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Enhancement of the Performance of Compound Parabolic Concentrator (CPC) Solar Collector by Using Three Pipes Covered by Glass Tubes

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ABSTRACT: *This paper will discuss the performance of solar collector compound parabolic concentrator (CPC) type with water as the working fluid. This CPC solar collector utilized three pipes covered by glass tubes. This paper has contribution to provide the temperature achievement between three pipes covered by glass tubes with and without glass cover of solar collector CPC type. The research conducted by varying the water flow rate of 1 l/m up to 6 l/m with three pipes arranged in series and parallel. From the results, the used of solar collector CPC type in the current study shows that the decrease of solar radiation, which was caused by climate change, did not influence the heat absorbance by water in the pipe. Therefore, the design of the solar collector in this research has potential to be used in future when solar radiation are used as the energy source.*
KEYWORDS – *Solar Collector, Compound Parabolic Concentrator, Glass Tube, Pipe, Performance*

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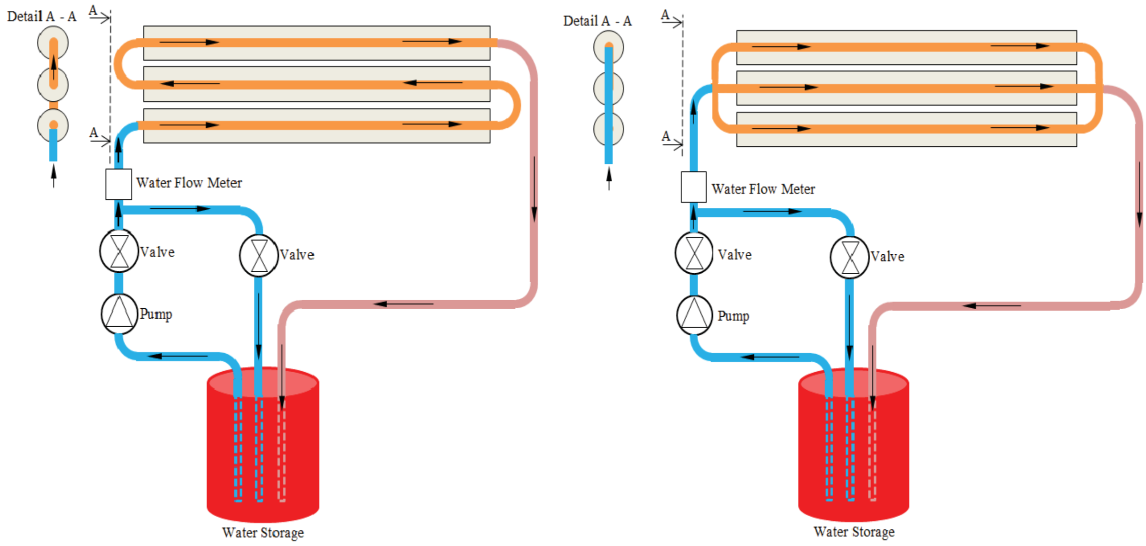
I. INTRODUCTION

Currently, the demand for energy is growing significantly, while pollution and environmental damage caused by fossil fuel uses is increasing [1].Fossil-fuel energy sources such as petroleum and coal availability are increasingly limited and have a serious impact on the environment, such as air pollution and global warming [2]. About eighty percent of the world's total primary energy supply is from fossil fuel (International Energy Agency [3]. The use of renewable energy is an effective way to solve the problem due to its little impacts to the environment. World energy consumption predicts that 45% of the energy demand in 2050 will be provided by solar energy [4]. The potential of solar energy as an energy source for heating water in Indonesia is very likely to be developed, because Indonesia is located near the equator which has a beam of sunlight throughout the year [5]. Solar collector is one of tools that can be used to convert the potential energy of sun into other forms of energy [6]. Solar energy as a renewable energy which is easily obtained, is widely used to generate electricity and produce heat. The potential of solar energy is quite high in Indonesia. It reaches 4.8 to 5.2 $kWh/m^2/day$. However, it has not been so intensively utilized for generation of electricity and in industrial processes [7]. Solar energy can be used for water heating using solar collectors called CPC solar collector with tubular shaped receiver. CPC is one of solar collector types which can collect solar radiation on the media concentrated to one point, and then converted into thermal energy which can be applied in the power generation system [8]. Research on the solar collector type CPC has been done, one of them is the comparison of various types of CPC to form absorber which vary with the obtained result is the best CPC is form tube arbsorber, because it can absorb sun light on all sides, cheap, low loss due to conduction, and improve performance in the absorption of sunlight [9]. Muhammad developed a CPC to heat the working fluid in the form of methanol [10]. The CPC can absorb solar energy with a maximum efficiency of 80%. Then Muhammad et al. studied the CPC with a total area of 32 m^2 aparture capable of absorbing radiation of 8-11 kW [11]. He developed a CPC with pipes installed in series with a total pipe length of 3m can raise the temperature of the fluid in to 2.5^o C addition out [12]. Therefore, this study was conducted to determine the best performance of a solar collector CPC type using 3 pieces of pipes arranged in series and parallel, and also to compare the differences between with and without the glass cover of the solar collector.

