

Energizing the Thermal Conductivity and Optical Performance of Salt Hydrate Phase Change Material Using Copper (II) Oxide Nano Additives for Sustainable Thermal Energy Storage

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Abstract. Due to intermittent nature of solar energy, scientists and researchers are working to develop thermal energy storage (TES) systems for effectively use the solar energy. One promising avenue involves utilizing phase change materials (PCMs), but primary challenge lies in their limited thermal conductivity, which results in slower heat transfer rate and lower thermal energy storage density. The present research work demonstrates, to develop and explore a PCM composite by embedding salt hydrate and copper (II) oxide to enhance the heat transfer mechanism for potential utilization of TES material. The optical behavior, and thermal conductivity were analyzed by using Ultraviolet visible spectrum, and thermal property analyzer. The developed copper oxide dispersed PCM composite displayed the thermal conductivity was energized up to 71.5 % without affecting the other properties. Also, the optical absorbance was remarkably enhanced and the transmittance reduced to 87 %. Increasing the concentration of copper oxide nanoparticles in the salt hydrate PCM improves the optical absorptivity and heat conductivity. With these extraordinary abilities the nanocomposite could play a significant role in progress of sustainable TES with significance to contribute towards sustainable development goal of affordable and clean energy and climate change.

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Key words: Thermal conductivity; Phase change materials; Copper (II) Oxide; Thermal energy storage.

1 Introduction

With increasing the usage of fossil fuels and global warming, the use of renewable energy like solar, wind, ocean hydro etc., obtain increasingly attention [1,2]. Among all renewable energies, solar power is one of the most believable, abundant and sustainable form of energy [3]. However, solar power can generate electrical and thermal energy using photovoltaics and thermal collectors [4–6]. The generated electrical energy can be stored in the battery and the thermal energy stored in the thermal energy storage (TES) materials. Phase change materials (PCMs) are capable of storing thermal energy while solar energy available and releasing, while solar energy unavailable. [7–9] PCMs possess a multitude of possible uses because to their high storage capacity and capability to distribute heat uniformly. Nevertheless, the restricted thermal conductivity (TC) of these materials imposes limitations on the speed at which heat can be absorbed and released. This constraint has a direct impact on the rate of solidification and melting, resulting in a decrease in speed. The available literature discusses many approaches that have been proposed to improve the TC of PCMs. These methods includes the dispersion of nanoparticles [10–12] the incorporation of metal fins [13,14] the use of metal foams [15,16], and the implementation of multiple PCMs [17]. Currently, there is a strong emphasis in the field of research on the dispersion of highly conductive nanomaterials within PCMs.

Recently, a researcher compared the functionalized and non-functionalized multi walled carbon nanotubes (MWCNTs) dispersed PCM for enhancing the TC. Due to the surface modification the nanoparticle had excellent intermolecular attraction between the PCM and nanoparticle, results excellent thermal network. The addition of 0.7 wt.% functionalized multi walled carbon nanotubes (FMWCNT) with salt hydrate, the TC improved 100 % than base PCM [18]. Imtiaz et al. examined the binary nanoparticle enhanced organic PCM for enhancing the light absorptance and TC. Due to the higher conductivity of nanomaterials the TC of the PCM was improved to 179 % compared to base PCM the maximum reduction in light transmittance was deduced to 39.9%, due to the excellent photo thermal property of the nanomaterials [19]. Recently. Reji Kumar et al. [11]. performed graphene nanopoweder infused with paraffin wax to enhancing the thermophysical properties and the developed nanocomposite is potential material for solar TES applications. The TC was enhanced 72.2% at 0.6 wt% graphene and light absorption capability was enhanced significantly. Kalidasan et al. [20] reported that adding hybrid silver-graphene enhanced the TC and the latent heat by 53.85% at 0.8 wt% of Gr-Ag. Zahid et aal. [21] reported that adding Al₂O₃ with RT-54 PCM improved the uniformity and the decline in battery temperature. John et al. [22] studied the battery thermal performance by using copper (II) oxide (CuO) nanoparticles with Stearic acid PCM at a different thickness of PCM. It was informed that maximum reduction in temperature of battery remained 39 °C. Also, found the use of 8mm thickness PCM has better performance. Recently, Kalidasan et al. [23] dispersed silver nanoparticles with inorganic PCM in order to enhance the thermal and optical properties. Findings shows the better optical property and TC of the samples with higher concentration of silver nanoparticles. Lu et al. [24] performed the performance of expanded graphite dispersed paraffin wax composite samples to improve the thermophysical properties of the PCM. It was found that the TC of increased to 1.49 W/mK from 0.355 W/mK. In addition, the light absorption was increased significantly. Similarly many researchers [25–28] reported that addition of highly conductive nanoparticle improve the TC of PCM as well as improve the other properties of the composite samples.

