ENHANCED THERMAL CHARACTERISTICS OF CuO EMBEDDED LAURIC ACID PHASE CHANGE MATERIAL

by

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A new composite phase change material was fabricated by adding 0.05, 0.1, 0.15, and 0.2 wt.% CuO nanoparticles into lauric acid, separately. The SEM was used to observe the morphological structures of as-prepared nanoparticles, and X-ray diffraction analysis was used to characterize their crystalline structure. The phase change properties (phase change temperatures and latent heats) of lauric acid and composite phase change materials were obtained using differential scanning calorimetry. Using a laser flash analyzer, the thermal conductivity enhancement of the composite phase change materials was evaluated. The thermal reliability analysis was implemented to ascertain the results of the composite phase change materials over long periods.

Key words: *phase change material, nanoparticles, thermal conductivity, melting, solidification*

Introduction

The continuous availability of thermal energy during the peak period is a significant challenge, whereas developing solar thermal systems like solar energy storage for buildings, water heaters, dryers, air heaters, and other solar energy storage applications [1, 2]. The Sun's energy is only obtainable for a short period and is exceptionally uncertain due to changing environmental and climatic conditions [3, 4]. Researchers are currently making much effort to develop various forms of solar energy storage systems. Researchers have paid more attention to latent thermal energy storage (LTES) because of its larger energy storage capacity than sensible thermal energy storage (STES). The LTES with phase change materials (PCM) has a high energy storage density relative to STES. The ability of PCM to change phases at constant temperatures improves system performance.

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Numerous PCM (inorganic, organic, and eutectic types) for the low temperature to high temperature applications were studied in the last two decades. Above all, organic type PCM are widely chosen over inorganic types owing to the following main features such as higher latent heat, no supercooling, low cost, thermal stability, easy availability, and thermal reliability [5]. They also have low thermal conductivity, restricting their applications in solar energy harvesting systems and building cooling/heating systems. The addition of metals and their oxides nanoparticles in the pure PCM is a commendable technique to improve their thermal characteristics [6-9]. Manoj Kumar *et al.* [10] studied the thermal characteristics of composite paraffin wax and SiO_2 nanoparticles, and the addition of 2 wt.% of SiO_2 nanoparticles has recorded a 33.34% improvement in the thermal conductivity. In another study, TiO_2 nanoparticles added to palmitic acid proved the increased thermal conductivity. The thermal conductivities of palmitic acid rise as the different weight fractions of TiO_2 nanoparticles increase [11]. Kole and Dey [12] developed a nanofluid comprising ethylene glycol (EG) and ZnO nanoparticles and studied its thermal energy storage behavior at different concentrations of ZnO nanoparticles. The thermal conductivity of EG has been enhanced by 40% due to the dispersion of ZnO nanoparticles at 3.75 vol.% into EG, correspondingly. Harikrishnan and Kalaiselvan [13] reported the phase-change properties of CuO nanoparticles combined with oleic acid as PCM. According to the author, the composite PCM improved their melting and freezing properties faster than oleic acid. Wu *et al.* [14] examined the influence of Al_2O_3 nanoparticles dispersed in water and observed that the dispersion of 0.2 wt.% of Al_2O_3 nanoparticles decreases the freezing time by 20.5%. Besides, a nanofluid containing Al_2O_3-water nanoparticles was studied to evaluate the enhanced heat transfer and time reduction throughout phase change processes [15]. Yuan *et al.* [16] investigated the lauric acid/SiO_2 nanoencapsulated PCM for TES, and the test results proved the excellent thermal reliability during the melting and freezing thermal cycles. Furthermore, prepared composite PCM consisting of lauric acid (LA)/SiO_2 for the TES system. It was stated that more excellent thermal stability was achieved due to SiO_2 nanoparticles into base PCM [17].

Although there is ample literature, reported on enhancing thermal properties by adding the nanoparticles in different mass factions, however, there is only limited literature available on the CuO nanoparticle for improving the thermal characteristics of lauric acid. In this study, various volume fractions of CuO nanoparticles were fabricated, and composite PCM were formed by adding nanoparticles to lauric acid. The result of nanoparticles on the thermal characteristics of lauric acid and Composite PCM was reported. The effect of thermal conductivity and thermal cycles of composite PCM for thermal energy storage systems was also reported.

