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PARABOLIC TROUGH COLLECTOR CONCENTRATING SOLAR POWER AS STEAM PRODUCER USING SOLAR IRRADIATION OF CEPU, BLORA, CENTRAL JAVA

PARABOLIC TROUGH COLLECTOR CONCENTRATING SOLAR POWER SEBAGAI STEAM PRODUCER DENGAN RADIASI MATAHARI CEPU, BLORA, JAWA TENGAH

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ABSTRAK

Energi alternatif telah mengalami perkembangan pesat, khususnya energi surya yang dimanfaatkan dengan Concentrating Solar Power (CSP) untuk menghasilkan steam yang akan diubah ke bentuk energy tertentu. Steam yang dihasilkan juga dimanfaatkan untuk industri perminyakan untuk mengurangi pemakaian bahan bakar pada boiler. Radiasi matahari harian sebesar 5,18001 – 5,21909 kWh/m^2 yang diterima Cepu, Blora, Jawa Tengah dapat digunakan pada CSP dengan parabolic trough collector (PTC) sebagai penghasil steam. Penelitian ini mendeskripsikan desain CSP PTC, kenaikan suhu yang dicapai PTC, dan suhu puncak yang dicapai 1 PTC. Kenaikan suhu yang dicapai PTC dengan radiasi matahari Cepu pada cuaca berawan, cerah, dan berawan-cerah-berawan sebesar 172^{o}C, 401,1^{o}C, dan 285,9^{o}C serta karakteristik kenaikan suhu linear dengan metode statistik regresi linier.

Kata Kunci: *energi, matahari, parabola, uap, Cepu*

ABSTRACT

Alternative energy sources has grown lately, especially for solar energy harnessed with Concentrating Solar Power (CSP) to produce steam that will be converted into a certain form of energy. The steam produced can also be used for petroleum industry to reduce the fuel usage in boilers. Daily solar irradiation of 5.18001 – 5.21909 kWh/m^2 received by Cepu, Blora, Central Java, is deemed sufficient for CSP with parabolic trough collector (PTC) as steam producer. This paper describes the designing of the parabolic trough collector CSP, temperature increase gained from PTC, and peak temperature gained from 1 PTC. The initial experiment of PTC in cloudy, sunny, and cloudy-sunny-cloudy weather resulting in water temperature increase gained to be 172^{o}C, 401.1^{o}C, 285.9^{o}C using Cepu District solar irradiation. Further experiments will be done to find out the relationship between temperature over time.

Keyword: energy, solar, parabollic, steam, Cepu

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I. INTRODUCTION

The increasing use of fossil fuel as an energy source for the past few decades has also directly increasing the negative effect of fossil fuel towards environment. This has started many projects recently to find new alternative sources of energy and implement the existing ones. Those alternative sources exist in many forms such as geothermal, tidal, and also solar power. Its growth has also been increasing in recent years. This promises a good hope for saving the environment. But the setback is that alternative energy usually has rather small efficiency compared to conventional energy sources, like fossil fuels for example.

As one of the alternative energy source, solar power actually has a potential to be an alternative source for its quite unlimited source and renewability. Solar power is obtained from solar radiation to be used as a heating medium or electrical power source. It could be very applicative in regions with climate characteristics such as low rainfall rate and high sun radiation intensity. Solar power is currently used in power plants or as an alternative power source for electronic devices. It can be harnessed using the already common solar panel with photovoltaic (PV) cells, or the relatively unheard Concentrating Solar Power (CSP).

Unlike PV cells, CSP works by harnessing solar irradiation as a heating medium for a heat transfer fluid or water to produce steam and generate electricity. The steam produced alone can also be used for industrial demand. The growth of CSP has also been increasing globallyin 2014 compared to the other renewable energy, with the growth rate second only (27%) to PV cells (30%) (REN21, 2015). The drawback of solar power in terms of electricityis its capacity factor (ratio of the actual electricity or heat output to the theoretical output). The use of PV cells has reportedly yielded a small capacity factor. But the previously mentioned CSP has been a solution to overcome the efficiency problem of solar power. CSP has 35-80% capacity factor which almost matched that of the geothermal power compared to 10-25% yielded from PV cells (REN21 2015).

Cepu District is located at Blora, Central Java.

Cepu is located in a region where numerous petroleum industry activities are present in its neighbouring district (ExxonMobil Cepu Limited & PT Tri Wahana Universal (Kalitidu, Bojonegoro), Central Processing Plant Gundih (Randublatung)), as well as within the district itself such as PT Pertamina Exploration Production (EP) Asset IV Field Cepu, and *Pusat Pendidikan dan Pengembangan Sumber Daya Manusia Minyak dan Gas* (PPSDM Migas) Oil Refinery. Cepu is not only known as a petroleum industry region, but also for its hot weather. Cepu receives daily solar irradiation as much as 5.18001 – 5.21909kWh/m^2. This made it relatively potential for Cepu to be implemented the use of CSP compared to other regions in Indonesia (Table 1). By correlating Cepu as a petroleum industrial region that demands steam and its solar irradiation potential, an implementation of CSP in this region seems beneficial as a means to reduce dependency on fossil fuel energy. But a test should be performed to ensure the capacity of producing steam as well as the power generated by harnessing solar irradiation of Cepu using PTC CSP.

Table 1
Solar irradiation of some regions in Indonesia (Nurliyanti, et al. 2012).

No.	Region	Daily Solar Irradiation
1	DKI Jakarta	4.97451 – 4.93333 kWh/m^2
2	Palembang, South Sumatera	4.75201 – 4.78750 kWh/m^2
3	Cepu, Blora, Central Java	5.18001 – 5.21909 kWh/m^2
4	Padang, West Sumatra	4.75720 – 4.78750 kWh/m^2
5	Buru, Maluku	5.44112 – 5.49250 kWh/m^2

II. METHODOLOGY

A. Type of Research

Type of research for this paper is experiment. In this method, an existing condition (control variable) is manipulated/changed by giving a certain treatment (independent variable) and a result (dependent variable) is obtained after the treatment (Priyono 2016). The variables for this research are:

1. Control variable is amount of PTCs (obtained in PTC design stage) to gain temperature beyond water saturation temperature at 101.3 kPa.
2. Independent variable is solar irradiation, considering the fact that weather pattern is always varying over time, solar irradiation will also change over time, and it is predicted that PTC exposure to sun and temperature increase gained to be fluctuative, thus giving different result for each weather pattern.

