EXPERIMENTAL STUDY ON THERMAL REGULATION IN ON-GRID AND OFF-GRID PHOTOVOLTAIC SYSTEMS BY USING CRUDE PALM OIL AND CALCIUM CHLORIDE DIHYDRATE AS PHASE CHANGE MATERIALS

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Background

Energy emphasizes a central role in this modern world. On 2nd January 2015, crude oil price reached $52.81/barrel and affected countries in the world differently. Therefore to lessen the dependency of fossil fuels, renewable energy is undoubtedly needed to perform energy security and reduce greenhouse gases. Solar energy is the most abundant, inexhaustible and clean of all the renewable energy resources until now. Indonesia has average daily irradiation 4.8kWh/m^2/day. One of the obstacle of solar Photovoltaic (PV) development is the rise in temperature. To inhibit the increase in temperature, two Phase Change Materials (PCMs), Crude Palm Oil (CPO) and Calcium Chloride Dihydrate, are used that will lead to better power output and electrical efficiency in on-grid and off-grid PV system.

Objectives

1. To find the thermal characteristic of PCMs using Differential Scanning Calorimetry (DSC) and Temperature History Method (THM)
2. To evaluate the real performance of solar panel system based on real-time application in Bandung, Indonesia
3. To investigate interdependence of solar insolation, daily power output, and efficiency in solar PV system performance
4. To observe the difference in power output and efficiency in on-grid and off-grid PV system, with and without cooling devices
5. To analyze the affiliation between position of PV system, which are on-roof and on-stand PV system, with the application of PCMs

Cooling System Design

Two different PCMs are poured into the aluminum tubes and slipped at the back of the PV module as shown in Figure 1. Based on the initial calculation, the volume of PCM needed in order to maintain the back PV surface temperature at 40°C is 156.9kg. In contrast, the available space at the back of solar module is only can store 109.4kg of PCM. Based on the theoretical calculation, the maximum temperature of PV module will be at 49 °C that will lead to higher power output difference and efficiency increase as high as 5.5% and 0.88%, respectively.

Figure 1. Aluminum tubes are attached at the back of PV module

Research Methodology

Two PCMs of different material classes were selected for combined Differential Scanning Calorimetry (DSC) and Temperature History Method (THM) measurements: Crude Palm Oil and Calcium Chloride Dihydrate. Before processed into two measurement, Calcium Chloride Dihydrate is measured to determine its concentration. Later on, these PCMs are used in with 1kWp on-stand on-grid PV system to observe the influence of PCMs application to the PV temperature as shown in Figure 2. Moreover, the PV position is moved into the ground and called on-roof PV system, both on-grid and off-grid PV system as illustrated in Figure 3, with the capacity of 0.8 kW at Standard Test Condition (STC).

Figure 2. One kWp on-stand PV system at 4th floor PAU ITB building

Figure 3. 0.8 kWp on-roof PV system both in on-grid and off-grid PV system

Results and Discussion

Tree repeated experiments to determine the concentration of Calcium Chloride Dihydrate is held. The average concentration is 58.19% and based on Dow Chemical Handbook, at temperature below 32°C there will be a portion of CaCl2.6H20 and CaCl2.4H20. Moreover, at 32°C the Calcium Chloride will start to melt and consist of CaCl2.4H20 and solution. At 62°C the Calcium Chloride will be completely melted and become solution.

From DSC result, it shows that the latent heat of CPO is as big as 23.84 kJ/kg. In addition, CPO starts to melt at 35.6°C and will be completely in liquid form at 55.3°C. On the other hand, from DSC result for Calcium Chloride Dihydrate highlights the latent heat is 255.99 kJ/kg. This is because the sample of Calcium Chloride Dihydrate is in the solid phase and cannot represent the whole mixture. In short, the numerical values of these DSC results are not comparative due to the imperfection during the sample selection process. Thus, in the next analyses only qualitative comparison will be discussed.

