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Proceeding Paper

To Investigate Thermal Conductivity of Phase Change Material by Incorporating Surfactants †

Qaiser Azim *, Shahid Mehmood and Azhar Hussain

Department of Mechanical Engineering, University of Engineering and Technology Taxila, Punjab 47050, Pakistan
* Correspondence: azimqaiser59@gmail.com

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Abstract: Phase change materials (PCMs) store or release heat during their phase transition. Their low thermal conductivity affects the performance of the latent heat energy storage system. This study aimed to investigate the thermal conductivity of PCMs by mixing surfactants. Surfactants with varying weights of sodium stearate (SS), gum arabic (GA), and sodium stearoyl lactylate (SSL) were mixed with paraffin wax. The charging and discharging rate of pure paraffin wax was compared to surfactant-mixed paraffin wax. Pure paraffin wax peaked at 66.76 °C. SSL's highest temperature was 68.3 °C at the critical micelle concentration (CMC) (the concentration of surfactants above which micelles form) and 69 °C above the CMC. GA reached 70 °C at the CMC and 71 °C above the CMC. Sodium stearate (SS) reached 72.12 °C at the CMC and 73.8 °C above the CMC. The melting time test revealed that a reduced melting time resulted in the higher heat conductivity of paraffin. When compared to the melting times of pure paraffin, those of composite PCM containing SSL (>CMC), GA (>CMC), and SS (>CMC) decreased by 6.12%, 14.28%, and 22.44%, respectively. The results show that a concentration above the critical micelle concentration of sodium stearate leads to the best results compared to other samples. Surfactants form micelle, which acted as the conducting medium inside the paraffin wax. Thus, paraffin wax's thermal conductivity was boosted, and the study's goal was met.

Keywords: PCM; paraffin wax; thermal conductivity; surfactants

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1. Introduction

Energy is a human need that is decreasing. Energy storage balances supply and demand. It is possible to store energy in a thermal storage system. The ability to store heat reduces the amount of energy required. Phase change materials (PCMs) can store thermal energy at a constant temperature throughout phase shift, making them excellent for solar energy storage, heating, and cooling. However, they have limited thermal conductivity, restricting their practical use in storage systems.

Different strategies are used to improve the phase change material's thermal conductivity. High-thermal-conductivity fillers improve a PCM's thermal conductivity. Metal particles, carbon fibers, extended graphite (EG), and nanoparticles improve PCM thermal conductivity but have downsides.

L. Xia et al. [1] made composite phase change materials with EG. The researchers found that EG networks became more compact as their mass fraction increased. In composite PCMs, increasing the EG content to 10% boosted thermal conductivity tenfold over pure paraffin. EG has a negative effect on a PCM's latent heat, which lowers as the EG fraction increases.

Areeg Shama et al. [2] enhanced paraffin wax's thermal properties by adding CuO nanoparticles in varying amounts. Their experiments showed that 1% paraffin wax/CuO is optimal. Composite PCM slows paraffin melting by 22.22%.

Hadi Fauzi et al. [3] added surfactants to eutectic PCMs. Sodium myristate, sodium palmitate, and sodium stearate at 0, 5, 10, 15, and 20% formed PCM eutectic mixes. Surfactant additions affected the eutectic mixtures' thermal properties and conductivity. The increased latent heat of fusion and thermal conductivity can be achieved by adding 5 percent SM, 5 percent SP, and 5 percent SS to an MA/PA eutectic mixture.

These methods had issues with nanoparticle segregation, leakage, and stability, as well as the poor dispersion of nanoparticles. In this study, we employed surfactants as nanoparticles. Surfactants improve the heat conductivity of paraffin wax because they form micelles at concentrations above the critical micelle concentration.

2. Materials and Methods

Three surfactants, sodium stearate (SS), gum arabic (GA), and sodium stearoyl lactylate (SSL), were chosen as nanoparticles. Six samples were generated by mixing three surfactant particles at and above the critical micelle concentration (CMC) with paraffin wax.

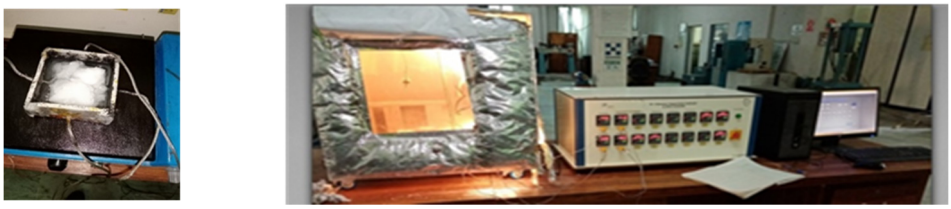
Sample Preparation

We placed 100 g of paraffin wax in a 250 mL glass beaker and heated at 75 °C as shown in Figure 1. Molten paraffin wax was mixed with surfactants at or above the critical micelle concentration. The magnetic hot-plate stirrer was then turned on at 75 °C. Surfactant and paraffin wax were mixed in a beaker by spinning a stirring bar. Magnetic pellets agitated the solution at 1500 rpm for 15 min when one gram of surfactant was added.

