UNIVERSITI TEKNIKAL MALAYSIA MELAKA

# Faculty of Mechanical Engineering

## A SIMULATION STUDY OF PHOTOVOLTAIC SYSTEM INTEGRATED WITH PHASE CHANGE MATERIAL USING ANSYS



**Nurfarhana binti Salimen**

**Master of Mechanical Engineering (Energy Engineering)**

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# A SIMULATION STUDY OF PHOTOVOLTAIC SYSTEM INTEGRATED WITH PHASE CHANGE MATERIAL USING ANSYS

**NURFARHANA BINTI SALIMEN**

**A thesis submitted
in fulfillment of the requirements for the degree of Master of Mechanical Engineering (Energy Engineering)**

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## DECLARATION

I declare that this thesis entitled "A SIMULATION STUDY OF PHOTOVOLTAIC SYSTEM INTEGRATED WITH PHASE CHANGE MATERIAL USING ANSYS" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



Signature : ..........................................

Name : Nurfarhana binti Salimen

Date : 8th AUGUST 2021

**APPROVAL**

I hereby declare that I have read this dissertation/report and in my opinion this dissertation/report is sufficient in terms of scope and quality as a partial fulfillment of Master of Mechanical Engineering (Energy Engineering).

Signature : ..........................................................................

Supervisor Name : Dr. Mohd Afzanizam bin Mohd Rosli

Date : 9 August 2021

**DEDICATION**

To Allah, my family, and ummah.

# ABSTRACT

Temperature regulation in photovoltaic (PV) systems is crucial for enhancing PV performance. Passive cooling with a phase transition material (PCM) is one approach for dealing with overheating. Crude Palm Oil (CPO), which is more sustainable, and abundant is preferred in Malaysia. The potential of CPO as a PCM is being studied further by a simulation study utilizing CFD software, ANSYS to model the temperature differences and distribution of the PV-PCM system. A comparison of the temperature difference for the front PV-PCM system with and without PCM, temperature distribution, and contour of the system was also done. The main findings show that the average temperature difference for PV systems with and without CPO is around 50.7%, indicating that the PV system without PCM heats up approximately twice as much as the system with PCM. For temperature distribution, the front surface of the system maintains the temperature at 326.6K for about 992.4s over the melting point of the PCM (T=308.8K), whereas the back appears to have a linearly increasing temperature with time. From comparison analysis, the CPO is the most practical approach for lowering the temperature of the PV-PCM system that works in the ambient temperature of 27$^{o}$C, suited Malaysian weather. CPO has tremendous potential for regulating system temperature. Additional experimental work can be performed to validate the simulation.

# ABSTRAK

*Pengaturan suhu dalam sistem fotovoltaik (PV) sangat penting untuk meningkatkan prestasi PV. Penyejukan pasif dengan bahan peralihan fasa (PCM) adalah salah satu pendekatan untuk menangani pemanasan yang berlebihan. Minyak Sawit Mentah (CPO), yang lebih lestari, dan sesuai di Malaysia. Potensi CPO sebagai PCM dikaji lebih lanjut melalui kajian simulasi yang menggunakan perisian CFD, ANSYS untuk memodelkan perbezaan suhu dan pengedaran sistem PV-PCM. Perbandingan perbezaan suhu untuk bahagian depan sistem PV-PCM yang mempunyai PCM dan tanpa PCM, pengedaran suhu, dan kontur sistem juga dilakukan. Penemuan utama menunjukkan bahawa perbezaan suhu purata untuk sistem PV yang mempunyai CPO dan tanpa CPO adalah sekitar 50.7%, menunjukkan bahawa sistem PV tanpa PCM memanaskan kira-kira dua kali ganda lebih banyak daripada sistem dengan PCM. Untuk pengedaran suhu, permukaan depan sistem mengekalkan suhu pada 326.6K selama kira-kira 992.4s pada titik lebur PCM (T = 308.8K), sedangkan bahagian belakang menunjukkan suhu yang meningkat secara linear dengan masa. Dari analisis perbandingan, CPO adalah pendekatan paling praktikal untuk menurunkan suhu sistem PV-PCM yang berfungsi pada suhu sekitar 27$^{o}$C, sesuai dengan cuaca di Malaysia. CPO berpotensi besar untuk mengatur suhu sistem. Kerja eksperimen lanjutan boleh dilakukan untuk mengesahkan simulasi.*

