Simulation and Experimental Study on Effect of Phase Change Material Thickness to Reduce Temperature of Photovoltaic Panel

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Abstract. Solar energy is promising renewable energy which can be applied in Indonesia. Average solar radiation in the country is 4.8 kWh/day/m². Weakness of silicon-based photovoltaic (PV) is efficiency reduction caused by temperature increase. Many attempts have been done to reduce PV temperature. In previous study, palm oil, which is widely available in Indonesia, is suitable to be used as phase change material (PCM) to reduce PV temperature. In this study, thickness of aluminium rectangular-tube containing phase change material oil is varied. The tube is placed at back part of PV. Numerical and experimental study was done to evaluate the effect of tube thickness to the temperature reduction of the PV. Variation of tube thickness used in the experiment is 50.8 mm, 76.2 mm, 101.6 mm. Both studies show that increase of PCM thickness reduces PV temperature. Higher PCM thickness cause large reduction on PV temperature. Simulation result shows there is an optimum thickness of the PCM which is applied to the PV.

1. Introduction
Energy plays important role to human’s life. Nowadays, fossil fuel is still dominant energy source in the world. However, fossil fuels such as oil, natural gas, and coal are non-renewable energy sources that its amount will always be depleted by use. Hence, the use of renewable energy sources as a substitute for non-renewable energy sources needs to be escalated. Numerous efforts have been carried out to raise the utilization of renewable energy in Indonesia. This effort is also supported by the government to set the application of new & renewable energy in 2025 as big as 17%.[1]

One of the most promising renewable energy sources is solar energy, based on its daily availability. One way to convert solar energy into electricity is by using photovoltaic (PV) cells. The use of PV modules in the world currently has reached 70 GW capacity with a significant grow in the 2010-2011 period amounted to 30 GW. Meanwhile, Germany is the largest user of solar PV technology.

The efficiency of solar modules that are commonly used today is about 16% [2], which is still relatively low. It means that only 16% of the total solar energy that can be converted into electrical energy, though the rest converted to heat and miscellaneous losses.

One of the aspects that closely related with efficiency is the PV module operating temperature. Generally, the rise in temperature will result in a decrease of solar module power output. Therefore, to improve the efficiency of solar PV system, a cooling system is necessary to be installed on the PV module in order to inhibit the rise in temperature at the PV panel.

Phase Change Material (PCM) has the ability as heat storage due to its latent heat capacity. PCM can absorb large amounts of heat in the form of latent heat at its melting temperature. By putting the...
PCM in the containment and mounted at the bottom surface of the PV module, this PCM will maintain the temperature at the wall as low as possible. Some examples of this PCM are paraffin, coconut oil, palm oil, and vaseline album [3].

In this study a simulation by using Computational Fluid Dynamic (CFD) (using ANSYS FLUENT package program) is developed in order to examine the temperature profile at the PV wall and to select the suitable PCM substance for PV application, especially for Indonesia condition. Moreover, an experiment is conducted to find the optimum thickness of PCM to inhibit the temperature rise on the PV surface and also to analyse the correlation between temperature, output power, and efficiency by mounting the aluminium tubes filled with PCM at the back surface of the module.

2. Methodology
A simulation and experimental set up was designed to investigate the best PCM thickness in order to reduce temperature at the surface of the solar panel.

2.1 Phase Change Material (PCM)
Phase change material (PCM) is a substance that can undergo solid-solid phase change, liquid-gas and solid-liquid. Solid-liquid PCM type is the most widely used both in research and everyday use applications [3]. PCM absorbs large amounts of energy as latent heat at the phase transition temperature, thus the PCM can be used as passive heat storage. Solid-liquid PCM type has been used as a temperature control on a wide variety of applications. From the few studies that have been done, PCM proved having a significant influence in an attempt to decrease the temperature of the various electronic components and buildings. [3] PCM used in this study is Crude Palm Oil (CPO) and coconut oil.

2.2 Simulation of PV/PCM with Computational Fluid Dynamics (CFD)
Simulation by using ANSYS FLUENT was done to evaluate the influence of PCM thickness to the PV surface temperature. Geometry modelling for the simulation is shown in Figure 1.

