The effect of variations in reflector material on the performance of a solar-powered parabolic trough collector

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Abstract

Concentrated Solar Power (CSP) is a technology that uses reflector mirrors to focus the sun on a receiver. The receiver changes the sun to heat energy. This study aimed to investigate the effect of variations in reflector material on the performance of the Parabolic Trough Collector (PTC). The parabolic design had a length of 1.5 m, an aperture width of 0.5 m and an absorber pipe with a diameter of 0.5 inch. The reflective material used for each PTC system was an aluminium sheet reflector (PTC\textsubscript{1}) and an aluminium solar concentrator (PTC\textsubscript{2}). The aluminium sheet reflector had a thickness of 0.3 mm and a reflectivity value of 85\% while the aluminium solar concentrator had a reflectivity value of 94\%. The experimental method used a K-type thermocouple to measure the temperature of the fluid in the absorber pipe. Two cable connectors were employed to detect the temperature of the fluid and Lux meters were used to measure the intensity of the sun. The research was conducted between the hours of 11:00 a.m. to 14:00 p.m. (Western Indonesian Time) at sun intensity values above 700 W/m\textsuperscript{2}. The mass fluid flow rate was 0.25 L/min. The results showed that the highest temperature of water coming out of PTC\textsubscript{1} was 46.4\degree C at an intensity of 811.33 W/m\textsuperscript{2} and efficiency of 45.67\%. However, in PTC\textsubscript{2}, the highest temperature was 41.7\degree C at an intensity of 882.43 W/m\textsuperscript{2} and efficiency of 30.36\%. Furthermore, the aluminium reflector exhibited a better performance than the aluminium concentrator.

Keywords: Concentrated solar power, efficiency, parabolic trough collector, reflector.

1. Introduction

Concentrated Solar Power (CSP) is a heat collection technology that uses reflective mirrors to focus sunlight onto a receiver. This receiver converts sunlight into heat energy. There are two major types of CSP; concentrating collectors and stationary collectors. A type of concentrating collector is the Parabolic Trough Collector (PTC) \cite{1}. The parabolic part of the system has a length of 1.5m, an aperture with a width of 0.5m and a copper absorber tube with a diameter of 0.5 inches. PTC uses a reflective mirror to focus sunlight onto an absorbent pipe that converts sunlight to heat. The heat is then transferred to the fluid inside the pipe \cite{2}.

The efficiency of the heat collection system depicts its performance. The performance is also influenced by the reflector material, drainage and absorption system \cite{3}. The optimal performance of the reflector material in the PTC system enhances the system’s efficiency. Valencia \textit{et al.} (2013) conducted a study with a PTC system that used an aluminium sheet reflector \cite{2}. The authors of the study documented that the outgoing water temperature was 47\degree C. A similar study conducted by Tayade \textit{et al.} (2015) documented that the outgoing water temperature was 65\degree C \cite{4}. Therefore, this research aimed to investigate the effect of reflector materials on the performance of PTC systems in Surakarta, Indonesia (-7.55611, 110.83167).

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2. Experimental Set-up and Methods

2.1. Experimental set-up

This experimental study was conducted to determine the effect of different PTC reflector materials on the fluid temperature inside the absorber pipe. PTC$_1$ uses an aluminium sheet reflector that has a thickness of 0.3 mm and a reflectivity value of 85\% [5]. PTC$_2$ uses an aluminium solar concentrator that has a reflectivity value of 94\% [6]. PTC$_1$ and PTC$_2$ are shown in Figs. 1a and 1b.

![PTC1 and PTC2](image)

Fig. 1. (a) PTC1- aluminium sheet reflector, (b) PTC2-aluminium solar concentrator.

