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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

A SIMULATION STUDY ON PHASE CHANGE MATERIAL (PCM) FOR PHOTOVOLTAIC THERMAL (PVT) APPLICATION

Siti Nur Dini Binti Noordin Saleem

Master of Mechanical Engineering
(Energy Engineering)

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SITI NUR DINI BINTI NOORDIN SALEEM

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

Faculty of Mechanical Engineering

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2022

DECLARATION

I declare that this thesis entitled " A Simulation Study on Phase Change Material (PCM) for Photovoltaic Thermal (PVT) Application " 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 : Siti Nur Dini Binti Noordin Saleem

Date : 28/3/2022

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	:	Prof. Madya Ir. Dr. Mohd Afzanizam Bin Mohd Rosli
Date	:	28/3/2022

DEDICATION

Dedicated to my beloved parents, Noordin Saleem bin Bashir Ali and Zarinah binti Abdul Latip

ABSTRACT

A comprehensive 3-dimensional model of photovoltaic thermal (PVT) system is executed to investigate the effects of PCM on the performance and efficiencies of the system. Phase Change Material (PCM) is integrated with the Solar Photovoltaic Thermal (PVT) acts as thermal storage to improve the performance of the system. Temperature rises have an undesirable effect on the reduction in the efficiency of a solar panel, resulting in a diminishment in the amount of energy produced by the solar PVT. Temperature is a significant factor to consider when evaluating the performance of the PVT system. Furthermore, Phase Change Material (PCM) is introduced in the Solar PVT model. Phase change materials contribute to the temperature adjustment function in several methods. The model is validated by comparison from published journals on the studies related to phase change material implemented in solar PVT. The validation is performed to determine the degree of accuracy of the model. Parametric analysis and temperature investigation are involved in improving the performance of the PVT-PCM system. The model of the PVT-PCM system is simulated transiently using Computational Fluid Dynamics Simulation (CFD) Ansys 16.2 Software. Fluid flow is considered to be in a laminar, fully developed, uniform, and incompressible flow regime. As a result, the proposed PVT-PCM produced surface and outlet temperature at 49.10˚C and 41.32˚C, respectively. The system was validated with a difference from 0.66% to 4.7%, denoting high accuracy. The thermal, electrical, and overall efficiency at an optimum mass flow rate of 10 kg/h obtained were 73.1%, 17.7%, and 90.8%, respectively. In addition, at optimum solar irradiance, the developed thermal, electrical, and overall efficiency were 73.082%, 17.741%, and 90.823%, respectively. This is due to the heat transfer process in PCM and the PVT system, which helps in the temperature reduction to optimize the performance of the PVT-PCM system. Overall, the research presented in this thesis has succeeded in making a contribution to understanding the optimum performance of PVT-PCM.

KAJIAN SIMULASI MENGENAI BAHAN PERUBAHAN FASA (PCM) UNTUK APLIKASI TERMA PHOTOVOLTAIK (PVT)

ABSTRAK

Model komprehensif 3-dimensi bagi sistem Solar Terma Fotovoltaik (PVT) dibangunkan untuk menilai kesan Bahan Perubahan Fasa (PCM) terhadap prestasi dan kecekapan sistem PVT-PCM. Bahan Perubahan Fasa (PCM) disepadukan dengan Solar Fotovoltaik Terma (PVT) bertindak sebagai storan haba untuk meningkatkan prestasi sistem. Kenaikan suhu mempunyai kesan yang tidak diingini ke atas pengurangan kecekapan panel solar mengakibatkan pengurangan dalam jumlah tenaga yang dihasilkan oleh solar PVT. Hal ini kerana suhu merupakan faktor penting untuk dipertimbangkan semasa menilai prestasi sistem PVT. Tambahan pula, Bahan Perubahan Fasa (PCM) akan diperkenalkan dalam model Solar PVT. Bahan Perubahan Fasa (PCM) dapat menyumbang kepada fungsi pelarasan suhu dalam beberapa kaedah. Model ini disahkan dengan perbandingan daripada jurnal yang diterbitkan mengenai kajian berkaitan Bahan Perubahan Fasa (PCM) yang dilaksanakan dalam solar PVT. Pengesahan dilakukan untuk menentukan tahap ketepatan model. Selanjutnya, analisis parametrik dan penyiasatan suhu terlibat untuk meningkatkan prestasi sistem PVT-PCM. Model sistem PVT-PCM disimulasikan secara berkadaran masa menggunakan perisian Ansys 16.2. Aliran bendalir yang digunakan berada dalam rejim aliran lamina, berkembang sepenuhnya, seragam dan tidak boleh mampat. Hasilnya, PVT-PCM yang dicadangkan menghasilkan suhu permukaan dan alur keluar masing-masing pada 49.10°C dan 41.32°C. Sistem ini disahkan dengan perbezaan dari 0.66% hingga 4.7% menandakan ketepatan yang tinggi. Kecekapan terma, elektrik dan keseluruhan pada kadar aliran jisim optimum 10kg/j yang diperolehi masing-masing ialah 73.1%, 17.7% dan 90.8%. Di samping itu pada sinaran suria yang optimum dalam kajian ini membangunkan kecekapan haba, elektrik dan keseluruhan masing-masing pada 73.08%, 17.74% dan 90.82%. Ini disebabkan oleh proses pemindahan haba dalam PCM dan sistem PVT yang membantu dalam pengurangan suhu untuk mengoptimumkan prestasi sistem PVT-PCM. Secara keseluruhannya, penyelidikan yang dibentangkan dalam kajian ini telah berjaya memberi sumbangan untuk memahami prestasi optimum PVT-PCM.

