# HIGH-PERFORMANCE MWCNT/GRAPHENE NANO-ENHANCE PHASE CHANGE MATERIALS FOR EFFICIENT THERMAL ENERGY STORAGE

MOHD ARIF FIKRI BIN ROSLI

DOCTOR OF PHILOSOPHY

UNIVERSITI MALAYSIA PAHANG
AL-SULTAN ABDULLAH

## SUPERVISOR'S DECLARATION

We hereby declare that We have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy.

_______________________________

(Supervisor's Signature)

Full Name : Ir. Ts. Dr. Mahendran Samykano

Position : Associate Professor

Date : 6/10/2023

_______________________________

(Co-supervisor's Signature)

Full Name : Prof. Dr. Adarsh Kumar Pandey

Position : Professor

Date : 6/10/2023

**STUDENT'S DECLARATION**

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang Al-Sultan Abdullah or any other institutions.

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(Student's Signature)

Full Name : Mohd Arif Fikri Bin Rosli

ID Number : PSM19002

Date : 5/10/2023

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MOHD ARIF FIKRI BIN ROSLI

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# ABSTRAK

Penyimpanan tenaga terma (TES) menggunakan Bahan Pengubah Fasa (PCM) mendapat banyak minat di dalam kalangan saintis di seluruh dunia sejak kebelakangan ini kerana potensinya untuk menjadi penyimpanan tenaga yang cekap. Walau bagaimanapun, PCM, secara amnya mempunyai kekonduksian terma yang rendah, yang mengehadkan kadar penyimpanan tenaga sistem storan. Penambahan nanopartikel boleh meningkatkan ciri termofizik mereka yang akan meningkatkan kekonduksian terma PCM. PCM yang dipertingkatkan dengan nano (NePCM) menunjukkan bahan terbaik yang sesuai dengan kebanyakan ciri seperti disimpan dan dilepaskan pada kadar yang lebih pantas semasa proses peralihan fasa tanpa sebarang bantuan daripada sumber lain. Kelemahan utama untuk kaedah ini ialah pemendapan dan penggumpalan yang berlaku apabila komposit berada dalam keadaan cecair. Akibatnya, pengubahsuaian permukaan nanopartikel berasaskan karbon mungkin berfaedah dalam memerangi pemendapan dan penggumpalan dalam PCM untuk aplikasi TES yang berkesan. Jadi, objektif utama tesis adalah untuk merumus, menfungsikan dan mencirikan NePCM berasaskan karbon untuk penyimpanan tenaga haba yang cekap. Objektif ini boleh dicapai dengan merumuskan pengubahsuaian permukaan di CBNP dengan pelbagai kaedah termasuk pendekatan kovalen dan bukan kovalen, menghasilkan dua kaedah menggunakan surfaktan dan kaedah kefungsian. Kemudian bahan-bahan ini akan menjalani beberapa kitaran haba yang mengecas dan menyahcasnya dengan tenaga haba untuk mensimulasikan kitaran lebur dan penyejukan dalam masa nyata. Kajian ini meneroka kesan peratusan berat Multiwalled Carbon Nanotubes (MWCNT) (0–1.0 berat%) dan nanoplatelet Graphene (GNP) dengan 2 pengubahsuaian permukaan iaitu penambahan surfaktan (Sodium Docecylbenzene Sulfonate (SDBS)) dan kefungsian (kumpulan Karboksil: -COOH) pada kekonduksian terma, suhu lebur, haba pendam lebur dan kestabilan terma lilin paraffin (PW) PLUSICE A70. PLUSICE A70 akan dicairkan dan CBNP (MWCNT & GNP) akan disonikasi berasama dengan campuran tersebut. Selain itu, langkah itu diulangi dengan kehadiran surfaktan dan kefungsian di dalam NePCM. Didapati kekonduksian terma maksimum ialah 0.498 W/m.K (109.452%) yang dipamerkan oleh A70/1.0wt% MWCNT dan bagi KNK, AG-1.0 menunjukkan 0.354 W/m.K iaitu 48.83% berbanding A70 tulen. Dengan menambahkan SDBS sebagai surfaktan, ASMW-1.0 menghasilkan 0.536 W/m.K, 125.078% lebih tinggi daripada A70 tulen dan ASG-1.0 menunjukkan 0.529 W/m.K (122.26%). Pasangkan kumpulan karboksil pada permukaan nanozarah berasaskan Karbon yang menjadikan nanokomposit AFMW-1.0 menghasilkan peningkatan kekonduksian terma tertinggi, 0.597 W/m.K (150.748%) dan untuk nanoplatelet Graphene, AFG-1.0 menunjukkan 0.573 W/m.8% (140.8%). Keputusan Pengimbasan Kalorimetri Berbeza (DSC) mendedahkan bahawa pengurangan haba pendam minimum sebanyak -1.74% untuk 1.0 wt% FMWCNT/A70 (AFMW-1.0) dan untuk penurunan maksimum, -6.86% untuk 1.0 wt% SGNP/A70 (ASG-1.0) masing-masing. Kemampuan penyaliran cahaya ASMW-1.0 berkurangan kepada 98.47% lebih daripada PCM PW tulen. Selain itu, tiada perubahan yang memberi impak besar dalam ketumpatan termofizikal dan kestabilan kimia selepas menjalani kitaran terma. Nanokomposit terbaik ini akan membawa kepada merapatkan jurang semasa dalam penyelidikan dan mengesyorkan untuk kerja masa depan pembangunan PCM dan NePCM baharu yang disepadukan dalam sistem storan tenaga terma untuk meningkatkan prestasi, jangka hayat yang lebih lama, sekali gus menambah faedah alam sekitar yang direalisasikan secara beransur-ansur penambahbaikan.