Materials and experiment

Materials

Lauric acid [$CH_3(CH_2)_{12}COOH$], sodium hydroxide (NaOH), ethanol, copper acetate ($CuC_4H_6O_4$), and glacial acetic acid (CH_3COOH) have been obtained from Hychem Laboratories, Telangana. The afforementioned chemicals have been used in the experiment without any further purification. The purified water has been used in this process.

Preparation of CuO nanoparticles

The CuO has been synthesized using the co-precipitation method, taking 0.04 M of copper acetate in a bowl and applying 2 mL of glacial acetate as a solution. The combined so-

lutions were mixed by magnetic stirrer at 650 rpm for one hour. The NaOH solution was added gradually until it reached 7-8 pH in the above-mixed solution. After that, it was centrifuged and rinsed with purified water four times. It has been dried in an oven at 120 °C for 30 hours before being ground to make the powder sample (CuO nanoparticles).

Preparation of composite PCM

The composite PCM have been processed by adding 0.05, 0.1, 0.15, and 0.2 wt.% of CuO nanoparticles to lauric acid. Therefore, the composite PCM were processed using the two-step process [18]. The lauric acid was first heated to 60 °C in a heating unit before being placed on a magnetic stirrer. Besides, the required 0.05, 0.1, 0.15, and 0.2 wt.% of CuO nanoparticles were gently added to the melted lauric acid individually. During preparation, the composite PCM were heated at the magnetic stirrer and stirred for 60 minutes, simultaneously. In addition, the mixture was kept inside the ultrasonicator for 60 minutes, to ensure low agglomeration. As a result, it could be helpful to achieve a homogeneous dispersion [19].

Analysis methods

The use of a field emmission SEM has characterized surface morphologies of as-synthesized CuO nanoparticles. To test the crystal sizes of the nanoparticles, Rigaku Japan's innovative lab used an X-ray diffractometer with CuK radiation to perform X-ray diffraction (XRD) measurements. The DSC 6110 series equipment (SII, Japan) was used to determine lauric acid's melting and solidification properties and composite PCM. The samples have been measured at a rate of 5 °C per minute in the temperature ranges from 20 °C to 70 °C. The heat conductivity of lauric acid and composite PCM has been measured using a laser flash analyzer (LFA 500, Linseis).

Results and discussion

Characterization of nanoparticle

Nanoparticle shape and size play an important role in supporting the heat transfer properties of pure lauric acid because it allows for a high surface area. It is seen in fig. 1 that the structure of the as-synthesized CuO particles seems to be the lamellar shape, and the shape of the CuO particles depends upon the molar weight of the reducing agent and type of solvent. The average particle size was measured to be 24 nm.

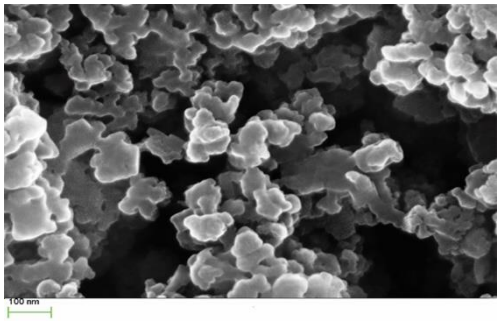

Figure 1. The FESEM image of CuO nanoparticle; EHT = 15.00 kV, signal A = InLens, WD = 5.3 mm, Mag = 260.52 KX

From the XRD pattern of CuO nanoparticles, as shown in fig. 2, CuO nanoparticles was confirmed to have a monoclinic form with a single phase, and the lattice parameters have been a = 4.72 Å, b = 3.51 Å, c = 5.41 Å. The XRD peaks for CuO nanoparticles at 36.23°, 39.34°, 47.87°, 54.42°, 57.96°, 65.98°, 68.12°, and 68.42° recorded as (002), (111), (−202),