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# LIST OF SYMBOLS

| | | |
|---|---|---|
| $A$ | - | Area |
| $\vec{F}_a, \vec{F}_b$ | - | Body force term |
| $q_{cond}$ | - | Conduction heat transfer energy |
| $q_{conv}$ | - | Convection heat transfer energy |
| $h_c$ | - | Convective heat transfer coefficient |
| $D(T)$ | - | Delta Dirac function |
| $\rho$ | - | Density |
| $\nabla$ | - | Divergence |
| $\varepsilon$ | - | Emissivity |
| $\vec{g}$ | - | Gravity |
| $L$ | - | Length |
| $m$ | - | Mass of the material |
| $\nabla p$ | - | Pressure gradient |
| $q_{rad}$ | - | Radiation heat transfer energy |
| $c_p$ | - | Specific heat capacity |
| $\sigma$ | - | Stefan-Boltzmann constant |
| $T_s$ | - | Surrounding temperature |
| $\Delta T, \partial T$ | - | Temperature difference |
| $\nabla T$ | - | Temperature gradient |
| $T_{module}$ | - | The temperature of the PV module |
| $k$ | - | Thermal conductivity |
| $\partial t$ | - | Time difference |
| Q | - | Total heat energy |
| $\vec{V}$ | - | Velocity |
| $\mu$ | - | Viscosity coefficient |

# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| 2-D | - | Two-dimensional |
| CPO | - | Crude Palm Oil |
| PCM | - | Phase Change Material |
| PV | - | Photovoltaic |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Study

Advancing technology is a key component of environmental issues and one of the primary causes of the issue. Green energy is intended to offer energy for an extended length of time rather than relying solely on non-renewable sources. Solar power is used in a variety of businesses as a means of utilizing renewable resources.

Photovoltaic (PV) technologies have been increasingly popular in recent years as a source of renewable energy around the world. One of the materials used to passively cool PV is phase change material (PCM).



Based on prior research, many types of phase change material (PCM) have been employed to date to help address the problem of overheating of solar PV above its working temperature, which affects the efficiency of the solar PV. The most commonly used organic PCM is unsustainable, unfriendly to the environment. Hence, the alternative for that is Crude Palm Oil (CPO). CPO is one of the abundant fatty acid resources in Malaysia, and it is suited for use in Malaysia where the ambient temperature is between 20°C and 30°C.

Luo et al. (2017) conducted a PV-PCM study in which the temperature change process of a PV-PCM panel with varying form-stable paraffin (ZDJN-28)/EG composite PCM material densities was simulated. Indartono *et al.* (2015) conducted another simulation study in which they used Crude Palm Oil and Coconut Oil as PCM to make comparison research and determine the best thickness for the PCM. Stropnik and Stritih (2016) investigate the experimental setup and simulation of heat extraction from a photovoltaic panel. Aneli, Arena and Gagliano (2020) performed a transient analysis on a simple two-dimensional fluid dynamic model.

The ideas of this research are to explore the potential of CPO by a simulation study. Through evaluating the temperature differential between PV systems with and without CPO as PCM to measure the rise in PV system temperature drop. Temperature distribution and contour inside the PV system are also required to determine if it is affected.

## 1.2 Problem Statement

In general, fast-growing technology is a major influence on environmental issues and one of the main causes of the crisis. Renewable energy is thus being implemented as a solution to supplying energy for a significant amount of time rather than using non-renewable technologies on their own. In Malaysia, solar energy has become one of the most potential renewable energy sources to be used as an energy source and has been used in various applications, such as the electricity provider.

Photovoltaic (PV) systems have been commonly used all over the world in recent years as one of the energy providers that is harvested from a renewable source, solar power. However, since solar energy not only provides light energy but also heat, the PV system overheats, particularly on sunny days when the ambient temperature is likely to be higher than the optimum operating temperature for PV. As a result, a cooling unit is invented to address overheating issues. One of the materials used to passively cool PV is phase change material (PCM).