3. Dependent variable is the water outlet temperature gained from the varying temperature increase.

Data obtained from the research will be analyzed with quantitative analysis. The aims of this research are to find out the ability of PTC CSP inproducing steam solar irradiation of Cepuand to calculate temperature and pressure range of steam's usability.

B. Tools and Materials

Tools and materials needed for constructing the PTC prototype are as follows.

a. Tools

1. FLUKE Thermal Imager Ti300
2. Pliers
3. Disc grinder
4. Screw drill and 8 mm drill bit
5. Paint brush
6. White cloth
7. Thermometer
8. Scissors
9. Solder

b. Materials

1. 1,2 m x 2,4 m x 0,8 polished stainless steel sheet
2. 2 cm thick teak wood (formed into3 buttress)
3. 3 m ½ in-diameter-steel tube
4. 3 m water hose
5. 2 hose to tube fittings
6. Metallic paint
7. 24 m slotted angle
8. 4 caster wheels
9. Wire
10. Tube insulation (for tube fittings)
11. Paper tape

In constructing the PTC, the availability of material is also considered and this inevitably has affect the design of prototype. All the measurements of material are adjusted with its availability in Cepu, and a problem was encountered in finding the glass cover for receiver tube and sun tracking system. Thus, the glass cover component is excluded from prototype design and sun tracking system is replaced with caster wheel component for the mobility of PTC.

C. Research Method

The research method is divided into 4 steps which are:

1. Designing the PTC

The data collection begins with performing some calculations for the design of PTC which were consisted of calculating focal point, focal length, area concentration ratio, insulation ability and heating value generated per m^2, and mathematical estimation of temperature increasing from 1 PTC. The result (estimated output temperature) will be multiplied by the amount of PTCs required to achieve a steam producing condition (reaching beyond water saturation temperature at a certain pressure) and later the static flow experiment result will describe the characteristic of PTC temperature increase over time. In calculating the amount PTCs required, the demand is set at condition of atmospheric pressure (101.3 kPa) with saturation tempareture 100^oC as the minimum range of steam's usability to find out whether the temperature gained from the PTC can reach the minimum range of steam's usability.

2. Building prototype

The dimension calculation result is used for building 1 PTC which will be tested at STEM Akamigas campus area.

3. Experiment

The PTC prototype is tested by static and dynamic flow method. Dynamic flow testing is carried out placing the PTC on a wide space in campus area. Before the data collection is started, PTC is covered with white cloth for 15 minutes. After raising the PTC temperature by letting it warmed up under sunlight for 5 minutes, the initial temperature of receiver tube, water, and parabola are measured using FLUKE Thermal Imager Ti300. After that 500 ml of water will be flowed through the receiver tube for 2 minutes. The final temperature of receiver tube, water, and parabola are also measured as the final condition data. The experiment with static flow will also be done. 3 holes at the right edge and 5 holes at the left edge of the receiver tube will be made as a pressure exit holes. It will be filled with 1 liter of water and the left edge of the tube is chosen as the place to perform the temperature measurement (where the thermometer is placed) at a certain time period. The result is temperature of water over a certain period of time and this data will be used for finding out the process characteristic. Process characteristic data in form of static flow experiment result graph and temperature estimation at a certain period of time using polynomial regression statistic method on Microsoft Excel will be obtained. An equation to estimate the temperature increase outside the data range will also be obtained. These data will be made as a supporting data and a reference to determine the output temperature of PTC system and modelling the process characteristic.

4. Data analysis

This research will only test 1 PTC. The dynamic flow experiment result will determine the number of PTC and estimate the output temperature that can be achieved. Whereas the static flow experiment result will describe the characteristic of temperature increase using polynomial regression statistic method. The temperature data obtained will be multiplied by the value of PTCs required that has been obtained at PTC designing stage. The amount will be directly multiplied if the process characteristic is raising linearly.Then the result is used for calculating pressure limit until the phase returns to liquid (vapor fraction = 0) at final water temperature using material stream calculation in Aspen Hysys 7.3.

D. Place and Time

The PTC construction and data collection will be done at STEM Akamigas campus, Cepu. Data collection will be done in a wide area/field located in the campus area. Construction of PTC will be carried out from December 9th to December 15th 2016, data collection will be carried out at December 16th 2016 (dynamic flow) and May 25th – 26th 2017 (static flow). Data collection is done on midday between 10.00 WIB – 12.00 WIB.

III. RESULT AND DISCUSSION

A. Design and Construction of PTC

Designing the construction of PTC begins with determining the focal line. Then, the distance from the center of parabola to the focal point (focal length) is needed to set the height of receiver tube on the collector. The parabolic trough is designed by using basic parabolic equations (Iqbal et. al., 2014).

The focal point can be determined with the equation:

$$y = ax^2$$

$$Focal\ Point = \frac{1}{4a}$$

This design use focal point of 15 cm, which means parabolic equation used for this design is:

Focal Point = 15 cm

$$15\ cm = \frac{1}{4a}$$

$$a = 0.01667$$

$$y = 0.01667x^2$$

The width of the material that will be used can be determined with the equation (Gaitan, 2012):

$$S = \left(\frac{pq}{t} + t\ln\left(\frac{p+q}{t}\right)\right)$$

$$q = \sqrt{t^2 + p^2}$$

$$t = 2\ in = 5.08\ cm\ (focal\ length)$$

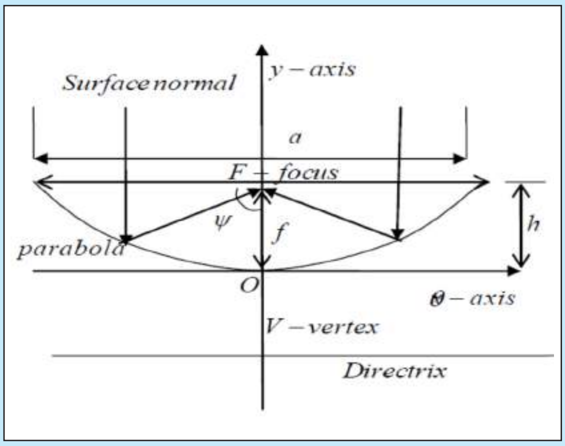


Figure 1
Schematic of the collector (Eltahir, 2013).