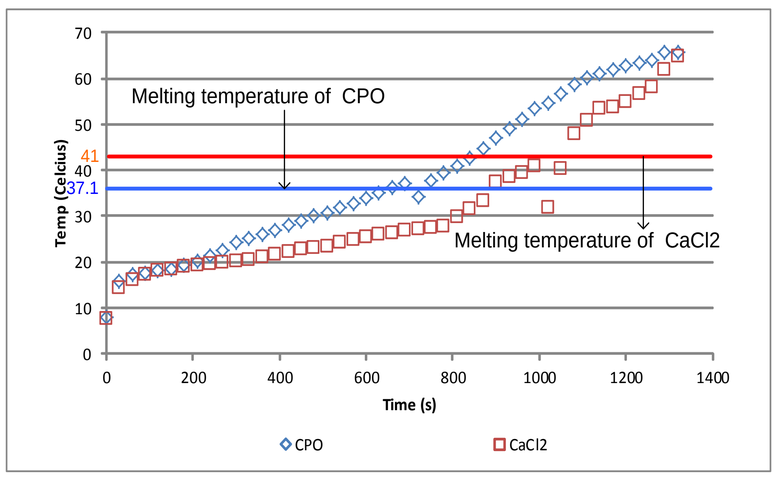

Figure 4. Heating process of both PCMs

Figure 4 represents the heating process in THM for both PCMs. From this curves, the melting temperature of CPO is around 37.1°C and for Calcium Chloride Dihydrate will be melted at 41°C.

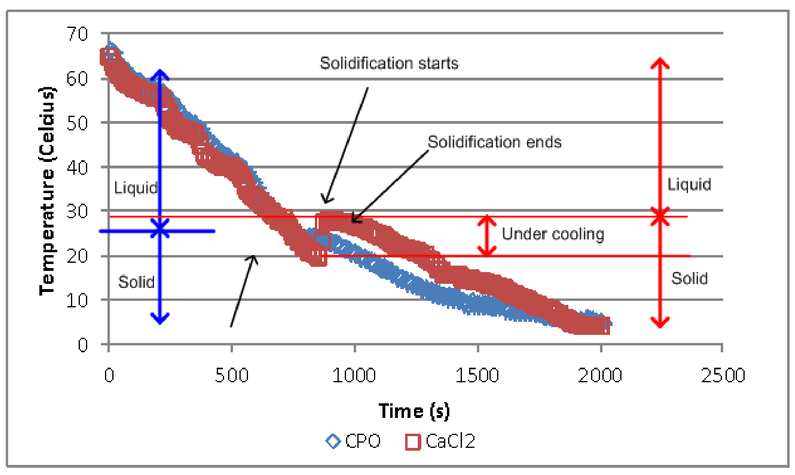

Figure 5. Cooling process of both PCMs

Figure 5 represents the heating process in THM for both PCMs. From this curves, the solidification temperature of CPO and Calium Chloride Dihydrate is averagely 25.7°C and 27.7°C, respectively. In addition, in Calcium Chloride Dihydrate, it is undesirable under-cooling phenomena that holds the temperature below its solidification temperature, approximately at around 19°C.

Table 1,2,3, and 4 show the result of PCMs application in all PV systems using CPO and Calcium Chloride Dihydrate. In short, the decrease in temperature will lead to higher PV power output and electrical efficiency.

Table 1. Summary of CPO temperature in all system

Position	Date	Average Irradiation (W/m²)	Average Temperature (°C)				Temperature Difference (°C)	
			PV/PCM		PV/Normal			
			Top	Bottom	Top	Bottom	Top	Bottom
On-stand	16/8/2014	844.8	45.0	34.7	41.2	27.9	-3.8	-6.8
	17/8/2014	849.8	49.5	38.7	47.4	33.0	-2.1	-5.7
	19/8/2014	750.9	45.9	39.4	43.1	35.1	-2.8	-4.3
On-roof on-grid	22/10/2014	668.56	44.4	42.8	50.0	46.5	5.6	3.7
	23/10/2014	652.64	42.6	42.6	44.6	46.4	2	3.8
	27/10/2014	739.28	46.2	45.4	48.9	49.2	2.7	3.8
On-roof off-grid	20/11/2014	645.24	58.6	46.8	61.2	50.7	2.6	3.9
	24/11/2014	738.53	52.7	44.8	55.8	49.9	3.1	5.1
	27/11/2014	646.80	54.1	42	55.7	47.6	1.6	5.6

Table 2. Summary of CPO power output and efficiency in all system

Position	Date	Duration (hours)	Average Irradiation (W/m²)	Total Daily Power Output (Wh)		Total Daily Power Difference (%)	Average electrical efficiency (%)		Average Electricity Increase (%)
				PV/PCM	PV/Normal		PV/PCM	PV/Normal	
On-stand	16/8/2014	4	844.8	1401.37	1439.5	-2.65	14.29	14.63	-0.34
	17/8/2014	4	849.8	1372.90	1390.16	-1.24	13.83	14.01	-0.18
	19/8/2014	4	750.9	1212.51	1225.95	-1.10	13.90	13.98	-0.08
On-roof on-grid	22/10/2014	8	668.56	1711.07	1670.02	2.46	13.90	13.59	0.31
	23/10/2014	8	652.64	1620.06	1599.00	1.32	13.18	13.03	0.15
	27/10/2014	8	739.28	1853.28	1821.76	1.73	13.11	12.95	0.16
On-roof off-grid	20/11/2014	5.25	645.24	737.49	726.53	1.51	7.72	7.63	0.09
	24/11/2014	6.5	738.53	1108.11	1084.35	2.19	8.97	8.81	0.16
	27/11/2014	4.25	646.80	536.15	528.23	1.50	7.30	7.20	0.10