One of the issues raised is that the most popular PCM used for PV cooling, especially in the organic category, is paraffin wax. Paraffin wax is unsustainable, expensive, particularly in Malaysia, and environmentally damaging. Thus, a much more sustainable, environmentally friendly, and cost-effective alternative is needed.

According to previous studies, Crude Palm Oil (CPO) is one of the alternatives for PCM. However, the temperature difference between PV systems with and without CPO as PCM had to be compared to calculate the value and percentage in PV system temperature reduction. Also, temperature distribution and contour across the PV system are needed to determine whether it is affected positively or negatively when CPO is used as PCM.

## 1.3 Objectives

The key objective of this research is to reduce the temperature of the PV system by using the selected phase change material. The main goal would be to meet the following objectives:

i. To evaluate the temperature differences between solar PV with and without Crude Palm Oil.
ii. To determine temperature distribution of PV-PCM system using Crude Palm Oil.

## 1.4 Scope of Study

Only three main elements of this study will be focused on. The scope of the research will be limited to evaluating the temperature differential of solar PV with and without CPO, determining the temperature distribution of CPO through ANSYS simulation software as well as a comparative study with other PCMs. A comparative analysis with previous studies focuses on the temperature difference between with and without PCM for the front PV-PCM system, temperature distribution, and its contour. Following that, the solar PV will be monocrystalline, and the phase change material used for the simulation will be CPO in a semisolid form that has been macro-encapsulated beforehand. The geometry model of the system will be two-dimensional vertically positioned with a $90^{o}$ inclined angle. On the front PV-PCM system, only direct heat flux is considered. Due to the computation limitation, the simulation only runs for 5000s for about 1 hour 30 min. Eventually, all of the simulation data would be in transient mode.

## 1.5 Significance of Study

The current study concentrates on the possibilities of improving PV-PCM by using Crude Palm Oil as a substitute for organic PCM, the increase in temperature differences between PV with and without CPO as PCM, and the PV-PCM temperature distribution under different working situations. The use of crude palm oil as a PCM has remained elusive, particularly in PV-PCM systems.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

This section includes a review of the literature on the Photovoltaic-Phase Change Material (PV-PCM) system using Crude Palm Oil (CPO) as the PCM material. For a deeper comprehension, the PV system cooling unit, PCM fundamentals, PV-PCM working principle, and CPO attributes will be discussed.

## 2.2 Photovoltaic (PV) System Cooling Unit

A photovoltaic (PV) system utilizes solar energy as its primary power source. Photovoltaics uses semiconducting materials such as silicon to convert sunlight into electricity, through a process known as the photovoltaic effect (Guerra *et al.*, 2018). PV system consists of one or several solar panels to absorb the sunlight and convert it to electricity. Since the converted electricity is in direct current form, thus it needs to be converted into alternating current by using a solar inverter which then will be supplied to the entire system as electricity or store in the battery.

Solar energy includes not only light energy but also heat energy. As a result, as time passes, there will be a phase where the temperature surrounding the PV device is higher than the operating temperature of the PV. This would have an impact on the system because high temperatures will cause the PV system's conversion efficiency and lifetime to decrease noticeably (Li *et al.*, 2019). The temperature of a solar panel can be altered by elements such as radiation intensity, dust deposition on its surface, wind speed, and humidity. The PV panel is exposed to an immersive area to harvest more power, yet all of these parameters are unpredictable in an outdoor environment. There is an effective approach for controlling the temperature by external sources (Verma *et al.*, 2020). The temperature must be reduced to the optimum operating temperature. Hence, the PV cooling unit is needed.