P states the distance from O to the end point of the parabola (Figure 1). Thus from the formula we can determine the width of the material to be used in constructing the parabola of 32 in (80 cm) width, which is 39.85 in (99.625 cm). The design of buttress is used as the collector support to keep the collector positioned perpendicular to sun position. Steel absorber tube is used for transferring the heat to heat ransfer fluid. It is made from black metal tube to maximize heat transfer.

Figure 2 is the construction design of PTC and below are mathematical calulations about the estimation of temperature that will be achieved by every PTC.

- Concentration Ratio (Abd-Ennour et.al. 2015)

$$C = \frac{A_c}{A_r} = \frac{96\ in \times 32\ in}{\pi\ x\ 0.5\ in\ x\ 96\ in} = 20.38$$

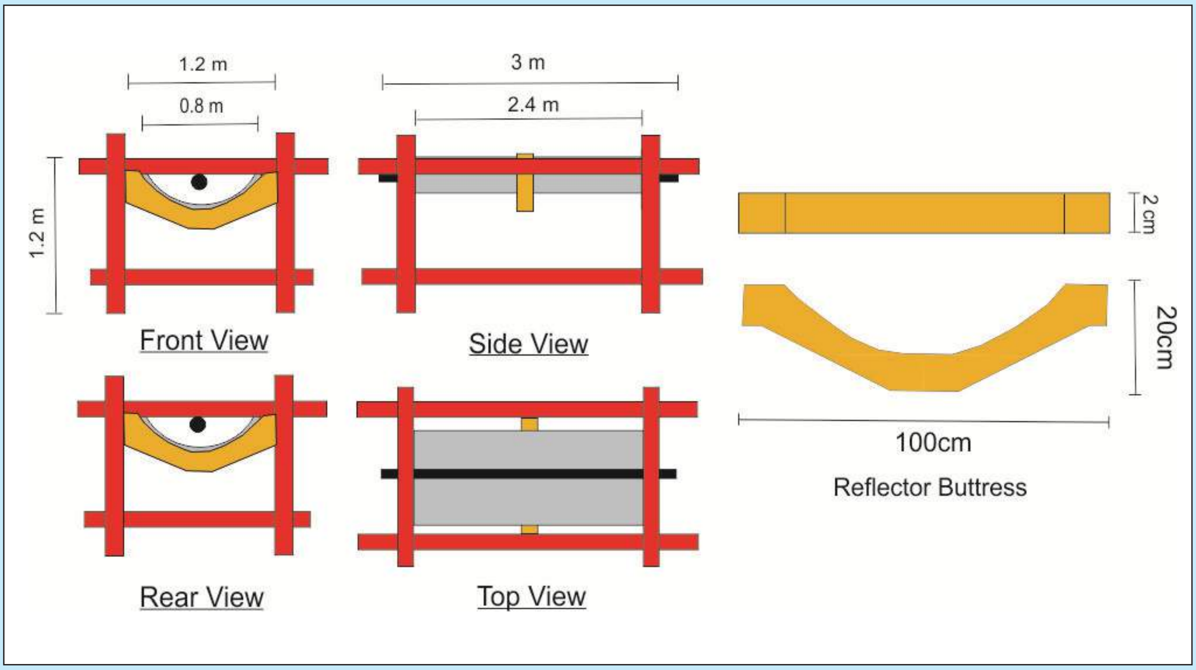


Figure 2
Design of the parabolic trough collector.

- Heating value of parabola reflection over the receiver tube (q_s) with solar irradiation of Cepu (5,180.01 W/m^2) (Gaitan, 2012)

$$q_s = C\ x\ I\ x\ C_R\ x\ K$$

$$q_s = 20.38\text{x}5{,}180.01\frac{W}{m^2}\text{x}0.8\text{x}0.7$$

$$q_s = 59{,}118.41813\frac{W}{m^2}$$

- Mathematical estimation of PTC output temperature (Gaitan, 2012). Assuming a steady state, incompressible heat transfer fluid (water) with constant properties and flow rate of 0.3 kg/s, Water Inlet Temperature (T_{inlet}) = 25°C.

$$A_s = \pi DL = \frac{\mu C_p(T_{Outlet} + T_{inlet})}{q_s}$$

$$\frac{\pi DLq_s}{\mu C_p} + T_i = T_o$$

$$\frac{\pi(0{,}0127\ m)(2{,}4m)(59{,}118.41813)\frac{W}{m^2}}{\left(0.3\frac{kg}{s}\right)(4210J/kgK)} + T_i = T_o$$

$$T_{output} = 4.47°C + T_{input}$$

$$= 4.47°C + 30°C$$

$$= 34.47°C$$

Table 2
Specifications of the designed PTC CSP

Total Height x Width of PTC	1.4 m x 1 m
Height of Collector	20 cm
Width of Collector	80 cm
Length of PTC	2.4 m
Geometric Concentration Ratio	20.38
q_s	59,118.41813w/m^2
Input Temperature Increase for 1 PTC	4.47°C(mathematical estimation)
PTCs required for 1 modular	25

At Table 2 is the specification of the PTC CSP based on the result of the mathematicalmodelling and calculations that have been done.

The saturation temperature of water at 101.3 kPa is 100°C and additional heat is required to complete the phase change process.With = 25°C and temperature increase 5.18°C, additional temperature needed to reach saturation temperature is approximately 70-80°C.

