.0**	**34.7**	**470**	**1.8**
3:00	**31.2**	**41.9**	**34**	**405**	**1.2**
3:30	**30.8**	**38.2**	**33.5**	**300**	**0.9**
4:00	**30.0**	**34.3**	**32.8**	**190**	**0.6**

Calculation for thermal efficiency corresponding to maximum outlet temperature of working fluid:

$\eta_{th} = Q_u*100/(A_a*H_s*\rho*R_b)$

Where,

Q_u = net useful heat gained by the working fluid in Watt = $m*C_p*(T_o - T_i)$

m = mass flow rate of working fluid in Kg/sec

C_p = Specific heat of working fluid = 4180 J/Kg K

T_o = Outlet temperature of working fluid in ^{0}C

T_i = Inlet temperature of working fluid in ^{0}C

A_a = Aperture area in m^2

H_s = Solar intensity in W/m^2

ρ = Reflectivity of refllector material

R_b = Tilt factor for beam radiation

Mass flow rate (m) = 0.00176 Kg/sec

For, inlet temperature of (T_i) = 34.20 ºC at 12:00 pm

And outlet temperature of (T_o) = 63.40 ºC at 12:00 pm

$Q_u = m*C_p*(To-Ti)$ = 214.82 W

$\eta_{th} = Q*100/(A_a*H_b*\rho*R_b)$ = 21.72 %

Case 2 – For PTC-2 having G.I. tube as receiver

Minimum ambient temperature: 32.8 ºC at 4:00 PM

Maximum ambient temperature: 38 ºC at 11:30 AM

Table 3: Experimental Data recorded for PTC-2

Time	**Inlet Temp (ºC) (Ti)**	**Outlet Temp (ºC) (To)**	**Ambient Temp (ºC) (Ta)**	**Solar Intensity (S.I.) (w/m²)**	**Wind Velocity (Wv) (m/s)**
9:30	**30.2**	**40.7**	**33.6**	**705**	**0.9**
10:00	**31.7**	**44.2**	**34.3**	**760**	**1.3**
10:30	**32.5**	**47.2**	**35.5**	**800**	**1.7**
11:00	**33.6**	**50.7**	**36.8**	**820**	**2.1**
11:30	**34.3**	**53.6**	**38**	**825**	**1.5**
12:00	**34.6**	**55.5**	**37.5**	**805**	**2.7**
12:30	**35.0**	**53.7**	**37.1**	**775**	**2.9**
1:00	**35.7**	**52.6**	**36.6**	**720**	**2.3**
1:30	**35.2**	**50.0**	**35.8**	**670**	**1.7**
2:00	**34.4**	**46.7**	**35.2**	**590**	**2.2**
2:30	**33.6**	**42.7**	**34.7**	**470**	**1.8**
3:00	**32.4**	**39.7**	**34**	**405**	**1.2**
3:30	**32.0**	**36.9**	**33.5**	**300**	**0.9**
4:00	**30.6**	**33.5**	**32.8**	**190**	**0.6**

Calculation for thermal efficiency corresponding to maximum outlet temperature of working fluid:

$\eta_{th} = Q_u*100/(A_a*H_s*\rho*R_b)$

Where,

Q_u = net useful heat gained by the working fluid in Watt = $m*C_p*(T_o - T_i)$

m = mass flow rate of working fluid in Kg/sec

C_p = Specific heat of working fluid = 4180 J/Kg K

T_o = Outlet temperature of working fluid in ^{0}C

T_i = Inlet temperature of working fluid in ^{0}C

A_a = Aperture area in m^2

H_s = Solar intensity in W/m^2

ρ = Reflectivity of reflector material

R_b = Tilt factor for beam radiation

Mass flow rate (m) = 0.00176 Kg/sec

For, inlet temperature of (T_i) = 34.60 ºC at 12:00 pm

And outlet temperature of (T_o) = 55.50 ºC at 12:00 pm

$Q_u = mC_p\ (T_o-T_i)$ = 153.76 W

$\eta_{th} = Q*100/(A_a*H_s*\rho*R_b)$ = 15.55%

VI. RESULTS & DISCUSSION

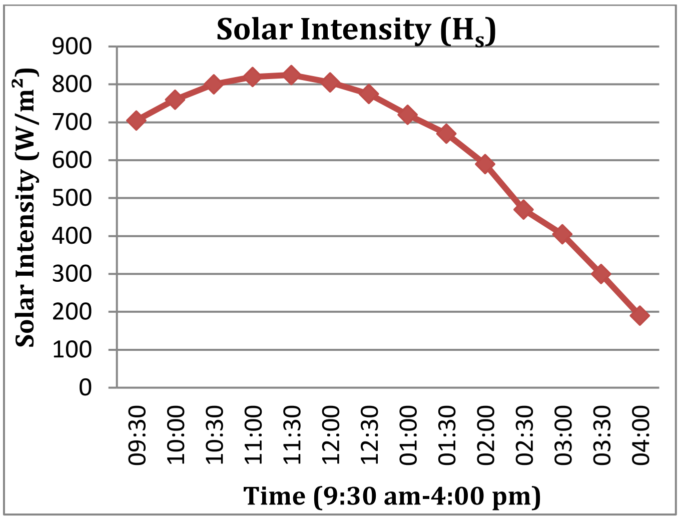

Figure 1 Variation of Solar Intensity with Time

Figure 1 indicates the variation of solar intensity with time. The maximum solar intensity obtained at around 11:30 am is 825 W/m².

