A SIMULATION STUDY OF PHOTOVOLTAIC THERMAL USING PHASE CHANGE MATERIAL

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A project report submitted in fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering (Hons.)

Faculty of Mechanical Engineering

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DECLARATION

I hereby declare that this project report entitled **"A Simulation Study of Photovoltaic Thermal Using Phase Change Material"** is based on my original work except for citations and quotations which have been duly acknowledged.

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Date : 9th JANUARY 2022

APPROVAL

I hereby declare that I have read this project report entitled **"A Simulation Study of Photovoltaic Thermal Using Phase Change Material"** and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Hons.).

Signature : ____________________________________

Supervisor's Name :____________________________________

Date : ____________________________________

DEDICATION

To my beloved mother and father, and myself.

ABSTRACT

Photovoltaic thermal (PVT) systems have arisen as a critical study topic in recent years, owing to the world's growing energy need. Phase change materials (PCMs) are regarded as the optimal materials for efficiently harvesting thermal energy from renewable energy sources. However, today's PCMs have a significant disadvantage in terms of thermal conductivity. Over the last several years, there has been an upsurge in study targeted at fixing the issue. Thermal conductivity increases the amount of heat stored and extracted during the melting and solidification processes. Besides, parameters such as the thickness of the PCM, the types of PCM, and the effect of the melting temperature can also affect the performance of the PVT/PCM system. Hence, a simulation study using ANSYS FLUENT has been done to investigate the effect of thickness and properties of PCM for weather conditions in Malaysia. The best PCM types and thickness for this model are also selected. The thermal and electrical efficiency of the system is also studied in this report. Based on the results, Lauric Acid has the best thermal and electrical efficiency when PCM thickness increases. An optimum thickness of 30 mm is selected for Lauric Acid as it shows the best results compared to all other PCMs in this study.

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LIST OF SYMBOLS / ABBREVIATIONS

A	Area, m^2
A_{mush}	Mushy zone constant
C_p	Specific heat capacity, J/kg.K
$\dot{E}$	Power, W
h	Enthalpy of fusion, J/kg
ΔH	Latent enthalpy, J/kg
H	Material enthalpy, J/kg
K	Thermal conductivity, $W/m^2.K$
$\dot{m}$	Mass flow rate, kg/s
P	Pressure, Pa
t	Time
T	Temperature, K
V	Velocity
α	Absorptivity
β	Liquid fraction
η	Energy efficiency, %
ε	Emissivity
ρ	Density, kg/m^3
μ	Dynamic viscosity, kg/m.s
τ	Glass cover transmissivity
eff	Effective
el	Electrical
f	Fluid

g	Glass cover
in	Inlet
out	Outlet
PCM	Phase change material
PV	Photovoltaic
PVT	Photovoltaic thermal
th	thermal

CHAPTER 1

INTRODUCTION

1.1 BACKGORUND

Economic growth has been accelerated by the fast rise of the human population, along with technical improvements. Overproduction of energy to meet consumer demand has led in the depletion of fossil fuels (prime source of energy generation). On the other side, human activities associated with energy generation and consumption have resulted in environmental problems such as ozone depletion and global warming, which can result in climate change. Thus, these negative environmental changes that have been wreaking havoc on the globe may be mitigated by utilizing renewable energy sources such as solar energy. Nowadays, solar energy is readily available on the market due to its abundance, pollution-free nature, and ability to be used for agricultural, residential, and commercial purposes. Although solar photovoltaic systems are expensive to construct, this technology is now widely known and has a low maintenance cost. Indeed, two of the world's greatest economies, China, and India, have already begun producing solar energy on a significant scale, making them the world's greatest solar energy producers. The solar photovoltaic panel converts solar radiation into electrical energy, while the remaining energy is absorbed or reflected by the photovoltaic module as thermal energy. (Reji Kumar, Samykano, Pandey , Kadirgama, & Tyagi, 2020).

However, the current solar photovoltaic (PV) technology has many drawbacks such as when the heat absorbed increases with time, the electrical efficiency of the solar PV panel decreases and the rest of the solar radiated into the panel is wasted as heat. This means that when the electrical efficiency of the PV panel decreases, the electrical energy that can be generated from the PV system also decreases. As a solution, a lot of research has been made to overcome this problem such as the introduction of Photovoltaic Thermal (PVT) system, a system which combines both solar PV and solar thermal system that produce both electrical energy and heat energy at the same time. This technology has gained popularity over the years. When solar radiation is absorbed by the photovoltaic cell and converted to electrical energy, a solar thermal system integrated into the PVT system provides a cooling effect that cools the PV cells and absorbs excess heat from the PV panel whenever their temperature rises, using either air or water as the cooling fluid in the system. The PVT system considerably improves the electrical efficiency of the system by absorbing surplus heat from the photovoltaic panel using another medium such as an air collector, a water collector, or a combination of both air and water collectors that operate as a coolant for the system. (Diwania, Agrawal, Siddiqui, & Singh , 2020).