Three different techniques of PV cooling that have been studied by Gharzi *et al.* (2020) are active, passive, and combined techniques. Active cooling systems, are typically powered by a fan or pump that needs electrical power or external energy to work (Gharzi *et al.*, 2020). Active cooling techniques include forced airflow, liquid or water film or liquid or water flow, jet impingement, water spray, microchannel, and thermoelectric. Meanwhile, passive systems do not require electricity or additional energy. In reality, these technologies typically extract module heat by using natural convection from the module's back surface, evaporating, splitting the spectrum, and so on, and preventing temperature rise (Gharzi *et al.*, 2020). Passive cooling techniques include a heat pipe, heat sink, phase change material (PCM), evaporative system, liquid or water immersion, liquid cooling, and coating by spectral splitting filter or water film. Combined methods are also used to maximize thermal use, efficiency, and durability. The examples for this group are nano-fluid or nano-PCM.

Sato and Yamada (2019) discuss the most recent photovoltaic (PV) module cooling technologies and review the performance of the radiative cooling technique in depth. PV module conversion efficiency and long-term reliability deteriorate when operating temperatures rise. Active or passive cooling methods by using heat pipe, natural or forced airflow, forced water flow, phase change material, direct liquid immersion or submerging, and passive heat sink has been reviewed to overcome this limitation. The schematic designs of the various active and passive cooling methods are illustrated in Figure 2.1.

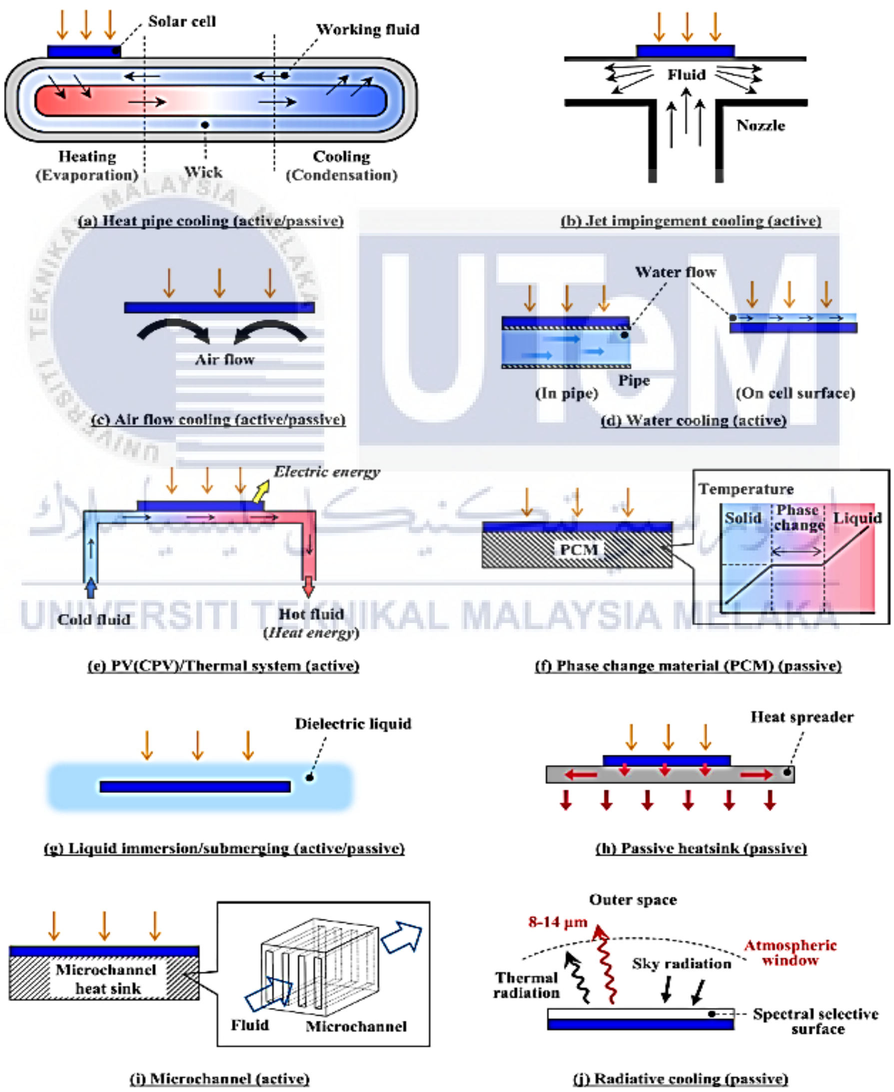


Figure 2.1: Various types of cooling solutions for photovoltaic modules are represented in schematic designs (Sato and Yamada, 2019).