Based on the aforementioned literature, it is apparent that the use of nano-sized CuO nanoadditives to improve the efficacy of the inorganic PCM with melting temperature 50 °C and has not yet been explored. Therefore, current research study, the authors conducted an experimental and numerical analysis to assess the photo-optical absorptivity properties and TC of the composite phase change material. The preparation of CuO enhanced PCMs is determined to be conducted at concentrations of 1.0%, 1.5%, 2.5%, 3.5% and 4.0 %. The transmissibility and absorptivity capabilities of the composite PCM are assessed utilizing a ultraviolet visible (UV-Vis) spectrometer. Additionally, the TC of the formulated samples examined by TEMPOS instrument. The article is organized into four pieces. The first portion focuses on the fundamental study conducted on nanoparticle dispersed salt hydrate PCM and highlights the novelty of the present research. The second section of the document adequately presents comprehensive information regarding the materials utilized and the specific facts pertaining to the instrument. The fourth section presents the results, discussions, and inferences in a clear and concise manner. In conclusion, the final section of the study article serves to synthesize the key findings and outline potential avenues for further research.

2 Materials and Methodology

2.1 Materials

Present study, a technical grade Inorganic PCM Plus Ice S50 with melting temperature 50 °C was acquired from Phase change products ltd, United Kingdom. The melting enthalpy values of salt hydrate is 100 J/g. A Copper (II) Oxide nano powder with 40 nm was obtained from Alfa Aesar, Thermo fisher scientific, to enhance the thermophysical property of the salt hydrate PCM. The Table 1 represents the thermophysical properties of S50 and Copper Oxide nano powder.

Table 1. Thermophysical properties of PCM and copper (II) oxide.

Properties	S50	Copper (II) Oxide
Latent heat (J/g)	100	-
Phase transition temperature (°C)	50	1326
Heat conductivity (W/mK)	0.43	35
Density (g/cm ³)	1.60	6.31
Size (nm)	-	45
Colour	Blueish white	Black

2.2 Preparation of nanoparticle enhanced PCM

A two-step technique is implemented for formulating the Copper Oxide fused organic PCM. The required amount of S50 PCM and copper oxide nano powder (1.0, 1.5, 2.5, 3.5 and 4.0 wt.%) was computed using micro balance (EX224, OHAUS). The weighed PCM was taken in a beaker, kept on the hot plate and heated above melting temperature, followed by added the measured Copper oxide nano powder in to the liquid PCM. The liquid sample was sonicated using bath sonicator for 90 minutes for uniform dispersion. The whole process the temperature of the hot plate was retained higher than the melting temperature of the PCM.

After completion of sonication the sample was permitted to cool at atm temperature. Similarly, the same procedure was used to formulate the nanocomposites with (1.0, 1.5, 2.5, 3.5 and 4.0 wt% copper oxide). The various nanocomposites were represented by code Salt hydrate (SH), Salt hydrate with 1.0 wt.% CuO (SHC-1), Salt hydrate with 1.5 wt.% CuO (SHC-1.5), Salt hydrate with 2.5 wt.% CuO (SHC-2.5), Salt hydrate with 3.5 wt.% CuO (SHC-3.5), and Salt hydrate with 4.0 wt.% CuO (SHC-4).

