SODIUM DODECYL-BENZENE SULFONATE ADDED PARAFFIN WAX WITH GRAPHENE NANOPLATELET FOR PHOTOVOLTAIC PANEL COOLING APPLICATION

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ABSTRACT

Photovoltaic (PV) panels are prone to overheating, ultimately decreasing PV efficiency. One of the solutions to prevent overheating of PV panels is by integrating nano-enhanced phase change material (NPCMs) at the back of the PV panel. Yet, it causes agglomeration, which degrades its thermophysical properties and becomes less effective in reducing the PV temperature. This leads to the addition of surfactants to NPCMs to reduce agglomeration. However, to date, no comparison studies reported how the addition of surfactant in NPCMs improves agglomeration and its thermophysical properties. Furthermore, the performance of this surfactant added NPCMs (SNPCMs) is still not fully explored when placed under field-testing conditions. Thus, this study aims to first evaluate the role of surfactants experimentally on reducing agglomeration and improving the thermophysical properties of NPCMs, followed by a comparison study and evaluation of the SNPCMs' temperature performance as a PV panel coolant under field testing conditions, and lastly, to evaluate the PV electrical performances when integrated with SNPCMs through simulation. The study was conducted in a few stages. The first stage of this study deals with the synthesis of NPCMs and SNPCMs at different nanoparticle weight percentages, followed by the addition of surfactants to the samples. Thermophysical properties, including charging/discharging rate, melting/solidifying temperature, latent heat, specific heat capacity, thermal conductivity, heat transfer rate, total heat stored, and morphological analysis were investigated for all the samples. The second stage of this study investigated the PV temperature reduction when samples were attached to the back of the PV panel. Solar irradiance, ambient temperature, and PV temperature for one sunny day were chosen for the analysis. Assessment of this material's potential electrical performance enhancement when applied to the PV panel was the focus of the final part of this study. Graphene nanoplatelet (GNP) with three different percentages (1wt%, 3wt%, and 5wt%) was used as nanoparticles of interest and added to paraffin wax (PW) to create NPCMs. Sodium dodecylbenzene sulfonate (SDBS) was used as a surfactant. The morphological study revealed that agglomeration and sedimentation were eliminated from the NPCMs when SDBS surfactant was added and led to the thermophysical improvement shown by sample PGS5 (PW/5wt% GNP with SDBS) which showed; (a) 56.3% improvement in charging and discharging rate, (b) 43.2% improvement in latent heat, (c) 69.5% improvement in specific heat capacity, (d) 73.45% enhancement of heat transfer rate, (e) can store the most heat with 64.13% improvement, and (f) relative enhancement by a factor of 25.94 in thermal conductivity. The on-site evaluation showed temperature reduction as high as 44.2% was recorded when sample PGS5 was applied to the back of the PV panel. With PV operating at a lower temperature, the simulation results show that PV produces higher output power with an increase of maximum output power by 16.92% and a 7.37% improvement in efficiency. These results revealed that SDBS surfactant plays a vital role in reducing the agglomeration by enhancing the adsorption forces between PW and GNP, leading to improved thermophysical properties of NPCMs, thus acting as superior material PV coolant, which can ensure a more reliable and efficient PV performance.