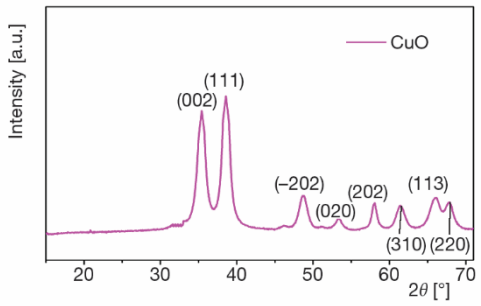

Figure 2. The XRD peaks of CuO nanoparticle

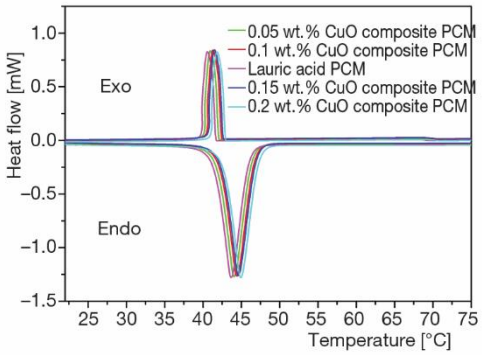

Figure 3. The DSC peaks of lauric acid and composite PCM for solidification and melting (*for color image see journal web site*)

(020), (202), (310), (113), and (220), respectively, with the standardized JCPDS file number: 01-089-5898 confirm the formation of the CuO nanoparticles with good purity.

Effect of thermal properties of composite PCM

Thermal characteristics could be altered owing to the addition of 0.05, 0.1, 0.15, and 0.2 wt.% of CuO nanoparticles in the lauric acid, so differential scanning calorimetry (DSC) calculations are unavoidable to determine the melt/solid properties of lauric acid and its composite PCM. Figure 3 illustrates the DSC results of the lauric acid and composite PCM samples. The DSC of the lauric acid and composite PCM samples can be obtained with phase transformation of peaks. Besides, phase transition (solid to liquid) would be the main factor in lauric acid, and it contains a large quantity of thermal energy in the latent heat of fusion form. Table 1 shows the observed values of the melt/solid properties of the lauric acid and composite PCM samples.

Table 1 reveals that minor aberrations between lauric acid and composite PCM on the values of melt/solid properties were found. Besides, when the nanoparticles added to the lauric acid are seen, the phase change temperature rises, while the latent heat reduces because of the physical change in the composite PCM [20]. It suggests that the nanoparticles were acting as nucleating agents and decreased the supercooling of lauric acid. Following the theory of mixture, the latent heats (solidification/melting) of composite PCM were diminished marginally due to an addition of nanoparticles. The degree of decrement in latent heat relies on the concentration of the nanoparticles which are added to the lauric acid.

Table 1. Thermal properties of lauric acid and composite PCM

Name of the PCM	Melting temperatures [°C]	Solidification temperatures [°C]	Melting latent heats [Jg^{-1}]	Solidification latent heats [Jg^{-1}]
Lauric acid PCM	43.92	40.84	183.23	183.68
0.05 wt.% CuO composite PCM	44.13	40.97	182.82	183.24
0.1 wt.% CuO composite PCM	44.38	41.18	182.54	182.83
0.15 wt.% CuO composite PCM	44.46	41.27	182.13	182.51
0.2 wt.% CuO composite PCM	44.65	41.36	181.81	182.31

Furthermore, the thermal characteristics of the nanoparticles could play a significant role in changing the latent heat. Besides, these de*via*tions clearly show a good interaction between the PCM and the nanoparticles [21-23]. These small changes in the melt/solid properties of composite PCM will never harm the success of LTES systems, and hence these tiny variations in composite PCM could be ignored.

Effect of thermal conductivity of composite PCM

Composite PCM were expected to improve the thermal conductivity due to the dispersion of nanoparticles in lauric acid. The thermal conductivity of lauric acid and composite PCM was calculated using laser flash analyzer and set at 32 °C during measurement. Even if temperature measures are improved to find the thermal conductivity, minor variations could be noted [20]. The result of adding 0.05, 0.1, 0.15, and 0.2 wt.% of CuO nanoparticles to lauric acid to measure heat conductivity is shown in fig. 4. In fig. 4, it is revealed that the heat conductivity of composite PCM using 0.05, 0.1, 0.15, and 0.2 wt.% of CuO nanoparticles has been greater than that of lauric acid. The composite PCM could reach a peak heat conductivity value upon seeing the test results. They concluded that the heat conductivity of 0.05, 0.1, 0.15, and 0.2 wt.% of CuO composite PCM enhanced by 34%, 50%, 60%, and 67%, relative to lauric acid, respectively. This improvement in the heat conductivity is primarily recognized to shape, size, mass fractions, and types of nanomaterials.