Additionally, the type of collector utilized in a PVT system is critical in decreasing the temperature of the photovoltaic panel. There are several varieties of thermal collectors available on the market, including PVT air collectors, PVT water collectors, and hybrid PVT air/water collectors are called PVT combi collectors. These thermal collectors each have their own unique method of collecting surplus heat from the photovoltaic panel, and each collector has its own set of advantages and disadvantages. For instance, PVT air collectors employ a single or double channel thermal collector and operate with air as the working fluid, whereas PVT water collectors employ a sheet and tube or roll bond absorber and operate with water as the working fluid. (Diwania, Agrawal, Siddiqui, & Singh , 2020).

Recently, the incorporation of phase change material (PCM), a substance capable of heat absorption, storage, and release, into the PVT system has been extensively investigated by individuals with varying specialties in the field of solar technology. The expansion of study into the PCM in PVT system was anticipated owing to its properties as a high-latent heat capacity storage material capable of collecting and releasing a considerable quantity of heat energy throughout the melting and solidifying processes (Reji Kumar, Samykano, Pandey , Kadirgama, & Tyagi, 2020). When the ambient temperature exceeds the temperature of the PCM material, heat is transmitted from the environment to the substance, which transforms to a liquid state. When the ambient temperature is lower than the PCM's temperature, heat is transmitted from the PCM to the surrounding, resulting in a warming effect, and the PCM returns to its liquid state.

In this report, a simulation study of the PCM in the PVT system will be simulated using computational fluid dynamics, analyzed, and compared with existing PVT/PCM system of different properties of PCM. A simulation study on the effect of thickness of PCM to the electrical and thermal efficiency of the system will also be presented in this report.

1.2 PROBLEM STATEMENT

Water, air, or other working fluids are used to remove heat in PVT systems. Solar energy, on the other hand, changes significantly during the day, making it impractical to use a PVT device to generate thermal energy. Indeed, solar radiation is lowest in the evening when demand for heat is greatest. In these instances, latent thermal energy storage technologies such as phase change material (PCM) can be employed to store and release solar energy absorbed by photovoltaic (PV) devices. Combining a PCM with a PVT system not only maximizes solar energy use, but also enhances the energy efficiency of the system. The primary disadvantage of today's PCMs is their low thermal conductivity. Recent years have seen an increase in research aimed at resolving the problem. Increasing thermal conductivity increases heat storage and extraction rates during the melting and solidification processes

(Kazemian, Salari, Hakkaki-Fard, & Ma , 2019). Apart from thermal conductivity, there are several additional characteristics that might impact the performance of a PVT system including PCM, including the thickness of PCM, types of PCM, and the influence of melting temperature. All these distinct factors provide findings that may be utilized to enhance the performance of the PVT system, but they must be thoroughly examined, simulated, and suggested before they can be implemented in the PVT system.

1.3 OBJECTIVE

The objectives of this project are as follows:

1. To study the simulation of Photovoltaic Thermal (PVT) system using phase change material (PCM) using computational fluid dynamics
2. To propose the best PCM for the proposed PVT/PCM system in Malaysia.
3. To compare the PVT system's electrical and thermal efficiency of the PVT system incorporated with PCM of different thickness.

1.4 SCOPE OF PROJECT

The scopes of this project are as follows:

1. Only water-based PVT/PCM system are presented and studied in this report. Although there are many types of working fluid in the PVT/PCM system, however, the working fluid that is used in this report is water.
2. The CFD simulation of the PCM in PVT system will only be simulated and validated based on past research paper.
3. The CFD simulation will be done using 3D transient flow.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will cover the literature review that will be used in this project. The literature will contain information relating to the PVT systems incorporating with and without PCM, the comparison of PCM between previous research studies, and the existing design of PCM and its simulation works.

2.2 OVERVIEW OF PVT/PCM SYSTEM

A photovoltaic thermal system (PVT) is a kind of solar energy system that generates both electrical and thermal energy. When a photovoltaic panel is exposed to solar radiation, the solar irradiation's effect is converted to different forms of energy. The solar panel converts a portion of the energy it absorbs to electricity, while the remainder is absorbed by the cooling fluid that travels through the solar panel. Figure 2.1 depicts a schematic representation of the PVT system. Photovoltaic panels, batteries, pumps, and heat exchangers comprise the PVT framework. When solar irradiation strikes a photovoltaic panel, only a small proportion (7–20 percent) of it is converted to electrical energy. The remaining irradiation is converted to heat energy, lowering the solar module's efficiency, and shortening the panel's life. Often, either air or water is used to cool the solar modules.

