THERMOPHYSICAL AND THERMAL CYCLIC BEHAVIOR OF NANO-ENHANCED MOLTEN SALTS FOR CONCENTRATED SOLAR POWER

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DOCTOR OF PHILOSOPHY

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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.

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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 or any other institutions.

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Thesis submitted in fulfillment of the requirements
for the award of the degree of
Doctor of Philosophy

Faculty of Mechanical and Automotive Engineering Technology

UNIVERSITI MALAYSIA PAHANG

FEBRUARY 2023

ACKNOWLEDGEMENTS

Thank you, Allah, for assisting me and providing me with the strength I needed to finish my Ph.D. study. I am grateful.

My sincere appreciation to my main supervisor Assoc. Prof. Ir. Ts. Dr. Mahendran Samykano and my co-supervisor Prof. Ir. Ts. Dr. Kumaran Kadirgama for their support and guidance throughout my study; their expertise and gaudiness pushed me to elevate my work to a higher level and complete it. I am grateful to them both.

I would like to thank Prof. Saidur Rahman and Prof. Adarsh Pandey from Sunway University for providing research facilities and lab. I am incredibly grateful to them for their assistance.

Before I say anything else, I would like to express my appreciation and gratitude to three people: my father, Ahmad Aljaerani (may Allah forgive him), my mother, Manoba Alsobi, and my wife, Alsagheerah Almahdi, for their patience, support, and assistance throughout my Ph.D. studies. Please accept my heartfelt gratitude on behalf of my brother, sisters, relatives, and friends, who have been and continue to be there for me.

Finally, I would not have been able to complete this dissertation without the assistance of the Libyan government, which supported me financially throughout my Ph.D. studies.

ABSTRAK

Terdapat kajian yang jelas menunjukkan kecekapan tenaga suria dapat ditingkatkan secara maksima melalui kuasa suria tertumpu dengan menggunakan garam cair. Ini lebih terbukti apabila kecekapan sistem janakuasa kuasa suria tertumpu dapat ditingkatkan dengan mengunakan minyak haba sebagai bendalir aliran haba dan sebagai penyimpanan tenaga haba. Walaubagaimanapun, garam cair ini mempunyai sifat-sifat penyimpanan tenaga haba yang terhad. Sifat-sifat fizikal haba ini boleh ditambah baik dengan menambahkan sedikit partikel nano kedalam garam asas. Tujuan kajian ini adalah untuk mengkaji penggunaan pelbagai partikel nano dan mengkaji kesan-kesan kepelbagaian partikel nano terhadap sifat-sifat fizikal haba keatas sampel-sampel garam cair. Ia juga adalah keperluan untuk mengkaji kestabilan kitaran haba secara jangka panjang dan juga kesan-kesan sifat fizikal haba garam cair dengan penambahan nano yang telah ditambah baik terhadap harga elektrik dan kecekapan terhadap kuasa suria tertumpu. Garam cair dengan penambahbaikan nano telah dihasilkan dengan menggunakan partikel nano CuO, TiO_2, dan h-BN secara berasingan dengan kepekatan yang berbeza (0.1, 0.5, and 1.0 wt.%). Seterusnya, keserasian dan sifat struktur nano garam cair dengan penambahbaikan nano ini dikaji. Sifat-sifat fizikal haba dan kitaran haba sampel-sampel garam cair dengan penambahbaikan nano ini dikaji untuk memperoleh sample yang paling optimum. Selain itu, kesan-kesan penambah baikan sifat-sifat fizikal haba terhadap kecekapan tenaga dan kos-kos elektrik juga turut dikaji. Kaedah persiapan basah telah digunakan untuk menformulasi sampel-sampel HITEC dan garam cair dengan penambah baikan nano. Keserasian HITEC bersama partikel nano telah dikaji dengan menggunakan spektroskopi FTIR. DSC telah digunakan untuk menganalisis muatan haba tentu, titik cair dan haba terpendam sampel-sampel HITEC dan garam cair dengan penambaikan nano. Kestabilan haba telah diukur dengan TGA manakala pengkajian ciri-ciri fizikal telah dikaji menggunakan FESEM dan EDX. Kestabilan kitaran haba untuk sampel yang paling optimum dalam kajian ini telah dikaji selepas 100 kitaran. Kaedah simulasi juga digunakan untuk memeriksa kesan-kesan applikasi sampel yang paling optimum terhadap kecekapan kuasa suria tertumpu dan kos-kos penghasilan elektrik dan hasil kajian ini telah dibandingkan dengan HTF dan TES garam suria yang digunakan kini. Keputusan mendapati 1wt.% partikel nano adalah kepekatan yang paling optimum dimana berjaya mencatatkan sifat fizikal haba yang terbaik. Muatan haba tentu telah ditambah baik sebanyak 5.6%, 27%, dan 5.5%, haba terpendam sebanyak 30%, 72%, dan 78% dan kestabilan haba sebanyak 9%, 7%, dan 5% untuk HITEC dengan 0.1 wt.% CuO, 0.1 wt% h-BN dan 0.1 wt.% TiO_2 partikel nano. Analisis morfologi mendedahkan partikel nano mempunyai penyebaran yang baik kedalam HITEC dengan penghasilan struktur nano membentuk seolah-olah rantai, berlaku kerana penbaran partikel nano. Analisis FTIR menunjukkan kestabilan campuran bendalir nano tanpa sebarang reaksi kimia diantara HITEC dan partikel nano. Kestabilan kitaran haba menujukkan komposit nano mempunyai kestabilan yang baik. Kajian terhadap kecekapan kuasa suria menunjukkan dengan penggunaan sampel yang paling optimum dapat menambah baik kecekapan sebanyak 1.4% dan dapat menjimatkan kos kuasa sebanyak 0.13 ¢/kWh. Hasil kajian ini dapat mengurangkan jurang pencarian terhadap garam yang optimum untuk system kuasa suria tertumpu dimana dapat mengurangkan harga elektrik dan meningkatkan kebergantungan kepada tenaga suria sebagai sumber tenaga elektrik yang bersih. Kajian ini telah menyumbang kepada 10-10 MYSTIE (No.1 Tenaga, dan No.10 Persekitaran dan Biodiversiti) dan 17 SDGs (No.7 Kemampuan dan Tenaga Bersih, dan No.13 Aksi Iklim).