Figure 1. Magnetic stirring of samples in the beaker placed on a hot-plate heater.

3. Experimentation Procedure

As shown in Figure 2, the heat sink was filled with composite paraffin wax. One end of a K-type thermocouple was attached to the DAQ controller and the other to the heat sink. The heat sink was positioned at the top of the hot-plate heater in this configuration. The heater for the hot plate was turned on. The signal was transmitted to the data logger using a K-type thermocouple sensor. A data collecting system monitored sample temperatures at multiple positions of the heat sink every minute. During the charging cycle (melting process), paraffin wax was heated for up to 90 min on a hot-plate heater in a testing chamber. The temperature was set at 75 °C. The hot-plate heater was turned off, enabling the composite paraffin wax to cool in the air for up to 90 min (discharging). Charging was the absorption of heat to heat and melt the paraffin wax. Discharging was the release of heat to solidify or cool the material to assess its thermodynamic and thermal heat release rate over time.



(**a**) (**b**)

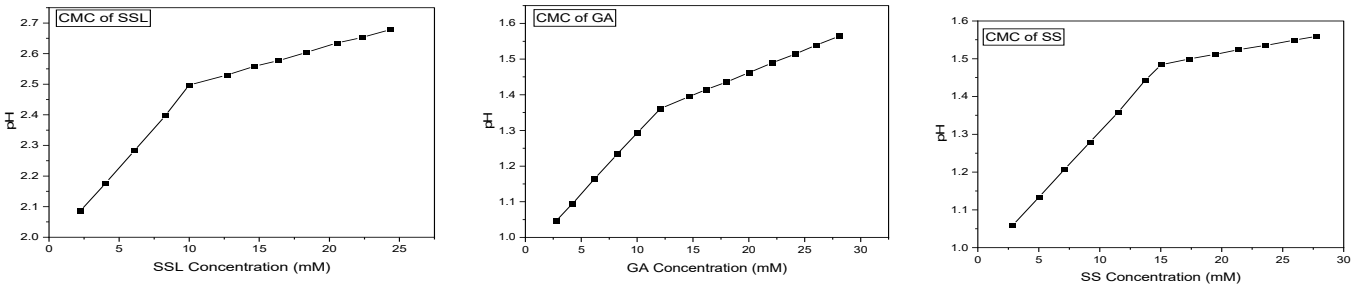
Figure 2. (**a**) Hot-plate heater melts paraffin wax; (**b**) data logger with a computer system records the temperature of paraffin wax and samples during heating and cooling.

4. Results and Discussion

Three different surfactants with concentrations equal to and greater than the critical micelle concentration (CMC) were mixed with paraffin wax. Two samples of each surfactant-based paraffin wax were prepared at and above the CMC. A data acquisition system recorded the charging and discharging behaviour of these samples. First, the charging and discharging behaviour of only pure paraffin wax was recorded and then compared with surfactant-based paraffin wax samples.

Critical Micellar Concentration Measurement

The CMC of a surfactant was determined by measuring the pH of the solution while adding surfactant particles to molten paraffin wax. We observed that two separate trend lines were found when the pH of the solutions was plotted against the surfactant concentrations. The CMC value relates to the point where the pH rate begins to change. The CMC of each surfactant was calculated using graphs, as shown in the Figure 3. The critical micellar concentrations for SSL, GA, and SS were 10 mM (Molar concentration),12 mM, and 15 mM, respectively.



(**a**) (**b**) (**c**)

Figure 3. (**a**) CMC of SSL; (**b**) CMC of GA; (**c**) CMC of SS.

The charging and discharging results of the samples above the CMC showed a better heat transfer rate than those at the CMC. Figure 4 shows that the maximum peak temperature obtained at the CMC was 68.3 °C and above the CMC was 69 °C in the case of sodium stearoyl lactylate (SSL). In the case of gum arabic (GA), the maximum peak temperature obtained at the CMC was 70 °C and above the CMC was 71 °C. In the case of sodium stearate (SS), the maximum peak temperature obtained at the CMC was 72.12 °C and above the CMC was 73.8 °C. Figure 4 indicates that the PCM's peak temperature increased after the addition of the surfactants. The highest heat transfer occurred in the sodium stearate (SS) mixed with paraffin wax. For the sodium stearate (SS)-based sample, the phase change temperature was 57.7 °C, and the peak temperature was recorded as 72.12 °C at the CMC concentration. A higher peak and phase temperature was recorded at 73.8 °C and 57.13 °C, respectively, for the concentration greater than the CMC.