ABSTRAK

Panel fotovoltan (PV) mudah terdedah kepada masalah suhu operasi terlampau tinggi, yang akhirnya menyebabkan penurunan prestasi PV. Salah satu penyelesaian untuk mengelakkan pemanasan panel PV adalah dengan mengintegrasikan bahan berubah fasa dipertingkatkan nano (NPCMs) di bahagian belakang panel PV. Namun, ia menyebabkan penggumpalan, yang menyusutkan sifat termofizikalnya dan menjadikan ia kurang berkesan dalam mengurangkan suhu PV. Ini membawa kepada penambahan surfaktan ke dalam NPCMs untuk mengurangkan penggumpalan. Namun, setakat ini, tidak ada lagi kajian perbandingan yang melaporkan bagaimana penambahan surfaktan ke dalam NPCMs membantu mengurangkan penggumpalan dan meningkatkan sifat termofizikalnya. Tambahan pula, prestasi bahan berubah fasa dipertingkatkan nano yang ditambah surfaktan (SNPCMs) ini masih belum diterokai sepenuhnya ketika ia diletakkan di bawah ujian lapangan. Oleh itu, kajian ini bertujuan untuk menilai terlebih dahulu peranan surfaktan terhadap pengurangan penggumpalan dan peningkatan sifat termofizikal NPCMs, diikuti dengan kajian perbandingan dan penilaian prestasi SNPCMs sebagai penyejuk panel PV di bawah ujian lapangan, dan akhir sekali, untuk menilai prestasi elektrik PV apabila diintegrasikan dengan SNPCMs melalui simulasi. Kajian ini dilaksanakan dalam beberapa tahap. Tahap pertama kajian ini berkaitan dengan sintesis NPCMs dan SNPCMs pada peratusan berat nanozarah yang berbeza, diikuti dengan penambahan surfaktan pada sampel. Sifat termofizikal, termasuk kadar pengecasan/nyahcas, suhu lebur/pemejalan, haba pendam, muatan haba tentu, kekonduksian terma, kadar pemindahan haba, jumlah haba yang disimpan dan analisis morfologi diselidik untuk semua sampel. Tahap kedua kajian ini pula menyelidiki penurunan suhu PV apabila sampel diletakkan di bahagian belakang PV. Sinaran matahari, suhu persekitaran, dan suhu PV untuk satu hari yang cerah dipilih untuk analisis. Penilaian potensi peningkatan prestasi elektrik PV panel apabila bahan ini digunakan pada panel PV menjadi fokus bahagian akhir kajian ini. Nanoplatlet grafin (GNP) dengan tiga peratusan yang berbeza (1wt%, 3wt%, dan 5wt%) digunakan sebagai nanozarah dan ditambahkan ke lilin parafin (PW) untuk penyediaan NPCMs. Natrium dodesilbenzena sulfonat (SDBS) digunakan sebagai surfaktan. Kajian morfologi menunjukkan bahawa penggumpalan dan pemendapan berjaya dihilangkan apabila surfaktan ditambah, dan membawa kepada peningkatan yang ditunjukkan oleh sampel PGS5 (PW/5wt% GNP dengan SDBS) iaitu; (a) peningkatan 56.3% dalam kadar pengecasan dan nyahcas, (b) peningkatan 43.2% pada haba pendam, (c) peningkatan 69.5% dalam muatan haba tentu, (d) peningkatan kadar pemindahan haba sebanyak 73.45%, (e) dapat menyimpan jumlah haba dengan peningkatan 64.13%, dan (f) peningkatan relatif dengan faktor 25.94 dalam kekonduksian terma. Penilaian ujian lapangan menunjukkan penurunan suhu setinggi 44.2% dicatatkan ketika sampel PGS5 digunakan pada bahagian belakang panel PV. Dengan PV beroperasi pada suhu rendah, keputusan simulasi menunjukkan daya pengeluaran maksimum meningkat sebanyak 16.92% dan peningkatan kecekapan sebanyak 7.37%. Hasil ini menunjukkan bahawa surfaktan SDBS memainkan peranan penting dalam mengurangkan penggumpalan dengan meningkatkan daya penjerapan antara PW dan GNP, yang membawa kepada sifat termofizikal NPCMs yang lebih baik, sekali gus bertindak sebagai bahan penyejuk PV yang unggul, serta dapat memastikan prestasi PV yang lebih dipercayai dan cekap.

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LIST OF ABBREVIATIONS

RE	-	Renewable energy
PV	-	Photovoltaic
PCMs	-	Phase change materials
NPCMs	-	Nano-enhanced phase change materials
NP	-	Nanoparticles
TC	-	Thermal conductivity
GNP	-	Graphene nanoplatelet
GO	-	Graphene oxide
G	-	Graphene
TiO_2	-	Titanium oxide
Al_2O_3	-	Aluminum oxide
Fe_2O_3	-	Iron (III) oxide
SiO_2	-	Silicon dioxide
Cu	-	Copper
CNT	-	Carbon nanotube
SiC	-	Silicon carbide
ZnO	-	Zinc oxide
SNPCMs	-	Surfactant added nano-enhanced phase change materials
SDBS	-	Sodium dodecylbenzene sulfonate
SDS	-	Sodium dodecyl sulfate
CTAB	-	Cetyltrimethylammonium bromide
PVP	-	Polyvinylpyrrolidone
STPP	-	Sodium tripolyphosphate
TEA	-	Triethanolamine
OA	-	Oleic acid
SSL	-	Sodium stearoyl-2-lactylate
FESEM	-	Field Emission Scanning Electron Microscope
DSC	-	Differential Scanning Calorimetry
DSLR	-	Digital single-lens reflex camera
STC	-	Standard test condition