Figure 1. Geometry modelling of aluminium rectangular-tube on back side of PV

While setting of boundary condition for the simulation can be seen in Table 1.
Table 1. Boundary condition used in the simulation

| No. | Area                                              | Boundary condition                     |
|-----|---------------------------------------------------|----------------------------------------|
| 1   | Front surface of PV wall                         | wall – radiation & convection          |
| 2   | Side wall of PV                                  | wall - adiabatic                       |
| 3   | Back surface of PV, PV material interface        | wall - coupled                         |
| 4   | Back surface of rectangular-tube                | wall – constant temperature*           |

*result of simulation would be compared with experiment of ‘PV on roof’. Therefore back surface of rectangular tube is the same with roof temperature (constant).

Heat transfer on PV module

The temperature on the surface of the solar module can be determined by considering the case of heat transfer that occurs between the solar cell modules with the surrounding environment. The three forms of heat transfer that appears in the solar cell module are conduction, convection, and radiation.

- **Convection**

  Total convection heat transfer in solar cell modules is formulated with:
  \[
  q_{\text{conv}} = h_c \cdot A \cdot (T_{\text{module}} - T_{\text{surrounding}})
  \]  
  \(1\)

  In the equation, \(T_{\text{module}}\) express the temperature at module surface and \(T_{\text{surrounding}}\) is the ambient temperature. Convective heat transfer coefficient (CHTC), \(h\) depends on the physical conditions around the module. Shao et al. (2009) suggested CHTC for PV panel as follows: \(4\)
  \[
  h = 6.91v + 3.9
  \]  
  \(2\)

  \(v\) in Equation (2) is air velocity.

- **Radiation**

  General form of the equation to express the radiation heat transfer is shown below
  \[
  q_{\text{rad}} = \varepsilon \sigma A (T_s^4 - T_{\text{module}}^4)
  \]  
  \(3\)

  Where \(q_{\text{rad}}\) is the solar irradiation on the surface of the module (\(I_{\text{rad}}\)), \(\varepsilon\) is the emissivity of the module material, \(\sigma\) is the Boltzmann constant \((5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4)\), \(A\) is the module area, and \(T_s\) express the temperature of radiation source \(5\).

- **Conduction**

  At steady state condition, heat flux of conduction can be expressed as:
  \[
  q_{x''} = -k \frac{\Delta T}{L}
  \]  
  \(4\)

  In above equation, \(k\) is the thermal conductivity of the material, \(L\) is the length between sides that has different temperature, and \(\Delta T\) states the temperature difference between two sides that is being considered \(6\).

2.3 Experimental set-up with different PCM thicknesses

Based on the simulation result of the correlation between PCM thicknesses with the decrease of temperature, it is appealing to compare this simulation with the experimental result. Therefore, an experimental is set up to analyse PCM thicknesses and PV temperature reduction \(7\). Moreover, the influence of CPO as the PCM to the electrical efficiency of the solar module can also be determined.
The experimental set-up is given in Figure 2. The system is installed on the roof top of PAU building at Institut Teknologi Bandung (ITB). Two 10 Watt peak mono crystalline solar modules with dimensions of 39.6 cm x 28.9 cm x 2.3 cm are used in this experiment. The back side of PV panels were directly in contact with the roof top. Therefore, there is no convection at bottom surface of the panels. This situation mimics Building Integrated PV structure on roof. The electricity produced by the solar modules is absorbed by the 10W 27Ω resistors, while the voltage and current are recorded by using multi meter. Five thermocouples connected to the OM-DAQ-USB-2400 data logger are located at top and bottom of both PV panels, and another one recorded ambient temperature every minute. To measure the insolation (incident of solar irradiation), a Lutron solar meter is installed near the PV module location. PV with CPO called as PV/PCM module, while the PV without CPO / normal PV act as a reference.

Table 1 shows the effect of different PCM thicknesses to decrease the operating temperature in the solar module. PCM thickness relation with the operating temperature of the solar modules can be seen in the Figure 4.

