AN ANALYSIS OF PHASE CHANGE MATERIAL (PCM) FOR SUBTERRANEAN COOLING OF THERMOELECTRIC ENERGY HARVESTING SYSTEM AT ASPHALT PAVEMENT

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DEDICATION

I dedicate this project to God Almighty Allah my creator, my strong pillar, my source of inspiration, wisdom, knowledge and understanding. He has been the source of my strength throughout this program. I also dedicate this work to my mom, my family, who has encouraged me all the way. Not to forget, my beloved partner whose encouragement has made sure that I give it all it takes to finish that which I have started. My supervisor, who has encouraged me attentively with her fullest and truest attention to accomplish my work for this Bachelor's degree.

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ABSTRACT

Thermoelectric generator (TEG) has offered a promising clean energy solution where it has persistently improved. In this project, a thermoelectric energy harvesting system (TEHs) that utilized the heat from the surface of asphalt pavement is studied. This thesis aimed to design a new TEHs with PCM as cold storage to retain subterranean cooling by simulation and experimentally. The design model consisted of asphalt base holder to hold the asphalt, top plate for heating, and bottom plate for cooling. The top plate is exposed on the asphalt surface to harvest heat from sunlight, and the bottom plate is submerged into the pavement. The bottom plate is then connected to the H-shape cooling element and a container filled with PCM with melting point of 30°C. Simulation and experiments were conducted to investigate the PCM's effects at TEG's output voltage. Furthermore, the best-selected model was used to study the charging capabilities of the TEHs on two 5F supercapacitors in series. From both simulations and experiments, it was discovered the new TEHs with PCM incorporation able to reach temperature difference (DT) 42°C with 1.5V open-circuit voltage. This gives an increment of over 170% more than a design without PCM incorporation. The 5F supercapacitors were successfully charged within 2 hours from 1.5V This project offers a new perspective for self-sustainable TEHs design that can be used for various purpose.

ABSTRAK

Penjana termoelektrik (TEG) telah menawarkan penyelesaian tenaga bersih yang sangat menjanjikan di mana ia telah bertambah baik secara berterusan. Dalam projek ini, sistem penuaian tenaga termoelektrik (TEHs) yang menggunakan haba dari permukaan turapan asfalt dikaji. Tesis ini bertujuan untuk merekabentuk sistem TEH baharu dengan PCM sebagai storan sejuk untuk mengekalkan penyejukan bawah tanah secara simulasi dan eksperimentasi. Model reka bentuk terdiri daripada pemegang asas asfalt untuk memegang asfalt, plat atas untuk pemanasan, dan plat bawah untuk penyejukan. Plat atas terdedah pada permukaan asfalt untuk menuai haba daripada cahaya matahari, dan plat bawah tenggelam ke dalam turapan. Plat bawah kemudiannya disambungkan kepada elemen penyejuk yang berbentuk H dan bekas yang diisi dengan PCM dengan takat lebur 30 darjah Celsius. Ini memberi kelebihan penyejukan bawah tanah kepada sistem dan mencapai perbezaan suhu tinggi antara plat atas dan bawah TEH. Simulasi dan eksperimentaso telah dijalankan untuk menyiasat kesan PCM terhadap voltan keluaran TEG. Tambahan pula, model pilihan terbaik digunakan untuk mengkaji keupayaan pengecasan TEH pada dua superkapasitor 5F secara bersiri. Daripada simulasi dan eksperimentasi, didapati TEH baharu dengan gabungan PCM mampu mencapai perbezaan suhu (DT) 42°C dengan voltan litar terbuka 1.5V. Ini memberikan peningkatan 170% lebih daripada reka bentuk tanpa penggabungan PCM. Kapasitor super 5F berjaya dicas dalam masa 2 jam dari 1.5V hingga 3.3V Projek ini menawarkan perspektif baharu untuk reka bentuk TEH lestari sendiri yang boleh digunakan untuk pelbagai tujuan.

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LIST OF SYMBOLS AND ABBREVIATIONS

MPPC	:	Maximum Power Point Collector
NIDAQ	:	National Instrument Data Acquisition
TEG	:	Thermo-electric Generator
TEHs	:	Thermo-electric Energy Harvesting system
VOC	:	Open Circuit Voltage

CHAPTER 1

INTRODUCTION

This chapter briefly explains the introduction of the project, problem statements on why the project is conducted. Other than that, this chapter also gives clarifications on the objectives and scopes of the project and along with its commercialization potential.

1.1 Introduction of the Project

Research and development of sustainable energy harvesting technology began in the early twenty-first century. Since then, various energy harvesting technologies have evolved, matured, and even been successfully turned into hardware prototypes for extending the operating lifetime of low-power electronic devices such as mobile phones, smart wireless sensor networks, and other low-power electronic devices. What exactly is energy harvesting? In 2020, H. Akinaga [1] wrote in his paper that tiny amounts of dissipating energy can be harvested and used as available electric energy from the environment around us. According to him, energy harvesting is a technology that gathers freely accessible renewable energy from the surrounding environment to replenish or put consumed energy back into energy storage devices without disturbing or even stopping the application's usual functioning. Progress in sustainable energy harvesting technologies research is still intact and continuous, thanks to the earlier knowledge and experience gained over a decade ago. These technologies are maturing, and strong synergies with certain application sectors are forming. It is an interesting method that has the potential to generate renewable and clean energy while also enhancing the sustainability of infrastructure. The evidence can be seen through the increasing development of photovoltaic panels, solar thermal, geothermal, and other similar solutions to harvest the ambient energy. This project deliberated on harvesting thermal energy.