PR	-	Performance ratio
MATLAB	-	Matrix laboratory
N/A	-	Not available
TCE	-	Thermal conductivity enhancer
I-V	-	Voltage-current
P-V	-	Power-voltage

LIST OF SYMBOLS

wt%	-	Percentages of weight
κ	-	Thermal conductivity
C_p	-	Specific heat capacity
L	-	Latent heat
Q_w	-	Heat absorbed by water
Q_s	-	Heat absorbed by a sample
Q_{bar}	-	Heat absorbed by a stainless-steel bar
kg	-	Kilogram
K	-	Kelvin
J	-	Joule
kJ	-	Kilojoule
L	-	Length of sample
A	-	Area of sample
T	-	Temperature
ṁ	-	Mass flow rate
°C	-	Celcius
kV	-	Kilovolt
min^{-1}	-	Per-minute
$°C^{-1}$	-	Per Celcius
ΔT	-	Temperature difference
V_{oc}	-	Open circuit voltage
I_{sc}	-	Short circuit current
P_{max}	-	Maximum output power
I	-	Current
I_D	-	Diode current
G	-	Solar irradiance
G_{ref}	-	Solar irradiance at STC
I_o	-	Reverse saturation current
n	-	Ideality factor
k	-	Boltzmann's constant

V_g	-	Bandgap voltage
q	-	Electronic charge
P_r	-	Rated power
I_L	-	Photocurrent
α	-	Temperature coefficient of short circuit current
β	-	Temperature coefficient of open-circuit voltage
γ	-	Temperature coefficient of maximum power
FF	-	Fill factor
P_o	-	Output power
η	-	efficiency
s	-	Second
h	-	Hour
min	-	minute
W	-	Watt
V	-	Volt
cm	-	Centimeter
mm	-	Millimeter

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CHAPTER 1

INTRODUCTION

1.1 Problem Background

As of recent times, the combustion process of fossil fuel has been proven to cause an increase in greenhouse effects. Thus, the idea of moving towards renewable energy (RE) is rapidly cultivated. It is gaining worldwide attention due to its non-depleting nature and its positive impact on the natural environment. RE emits little to no greenhouse gases or pollutants into the air compared to fossil fuels. Thus, the interest in one of the largest RE sources, Photovoltaic (PV), has broadened among researchers due to its advantages. PV offers the most reliable, profuse, and pollution-free energy in the world [1, 2]. PV is a technology that can capture sunlight and convert it into electricity. Energy conversion efficiency has high as 23% has been achieved using PV technology [3].

However, in hot climate countries, the increment of PV panels temperature is the primary concern. A previous study showed that for every 1°C increment in operating temperature, the amount of PV electricity generated is reduced by as much as 0.4% [4]. Despite the effectiveness of methods such as water sprinklers [5], forced ventilation [6], and high ventilation [7] in cooling PV panels, these approaches require high capital outlays and are expensive to maintain in terms of water and electricity consumption. In addition, long-term exposure to humidity can lead to corrosion in systems that use water-based sprinklers, thereby shortening the life span of the panels.

Phase-change materials (PCMs) [8-16] offer a cheaper alternative as coolants for PV modules. In addition, PCMs also easily scalable, offering added advantage of covering big surface areas without occurring huge cost. Not to mention it is easier to maintain for a more extended period. Moreover, PCMs are abundantly available and cheap, and they can be easily obtained, ensuring economic viability and market penetration [17].

However, PCMs alone have several undesirable thermal characteristics. They are generally characterized by low specific heat capacities [18], low thermal conductivity [19], and low latent heat, which contradict the characteristics of good coolant material for PV modules. To improve the properties of existing PCMs, they are often combined with other materials such as microfin [17, 20-24], other types of PCMs [25], carbons [26, 27], and nanoparticles. A PCMs blended with nanoparticles is known as a nano-enhanced phase-change material (NPCMs). Examples of nanoparticles used in NPCMs include graphene oxide (GO) [28] , titanium oxide (TiO_2) [29-35], aluminum oxide (Al_2O_3) [8, 36-38] , iron oxide (Fe_2O_3) [39] , silicon dioxide (SiO_2) [37, 39] , cobalt oxide (CoO) [40], copper oxide (CuO) [41-45] and zinc oxide (ZnO) [39] [46]. Since the tiny nanoparticles have larger surface-area-to-volume ratios, they foster the interaction of nanoparticles with the PCMs, thus adjusting the PCM's thermal properties [47]. In addition, NPCMs have been proven to enhance panel performance by enhancing their thermophysical properties. However, despite these advantages, the use of NPCMs was reported to cause agglomeration, a phenomenon in which nanoparticles cluster and suspend together, thereby increasing the effective size of the nanoparticles. After several melting–solidification thermal cycles (increased hours of operation), this severe agglomeration will ultimately lead to reliability issues in NPCMs. Therefore, it is important to avoid agglomeration as it can degrade the thermophysical properties of NPCMs, making them less effective in reducing PV module temperature.