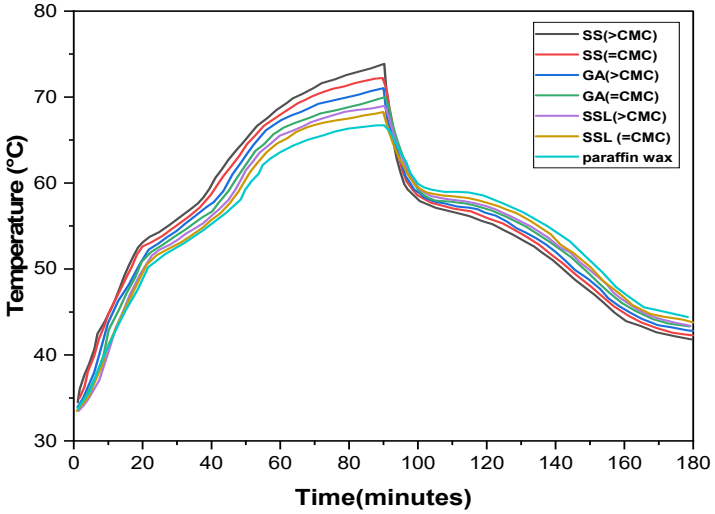


Figure 4. Comparison of charging and discharging profiles of samples with pure paraffin.

Figure 4 also compares the charging and discharging of pure paraffin wax with composite paraffin wax. It shows that composite paraffin wax melts and solidifies faster than pure paraffin wax. The peak temperature of the sodium stearoyl lactylate (SSL) composite increased by 2.30677% and 3.3553% compared to pure paraffin wax at and above the CMC. For the gum arabic (GA) composite, the peak temperature increased by 4.85321% and 6.35111% at and above the CMC. The peak temperature increased by 8.02876% and 10.5452% in sodium stearate (SS) composite at and above the CMC. The increase in paraffin's thermal conductivity was evaluated by contrasting the melting times of composite PCMs with those of paraffin. The melting time was measured from temperature curves until the PCMs reached their melting point (58 °C) from the starting temperature (34 °C). Pure paraffin and the composite PCMs with SSL (=CMC), SSL (>CMC), GA (=CMC), GA (=>CMC), SS (=CMC), and SS (>CMC) melted in 49, 47, 46, 44, 42, 40, and 38 min, respectively, indicating that the composite PCM melting times lowered by 4.08%, 6.12%, 10.20%, 14.28%, 18.36%, and 22.44%, respectively, compared to pure paraffin. The composite PCMs melted faster due to the paraffin's improved heat conductivity. The thermal conductivity of pure paraffin and the composite PCMs with SSL (=CMC), SSL (>CMC), GA (=CMC), GA (>CMC), SS (=CMC), and SS (>CMC) was 0.2 $Wm^{-1}K^{-1}$, 0.22 $Wm^{-1}K^{-1}$, 0.24 $Wm^{-1}K^{-1}$, 0.27 $Wm^{-1}K^{-1}$, 0.3 $Wm^{-1}K^{-1}$, 0.33 $Wm^{-1}K^{-1}$, and 0.36 $Wm^{-1}K^{-1}$, respectively.

5. Conclusions

This study experimented with the charging and discharging of paraffin wax and composite paraffin wax (surfactant). The thermocouples detect the increase in peak temperature during the phase transition process during a specified heating period. Surfactants at different concentrations generate micelles, which act as a heat-transmitting medium in the PCM.

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References

1. Xia, L.; Zhang, P.; Wang, R.Z. Preparation and Thermal Characterization of Expanded Graphite/Paraffin Composite Phase Change Material. *Carbon* **2010**, *48*, 2538–2548. [CrossRef]
2. Shama, A.; Kabeel, A.E.; Moharram, B.M.; Abosheiasha, H.F. Improvement of the Thermal Properties of Paraffin Wax Using High Conductive Nanomaterial to Appropriate the Solar Thermal Applications. *Appl. Nanosci.* **2021**, *11*, 2033–2042. [CrossRef]
3. Fauzi, H.; Metselaar, H.S.C.; Mahlia, T.M.I.; Silakhori, M.; Nur, H. Phase Change Material: Optimizing the Thermal Properties and Thermal Conductivity of Myristic Acid/Palmitic Acid Eutectic Mixture with Acid-Based Surfactants. *Appl. Therm. Eng.* **2013**, *60*, 261–265. [CrossRef]