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LIST OF SYMBOLS AND ABBREVIATIONS

ρ	-	Density
T_{MP}	-	Melting Point
C	-	Specific Heat Capacity
λ	-	Thermal Conductivity
H	-	Enthalpy of Fusion
T	-	Temperature
T_{solid}	-	Solidus Temperature
T_{liquid}	-	Liquidus Temperature
$\vec{V}$	-	Fluid Velocity
P	-	Pressure
μ	-	Viscosity
β	-	Liquid Volume Fraction
t	-	Time
L	-	Latent Heat
m	-	Mass
E	-	Heat Absorption
τ_g	-	Transmissivity of Glass Cover
α_{cell}	-	Absorptivity of PV Cells
G	-	Area of Solar Panel
m_f	-	Mass Flow Rate
η_{th}	-	Thermal Efficiency
η_{el}	-	Electrical Efficiency
η_{ov}	-	Overall Efficiency

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

International energy demand is rising rapidly, leading opportunities to examine into the availability of alternative energy sources as a solution. Energy from non-renewable resources such as natural gas, fossil fuels, petroleum, coal, or nuclear sources is referred to as conventional energy. Renewable energy, on the other hand, is a type of energy that is derived from naturally renewing and never diminishing energy resources. By 2050, renewable energy is expected to account for roughly 66% of the world's energy consumption. The road plan predicts that renewable energy sources will account for 58% of electric power generation, 29% of heating, and 13% of transportation (Chandrasekar and Senthilkumar, 2021).Solar energy is accomplished using a range of devices that use a variety of light energy conversion techniques to convert solar energy into usable energy (Hu et al., 2021). Solar energy conversion systems are absolutely critical for solar energy's powerful commercialisation.

Numerous conversion processes are used to transform solar energy into usable energy such as photoelectric (solar photovoltaic system), photoelectric-thermal (solar photovoltaic thermal system), and photothermal (solar collectors such as flat plate, evacuated tube, line focus and point focus) (Shah and Ali, 2019). The performance of these systems is mostly determined by the properties of the working fluid and cooling medium used in energy conversion or conveyance (Ginley et al., 2008).

Photovoltaic Thermal (PVT) Systems integrate solar thermal and photovoltaic technology. This approach utilises both the light and heat energy stored in solar radiation to generate electricity and hot fluids. PVT system research is advancing at a rapid trend, with new methods and techniques being developed to enhance overall efficiency, lower costs, improve modelling, and maintain the system for extended periods of time, as well as deploying them for appropriate applications (Al-Waeli et al., 2017a).

In this research, a comprehensive 3-dimensional model of photovoltaic thermal system integrated with phase change material (PVT-PCM) is simulated. Phase Change Material (PCM) is chosen as the passive cooling medium to increase the performance of the solar PVT. Integrating the phase change materials with photovoltaic cells enhance the capacity of electrical conversion by storing heat in the form of latent heat. PCM selection based on thermophysical characteristics is a critical factor for optimising solar PVT performance.