# ABSTRACT

Thermal Energy Storage (TES) using Phase Change Materials (PCMs) has garnered substantial interest among scientists around the globe due to their potential as an efficient energy storage medium. PCM offers a solution with good phase-change characteristics, small temperature variation during charging or discharging cycles, and higher energy storage densities. However, PCMs suffer from low thermal conductivity. The addition of nanoparticles has been proven to enhance the thermophysical characteristics of base materials and this formulation is known as Nano-enhanced Phase Change Material (NePCM). NePCM exhibits quicker storing and releasing rate during the phase transition process. Even though the behaviour of the PCMs improved by adding nanoparticles, they also resulted in several drawbacks. The major drawbacks are sedimentation and agglomeration when the composite transforms into a liquid state. Incorporating Carbon-based nanoparticles (CBNP) into PCM for TES systems is an underexplored option. Furthermore, sedimentation and agglomeration of CBNP in PCMs are critical problems that must be overcome before their effective use as passive thermal energy storage media in industrial or everyday applications. Therefore, surface modification of the CBNP might be beneficial in reducing sedimentation and agglomeration in PCMs for effective TES applications. As such, the main objective of the present work is to formulate, functionalize, and characterize the Carbon-based NePCM for efficient thermal energy storage. These objectives are achieved by surface modification of CBNP using surfactants and functionalization methods (covalent and non-covalent approaches). The formulated materials later undergo various characterizations to investigate various properties and their performances. The present study explores the effect of multi-walled carbon nanotube (MWCNT) weight percentage (0–1.0 wt%) and Graphene nanoplatelets (GNP) with 2 surface modifications which are surfactants addition (Sodium Docecylbenzene Sulfonate (SDBS)) and functionalization (Carboxyl group: -COOH) on the thermal conductivity, melting temperature, melting latent heat and thermal stability of Paraffin Wax (PW) PLUSICE A70. The PLUSICE A70 will be melted and CBNP (MWCNT & GNP) will be sonicated inside the mixture. Beside that, the step are being repeated with the presence of surfactant and functionalization inside the NePCMs. It is found that the maximum thermal conductivity is 0.498 W/m.K (109.452%) exhibited by A70/1.0wt% MWCNT, and for GNP, AG-1.0 showed 0.354 W/m.K, which is 48.83% compared to pure A70. By adding SDBS as a surfactant, ASMW-1.0 produced 0.536 W/m.K, 125.078% higher than pristine A70, and ASG-1.0 indicated 0.529 W/m.K (122.26%). Attaching the Carboxyl group at the surface of CBNP, makes the nanocomposite of AFMW-1.0 produce the highest thermal conductivity enhancement, 0.597 W/m.K (150.748%), and for GNP, AFG-1.0 showed 0.573 W/m.K (140.88%). The Differential Scanning Calorimetry (DSC) results revealed that the minimum decrement latent heat by -1.74% for 1.0 wt% FMWCNT/A70 (AFMW-1.0) and for maximum decrement, -6.86% for 1.0 wt% SGNP/A70 (ASG-1.0) respectively. Light transmittance of ASMW-1.0 reduced to 98.47% more than pure PW PCM. Furthermore, there is no sufficient change in the thermophysical and chemical stability of all materials after undergoing thermal cycles. The best nanocomposites will lead to bridging the current gaps in the research and recommend future work on developing new PCMs and NePCMs integrated in TES systems to improve performance, and longer life, thus adding to the environmental benefits of realized gradual improvement.

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