Concentration ratio ($Cr$) can be defined as the ratio between the area of the aperture and the receiver [7]. $Cr$ can be calculated by using equation 1. The specifications of the PTC system is shown in Table 1.

\[
Cr = \frac{A_s}{A_r}
\]

(1)

| Specification                  | Value         |
|-------------------------------|---------------|
| Length of parabola            | 150 cm        |
| Aperture                      | 50 cm         |
| Angle of rim                  | 90°           |
| Focus distance                | 12.5 cm       |
| Comparison of $Cr$            | 12.54         |
| Depth of Collector            | 12.5 cm       |
| Height of parabola            | 70 cm         |
| Material absorber pipe        | Copper, 1.27 cm |
| Mass flow                     | 0.25 L/min    |
| Fluid                         | Water         |

Table 1. Specification of PTC system

![Solar water heater](image)

Fig. 2. Solar water heater type parabolic trough collector

There are three main parts of the water heating system shown in Fig. 2: inlet water storage pond, parabolic area, and outlet water storage pond. The inlet water pool is covered with aluminium foil to
reduce the direct effects of heat generated by solar radiation. Patel et al. (2012) stated that the fluid used as a heat transfer medium must have a high specific heat capacity [8]. The fluid used in this study is water, which has a specific heat capacity (Cp) of 4,200 J/kg °C. The water delivery system from the inlet pond to the parabolic area uses a water pump. Heated water moves through the outlet channel into the outlet pool.

2.2. Methods

The instrument used to measure the temperature of the fluid in the absorber pipe was a K-type thermocouple. This device has uses two cable connectors to detect the temperature of the fluid. The first connector cable was placed in the inlet water storage basin while the second connector cable was installed in the outlet after the parabolic area. The resulting data was automatically recorded in the computer. Lux meters were used to measure the intensity of the sun. The measurements were conducted from 11 a.m. to 2 p.m. at a time interval of 15 minutes. The data obtained was used to calculate the efficiency of the system.

3. Results and Discussion

3.1. Thermal evaluation of PTC

The absorption of radiation by the absorber pipe caused an increase in temperature of the pipe. The heat generated by the pipe was absorbed by the fluid that flowed through it. The value of the sun’s intensity affects the temperature of the fluid in the absorber pipe. Fig. 3 shows that the incoming fluid temperature (T1) increased to 31° C in the pipe. After passing through the parabolic area, the temperature of the outgoing fluid (T2) increased to 40° C.

Fig. 3. Temperatures (inlet and outlet) of water and intensity of the sun measured during the thermal evaluation of PTC.

The magnitude of T1 was influenced by the heat energy absorbed by the absorber pipe. The greater the intensity value of the emitted sun, the more the fluid temperature in the absorber pipe will increase. The PTC system test results documented by Singh et al. (2016) reported an outgoing water temperature of 46.4° C at an intensity of 369.89 W/m² [9]. The authors further stated that the intensity value increased to 516.81 W/m² and resulted in a subsequent increase in outgoing water temperature. This shows that an increase in the intensity of the sun results in an increase in the average value of T2 while a decrease in the value of the intensity of the sun causes a decrease in the value of T2. The results of this study showed that the highest T2 value reached was 46.4° C when the intensity of the sun was 816.07 W/m² at 1 p.m. The decrease in the intensity value (from 816.07 W/m² to 707.05 W/m²) at 2 p.m. resulted in a decrease in the value of T2 to 39.7° C.
3.2. Thermal evaluation of PTC$_2$

The graph generated by the PTC$_2$ test shows that the intensity of the sun has a significant effect on the fluid temperature in the absorber pipe. Fig. 4 shows that the highest $T_2$ value was 41.7$^\circ$C when the intensity of the sun increased to 882.43 W/m$^2$ at 11:45 a.m.

![Graph showing temperature and intensity variations](image)

Fig. 4. Temperatures (inlet and outlet) of water and intensity of the sun measured during the thermal evaluation of PTC$_2$.