2.3 Characterization and instruments used

The thermal and optical properties of the formulated samples were examined by various equipment's. UV-Vis, Perkin Elmer, LAMBDA 750, USA was engaged to analyze the optical transmission and absorptivity of the samples. In order to gain insights into the photo-optical absorptivity characteristics, light rays were passed through the samples in the range of 280nm to 1400 nm at room temperature. The heat conductivity of the formulated samples was examined by Thermal properties analyzer (TEMPOS) dual needle SH-3 instrument at atm temperature.

3 Results and discussion

To access the enhanced performance of the composite samples, we conducted evaluations focusing on thermal conductivity and optical behaviors. This section will delve into discussion these factors.

3.1 Thermal conductivity

TC of the PCM is an important parameter and highly influence the rate of heat transfer, heat storage and discharge of thermal energy. Present study, the TC of the formulated nanocomposites was determined by TEMPOS, at room temperature. The figure shows the experimental results of SH PCM with CuO nanoparticles at various concentrations. It was found that the enhancement in TC are 15.8%, 49.2%, 55.9% and 71.5%, and 60.4% for SHC-1.0, SHC-1.5, SHC-2.5, SHC-3.5, and SHC-4.0, respectively compared to base PCM. the maximum enhancement was noticed 71.5% at 3.5 wt.% of CuO. The enhancement is due to the higher surface area to volume (aspect ratio) creates excellent thermal network s and increases the thermal conductivity. At higher concentration the nanoparticles are agglomerated, clustering and shows settling the nanoparticles, due to that the thermal network breaks, results slightly drop in TC. Due to the higher TC of developed nanocomposite (SH with 3.5 wt.% CuO) to be best suited nanocomposite for TES applications, and their thermal reliability, optical performance and melting enthalpy were further investigated.

The TC of the PCM is highly dependent on the nanoparticle's thermal conductance and interfacial bonding between nanomaterials and PCM composites. The parameters such as fraction of filler, nanostructure of composite, shape of nanoparticles and uniform distribution were added important parameters that impact on the developed nanocomposites thermal conductivity. The present study the experimentally calculated values were compared with numerical values. The figure shows the numerically calculated parallel & series model, Hamilton model, Maxwell and Bruggeman model thermal conductivity values. To start with parallel model, the nanoparticles are properly dispersed with SH PCM and excellent thermal network between nanoparticles with effective heat transfer rate. In series model the thermal conductivity was lower than parallel model due to the agglomeration of nanoparticles. Both parallel and series models of nanoparticles arrangement are extracted from Fourier heat conduction approach. Furthermore, Maxwell model potentially extracts TC where the

nanoparticles have random dispersion in SH PCM. Hamilton modified model's thermal conductivity was potentially enhanced due to the nanoparticles are distributed uniformly. Bruggeman model shows very lower value of thermal conductivity, which is only effective for two-phase polymeric composites. In conclusion, the parallel model is the best suitable model for determine the TC of CuO enhanced PCM. he Bruggeman and Hamilton crosser models not preferred for determine the TC of CuO enhanced SH PCM.

