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

Ayub Setyaji[a], Nugroho Agung Pambudi[b], Bayu Rudiyanto[c], Basori Basori[b], Nyeyep Sri Wardani[b], Adhi Susanto[b], Setyo Pranoto[b], Nova Dany Setyawan[b], Rusdi Febriyanto[b], Kukuh Mukti Wibowo[b]

[a] *Graduate Program in Vocational Teacher Education, Universitas Sebelas Maret, Jl. Ir. Sutami No.36A, Surakarta, Jawa Tengah 57126, Indonesia*

[b] *Department of Mechanical Engineering Education, Universitas Sebelas Maret, Jl. Ir. Sutami No.36A, Surakarta, Jawa Tengah 57126, Indonesia*

[c] *Energy Engineering Laboratory, Department of Renewable Engineering, Politeknik Negeri Jember, Jember 68121, Indonesia*

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_1) and an aluminium solar concentrator (PTC_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^2. The mass fluid flow rate was 0.25 L/min. The results showed that the highest temperature of water coming out of PTC_1 was 46.4^{o}C at an intensity of 811.33 W/m^2 and efficiency of 45.67%. However, in PTC_2, the highest temperature was 41.7^{o}C at an intensity of 882.43 W/m^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) [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 [2].

The efficiency of the heat collection system depicts its performance. The performance is also influenced by the reflector material, drainage and absorption system [3]. The optimal performance of the reflector material in the PTC system enhances the system's efficiency. Valencia *et al.* (2013) conducted a study with a PTC system that used an aluminium sheet reflector [2]. The authors of the study documented that the outgoing water temperature was 47^{o}C. A similar study conducted by Tayade *et al*. (2015) documented that the outgoing water temperature was 65^{o}C [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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Corresponding author. *E-mail address:* agung.pambudi@staff.uns.ac.id.

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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.

(a) (b)

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.

$$Cr = \frac{Aa}{Ar} \tag{1}$$

Table 1. Specification of PTC system

Specification	Value
Length of parabola	150 cm
Aperture	50 cm
Angle of rim	90^o
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

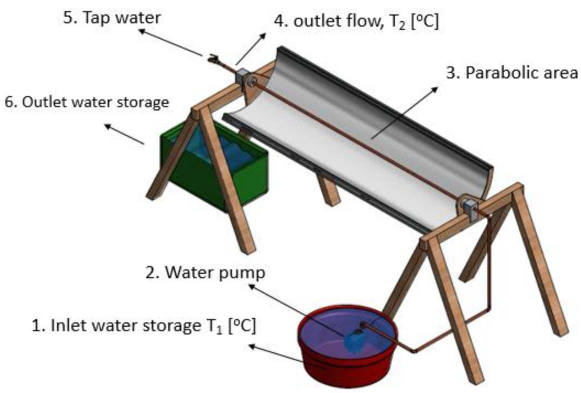

Fig. 2. Solar water heater type parabolic trough collector

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 ^{o}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$_1$

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 31oC in the pipe. After passing through the parabolic area, the temperature of the outgoing fluid (T2) increased to 40oC.

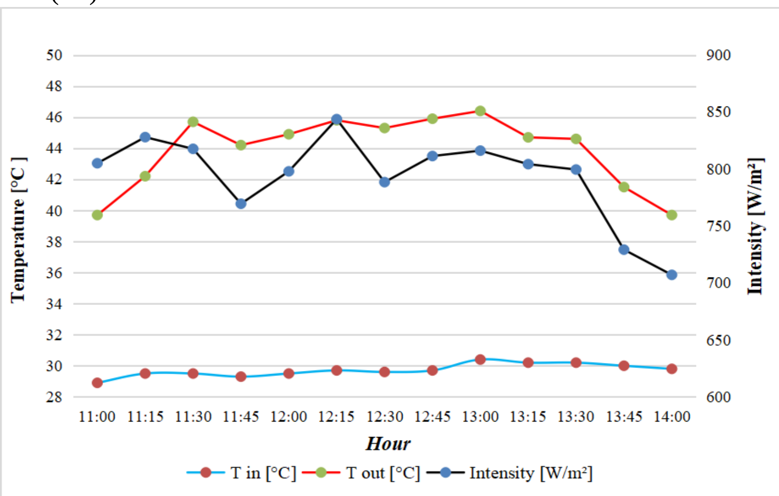

Fig. 3. Temperatures (inlet and outlet) of water and intensity of the sun measured during the thermal evaluation of PTC$_1$.