II. EXPERIMENTAL SETUP

The apparatus set up is shown by Figure 1.



(a) Serial flow (b) Paralel flow
FIGURE 1. Tools set up

The experimental apparatus consisted of a CPC, pipes, a flow meter, valves, and a water storage. CPC was fabricated at Northern Illinois University, DeKalb, IL. The design was based on the equation as shown by Eqs.1 up to Eqs. 4.

$$\eta = Q'/A_{aparture} x G x n \qquad (1)$$

The value of Q (W) is the energy used to heat the working fluid, and the value of G is the heat of sun per area (W/m^2), and the value of n is the number of desired CPC. The efficiency was assumed as 73% so the aperture area value was 0.5 m^2 with the length and wide of CPC were 1 m and 0.5 m, respectively. Then the length of pipe of the CPC can be determined by Eqs. 2. The concentration ratio (CR) used was 2.089.

$$CR = A_{aparture}/A_{absorber} \qquad (2)$$

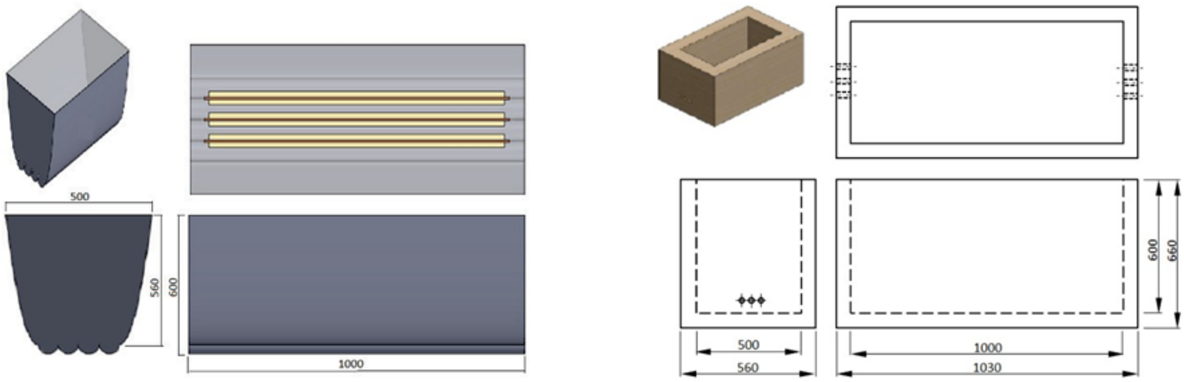
The total length of pipe in the CPC was 3 m with outer diameter of 2.54 cm. The pipe then arranged serially and parallelly. The pipe was made from copper and covered by glass pipe as absorber with the length of 1 m and inner diameter of 5,14 cm. Figure 1 shows how the pipe was arranged in serial (left) and parallel (right). Then the half acceptance angle was calculated by Eqs. 3.

$$\Theta = \sin^{-1}(1/CR) \qquad (3)$$

The value of acceptance angle is 28.6o . And then the height of the CPC could be calculated by Eqs. 4.

$$h = 3a/2\ (1/\sin \Theta \tan \Theta + ½ + 1/\pi \sin \Theta) \qquad (4)$$

The final design of the CPC is shown by Figure 2a. and thermal isolation used wood with 3 cm wide for all side is shown by Figure 2b.