![Figure 2. Experimental set-up with two 10 Wp solar panels.](image)

3. Result and Analysis

3.1 Simulation results

- The difference between coconut oil and CPO as PCM

Figure 3 shows the curve of the front wall temperature rise of normal modules, modules with coconut oil, and modules with palm oil (CPO). At the beginning, the normal module temperature has increased sharply, while the module with palm oil increases faster than the module with coconut oil. But at 27°C, coconut oil is already melted, and it causes no inhibition of the temperature rise [8]. With the rate of temperature increase is relatively constant, the temperature of coconut oil would exceed the module with palm oil. Therefore, it can be concluded that palm oil is more appropriately used as a phase change material for solar modules operated in Bandung, Indonesia with ambient temperature around 27-30°C.
The impact of PCM thickness
A simulation was then performed to determine the effect of the PCM thickness and to find the optimum PCM volume. Simulation was done by making several models of solar module systems with various PCM thicknesses, i.e. 40, 60, 80, and 90 mm. Result of this simulation is shown in Figure 4.

In the temperature curves, it appears that all four modules with different PCM thicknesses have the similar temperature-suppression characteristic. The slightly different temperature-profile was caused by thicker/greater volume of PCM used; while greater volume of PCM resulted longer time it takes to melt the entire PCM. From the Figure 4, temperature-profile of PCM with 80 mm and 90 mm thickness is not significantly different. Therefore, it can be concluded that the optimum thickness of PCM is 80 mm.

3.2 Experiment Result
Table 2 shows temperature difference between reference PV (PV without PCM) and PV/PCM for various PCM thicknesses.
Table 2. PV/PCM and PV/reference temperature difference comparison.

| PCM thickness [mm] | Front surface temperature difference | Back surface temperature difference |
|-------------------|--------------------------------------|-------------------------------------|
|                   | Maximum (°C) | Average (°C) | Maximum (°C) | Average (°C) |
| 50.8              | 4.7         | 2.4         | 6.0         | 3.6         |
| 76.2              | 6.5         | 3.8         | 8.9         | 5.3         |
| 101.6             | 12.0        | 8.3         | 14.8        | 10.9        |

The thicker the PCM is mounted on the solar module, the greater the drop in temperature experienced by the solar modules, especially at the back side of the solar module. This is due to the thickness of the PCM proportional to the total volume of PCM is used. If the PCM volume is larger, then it needs more time to melt all the PCM. Moreover, it will cause the temperature of the PV/PCM panel may rise slowly.

Comparison of the electrical power generated by the PV/PCM with 3 types of PCM thickness variation can be seen in Table 3 below. It can be seen that the maximum power generated by the PV/PCM increases with higher PCM thickness attached to the solar module.

Table 3. PV/PCM and PV/reference power comparison.

| PCM thickness [mm] | Power difference between PV/PCM and PV/reference [W] | The increase of average power (%) |
|-------------------|------------------------------------------------------|----------------------------------|
| 50.8              | 0.9                                                  | 18.8                             |
| 76.2              | 1.1                                                  | 20.8                             |
| 101.6             | 1.3                                                  | 23.8                             |

Comparison of the PV/PCM efficiency at various PCM thicknesses is described in Table 4 below. It can be concluded that the maximum electrical efficiency of PV/PCM increases with the addition of PCM thickness in solar module.

Table 4. PV/PCM and PV/reference comparison in electrical efficiency.

| PCM thickness [mm] | Efficiency difference between PV/PCM and PV/reference [%] | The increase of average efficiency [%] |
|-------------------|----------------------------------------------------------|---------------------------------------|
| 50.8              | 1.7                                                      | 24.1                                  |
| 76.2              | 1.9                                                      | 26.2                                  |
| 101.6             | 2.1                                                      | 29.3                                  |

4 Conclusion
Both from the simulation and experiment, it can be concluded that PCM can reduce the average temperature of PV module. Thickness of the PCM greatly affects the inhibition of temperature rise of the PV surface. From simulation result, the optimum thickness of the PCM is at 80 mm, and Crude Palm Oil (CPO) has better performance than coconut oil in ambient temperature around 27-30°C. Meanwhile from experiment, the biggest temperature difference between reference PV and PV/PCM occurred at 102 mm PCM thickness, i.e. 9.6°C. With 102 mm PCM thickness, output power and efficiency of the PV are higher than the reference, i.e. 23.8% and 2.1%, respectively.

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