To mitigate the agglomeration problem, surfactants can be added to the NPCMs matrix [48, 49], producing so-called surfactant added NPCMs (SNPCMs). As a result, the surface tension between the nanoparticles and the PCMs is reduced, making the PCMs and nanoparticles disperse better, reducing the agglomeration and, in turn, improving their thermophysical properties.

Paraffin wax (PW) was employed as base PCMs material due to its low cost and characteristics such as (a)non-corrosive and non-toxic nature, (b) lack of sub-cooling, and (c) and high heat capacity and latent heat. In addition, PW can store and release large amounts of latent heat energy while transitioning from a solid to a liquid and remains constant throughout a phase change [50]. Graphene nanoplatelet (GNP) has been utilized as a nanoparticle because it has an excellent thermal conductivity [51] and is a cationic nanoparticle [52]. In addition, they are non-reactive with PW, which prevents hazardous substances during the material development phase resistance. Sodium dodecyl-benzene sulfonate (SDBS) was used as a surfactant due to its low cost, ease to purchase, and anionic properties [52]. SDBS is an anionic surfactant, while GNP is a cationic nanoparticle, which leads to more stable dispersion when an oppositely charged surfactant and nanoparticles are used [52].

1.2 Problem Statement

Overheating of the PV panel is a common phenomenon that could affect the PV system's efficiency. Increasing temperature increases the charge carrier concentration, increasing the saturation current due to a reduced bandgap, causing the open-circuit voltage to drop [53]. This occurs due to increased recombination rates, thereby reducing the PV's overall power output. As a result, heat can severely reduce the PV panel's power production. Therefore, as time passes, many researchers try to investigate a method for cooling the PV panel and maintaining the temperature close to their nominal operating value besides being economically viable. This is to ensure that there will be minimum power loss with the increasing temperature on the PV panel, and where it can stand hot climate for a more extended period, thus would help to reduce the cost of maintenance.

PCMs currently one of the most reliable techniques to cool and regulate PV panels' temperature and improve electrical efficiency. Integrating PCMs into the back of the PV panel may regulate the PV panel's thermal behaviors and performance [54]. PCMs play a significant role in improving the heat transfer, thus reducing the temperature variation resulting in a more efficient PV system. Nevertheless, due to

PCM's poor thermal conductivity, nanoparticles are often added to the PCMs, to create NPCMs with improved conductivity. Many researchers used nanoparticles into PCMs in the even or odd sequences of the number. The use of 1 wt%, 3 wt%, and 5 wt% in previous and current studies was the common amount that has been frequently used. Besides, a study by Sharma et al. [29] also shows that 5wt% is the optimum percentage of nanoparticle weight in improving the PCM's properties even with agglomeration.

However, agglomeration of NPCMs worsened over time, which led to the addition of surfactants to the NPCMs [48, 49], producing surfactant added NPCMs (SNPCMs). Nevertheless, studies show that the optimum thermal conductivity, uniform dispersion, and less agglomeration were achieved using the surfactant-to-nanoparticle ratio of 1:1 [29, 55]. Despite the various studies reported on using SNPCMs with several different characterizations, an absence of comparison studies reported on how SDBS surfactant in a paraffin wax/graphene nanoplatelet NPCMs matrix plays a role in eliminating agglomeration and improving its thermophysical properties. Moreover, no studies have assessed its performance in enhancing the temperature-reduction characteristics of PV panels under field-testing conditions. In addition, no studies on the predicted/expected improvement of the PV electrical performance when applied with SNPCM using simulation. Therefore, it is essential to analyze the role of surfactants in enhancing the thermophysical properties of the NPCMs to ensure the best formula in cooling PV panels, which can offer not only significant advantages of the simpler method without the need for any controlled environment but also economically viable approach for long term reliability of PV modules. Furthermore, it is also important to do a simulation to prove the effectiveness of regulating the PV temperature on its electrical performance without the hassle of testing it, which could involve high cost. Besides, all PV components, parameters, and interactions are considered through simulation, thus making it as accurate as experimental testing. Consequently, the implementation of the materials in the PV panel in this work thus can be regarded as a novel attempt that can contribute to enhancing knowledge mainly in the area of photovoltaic panels coolant application.