(a) Solar Collector (b) Thermal Isolation

FIGURE 2. CPC Design

The pipe outside the CPC had outer diameter of 2.54 cm. The CPC was placed inside a thermal insulation of wood which had thickness of 3 cm for all side. Glass cover is made from common building window application. Thermocouples used for temperature measuring were the K type thermocouples which were calibrated using standard thermocouple. Thermocouples were placed in the working fluid before and after the CPC, inside the room of the CPC, on the wall of the CPC, on the CPC glass cover, and outside of the CPC to measure ambient temperature. Flow meter was calibrated using measuring cup. Water was used as the working fluid. The variation of the flow rate were 1, 2, 3, 4, 5, and 6 l/min. Data gathering was done using two methods, i. e. with and without CPC glass cover under steady state condition. Data gathering for each experiment was conducted for six hours from 9 a.m. to 3 p.m. The heat absorbed by water was calculated using Eqs. 5.

$$Q' = m'c(T'_{fo} — T_{fl}) \quad (5)$$

Where, m', T_{fo} and T_{fl} are mass flow rate (kg/s), specific heat (J/kg.°C), outlet temperature of working fluid (°C) and inlet temperature of working fluid (°C), respectively. The experiment was conducted in the month of July 2020 in the city of DeKalb, IL, whose condition is shown by Table 1.

TABLE 1. Condition of DeKalb, IL (July, 2020)

Parameters	Remarks
Location	DeKalb, IL, USA
Average altitude	190 m (minimum), 330 m (maximum) above sea level
Monthly average temperature	26°C
Monthly lowest temperature	21.8°C
Monthly highest temperature	30.4°C
Humidity	70%
Rainfall each year	3500-4000 mm
Months with the highest rainfall	December, January

III. RESULTS & DISCUSSION

The water temperature entering and leaving the CPC, and CPC room temperature for flow rate of 1, 2, 3, 4 and 5 l/min of serial flow type with the solar collectors without glass cover. The data consists of value for 6 hours experiment, i. e. from the 1st until the 21600th second. From the graphs, it is shown that the value of solar heat, q_{sun}, fluctuates. This could be caused by clouds which sometimes cover the sun's light. From the chart, the highest value of the solar heat is generally in the mid of the data retrieval. This is because the CPC facing upwards when usually the sun is in its peak to produce heat. This is proven by the value of the solar heat that tends to fall by the end of data collection. It means that the water always received heat after entering the CPC. It is also proven by the graph of water temperature entering and leaving the CPC which rise gradually along the data gathering. Those phenomena are always the same for the other data so the further analysis will be performed using its average value.