Table 3. Summary of Calcium Chloride Dihydrate temperature in all system

Position	Date	Average Irradiation (W/m²)	Average Temperature (°C)				Temperature Difference (°C)	
			PV/PCM		PV/Normal			
			Top	Bottom	Top	Bottom	Top	Bottom
On-stand	4/1/2015	658.67	41.3	37	40.3	36.3	-1	-0.7
	5/1/2015	783.27	43	37.9	42.3	37.1	-0.7	-0.8
	6/1/2015	750.69	42.5	37.9	41.6	36.8	-0.9	-1.1
On-roof on-grid	17/12/2014	711.04	49.7	45.6	57.8	53.1	8.1	7.5
	18/12/2014	772.93	47.9	41.1	51.8	48.6	3.9	7.5
	19/12/2014	627.78	47.0	40.1	51.0	48.7	4.0	8.6
On-roof off-grid	14/12/2014	920.60	57.6	47.8	61.7	55.4	4.1	7.6
	15/12/2014	848.37	57.2	48.2	60.9	53.6	3.7	5.4
	16/12/2014	433.78	49.1	40.6	54.5	44.5	5.4	3.9

Table 4. Summary of Calcium Chloride Dihydrate power output and efficiency in all system

Position	Date	Duration (hours)	Average Irradiation (W/m²)	Total Daily Power Output (Wh)		Total Daily Power Difference (%)	Average electrical efficiency (%)		Average Efficiency Increase (%)
				PV/PCM	PV/Normal		PV/PCM	PV/Normal	
On-stand	4/1/2015	4	658.67	1069.6	1073.68	-0.38	13.98	14.01	-0.02
	5/1/2015	4	783.27	1283.89	1292.98	-0.70	14.38	14.50	-0.12
	6/1/2015	4	750.69	1237.70	1242.55	-0.39	13.93	14.08	-0.15
On-roof on-grid	17/12/2014	5.5	711.04	1286.46	1228.78	4.69	14.04	13.44	0.60
	18/12/2014	7	772.93	1769.49	1707.38	3.63	13.96	13.38	0.58
	19/12/2014	6	627.78	1198.12	1152.19	3.99	13.75	13.20	0.55
On-roof off-grid	14/12/2014	5.25	920.60	1221.27	1191.63	2.49	10.14	9.88	0.25
	15/12/2014	6	848.37	1264.02	1232.55	2.55	9.24	9.02	0.22
	16/12/2014	3.25	433.78	205.6	201.08	1.98	5.33	5.23	0.10

Conclusion

- CPO
  - From DSC, the melting temperature starts at 35.6°C and completely melted at 55.3°C and from THM, the melting temperature starts at 25°C and completely in liquid form at 40°C
  - In on-roof on-grid PV system, CPO decreases the surface temperature. As a result, 1.84% total daily power output difference and 0.21% average electrical efficiency increase are obtained
  - In on-roof off-grid, CPO can lower the surface temperature and leads to better total daily power output as big as 1.73% and average electrical efficiency increase as high as 0.12%
- Calcium Chloride Dihydrate
  - From DSC, the melting temperature starts at 62.4°C and completely melted at 95°C and from THM, the melting temperature starts at 30°C and completely being liquid at 40°C. Average solidification temperature is 27.7°C with under-cooling phenomena at 19°C
  - In on-roof on-grid PV system, Calcium Chloride Dihydrate decreases the surface temperature. As a result, 4.1% total daily power output difference and 0.58% average electrical efficiency increase are obtained
  - In on-roof off-grid, Calcium Chloride Dihydrate can lower the surface temperature and leads to better total daily power output as big as 2.34% and average electrical efficiency increase as high as 0.19%
- Overview Analysis
  - In on-stand PV system, CPO and Calcium Chloride Dihydrate are not recommended
  - In normalized daily statistic chart, on-grid PV/PCM system has lower thermal capture losses due to the cooling effect of PCM and lower miscellaneous losses because of the MPPT embedded in inverter than off-grid PV/Normal

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