Many cities, as well as states, are developing ambitious sustainable energy plans [2]. Various surveys have shown that we waste at least 70% of our primary energy, which dissipates as waste heat. H. Akinaga [1] surveyed that the temperature of the dispersing heat voted was mostly below 100 degrees Celsius. Additionally, Farahani and her team [3] made an analysis of meteorological parameters in Peninsula Malaysia. They stated that the climate features a tropical rainforest climate where it experiences a dry and hot season and a rainy season. The dry and hot season occurs when seasonal winds from southwest Sumatra, Indonesia, blow and move towards the west coast of Peninsular Malaysia, and are blocked by the Titiwangsa Mountain Range. The temperature can reach up to 40 ◦C but mostly varies from 23 ◦C to 32 ◦C. Aside from having hot and humid temperatures, Malaysia also seems to have a decent road length of the freeways. As of 2021, PLUS updated that the North-South Express (NSE) is the longest expressway in Malaysia with a total length of 748 kilometers running from Bukit Kayu Hitam in Kedah near the Malaysia-Thai border to Johor Bahru at the southern portion of Peninsular Malaysia. The highway connects numerous major cities and towns in western Peninsular Malaysia, serving as the peninsula's "backbone.". It provides a faster alternative to the old federal route, thus reducing traveling time between various towns and cities.

Given all of these advantages, Malaysia can highly make a profit by harvesting those thermal energies. How can it be harvested? Abundant methods for harvesting heat energy from asphalt pavement were reviewed multiple times and this project entertained the idea of using a Thermo-electric Energy Harvesting system (TEHs) which utilizes the function of a thermoelectric generator (TEG). It is one of the best ways on gaining traction as a method for providing an independent power supply for various IoT devices, which may gather and transform the minute energy of such heat into electrical power. A TEG module can brilliantly convert heat flux or temperature difference directly into electrical energy. This occurrence is called Seebeck effect. Alas, there are some flaws to this device.

1.2 Problem Statements

There are a few problems with the previous research on TEHs at asphalt pavement [4]. Firstly, the ambient temperature can easily give impact to the small-scaled TEG module. Environmental factors such as cloudiness, dryness, sunshine, wind, rain and even the asphalt itself can influence the heat conducted to the system. There are seemingly high possibilities that these factors can badly reduce the output voltage of the TEG when weather is not in the good term.

Second, the temperature on the cold side of the TEG can rises rapidly when the ambient temperature around the heat sink is heated by the solar and the convection between them decreases [5]. This problem brings TEG to the downside as it does not let the module working to its fullest. Since TEG mainly relies on the heat flux between the cold side and the hot side, it is crucial to maintain or improve the convection between the sides.

To add, a straight-up physical model construction would lead to high-cost consumption and the generalizability of much-published research on this issue is problematic. To avoid, this TEHs will be simulated using Finite Element Analysis (FEA). FEA is used to help simulate physical phenomena while allowing for the optimization of components as part of the design process of a project. In this project, COMSOL Multiphysics software will be used similarly in [4].

1.3 Objectives of the Project.

The objectives of this project are:

a) To design a new TEHs with PCM as cold storage to retain subterranean cooling by simulation and experimentally.

b) To analyze the latent heat effect of a PCM to increase output voltage of TEG.

c) To investigate the charging capabilities using new TEHs with PCM subterranean cooling.

1.4 Scopes of the Project

This project is divided into two sections. The first section mainly focuses on the simulation of the TEHs. This is where the model of the TEH is designed and simulated to predict the thermal response conditions before commencing it into an actual experiment. Moving on to the next stage, the experiment or field testing with the physical model. The data from both stages is compared for validations.

PSM I

a) Collects related articles on TEHs and PCM then analyzes the data.

b) Simulate design by using a cross-platform finite element analysis, solver, and multi-physics simulation software called COMSOL.

    i. To predict thermal response conditions before commencing into an actual experiment.

c) Obtain preliminary data and finding on PCM.

    i. A sufficient latent heat

ii. A suitable fusion temperature

iii. A sufficient volume

PSM II

a) Validation of the simulations.

b) Students will be exposed to the sun during the daylight experiment for data gathering.

c) Experimental work on testing the Phase Change Material (PCM).

1.5 Expected Outcome

I. COMSOL prototype model simulations.

II. A prototype of TEHs at asphalt pavement with PCM.

III. A better, cost-effective architectural design of TEHs that can generate high power using a subterranean cooling approach.

1.6 Applications & Commercialization Potential

Thermoelectric energy has a vast range of applications in various fields like; electricity generation, refrigeration, air conditioning, particular heating/cooling, biomedical devices, etc. due to its simple construction and mechanism, portability, require DC supply to run, etc. With this project, it can be implemented at the asphalt pavement along the freeway. The output power obtained can be used for multiple applications such as streetlights, traffic lights or even for charging small storage cells. Based on [5], the electricity cost can be saved up to RM592 per year if H-shaped TEHs are employed. The upgraded TEHs with PCM could save way more than the said number.

1.7 Project Significant

I. It can be implemented at the asphalt pavement along the freeway.

II. The output power obtained can be used for multiple applications such as streetlights or traffic lights.

III. It can be utilized to charge supercapacitor, a storage for electrical energy.

CHAPTER 2

LITERATURE REVIEW

This chapter expounds on the basic studies for this project which is an analysis of the energy harvesting systems at asphalt pavement. The chapter includes thermoelectric generator, phase change material, and finite element analysis.