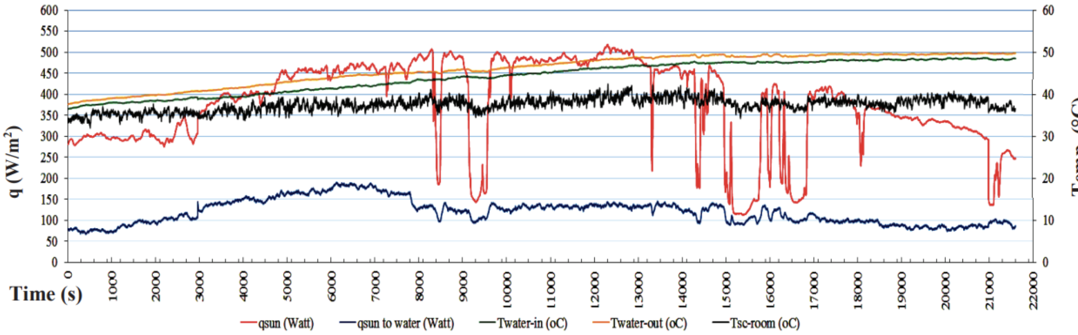


FIGURE 3. Data for 1 l/min flow rate, serial type flow, CPC without glass cover

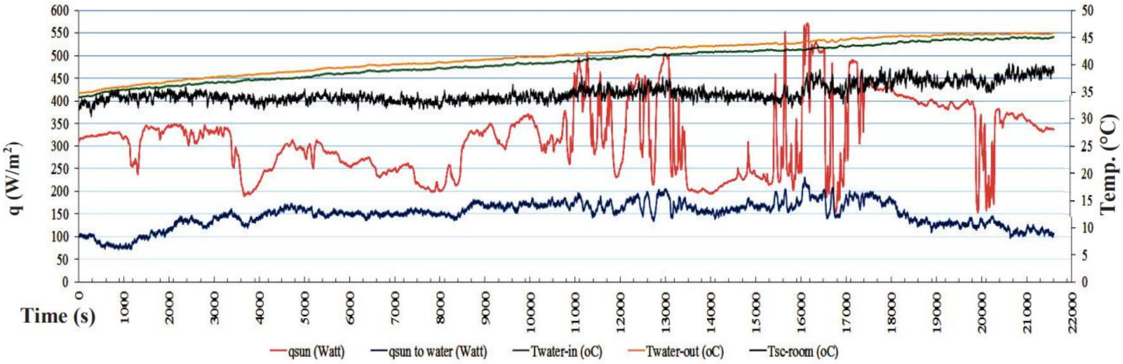


FIGURE 4. Data for 2 l/min flow rate, serial type flow, CPC without glass cover

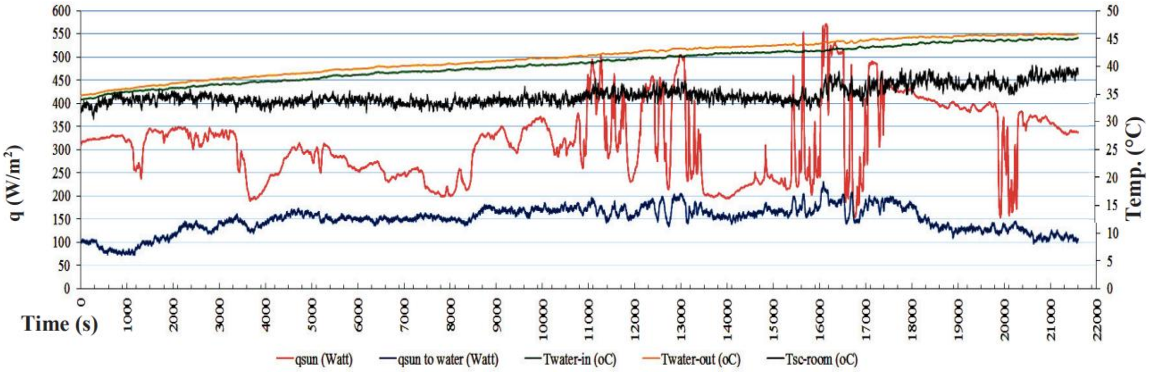


FIGURE 5. Data for 3 l/min flow rate, serial type flow, CPC without glass cover

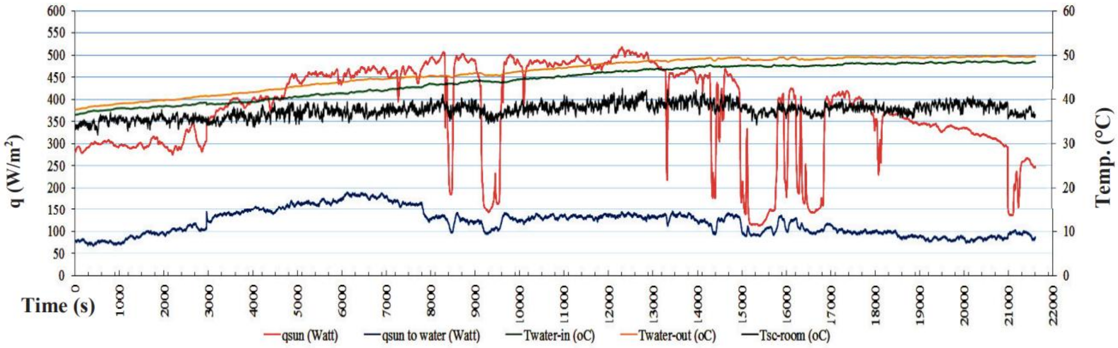


FIGURE 6. Data for 4 l/min flow rate, serial type flow, CPC without glass cover

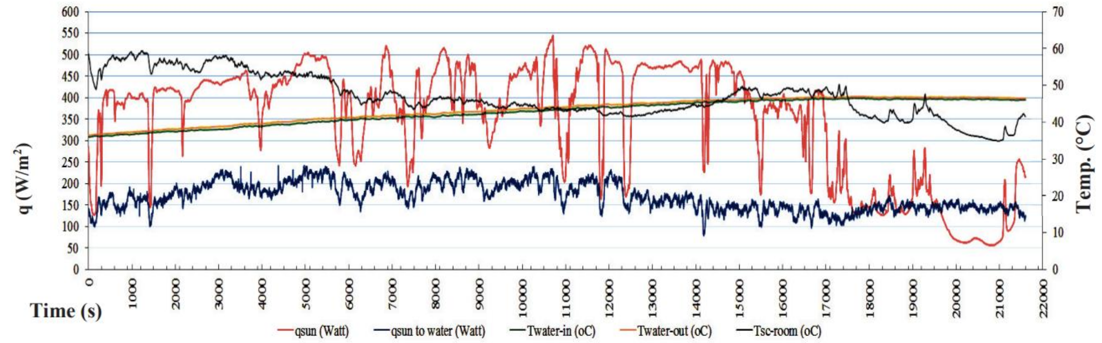


FIGURE 7. Data for 5 l/min flow rate, serial type flow, CPC without glass cover

Figure 8 and 9 show the comparison of average heat absorbed by the water for all pipe arrangement and CPC with and without glass cover. All the graphs show that the heat absorbed by the water tends to rise as the flow rate increases except the end graph of the CPC without glass. It means that the fluctuation of sun heat flux, q"sun, did not influence the value of the heat absorbed by the water. It confirms the previous discussion which said that the heat absorbed by the water was always positive which means that the heat transferred from the sun might be trapped and accumulated in the CPC. The highest heat absorbed by the water are for flow rate of 5 l/min for CPC without glass cover and 6 l/min for CPC with glass cover. In