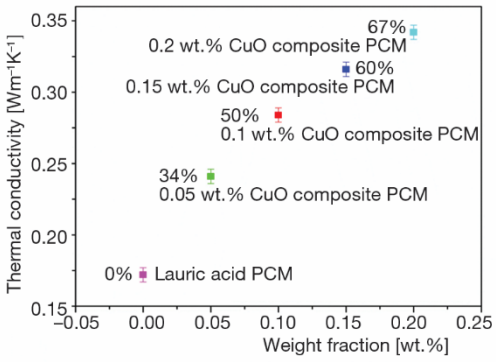

Figure 4. Effect of thermal conductivity of lauric acid and composite PCM

Furthermore, nanomaterials have a very high surface area, which means that they have unique properties. As a result, it is perceived that adding nanoparticles with more heat conductivity to lauric acid will enhance their heat conductivity. We understand that the heat conductivity of 0.2 wt.% of CuO-based composite PCM has been improved more than that of another composite PCM because of the higher intrinsic heat conductivity of the particles.

Figure 5 illustrates the comparison of thermal conductivity and thermal cycles. As shown in fig. 5, the heat conductivity of lauric acid and composite PCM has decreased as the thermal cycles counted increase. The decreases in heat conductivity after 4000 thermal cycles was measured as 2.81%, 1.73%, 1.22%, 1.79%, and 2.38% for lauric acid and 0.05, 0.1, 0.15, and 0.2 wt.% of CuO composite PCM. It can be shown that owing to impurities, the heat conductivity of the lauric acid

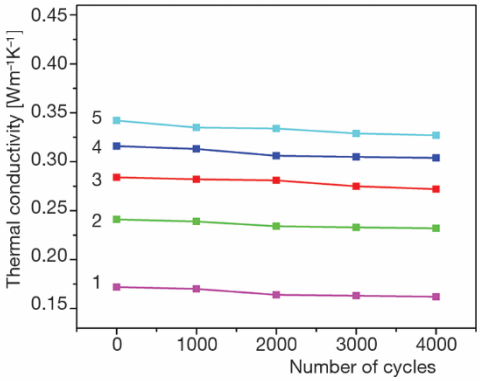

Figure 5. Thermal cycles *vs.* thermal conductivity; *1 – Lauric acid PCM, 2 – 0.05 wt.% CuO composite PCM, 3 – 0.1 wt.% CuO composite PCM, 4 – 0.15 wt.% CuO composite PCM, and 5 – 0.2 wt.% CuO composite PCM*

and composite PCM changes slightly after 4000 thermal cycles. These small deviations in thermal conductivity will never affect the potential of the storage and release rates of the composite PCM, severely. Nanoparticles played as the nucleating agents, and besides, they improved the thermal characteristics of lauric acid.

Conclusions

In this study, an experimental study was carried out on composite PCM using 0.05, 0.1, 0.15, and 0.2 wt.% of CuO nanoparticles separately dispersed in lauric acid to find the thermal properties. Conclusions were drawn, some of the main conclusions are as follows.

- The CuO nanoparticle was synthesized *via* the co-precipitation method. The field emission SEM was used to find the surface morphologies of as-prepared nanoparticles since different morphology provides different heat contact surfaces to the heat. The XRD patterns of CuO nanoparticle was in good agreement with their respective JCPDS files.
- When nanoparticles are dispersed to lauric acid, the small variations in the melting and solidification temperatures are ignored. Furthermore, the latent heat for melting and solidification is decreased.
- The thermal conductivity of lauric acid using 0.2 wt.% of CuO was considerably improved compared to other composite PCM due to nanomaterials' high surface area.
- Hence, it is proposed that the fabricated composite PCM may be used for residential heating, which was confirmed by the study's findings.

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