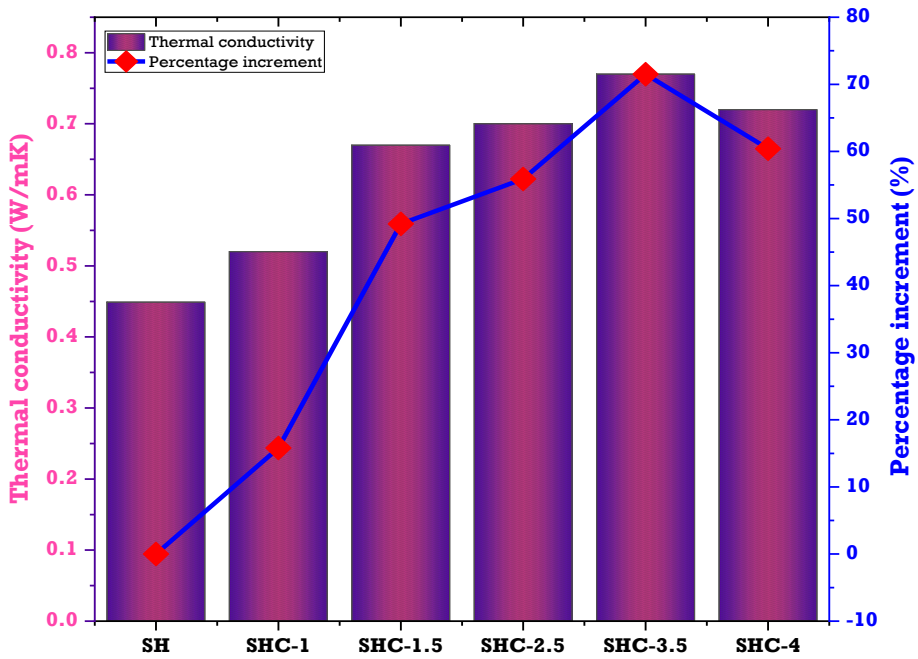


Fig. 1. Thermal conductivity analysis of SH with various percentage of CuO.

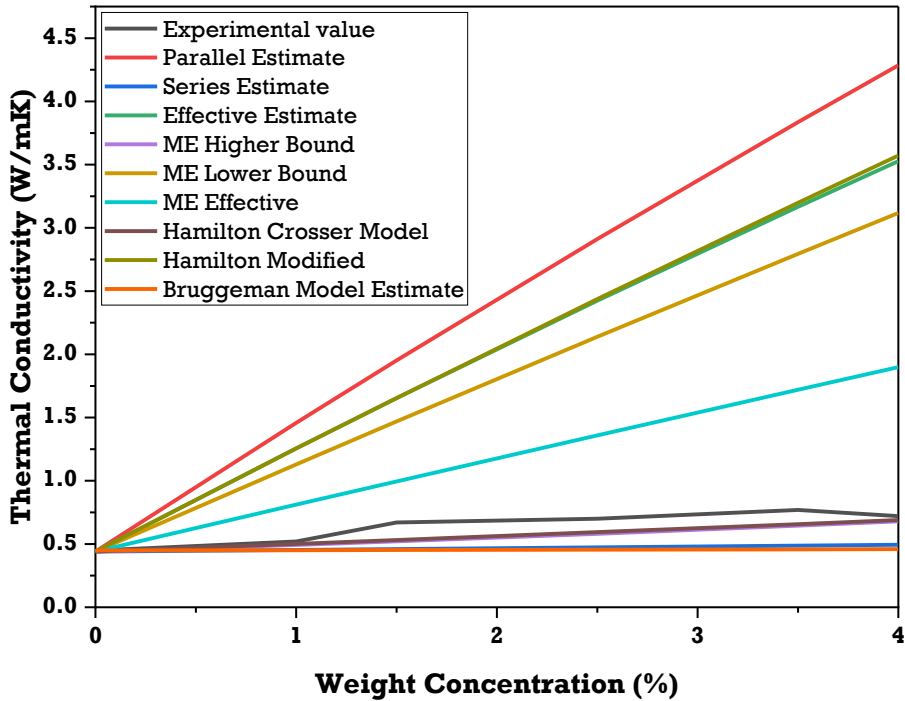


Fig. 2. Numerical results of thermal conductivity of various weight concentration of CuO.

3.2 Optical property

The utilization of PCMs is a notably efficient approach for the storage of thermal energy. PCMs has the ability to efficiently store thermal energy through a notable phase changeover process. This stored energy can then be released in a regulated manner, in accordance with their intended applications. Solar energy is of great importance on a global scale owing to its inherent characteristics as an electromagnetic wave. PCMs are preferred for energy storage due to their ability to effectively mimic high irradiation absorption capabilities. Inorganic PCMs are particularly favoured in light of their advantageous characteristics in relation to transmittance, which manifest in outstanding brilliance and the distinctive capacity to transmit rays.