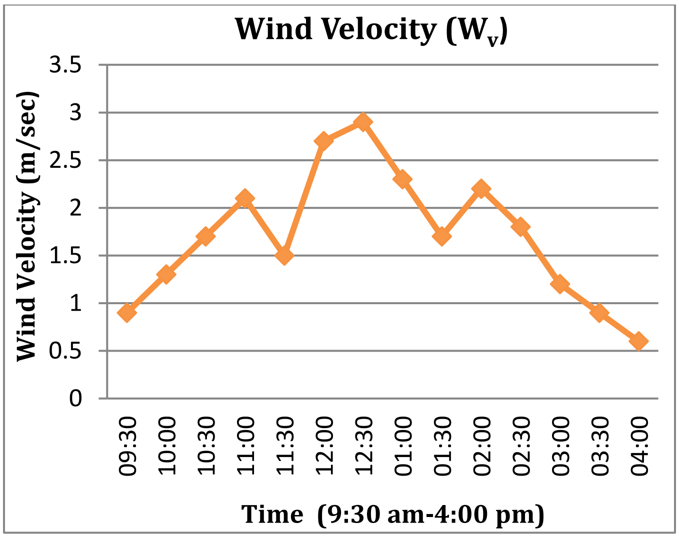

Figure 2 Variation of Wind Velocity with Time

Figure 2 indicates the variation of wind velocity with time. The projected system is very efficient and capable in offering a good resistance to wind.

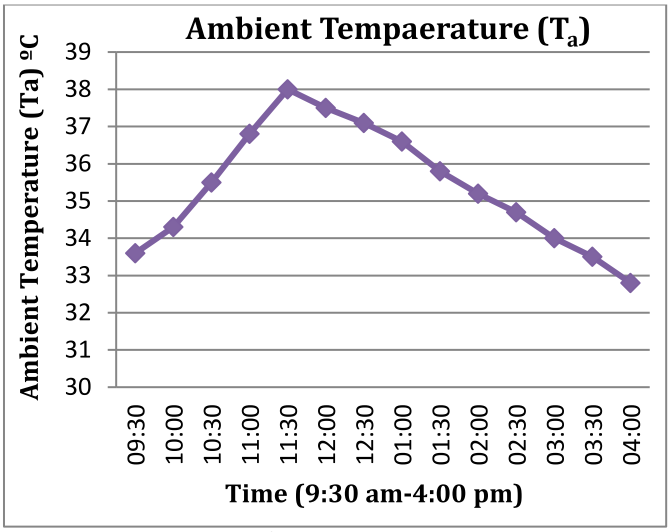

Figure 3 Variation of Ambient Temperature with Time

Figure 3 indicates the variation of ambient temperature with time. The maximum ambient temperature obtained at around 11:30 am is 38ºC.

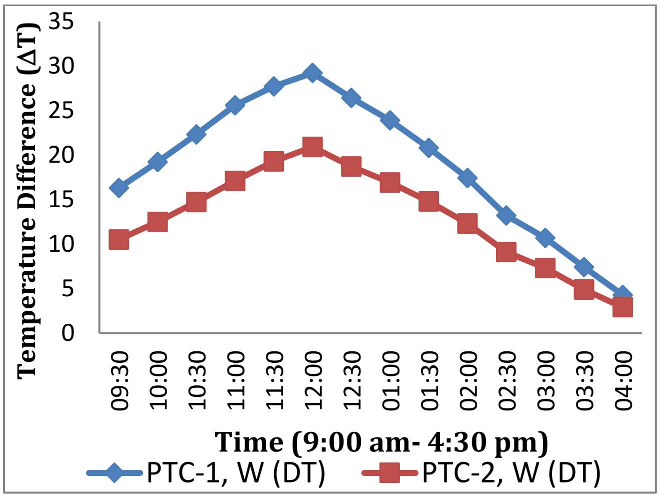

Figure 4 Variation of Temperature Difference with Time

Figure 4 indicates the variation of temperature difference i.e. the difference of outlet temperature and inlet temperature with time. The red line indicates temperature difference of PTC-2 (galvanized iron as receiver tube), the blue line shows temperature difference of PTC-1 (copper as receiver tube). The maximum temperature difference for PTC-2 obtained at around 12:00 pm is 20.9ºC. The maximum temperature difference for PTC-1 obtained at around 12:00 pm is 29.2ºC.