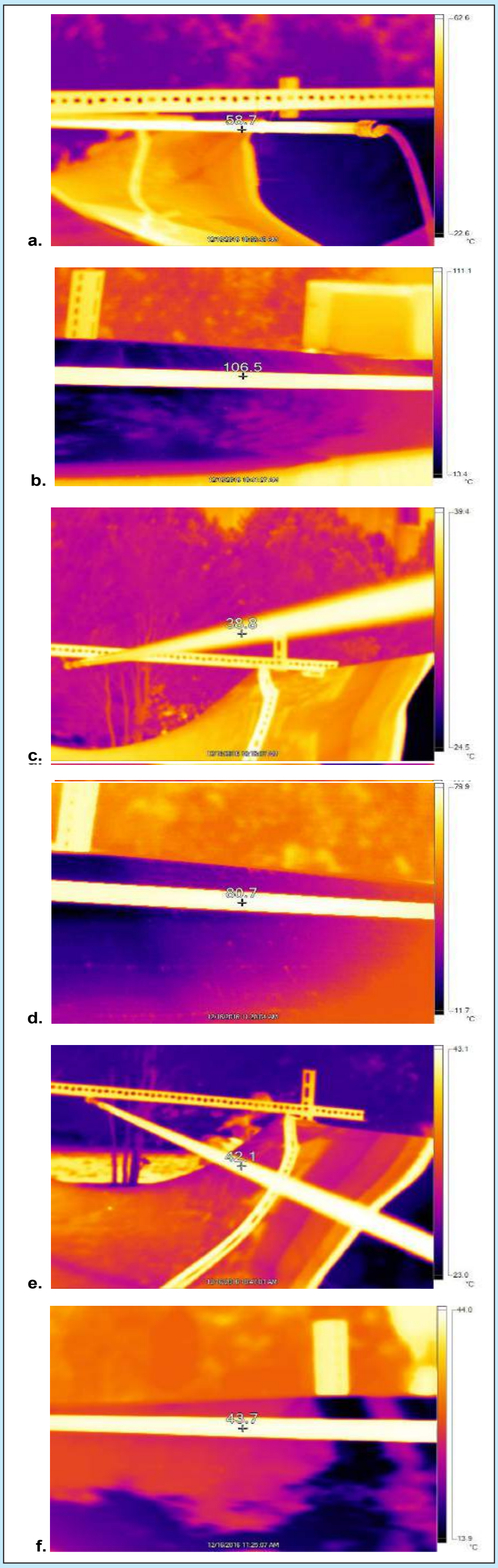


Figure 3
Receiver tube initial (a – c) and final (d – f) temperature thermal imaging result with FLUKE thermal imager Ti300.

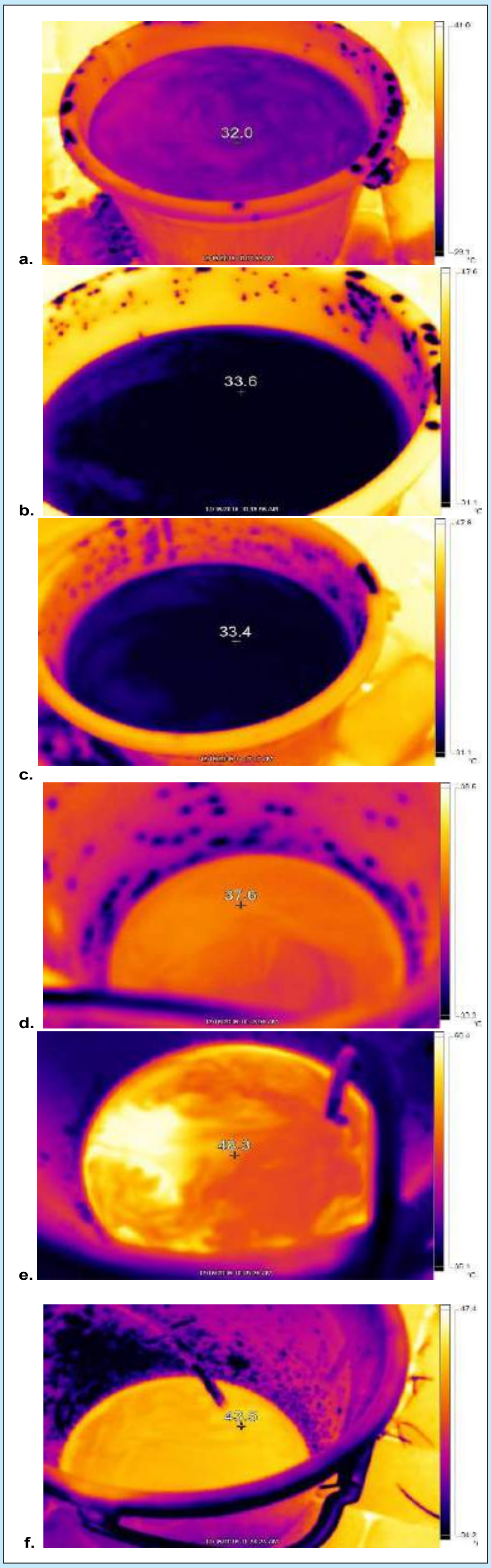


Figure 4
Water initial (a-c) and final (d-f) temperature thermal imaging result with FLUKE thermalimager Ti300.

Table 3
Temperature and weather experiment data

Initial Temperature	Experiment 1	Experiment 2	Experiment 3
Receiver Tube	58,7°C	106.5 °C	80.7°C
Water	32°C	33.6 °C	33.4 °C
Parabola	45 °C	49 °C	48.4 °C
Final Temperature	**Experiment 1**	**Experiment 2**	**Experiment 3**
Receiver Tube	38.8°C	42.1°C	43.7°C
Water	37.6°C	48.3°C	43.5 °C
Parabola	39.9°C	43.2°C	45.6°C
Weather	Cloudy	Sunny	Cloudy-Sunny-Cloudy

Table 4
Flow rate experiment data

	Experiment 1	Experiment 2	Experiment 3
Theoretical Water Discharge	500 ml	500 ml	500 ml
Actual Water Discharge	493 ml	460 ml	442 ml
Time		120 s	
Temperature Inlet	32°C	33.6°C	33.4°C
Water Inlet Density	995.02 kg/m^3	994.50 kg/m^3	994.57 kg/m^3
Volumetric Flow Rate	4.10 ml/s	3.83 ml/s	3.68 ml/s
	4.10 x 10^{-6} m^3/s	3.83 x 10^{-6} m^3/s	3.68 x 10^{-6} m^3/s
Mass Flow Rate*	4.08 x 10^{-3} kg/s	3.80 x10^{-3} kg/s	3.65 x10^{-3} kg/s
	14.68 kg/h	13.70 kg/h	13.17 kg/h
Average		13.85 kg/h	
Flow Rate in 25 PTCs		346.25 kg/h	