From 11:00 to 11:45 PM, the sun’s intensity increased significantly. This increase was followed by an increase in water temperature (from 37.3$^\circ$C to 41.7$^\circ$C) coming out of the absorber pipe. The decrease in the intensity of the sun to 807.38 W/m$^2$ at 12:15 p.m. resulted in a decrease in the value of $T_2$ to 39.4$^\circ$C. The decrease in the intensity of the sun was followed by a significant decrease in $T_2$ temperature between the hours of 1:30 p.m. and 2:00 p.m. The study conducted by Valencia et al. (2013) using a PTC system with a temperature of 45$^\circ$C and an intensity of 830 W/m$^2$ reported that the decrease in the value of the intensity to 520 W/m$^2$ resulted in a decrease in $T_2$ to 35.5$^\circ$C.

3.3. Useful energy

![Table showing useful energy values](image)

| Hour | 11:00 | 11:15 | 11:30 | 11:45 | 12:00 | 12:15 | 12:30 | 12:45 | 13:00 | 13:15 | 13:30 | 13:45 | 14:00 |
|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| PTC$_1$ | 188.7 | 221.8 | 283.0 | 260.3 | 269.0 | 281.3 | 274.3 | 283.0 | 279.5 | 253.3 | 251.6 | 200.93 | 172.97 |
| PTC$_2$ | 148.5 | 174.7 | 174.7 | 200.9 | 181.7 | 169.4 | 174.7 | 165.9 | 176.4 | 167.7 | 174.7 | 167.73 | 162.49 |

Fig. 5. The amount of useful energy, $Q_{out}$ (J/s) in each PTC variation.

The highest amount of useful energy from PTC$_1$ was 283.05 J/s at 11:30 and 12:45 p.m. Overall, the average amount of useful energy from PTC$_1$ was 247.70 J/s. On the other hand, the highest amount of useful energy from PTC$_2$ was 200.93 J/s at 11:45. The overall average value of energy from PTC$_2$ was 172.30 J/s. This data indicates that the amount of useful energy from PTC$_1$ is higher than the amount of useful energy from PTC$_2$.

3.4. Efficiency of the system

The value of the intensity of the sun and the magnitude of the difference in temperature ($\Delta T$) was obtained from the measurement data. The system efficiency was calculated with the following equation (2).
In the PTC\textsubscript{1} system, the highest efficiency of 46\% was obtained at 12:45 p.m. when the intensity of the sun was 811.33 W/m\textsuperscript{2} and ΔT of 16.2. The PTC\textsubscript{1} system’s efficiency ranged from 31.25\% to 46.52\%. On the other hand, PTC\textsubscript{2} system obtained an efficiency value of around 28\%. The highest efficiency achieved by the system was 30.36\% at 11:45 a.m. when the intensity of the sun was 882.43 W/m\textsuperscript{2} and ΔT of 7.6. This shows that the PTC\textsubscript{1} system is more efficient than the PTC\textsubscript{2} system.

4. Conclusion

Concentrated Solar Power (CSP) is a technology with a high potential for use in tropical countries such as Indonesia due to its high source of solar energy. The reflection mirror is an important tool that converts sunlight into heat energy. Thus, this study investigated the effects of variations in the reflector material on the performance of the Parabolic Trough Collector (PTC). The parabolic design had a length of 1.5 m, an aperture width of 0.5 m and an absorber pipe with a diameter of 0.5 inch. We use different reflectors that affected to the performance of the system. Ada dua material reflektor yaitu aluminium sheet reflector and an aluminium solar concentrator. The maximum efficiency in PTC\textsubscript{1} system was 46.52\% with T\textsubscript{2} of 45.9°C at an intensity of 811.33 W/m\textsuperscript{2} while the maximum efficiency of the PTC\textsubscript{2} system was 30.36\% with T\textsubscript{2} of 41.7°C at an intensity of 882.43 W/m\textsuperscript{2}. Therefore, the performance of PTC\textsubscript{1} systems better than the performance of the PTC\textsubscript{2}.

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