Solar rays are commonly classified into three distinct zones based on their wavelengths: violet (280-380 nm), visible (380-740 nm), and near infrared (740-1400 nm). Figure 6 illustrates the transmittance of PCM and nanocomposites distributed with varying concentrations of CuO. Nevertheless, the incorporation of CuO into PCMs results in a reduction in light transmission while simultaneously improving their absorption capacity. The transmittance percentage was determined by analyzing the transmission produced samples in respect to sun spectrum data from NREI [29]. This analysis was conducted for wavelengths spanning from 250 to 1400 nm. The transmittance of pure PCM was found to be 60.4%, whereas the nanocomposites developed, namely SHC-1.0, SHC-1.5, SHC-2.5, SHC-3.5 and SHC-4.0, exhibited transmittance percentages of 11.25%, 9.01%, 11.2%, 7.79%, and 8.15%, respectively. The maximum percentage reduction was found to be 87 % compared to pure salt hydrate PCM, at SHC-3.5 samples. The decrease in transmittance can be attributed to the inclusion of CuO nanoparticles into the PCM.

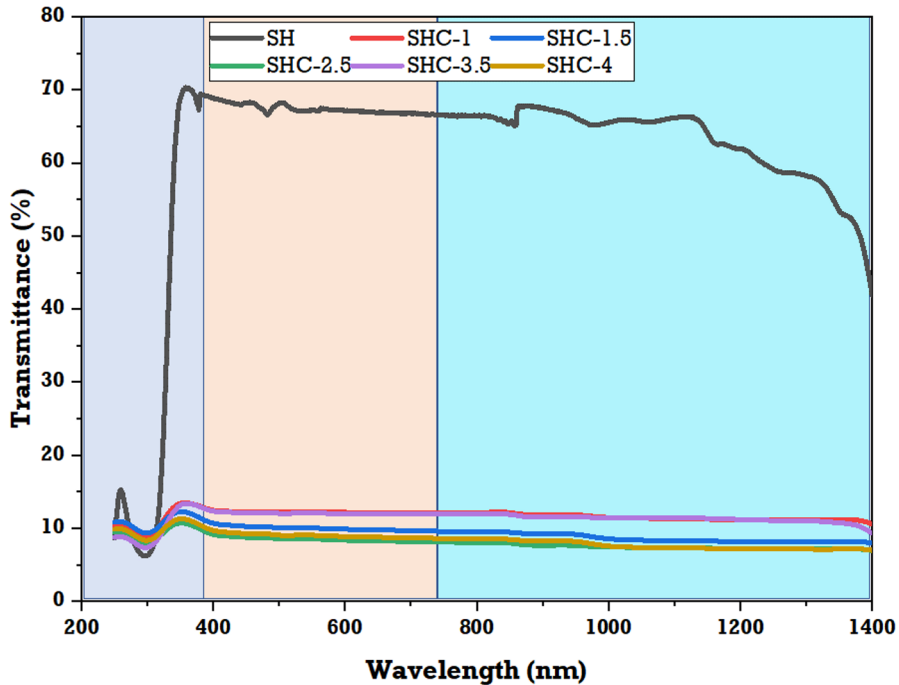


Fig. 3. Transmittance results of various weight concentration of CuO nanoparticles.

4 Conclusion

The present research, five samples of CuO nano powder dispersed SH PCM were prepared at 1.0 1.5, 2.5, 3.5 and 4.0 weight concentrations. The newly developed nano composites optical property, and thermal conductivity were investigated. The TC of the developed composites enhanced from 0.449 to 0.77 W/mK, which is 71.5 % higher than base PCM due to uniform dispersion, well developed thermal network. The developed nanocomposites light transmission was significantly reduced to 87% than base PCM and the light absorbance was remarkably increased, which indicated the developed nanocomposite is well suitable material for energy storage applications. Furthermore, we conducted numerical assessment of thermal conductivity utilizing various nanoparticle concentrations, employing established numerical models. From the results, it can be seen that 3.5 wt.% CuO dispersed SH PCM nanocomposite exhibits excellent thermal, chemical, and optical characteristics. So, we recommended that the developed nanocomposite in well suitable for medium temperature sustainable energy storage applications. Also, the present research contributes the SDGs framed by United Nations related to number 7 and 13, which focus on ensuring access to affordable & clean energy and climate change. Future studies could explore the morphology, thermal reliability, thermal stability, chemical stability, and melting enthalpy. Additionally, a real time investigation is planned, involving the placement of the CuO nanoparticle dispersed within a commercialized solar simulator setup to analyse its performance.

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