*Mass Flow Rate
Mass Flow Rate = Volumetric Flow X Water Inlet Density

The efficiency of 90% is assumed to be the same for every PTCs and resulting the same amount of performance. Thus, the amount of PTCs required to reach saturation temperature of water can be directly calculated with temeperature increase gained, which amounted to 14-16 PTCs. But, to raise the saturation temperature and produce steam as well as compromising the heat loss (unaccounted yet in this research) and unsupportive weather condition, 25 PTCs for 1 modular are deemed sufficient to reach beyond 100°C to produce steam and will be applied for this research.

B. Prototype Testing

Prototype testing has been done at December 16th 2016 in a wide area of STEM Akamigas campus from 10.00 WIB – 11.30 WIB. The data obtained are temperature thermal imaging of water inlet and outlet, receiver tube, and parabola. Whereas the water flowing time is 2 minutes and volume of water flowed through receiver tube is 500 ml (with some volume of water still left inside receiver tube). The volume of water is the flow rate value in 1 PTC, for 25 PTCs, the average mass flow rate will be multiplied by 25. The volume of water must be converted into mass flow rate to be able to perform calculations needed in Aspen Hysys 7.3, resulting in data at Table 4.

The water and receiver tube temperature thermal imaging photo can be seen in Figure 3 & 4. As for the static flow experiment, the temperature can only be measured until both 92^{o}C and 84^{o}C because the water is running out due to increase in pressure forcing water out of the tube through the tube leakages from the pressure exit holes. For Table 5 & **7** Multiple R and R square values stating Percentage of Temperature Dependency of Time. Standard errors stating the difference between estimated temperature and actual measurement result. Data obtained from the prototype testing are as follows.

Using the static flow experiment result and polynomial regression statistic method on Microsoft Excel, an equation that describes the characteristic of temperature increase over time can be obtained. This mathematical model will state the condition inside and outside of the result data range. Thus, this equation can be used for estimating the temperature increase achieved by PTC on sunny and sunny-partly cloudy weather using solar irradiation of Cepu outside the period in data range. But, the equation will have an increase in error at the period outside of data range and the presence of error must be taken into consideration. Below are the equations of temperature increase estimation of PTC on sunny-partly cloudy and sunny using solar irradiation of Cepu (x states period, 1 period = 1 minute):

- Temperature estimation at sunny-partly cloudy weather:

  T estimate

  = With the value of temperature dependency towards time 97.90 % and standard error 5.293.

- Temperature estimation at sunny weather:

  T estimate

  = With the value of temperature dependency towards time 98.80 % and standard error 2.223.

Analysis

Different weather condition in each experiment has led to a very significant difference in each experiment result, especially for temperature increase. As seen in Table 3, the temperature

Table 5
Regression statistics for static flow experiment at sunny-partly cloudy weather

Regression Statistics	
Multiple R	0.988196513
R Square	0.976532348
Adjusted R Square	0.973179826
Standard Error	2.233330143
Observations	17

Table 6
Equation coefficients for temperature estimation at sunny-partly cloudy weather

	Coefficients	Standard Error
Intercept	26.20357143	3.702835
x1	4.767445055	1.322679
x2	0.063873626	0.098097

Table 7
Regression Statistics for static flow experiment at sunny weather

Regression Statistics	
Multiple R	0.979090708
R Square	0.958618615
Adjusted R Square	0.951094727
Standard Error	5.293623763
Observations	14

Table 8
Equation coefficients for temperature estimation at sunny weather

	Coefficients	Standard Error
Intercept	38.32198142	1.450951
X1	2.286893705	0.420642
X2	0.02373581	0.025366

increase gained by 1 PTC for experiment 1, 2, and 3 is 5.6°C; 14.7°C; and 14.7°C. After multiplying the result with PTCs required to achieve the temperature for producing steam, the final temperaturesare now 172°C, 401.1°C, and285.9°C respectively with the average of 286.33°C. 25 PTCs has excelled the need to achieve a steam producing condition (reaching beyond its saturation temperature at a certain pressure point) at 101.3 kPa with final water temperature average of 286.33°C which is above its saturation temperature at atmospheric pressure.

Based on the static flow experiment of PTC temperature increase over time, it can be seen that temperature increase at a certain time period tends to be always linear as referred at Figure 5 & 6.

At periods outside the data range, the temperature keep increasing. This means that at the same condition the water/fluid temperature will keep increasing (keep receiving heat) until the receiver tube has reached its thermal equilibrium with sun as the source of heat and heat transfer no longer occured.

The same aspect also applies to a PTC system consisted of 25 PTC with same size. The number of PTC will increase the heat from solar irradiation received by the water and thus allowing the water to reach the desired output temperature in less time. However, the interchangeable weather condition resulting a fluctuative output temperature, thus making the water outlet temperature to not reach the desired output temperature and the water has to be re-heated. A closed/looping system for the PTC can be made to ease up the water flow in reaching the desired temperature.

Figure 7 shows the basic scheme of looping system that can be applied for the PTC. This sytem is designed with automation based on (PLC) which consisted of transmitter (temperature measurement component), PLC (system central controller), solenoid valve (to redirect water flow back into the PTC system if the desired outlet temperature is not reached), and control valve (to regulate the water inlet flow).

However, to utilize the steam, PTC system has to be closed to be able to trap the steam and flowing it to its equipment demand thus increasing pressure on water more than atmospheric pressure and saturation temperature point will also increase. The pressure must also be determined first with feed pump before water is entering steam producing condition.