The magnitude of T_1 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^{o}C at an intensity of 369.89 W/m^2 [9]. The authors further stated that the intensity value increased to 516.81 W/m^2 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 T_2 while a decrease in the value of the intensity of the sun causes a decrease in the value of T_2. The results of this study showed that the highest T_2 value reached was 46.4^{o}C when the intensity of the sun was 816.07 W/m^2 at 1 p.m. The decrease in the intensity value (from 816.07 W/m^2 to 707.05 W/m^2) at 2 p.m. resulted in a decrease in the value of T_2 to 39.7^{o}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°C when the intensity of the sun increased to 882.43 W/m^2 at 11:45 a.m.

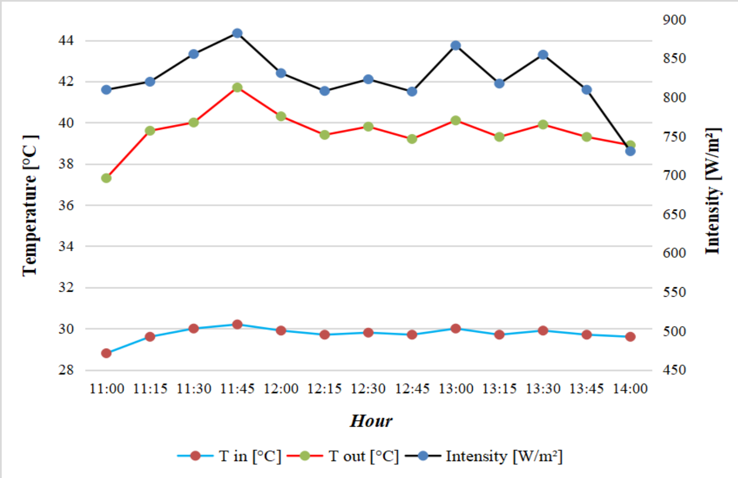

Fig. 4. Temperatures (inlet and outlet) of water and intensity of the sun measured during the thermal evaluation of PTC_2.

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 ℃ to 41.7 ℃) 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°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°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°C.

3.3. Useful energy

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	188.70	221.89	283.05	260.33	269.07	281.30	274.31	283.05	279.55	253.34	251.60	200.93	172.97
PTC_2	148.51	174.72	174.72	200.93	181.71	169.48	174.72	165.98	176.47	167.73	174.72	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 (ΔT) was obtained from the measurement data. The system efficiency was calculated with the following equation (2).

$$\eta_c = \frac{\dot{Q}_{out}}{\dot{Q}_{in}} = \frac{\dot{m}\ Cp\ (To - Ti)}{I\ A} \tag{2}$$

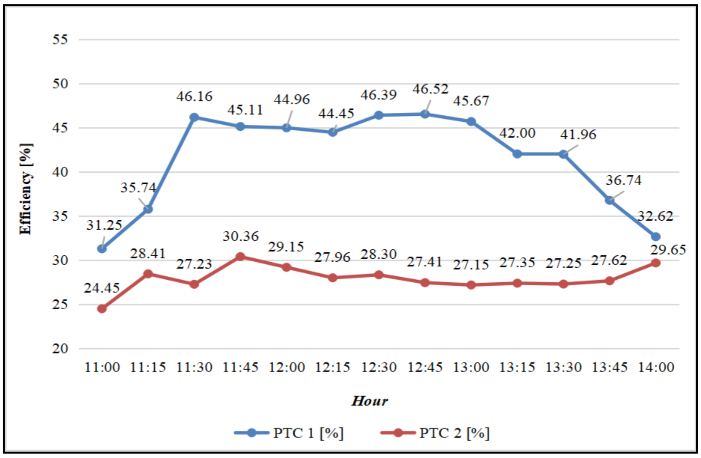

Fig. 6. The value of efficiency in each PTC variation.

In the PTC_1 system, the highest efficiency of 46% was obtained at 12:45 p.m. when the intensity of the sun was 811.33 W/m² and ΔT of 16.2. The PTC_1 system's efficiency ranged from 31.25% to 46.52%. On the other hand, PTC_2 system obtained an efficiency value of around 28%. The highest efficiency achieved by the system was 30.36% at11:45 a.m. when the intensity of the sun was 882.43 W/m² and ΔT of 7.6. This shows that the PTC_1 system is more efficient than the PTC_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_1 system was 46.52% with T_2 of 45.9°C at an intensity of 811.33 W/m² while the maximum efficiency of the PTC_2 system was 30.36% with T_2 of 41.7°C at an intensity of 882.43 W/m². Therefore, the performance of PTC_1 systems better than the performance of the PTC_2.

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