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Optimizing thermal properties and heat transfer in 3D biochar-embedded organic phase change materials for thermal energy storage

Aman Yadav [a], M. Samykano [a,f,**], AK Pandey [b,d,e,*], Tareq Kareri [c], B. Kalidasan [b]

[a] Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, Pekan 26600, Pahang, Malaysia
[b] Research Centre for Nano-Materials and Energy Technology (RCNMET), School of Engineering and Technology, Sunway University, No. 5, Jalan Universiti, Bandar Sunway, Petaling Jaya 47500, Selangor Darul Ehsan, Malaysia
[c] Department of Electrical Engineering, College of Engineering, Najran University, Najran 11001, Saudi Arabia
[d] Center for Transdisciplinary Research (CFTR), Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, India
[e] CoE for Energy and Eco-sustainability Research, Uttaranchal University, Dehradun, Uttarakhand 248007, India
[f] Centre for Research in Advanced Fluid and Process, University Malaysia Pahang Al-Sultan Abdullah, Lebuhraya Tun Razak, Gambang, Kuantan 26300, Pahang

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ABSTRACT

Enhancing the thermal properties and light-absorbing capabilities of phase change materials (PCMs) through the utilization of environmentally friendly, economically viable biochar materials is pivotal for optimizing solar energy capture and utilization. Herewith, initially, a green, three-dimensional, eco-friendly carbon nano inclusion is synthesized from Prosopis juliflora through vacuum oven carbonization at 130 °C, followed by size reduction via ball milling, promising high-impact contributions. Subsequently, green-synthesized nano-inclusions are dispersed in PEG-1000, creating advanced nano-enhanced phase change materials with improved thermo-physical properties using a two-step ultrasonication technique for enhanced thermal conductivity. This innovative study comprehensively explores the morphological behaviour, chemical stability, optical absorptivity, thermal properties, and reliability of the PEG-PJ composite. Remarkably, present research revealed that the composite achieved its highest thermal conductivity, an impressive 0.49 W/m·K, at 0.7 wt% of 3-D (PJ) biochar. Notably, the melting temperatures of the PEG-PJ composites consistently ranged from 40.1 °C to 40.5 °C. At the same time, their latent heat capacities displayed a notable increase, ranging from 145 J/g to 152.7 J/g, marking a substantial enhancement of 3.968% and 1.758%, respectively. Furthermore, to confirm the reliability and consistency of experimental findings, 500 thermal cycles were performed. Additionally, a numerical analysis study is conducted by utilizing 2-D energy modelling software to simulate the heat transfer rate owing to the improved thermal conductivity of the developed PEG-PJ composite PCM compared to PEG-1000. In conclusion, developed composites optimize solar storage, improve building thermal control, and enhance industrial heat exchangers for sustainable innovation in energy.

1. Introduction

Solar energy offers a better possibility of thermal energy storage (TES) arrangements to accomplish energy reserves [1], diminishing the environmental effect of energy usage. These arrangements rectify the mismatch regularly observed between energy supply and demand [2]. Storing latent heat is an effective method for TES [3]. Unlike sensible heat storage, latent heat storage stores and releases heat at constant temperatures. TES recommends PCMs. Organic PCMs store thermal energy well due to their high heat of fusion [4]. PCMs store energy at a constant temperature in many applications, such as building heating & cooling, solar energy systems, and thermal comfort textile. Whenever phase change material (PCM) goes through either (a) a solid-liquid phase transition or (b) a liquid-solid phase transition, heat energy is transferred. The groups of PCMs are organic-inorganic and eutectic [5]. Organic PCMs are thermally robust and non-corrosive, and no

* Corresponding author at: Research Centre for Nano-Materials and Energy Technology (RCNMET), School of Engineering and Technology, Sunway University, No. 5, Jalan Universiti, Bandar Sunway, Petaling Jaya 47500, Selangor Darul Ehsan, Malaysia.
** Corresponding author at: Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, Pekan 26600, Pahang, Malaysia.
E-mail addresses: mahendran@ump.edu.my (M. Samykano), adarshp@sunway.edu.my (A. Pandey).

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