This value of pressure is facultative depending on power output demand, because in producing steam, before starting

Table 9
Temperature gained after multiplication with amount of PTCs required

	Temperature Increase	PTCs Required	Temperature Gained
Experiment 1	5.6 °C	25	172°C
Experiment 2	14.7 °C	25	401.1°C
Experiment 3	10.1 °C	25	285.9 °C
Average			286.33°C

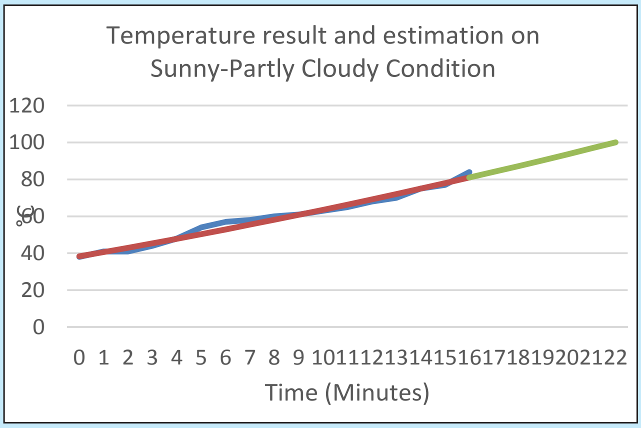
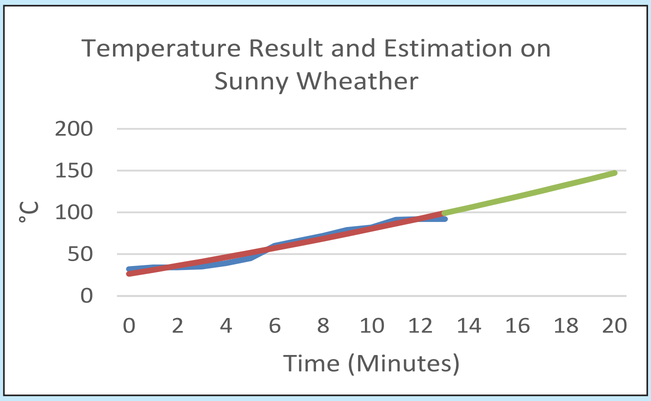


Figure 5
Static flow experiment result on sunny-partly cloudy weather.

Figure 6
Static flow experiment result on sunny weather.



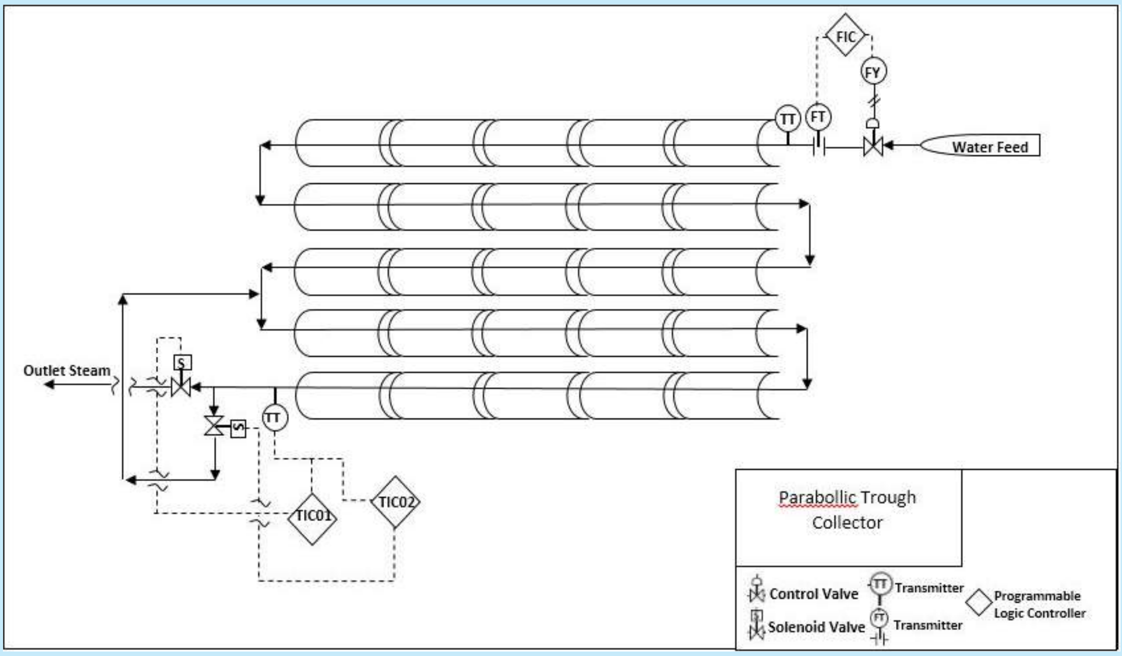


Figure 7
Looping system for PTC.

the steam producing operation, pressure must be constant to prevent the saturation temperature of water from being fluctuative. Also, in producing superheated steam, pressure on the water must be constant to allow the water to expand as it is heated further above its saturation temperature.

Pressure value is determined by the selection of pump and design of PTC. Because this research do not choose a particular equipment to be tested and only finding out the ability of Cepu solar irradiationto achieve a steam producing condition with PTC (reaching beyond its saturation temperature at a certain pressure point), this research will calculate the pressure range of steam's usability, by calculating the pressure limit where the vapor fraction is 1 at the temperature condition gained with 25 PTCs. This is done to set the range for usability of steam produced from PTC in terms of the pressure limit wherewater returns to its liquid phase.

Because of the temperature data fluctuation, the range of pressure will also be varying in each experiment. To determine the exact temperature and pressure range of steam's usability, the temperature data are needed to be uniform. By entering the average temperaturedata as well as into material stream in Aspen Hysys 7.3, the pressure at which the vapor fraction returns to 0 can be calculated and resulting in 7137 kPa.