ABSTRACT

There are definite trends towards maximizing the utilization efficiency of solar energy through concentrated solar power (CSP) by using molten salts, which have enhanced the efficiency of CSP plants since they replaced thermal oil as heat transfer fluids (HTF) and as thermal energy storage (TES). However, these molten salts have limited TES properties. These thermophysical properties can be enhanced by adding a small amount of nanoparticles to the base salt, which may enhance the overall efficiency of the CSP systems. The purpose of this work is to characterize HITEC with various nanoparticles and assess the impact of varying nanoparticle concentrations on the thermophysical properties of the formulated Nano-Enhanced HITEC Molten Salt (NEHMS) samples. It also seeks to examine the long-term thermal cycle stability of these properties as well as to assess the impact of the improved thermophysical properties of NEHMS on electricity price and the efficiency of the CSP plant. NEHMS were synthesized using CuO, TiO_2, and h-BN nanoparticles separately at different concentrations (0.1, 0.5, and 1.0 wt.%). The NEHMS samples were characterized for compatibility and nanostructure analysis. The thermophysical properties and thermal cyclic behaviour of the nano-HITEC samples were evaluated to find the optimum sample. Furthermore, the impact of improving thermophysical properties on efficiency and electricity cost was assessed. The wet preparation method was used to formulate HITEC and NEHMS samples. The compatibility of HITEC with the nanoparticles was analysed with FTIR spectroscopy. DSC was utilized to evaluate the specific heat capacity, melting point, and latent heat of HITEC and NEHMS samples. Thermal stability was measured by TGA while the characterization analysis was performed using FESEM, and EDX. The thermal cyclic stability of the optimum samples was done in this study to evaluate the stability of the enhanced properties after 100 cycles. Also, the simulation was used to examine the effect of applying the optimum samples on the efficiency of the CSP plant and the cost of producing electricity and compared the results of the optimum sample with those of the currently used HTF and TES solar salt. The results showed that 0.1wt.% nanoparticles is the optimum concentration which resulted in the best thermophysical properties enhancement. The heat capacity was enhanced by 5.6%, 27%, and 5.5%, latent heat by 30%, 72%, and 78%, and thermal stability by 9%, 7%, and 5% for HITEC with 0.1 wt.% CuO, 0.1 wt.% h-BN, and 0.1 wt.% TiO_2 nanoparticles respectively. The morphological analysis revealed a good dispersion of nanoparticles in HITEC and the formation of a bright chain-like nanostructure due to nanoparticle dispersion. The FTIR showed the stability of the nanofluid mixture without any chemical reaction between HITEC and the used nanoparticles. The thermal cyclic stability showed the stability of the nanocomposite and the enhanced properties. The CSP efficiency evaluation revealed that employing the optimum sample would improve CSP plant efficiency by 1.4%, and lower power costs by 0.13 ¢/kWh. The outcomes of this research reduce the gap of finding the optimum salt for CSP systems which may result in a reduction of the electricity price and an increase in the dependency on solar energy as a clean electricity source. This study contributes to the 10-10 MYSTIE (No.1 Energy, and No.10 Environment and Biodiversity) and the 17 SDGs (No.7 Affordable and Clean Energy, and No.13 Climate Action).

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