the Figure 9, the sun's heat flux for the parallel arrangement has a relatively greater value than the serial arrangement which made the heat absorbed by the water higher. Due to the CPC uncovered, the velocity of surrounding air might also influence the value of heat absorbed by the water. If the velocity of surrounding air was relatively high, the heat convected to the air would be higher which made the heat absorbed by the water relatively low. In Figure 10, the sun's heat flux value for the both pipe arrangements graphs are relatively high. From the graph of serial arrangement, the heat absorbed by the water increases as the flow rate rise with the highest value for flow rate of 6 l/min. For the graph of parallel arrangement, there is decrease of heat absorbed by the water for flow rate of 1 l/min to 2 l/min. It may be because the arrangement of the pipe influence the water distributed in the pipe. After the flow rate rise to 6 l/min, the heat absorbed reaches the highest which is higher than the serial arrangement. It may be because the flow becomes fully developed that makes the contact area between the water and the inner tube wall greater thus makes the heat absorbed by the water higher.

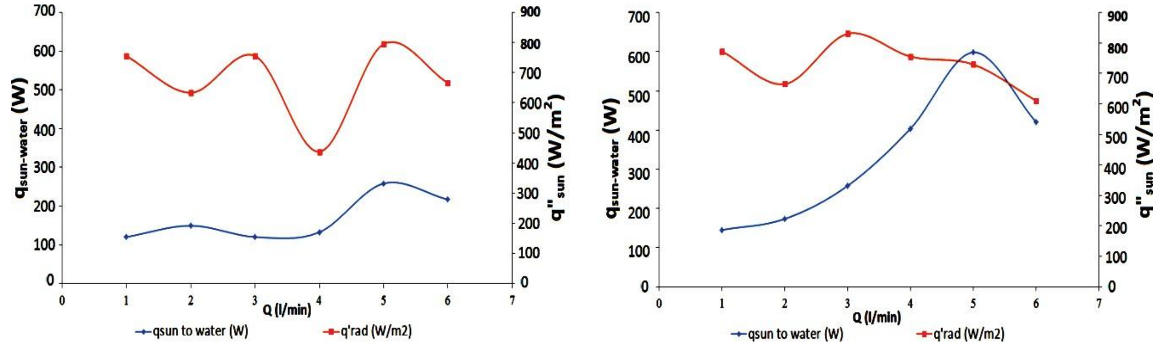


FIGURE 8. Data for serial (left) and paralel (right) pipe arrangements, CPC without glass cover