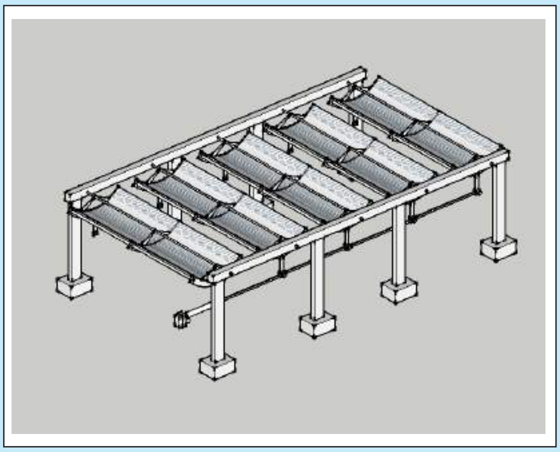


Figure 8
Revised PTC design image of 10 PTCs equipped withsun tracking actuator and structure foundation.

The pressure limit of steam's usability is set at 7136 kPa, 1 kPa less than the actual limit, which still resulted in vapor fraction = 1. Thus, steam produced by PTC CSP can be used on a demand between 100 – 286.33^{o}C and 101.3 – 7136 kPa.

Using the average temperature increase gained, the temperature range of steam's usability/the conditions at which the water is still in vapor phase/ steam is between 100 – 286.33^{o}C at 101.3 – 7136 kPa. The steam can be used at operation condition between the range depending on the demand of an equipment as long as the value is within both the pressure and temperature limit. The pressure of PTC CSP system can also be set by selecting the equipment with performance within the range.

Optimization

The following optimization can be done to increase the performance of PTC:

1. Changing the tube material with copper because its higher value (386 W/m K) of heat conductivity.
2. Adding glass tube cover component will minimize heat loss on receiver tube by preventing convectional heat loss from taking place on the receiver tube surface.
3. Adding sun tracking component will increase the mobility of PTC and ease up the process for adjusting PTC position to get maximum solar irradiation exposure as the sun moves from east to west.
4. Changing the PTC design, if all the materials can be obtained, the design at Figure 8 can be applied based on the optimization that has been mentioned previously with the inclusion of sun tracking component and glass tube cover.

Material Cost Calculation

Cost spent on materials is at Table 10.

IV. CONCLUSIONS AND SUGGESTIONS

Conclusions

Based on the research that has been conducted, solar irradiation of Cepu District can be used to produce steam by using 25 PTCs with temperature 172°C, 401.1°C, and 285.9°C in 3 different weather conditions (cloudy, sunny, cloudy-sunny-cloudy). The average temperature of steam produced is 286.33°C and the pressure limit of steam to maintain its vapor phase at the temperature is 7137 kPa. Thus, the steam produced can be used at the demand between 100 – 286.33°C and 101.3 – 7136 kPa.

Table 10
Cost Spent on Materials for Constructing 1 PTC

No	Usage	Cost
1	2.4m x1.2 mx0.8 mpolished stainless steel sheet	Rp475.000,00
2	Metallic paint	Rp17.500,00
3	3 m ½ inch-diameter-steel tube	Rp50.000,00
4	2 hose-to-tube fittings	Rp35.000,00
5	24 m slotted angle	Rp407.500,00
6	4 caster wheels	Rp160.000,00
7	2 cm-thick-teak wood (formed into 3 buttress)	Rp450.000,00
	2 m water hose	Rp5.000,00
	Tube insulation	Rp2.000,00
	Screws	Rp30.000,00
	Total	**Rp. 1.632.000,00**

Suggestion

The optimization that has been previously mentioned can be done to improve the performance and minimize the heat loss of PTC. Steam produced by PTC CSP can also be tested to a certain steam equipment to find out its actual performance when using the steam produced on the demand within range of steam's usability.

Appendix

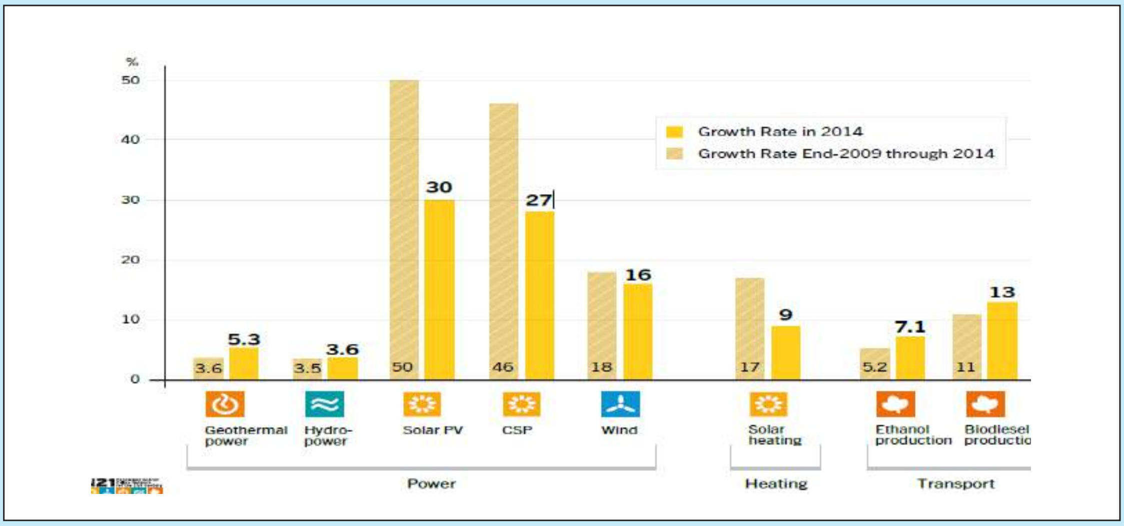


Figure 9
Growth rate of various renewable energy sources (REN21, 2015).

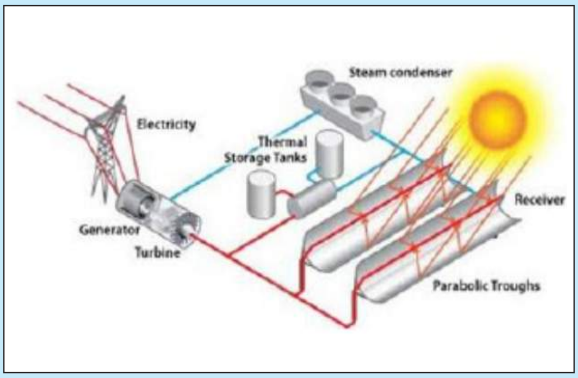


Figure 10
Schematic diagram of direct steam generation with PTC as solar power collector (Gunther et al. 2012).