1.3 Research Objectives

This study aims to investigate the enhancement of PV performance through the integration of the surfactant added nano-enhanced phase change materials (SNPCMs). To achieve this aim, the following objectives were identified:

(a) To synthesis different ratios of paraffin wax/graphene nanoplatelet NPCMs with and without SDBS, investigate and compare the thermophysical (charging and discharging rate, latent heat, specific heat capacity, heat transfer rate, thermal conductivity, and total heat stored) and the morphological effect of SDBS surfactant on the NPCMs.

(b) To analyze the temperature reduction of PV panels under field-testing conditions (at the same location, irradiance, ambient temperature, and wind speed) by using the prepared paraffin wax/graphene nanoplatelet with SDBS SNPCMs.

(c) To evaluate the PV electrical performances (short circuit current, open-circuit voltage, output power, performance ratio, and efficiency) by inputting parameters from the field-testing experiment such as solar irradiance, ambient temperature, and PV surface temperature when integrated with paraffin wax/graphene nanoplatelet with SDBS SNPCMs through simulation.

1.4 Scope of Research

This research was conducted with the following scope:

(a) The fabricated PV coolant that focused on nano-enhanced phase change materials are; paraffin wax (PW), which was used as the base material with the addition of 1wt%, 3wt%, and 5wt% of nanoparticles which are graphene nanoplatelets (GNP)

(b) The surfactant was added to nano-enhanced phase change material using the two-steps method, and sodium dodecylbenzene sulfonate (SDBS) was used as a surfactant. The addition of SDBS was varied to study the effect of SDBS on the thermophysical properties of the NPCMs sample. The morphological analysis of NPCMs with SDBS (SNPCMs) and NPCMs without SDBS was conducted using FESEM.

(c) Laboratory investigations were carried out on NPCMs and SNPCMs to study their thermophysical properties, charging and discharging rate, latent heat, specific heat capacity, heat transfer rate, thermal conductivity, and total heat stored.

(d) A stopwatch was used to observe charging and discharging rate, differential scanning calorimeter (DSC) was used to measure melting and solidification temperature, latent heat and specific heat capacity, the thermal camera was used to measure heat transfer rate, thermal conductivity apparatus was used to measure thermal conductivity, and lastly, total heat stored was calculated from the data obtained.

(e) The prepared SNPCMs were integrated into the back of the PV panel. The PV panel were left under the same field-testing conditions (solar irradiance, ambient temperature, wind speed, and location) for one week to study the PV temperature reduction compared to conventional PV.

(f) The Sunwaysolar SW10P-36, a typical 10W PV panel, used for the experiment, was chosen to simulate the electrical performance of the PV panel, open-circuit voltage, and output power.

The following were limitations of this study:

(a) In this study, the chosen nanoparticles' weight percentages were 1 wt%, 3wt%, and 5wt%. These weight percentages were the common amounts frequently used in previous research, which also agreed with the previous work done by researchers in references [56] [29].

(b) This work only focuses on the effect of one type of surfactant, SDBS, and using a fixed amount. It does not consider other surfactants due to its easy availability and low cost compared to other surfactants.

(c) The electrical performance of the PV panel, open-circuit voltage, and output power were simulated instead of field-testing due to difficulties in getting the device to measure all these parameters at the exact location, time, and conditions, which are costly and time-consuming.

1.5 Significance of Study

The contributions of this study are listed below:

(a) An SDBS surfactant was used to reduce the formation of agglomeration. Hence the uniform GNP distribution inside the PW was achieved. Furthermore, SDBS had shown promising results when the compatibility between GNP and its PW matrices was improved, thereby enhancing the thermophysical properties of the nano-enhanced phase change material. The effect of SDBS on charging and discharging rate, melting and solidification temperature, latent heat, specific heat capacity, thermal conductivity, heat transfer rate, and total heat stored have been carried out for the first time accordingly.