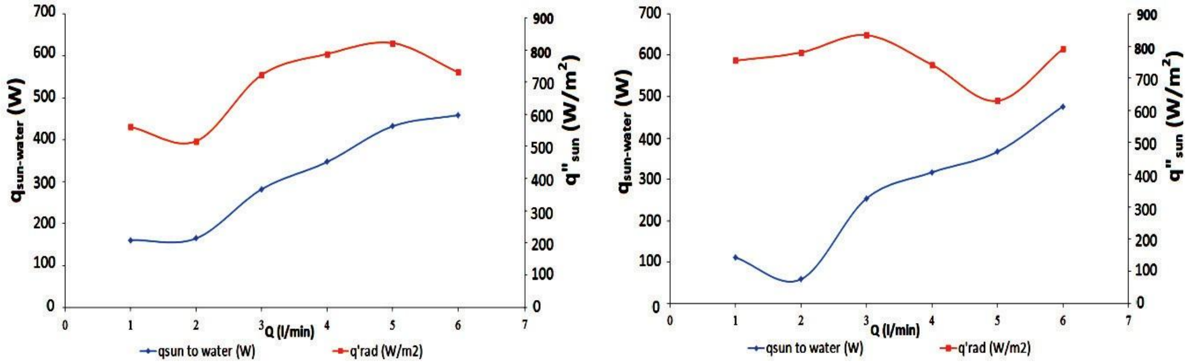


FIGURE 9. Data for serial (left) and parallel (right) pipe arrangements, CPC with glass cover

For the relatively same intensity of solar radiation, the result from the CPC without glass cover shows higher value than from the CPC with glass cover. It might be because of the ultraviolet light could not pass through the glass cover which decreased the heat absorbed by the water. Therefore, further investigation should be done to study the influence of ultraviolet radiation for the building glass material is transparent to ultraviolet A (UVA).

IV. AVERAGE SOLAR HEAT FLUX

Solar radiation is an electromagnetic radiation with the range between about 0.25 to 4.5 μm in wavelength, including ultraviolet, infrared and visible light radiation. The sun has power called solar irradiance and represented in W/m^2 or kW/m^2. The average of solar irradiance outside the atmosphere about 1366 W/m^2. The rating condition which is use for rating the heat flux is 1000 W/m^2 on a surface facing the sun on a clear day is called *peak value* (PV) (Jim Dunlop Solar, 2012). Table 2 shows the value of the average heat flux along the experimental data gathering. It can be seen that the solar energy potential of the location where the experiment was conducted is high enough. It reaches the maximum average value of about 830 W/m^2.

TABLE 2. Average Sun Heat Flux

No.	Pipe arrangements	Average sun heat flux (W/m^2)					
		1 l/min	2 l/min	3 l/min	4 l/min	5 l/min	6 l/min
CPC without Glass Cover							
1	Serial	553.66	510.26	713.25	777.51	811.20	721.73
2	Paralel	754.89	780.06	834.28	742.20	629.73	790.73
CPC with Glass Cover							
3	Serial	755.29	633.28	437.78	704.08	794.79	665.69
4	Paralel	772.80	665.61	830.74	755.72	729.66	610.57

V. AVERAGE SOLAR HEAT FLUX

The solar collector CPC type in the current study has been experimentally shown that it can capture energy in the form of heat from solar radiation in the condition with or without a glass cover. Water flow rate that could receive maximum heat was between the value of $4 < Q < 6$ l/min. The used of solar collector CPC type in the current study showed that the decrease of solar radiation intensity which was caused by climate change did not influence the heat absorbance by water in the pipe. Therefore, the design of the solar collector in this research has potential to be used in future when solar radiation hat is used as the energy source.

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