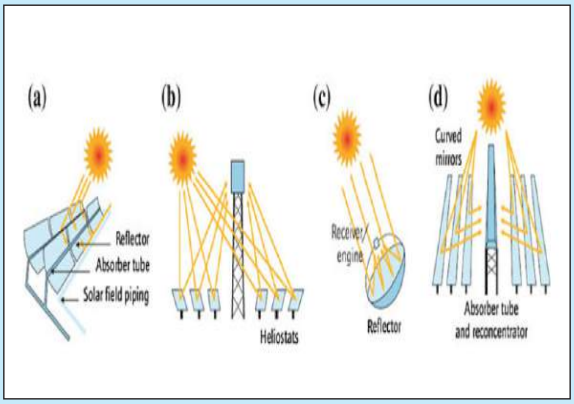


Figure 11
Approaches to concentrate solar power: a. Parabolic trough collector; b. Solar tower; c. Parabolic dishes; d. Linear fresnel (Martin et al. 2016).

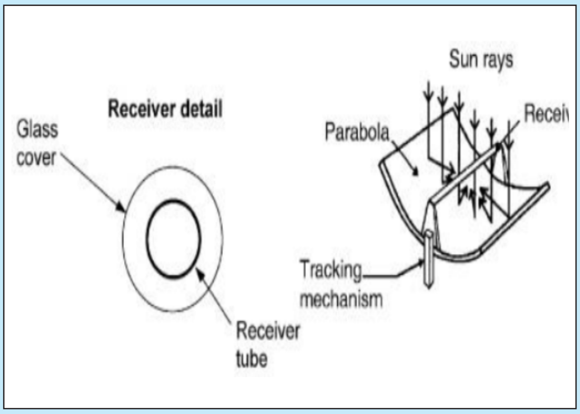


Figure 12
Parabolic trough collector (Chu 2011).

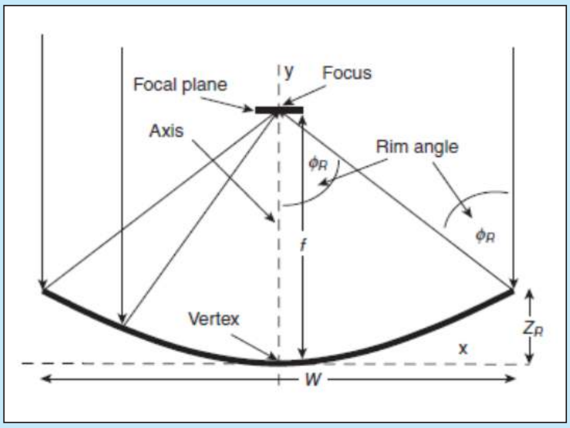


Figure 13
Reflection principle in parabolic trough collector (Lovegrove & Stein 2012).

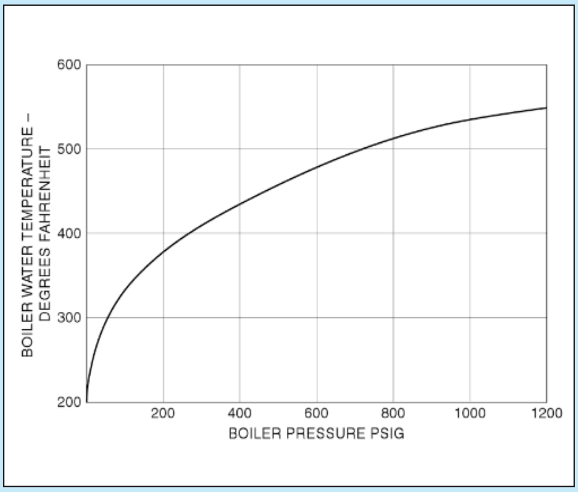


Figure 14
Pressure temperature graph for water (Langley & Sacks 2010)

Figure 15
FLUKE thermal imager Ti300.

Figure 16
Data collection process with FLUKE thermal imager Ti300.

Figure 18
Constructed PTC prototype

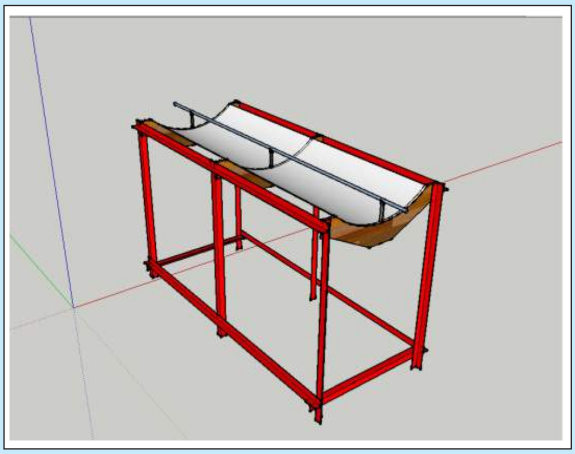


Figure 17
Isometric view of the constructed PTC prototype.

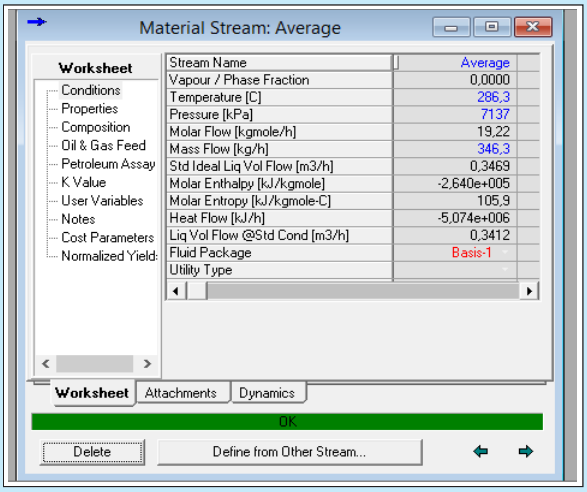


Figure 19
Aspen hysys 7.3 material stream calculation of steam usability pressure limit.

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