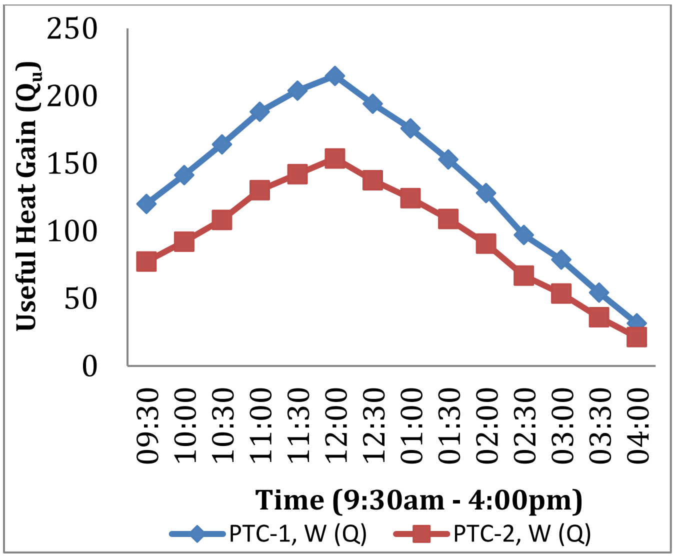

Figure 5 Variation of Useful Heat Gain with Time

Figure 5 indicates the variation of useful heat gain with time. The red line indicates useful heat gain of PTC-2 (galvanized iron as receiver tube), the blue line shows useful heat gain of PTC-1 (copper as receiver tube). The maximum useful heat gain for PTC-2 obtained at around 12:00 pm is 153.75 W. The maximum useful heat gain for PTC-1 obtained at around 12:00 pm is 214.82 W.

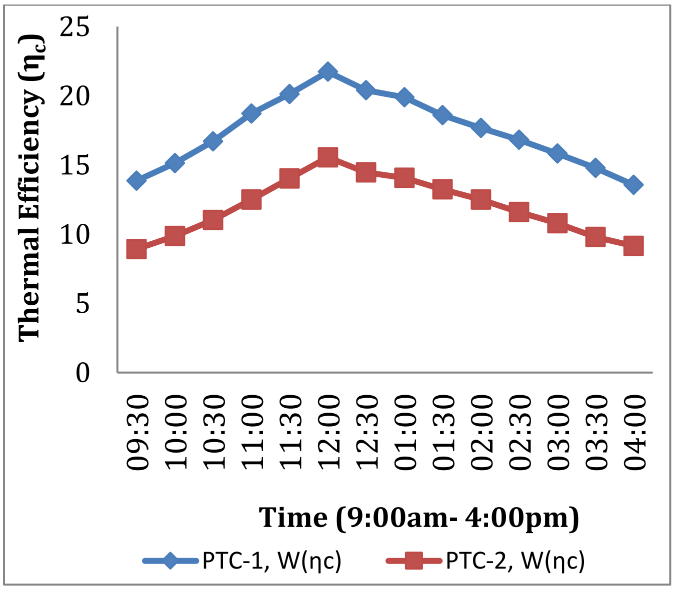

Figure 6 Variation of Thermal Efficiency with Time

Figure 6 indicates the deviation of instantaneous thermal efficiency with time. The red line show instantaneous thermal efficiency of PTC-2 (galvanized iron tube as receiver), the blue line shows instantaneous thermal efficiency of PTC-1 (copper tube as receiver).The maximum instantaneous thermal efficiency for PTC-2 (galvanized iron tube as receiver) is 15.55%. The maximum instantaneous thermal efficiency for PTC-1 (copper tube as receiver) is 21.72%.

VII. CONCLUSION

From the collected data, tables and graphs, in relation to the results and discussions, this research paper conclude that the fabricated PTC is quite efficient. The maximum outlet temperature obtained from the PTC-1 was 63.4ºC and the maximum outlet temperature obtained from the PTC-2 was 55.5ºC. The maximum temperature difference obtained from the PTC-1 was 29.2ºC and the maximum temperature difference obtained from the PTC-2 was 20.9ºC. The maximum useful heat gain obtained from the PTC-1 was 214.82 W and the maximum useful heat gain obtained from the PTC-2 was 153.75 W. The maximum instantaneous thermal efficiency obtained from the PTC-1 was 21.72% and the maximum instantaneous thermal efficiency obtained from the PTC-2 was 15.55%. The result concludes that the instantaneous thermal efficiency obtained from the PTC-1 having copper tube as receiver is 6.17% more in comparison to PTC-2 having G.I. tube as receiver.

VIII. FUTURE SCOPE

There is a lot of future work that can be carried out which are as follows:

1. Performance analysis can be performed by using different type of reflector surface.
2. Different coating materials can be tested to see their effects on the performance.
3. Different mass flow rate may be taken to see their effects on the performance.
4. Different diameter of receiver tubes can be tested to see their effects on the performance.

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