The cooling fluid absorbs heat from the solar module by flowing through the back side of the module. The battery generates electrical energy and stores it for later use.

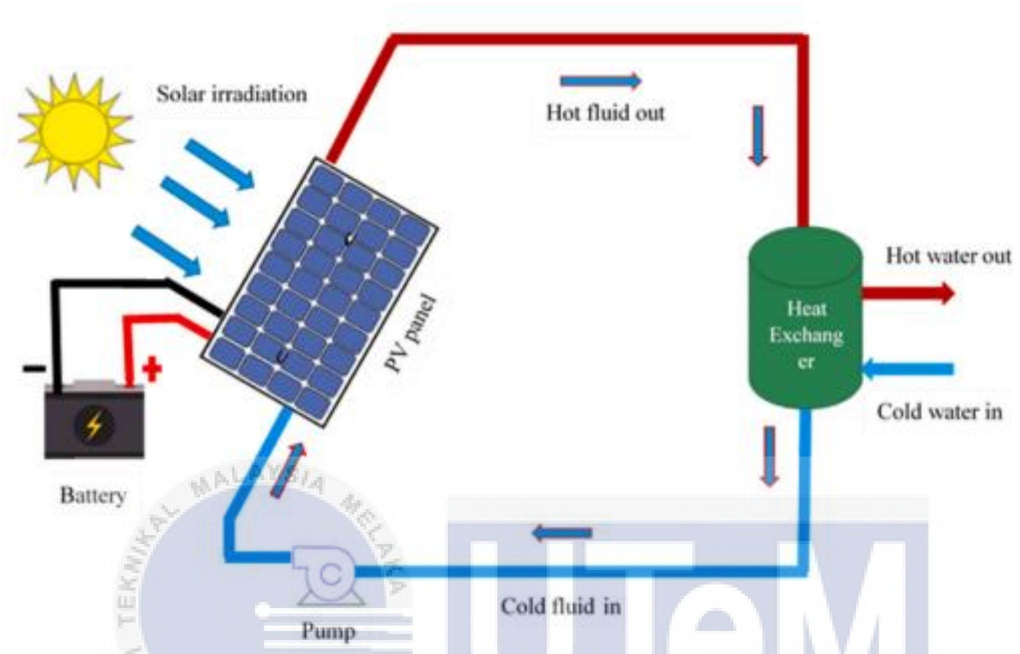

Figure 2.1 - schematic diagram of PVT system (Reji Kumar, Samykano, Pandey , Kadirgama, & Tyagi, 2020).

Solar thermal energy is capable of being stored in a variety of ways. Thermal energy storage is a method of using stored heat energy rather than dissipating it into the environment. Physical and chemical energy storage are both important means of storing energy. Each kind of thermal energy storage technology has a unique set of benefits and drawbacks. The heat transfer system conserves energy by using the physical approach of thermal energy storage, and the capacity of the material to store energy is determined by its thermophysical parameters. Energy is stored as internal energy in the form of latent and sensible heat in physical storage. Heat energy may be stored or released by raising or reducing the temperature of a medium during a sensible heating or cooling operation. Latent heat (LH) is the energy retained or released during the transformation of a material from solid to liquid to solid and vice versa. (Tyagi, Reji Kumar, Samykano, Pandey, Kadirgama, and Kadirgama, 2020).

Thermal energy storage (TES) and latent heat storage materials are examples of PCMs. When a substance transitions from solid to liquid at constant temperature, heat may be kept inside the material or released when the material changes phase from liquid to solid. Per unit volume, PCMs can store 5–14 times the amount of heat as sensible heat (Reji Kumar, Samykano, Pandey , Kadirgama, & Tyagi, 2020).

2.3 PHASE CHANGE MATERIAL

A phase change material (PCM) is introduced here as a latent heat storage medium. It is also referred to as a substance that stores latent heat. When heated, cooled, or phase transitioned, it has the ability to store and release thermal energy.

Latent heat storage materials initially function similarly to sensible heat storage materials, since they absorb heat in the solid state as the temperature increases. When materials reach their melting point, however, they absorb heat at a constant rate equal to their melting point. After completely converting to the liquid state, the materials retain their ability to absorb heat in the liquid form. Thus, latent heat storage is more effective at storing heat per unit volume than sensible heat storage.