The purpose of the present study is to determine the behaviour changes in outlet temperature and surface temperature of PVT-PCM on changes in mass flow rate and various solar irradiances. A transient simulation of the PVT system is performed in ANSYS Fluent 16.2 utilising a pressure-based finite volume approach and the SIMPLE algorithm for the pressure and velocity components. The model is validated by comparison from published journals on the studies related to phase change material implemented in solar PVT. The validation is performed to determine the degree of accuracy and reliability of the model. Additionally, simulation and validation study able to produce low cost improvement and reduce errors to produce satisfactory design.

1.2 Problem Statement

A significant aspect in the performance of solar PVT is temperature changes. When the PVT temperature rises, the output current climbs exponentially while the voltage output decreases linearly. As a consequence, this may significantly reduce solar panel power production. In addition, temperature rises have an undesirable effect on the efficiency of solar panels. When the efficiency of a solar panel decreases, the solar panel energy production reduces. Hence, temperature is an important aspect that needs to be analysed to monitor the performance of the PVT.

Furthermore, Phase Change Material (PCM) is introduced in the Solar PVT model. Phase change materials contribute to the temperature adjustment function in several methods. Additionally, the usage of phase change materials (PCM) for thermal energy storage is a very promising technology since it can collect and release a large amount of latent heat during the phase transition process (Mohd Rosli et al. (2014) and Lebedev and Amer, (2019)). However, there are an abundance of PCMs available in the market, different properties of PCM will provide different performance based on its usage. Therefore, this study investigates the temperature output of the system and performance of the selected PCM based on the tropical climate conditions.

1.3 Research Objectives

The objectives of this research are as follows:

i. To analyze the surface temperature of PVT-PCM on RT44HC.

ii. To analyze the outlet temperature of the PVT-PCM on RT44HC.

iii. To evaluate the performance of PVT integrated with PCM utilizing parametric analysis

1.4 Scope of Research

The primary emphasis of this study is simulation of 3-dimensional modelling on phase change material (PCM) integrated with solar photovoltaic thermal (PVT). Due to the fact that there are many types of PCMs available with varying thermophysical characteristics, only one type is chosen based on the melting point, enthalpy of fusion, thermal conductivity, and heat capacity of the PCM. In this study, the scopes of the research are defined as follows:

i. The PVT system is transiently simulated in ANSYS Fluent 16.2 using a pressure-based finite volume technique selected for pressure and velocity components.

ii. The selection range of PCM paraffin wax provided by Rubitherm GmbH, Germany was RT44HC.

1.5 Research Question

Validation verifies the accuracy of the model's representation of the real system. However, due to the limitations of data provided to simulate the PVT model, several combinations of data from various published journals are required to produce the output data that closely resembles the validation. Hence, certain issues are raised related to this research. For instance:

i. What is the range of temperature reduction on PV by implementing the PVT-PCM?

ii. What is the suitable PCM to operate under Malaysia Climate?

iii. What is the optimum configuration of temperature inlet and water mass flow rate for selected PVT PCM?

1.6 Thesis Outline

Based on the objectives previously presented and on the approach proposed before, this thesis is made up of five (5) chapters, which contents are summarized as follows:

- Chapter 1 - Introduction: This chapter presents the background of the study, research problems, objectives, scopes, contributions and significance of the research.
- Chapter 2 - Literature review: This chapter start with the current development of solar technologies and sustainability issues. A brief summary of the usage of PCM as thermal storage. Next, a brief overview of the efficiencies on solar photovoltaic thermal integrated with PCM. Other components in the PVT-PCM such as type of tube collector also were reviewed based on the efficiencies. Also, factors to be considered when choosing the best type of PCM under Malaysia climate conditions.

- Chapter 3 – Methodology: This chapter presents the methodology that has been developed for PVT-PCM based on the selected type of PCM. Validation and Grid Independence Test are crucial procedures in numerical studies.
- Chapter 4 – Results and Discussion: In this chapter, the developed models have been tested and verified through previous researchers to indicate reasonable accuracy and reliability of the simulations. Performance and temperature of the PVT-PCM also were studied. Additonally, parametric analysis of the PVT-PCM also included in this research.
- Chapter 5- Conclusion and Future Works: This chapter summarizes the main conclusions as well as achievements of the work undertaken in this research and suggests areas for future work.