## 2.3 Phase Change Material (PCM) for PV Cooling

The essential benefit of passive cooling solutions such as phase change material is their self-sufficiency and minimum of supplementary power consumption while retaining a simple design (Maleki *et al.*, 2020). A phase change material, or PCM, is a material that can accumulate or release a certain amount of external sensible heat during its phase transition for useful heat or cooling without changing the material's internal temperature. The heat is absorbed in the form of latent heat and the heat is used to weaken or form chemical bonds while maintaining the body's kinetic energy and therefore it is thermally stable during the phase transition. The phase transition cycle for PCM can be seen in Figure 2.2. The surrounding temperature must be greater than the PCM's melting point for the PCM to undergo a phase transition, and when the temperature drops below the melting point, the PCM will begin a new cycle (Casini, 2016).

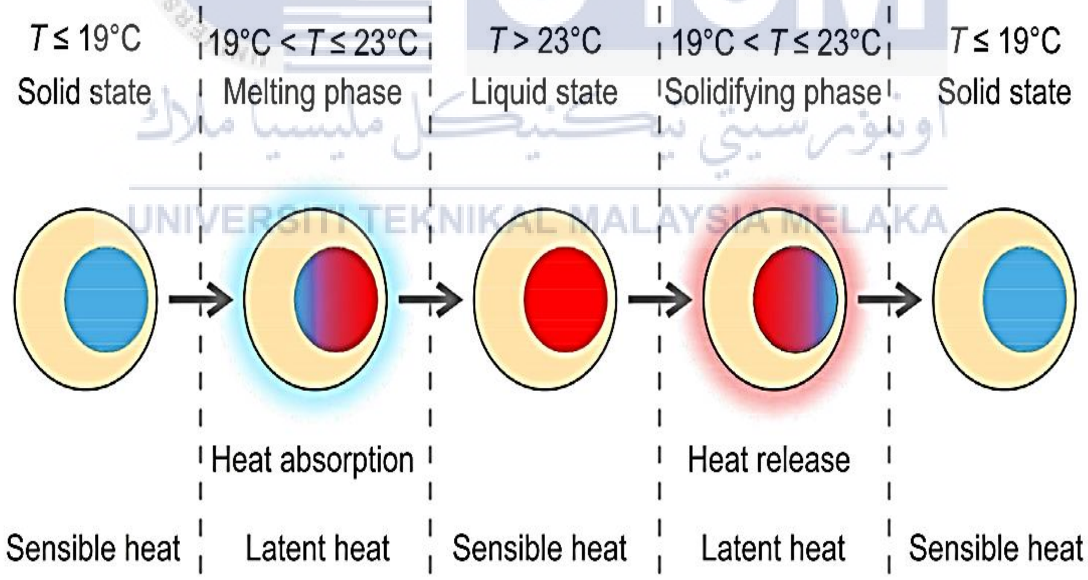


Figure 2.2: Phase change material cycle (Casini, 2016).

The total heat storage potential of a PCM is thus the amount of both the latent heat enthalpy in the phase transition temperature range and the sensible heat otherwise reserved for lower or higher temperatures as expressed in Equation 2.1 (Casini, 2016).

$$Q = m\left[(c_p \Delta T)_{sensible} + (c_p \Delta T)_{latent}\right] \quad [2.1]$$

Based on the equation 2.1, $m$ represents the mass of the material, $c_p$ is the specific heat capacity of the material, and $\Delta T$ is the temperature difference.

Thus, because of their high latent heat capacities, their phase transition is isothermal. As a result, they can be used to regulate the temperature of PV and concentrated PV systems (Gharzi *et al.*, 2020). As stated by Hasan *et al.* (2017), PCM has many benefits in terms of thermal management such as higher heat transfer rate compared to forced air and forced water circulation, higher heat absorption due to latent heating, isothermal nature of heat removal, no energy usage, passive heat exchange, no noise and maintenance cost, and on-demand heat supply.