PCMs are employed in a variety of areas and serve as a thermal energy storage medium. Numerous researches have established that PCM enhances the performance of a wide number of applications. In PVT/PCM system, (Huang, Eames, & Norton, 2004) discovered that a PCM with an appropriate phase change transition temperature might help keep the PV cells cool due to the PCM's ability to store solar energy for an extended period of time. Due to PCM's consistent heat storage capacity at constant temperature, it is advantageous to include a heat sink into the system for temperature management and performance improvement of PV/T (Waqas Adeel & Ji, 2017).

2.3.1 CLASSIFICATION OF PHASE CHANGE MATERIAL

There are various forms of PCM found across the globe, and they are normally classified according to the physical state of the material before to and during the phase transition process. PCMs are classified as solid-liquid, liquid-gas, or solid-gas.

Among the several types of PCMs, solid-liquid PCMs are the ones that are most commonly used in a wide array of technological applications. When compared to other types of PCMs, they benefit from a low volume change and a high latent heat capacity during the phase transition process. While phase transitions involving gases may yield enormous quantities of thermal energy, confining a large quantity of gas requires the use of a pressure vessel, which is costly and potentially dangerous. (Lin, Jia, Alva, & Fang, 2017).

Furthermore, there is another approach to classify PCMs based on their chemical composition. The categorization of phase change materials is depicted in the figure. They are classed as organic PCMs, inorganic PCMs, or eutectic PCMs.

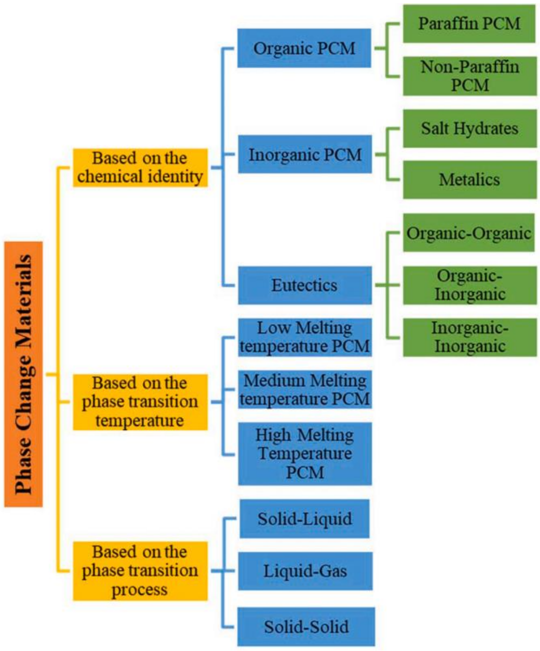

Figure 2.1- classification of PCMs (Reji Kumar, Samykano, Pandey , Kadirgama, & Tyagi, 2020).

Organic PCMs are further classed as paraffin and nonparaffin type, and they have the benefits of being nontoxic, noncorrosive, chemically stable, consistent melting, and have almost no supercooling. The disadvantage of organic PCMs are flammable and have a low thermal conductivity.

Moreover, when compared to organic PCMs, inorganic PCMs such as salt hydrates or metallics have the benefits of being less expensive, non-flammable, and having a high latent heat. However, there are a number of disadvantages, including a substantial volume change during the phase change process, limited temperature stability, and corrosive nature.

Eutectic PCMs, are PCMs that include two or more soluble compounds. They are often superior to organic and inorganic PCMs due to their high heat conductivity, lack of material separation during solidification, and simultaneous melting. However, eutectic PCMs is too expensive.

2.3.2 SELECTION CRITERIA FOR PHASE CHANGE MATERIAL

The selection of PCM for latent heat storage is mostly determined by the intended application, as each material has unique material characteristics. However, the most critical parameter to consider when selecting the appropriate PCM for latent heat storage is the material's thermal characteristics.

Firstly, it is necessary to know the phase change temperature of the substance. The operating temperature of the system for heating and cooling should match the phase change temperature of the PCM (Wang, et al., 2015).

Furthermore, the PCM's latent heat value and specific heat capacity should be high in both the liquid and solid forms to store more energy, since the PCM's purpose is to act as a thermal energy storage device and store heat energy. As more heat energy is conserved, thermal energy storage becomes more efficient.

Thermal conductivity of PCM is also a key consideration when selecting a material. Because thermal conductivity is crucial in charging and discharging process of thermal energy storage, a material with a high thermal conductivity is desired because it results in increased thermal energy storage performance.

Apart Apart from the thermal characteristics mentioned above, other factors such as physical, chemical, and kinetic qualities, as well as economic and market availability, should be addressed before choosing a material (Ibrahim, Al-Sulaiman, Rahman, Yilbas, & Sahin, 2017). The advantages of PCMs for latent heat storage are summarised in Table 2.1.