(b) The addition of SDBS into the NPCMs has improved the thermophysical properties of the material. In particular, the charging and discharging rate, latent heat, specific heat capacity, heat transfer rate, thermal conductivity, and total heat stored have been improved. Hence, the addition of SDBS into NPCMs was successfully done to identify the best formulation that enhanced the material's thermophysical properties as a PV panel coolant.

(c) The newly prepared SNPCMs integrated behind the PV panel have reduced the PV panel temperature. Hence, it proved the effectiveness of SNPCMs as a PV coolant.

(d) A simulation on the PV electrical performance, open-circuit voltage, and output power show that the PV panel integrated with SNPCMs has better performance than PV without SNPCMs. Hence, it was successfully proven that SNPCMs also improve the PV panel's performance, leading to a more efficient PV panel.

(e) This study has used SDBS to reduce the agglomeration between GNP and PW. It is remarkably found that the PW/5wt% GNP with SDBS exhibits the most excellent thermophysical properties and reduced the PV temperature as high as 31.6 °C. Furthermore, the simulation shows that PV with SNPCMs has the highest open-circuit voltage and output power with 13.27% and 16.92% improvement, respectively.

1.6 Thesis Outline

The thesis is organized as follows:

Chapter 2 presents a comprehensive review of PV panels, other cooling techniques of PV panels, concepts of phase change material, and nano-enhanced phase change material. The concept of adding surfactants into nano-enhanced phase change materials and their advantages is described here. Previous studies on surfactant added nano-enhanced phase change material for different applications, PV panels integrated with phase change material, and nano-enhanced phase change material was also presented and reviewed.

Chapter 3 presents the research methodology that explains the experimental setup and procedures employed in this study. It includes a description of the materials used and a detailed procedure of synthesizing surfactant added nano-enhanced phase change material. The experimental setup used for measuring charging and discharging rate, differential scanning calorimeter, thermal conductivity, heat transfer rate measurement, calculation of total heat stored, and morphology have also been described. The modification of the PV panel by integrating SNPCMs and the experimental setup to study the PV temperature reduction has also been described. Finally, a detailed description of the simulation of PV electrical performance was explained thoroughly.

Chapter 4 describes the main results and analysis of data collected in this study; The effect of surfactants on the NPCMs. In addition, the morphological and structural analysis explained thermophysical properties such as; charging and discharging rate, latent heat, specific heat capacity, heat transfer rate, thermal conductivity, and total heat stored. Chapter 4 also describes the analysis of PV temperature performance that was field-tested. Finally, the simulation study of PV electrical performance, including open-circuit voltage and output power using MATLAB, was explained.

Chapter 5 concludes the study's findings, and some recommendations are also included for future work.

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APPENDIX F

LIST OF PUBLICATIONS

1. **N. H. Muhd Zaimi**, A. Nawabjan, S. F. A. Rahman, S. M. Hussin, 2019, "*Effect of Graphene Oxide Nanoparticles on Thermal Properties of Paraffin Wax*," InECCE2019, Lecture Notes in Electrical Engineering (LNEE), volume 632, pages 767-781, Springer, (Scopus Indexed)

2. **N. H. Muhd Zaimi**, A. Nawabjan, S. F. Abdul Rahman, S. M. Hussin, H. Abdul Rahman, 2021, "*Evaluating performance enhancement of surfactant-added nano-enhanced phase change material (SNPCM) on PV module,"* InECCE2021, already accepted and will be published in LNEE Springer, (Scopus Indexed)

3. **N. H. Muhd Zaimi**, A. Nawabjan, S. F. Abdul Rahman, S. M. Hussin, 2021**,** *"Evaluating the role of sodium dodecylbenzene sulfonate as surfactant towards enhancing thermophysical properties of Paraffin/Graphene nanoplatelet phase change material: synthesis and characterization in PV cooling perspective,"* already accepted and will be published in International Journal of Thermophysics (IJT), Springer, (ISI indexed, Q3)

4. **N. H. Muhd Zaimi**, U. I. Zahin, M. F. Ismail, A. Nawabjan, 2021, "Chapter 1: Numerical Modelling and Improvement of Open Circuit Voltage in Silicon Solar Cell P using PC-1D," submitted to Micro-Nano Systems Engineering, Volume 6, (Book Chapter)

5. **N. H. Muhd Zaimi**, M. F. Ismail, M. A. Aizat, A. Nawabjan, 2021, "Chapter 2: Improving Short Circuit Current in Silicon Solar Cell using Fast and Easy 1D simulation," submitted to Micro-Nano Systems Engineering, Volume 6, (Book Chapter)