# INTENSIFICATION OF PCM THERMAL CONDUCTIVITY WITH NANOMATERIALS FOR THERMAL ENERGY STORAGE APPLICATIONS

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Received 18 July 2022
Accepted 02 October 2022

## ABSTRACT

*The introduction of phase-change materials (PCM) has revolutionized the thermal energy storage industry. The thermal conductivity of the materials is a significant constraint for nearly all typical PCMs. This investigation focuses primarily on the thermal conductivity of $SiO_2$ nano-PCM in various reference materials. The thermal energy storage capacity of PCMs such as $Zn(NO_3)_{6H2O}$, paraffin wax, and sodium thiosulfate pentahydrate, $Na_2S_2O_3{\cdot}5H2O$ were determined. The outcomes of these experiments were analyzed to determine the effects of temperature and silicon dioxide nanoparticle concentration on the rate at which polychlorinated biphenyls (PCMs) emit heat. Nano-PCM was evaluated based on the volume fraction concentration and temperature at temperatures ranging from 20°C to 65°C. As concentration and temperature were increased, the thermal conductivity percentage of $SiO_2$/Paraffin Wax, $SiO_2$ /$Zn(NO_3)$ $6H_2O$, and $SiO_2$/$Na_2S_2O_3{\cdot}5H_{2O}$ increased. An increase in nano-PCM concentration affects enhancement more than a rise in temperature.*

*Keywords: PCM, thermal conductivity, $SiO_2$ nanoparticle, paraffin wax, sodium thiosulphate pentahydrate, zinc nitrate hexahydrate.*

## INTRODUCTION

Latent heat storage has become a major concern due to its productive utilization and energy savings [1, 2]. Latent heat storage has conventionally been identified as phase change thermal energy storage, which is accomplished by absorbing and releasing heat during the transitional phase. Latent heat storage systems, like sensible thermal energy storage devices, permit less weight and volume, resulting in relatively low costs [3]. Almost all plain PCMs, with the exception of metallic PCMs, have poor thermal conductivity [4]. Therefore, increasing the thermal conductivity of phase change materials enables thermal energy storage systems to achieve a faster battery charging and discharging rate. Developing PCM resources has required significant effort. In addition, a small number of theoretical and practical studies have been conducted on the thermal energy mechanisms of various latent heat storage systems [5].

The application of multiwalled carbon nanotubes to assess the enhancement of palmitic acid's thermal conductivity has been reported [6]. Due to the dispersibility and dispersion of the carbon nanotubes in the PA matrix, the conductivity of the PA/MWNTs composite was found to have increased. The thermal conductivity and tensile strength of hybrid phase change material (PCM) derived from palmitic acid (PA)/graphene nanoplatelets (GNPs) has been studied [7]. The authors found that the thermal conductivity of nano-PCM increased tenfold faster than that of PA. According to their reasonable thermodynamic properties, good heat durability, chemical strength, and excellent thermal conductivity, the developed posture- stabilized materials are highly conductive PCMs for heat energy harvesting applications.

The thermal conductivity of carbon nanotubes (CNTs) was determined with polyhydric alcohols composite PCMs using the hot disc method [8]. The thermal conductivity of grafted CNTs/paraffin composite PCMs was found to be greater than that of ungrafted CNTs/paraffin composite PCMs. The effects of synthetic PCM density, temperature, and EG mass fraction on the thermal conductivity of an organic phase change material (PCM). They stated that the improvement in thermal conductivity of composite PCMs was due to the increase in EG mass fraction and bulk density.

The thermal conductivity and viscosity of the nano-encapsulated phase change material (NEPCM) were determined [10]. They processed NEPCM by encapsulating n-nonadecane as a phase change material with diethylenetriamine and toluene-2,4-diisocyanate using an interfacial polymerization process. They discovered that as the temperature rose, the thermal conductivity of nanofluids increased. In addition, the density of solids improved the thermal conductivity. The physical properties of composite materials comprising microencapsulated PCM/multiwall CNTs (MWCNT) were investigated [11]. They reported an increase in thermal conductivity as a result of an increase in MWCNT mass fraction. In addition, they reported that the melting time decreased as the percentage of MWCNTs increased after the thermal conductivity increased.

An experiment was conducted to determine the impact of alumina nanoparticles on the performance of sodium stearoyl lactylate PCM [12]. Thermal conductivity increased by 31 % in the solid state and 13 % in the liquid state at a 10 % weight fraction of alumina nanoparticles. In addition, they reported a 27 % increase in the melting rate. The loading rates of alumina nanoparticles in composites of Paraffin Wax (PW) and Microcrystalline Wax (MW) Phase Change Materials (PCM) (0.5, 1 and 2 wt. percent) were examined. They have found that nanopowder charging improved the latent heat and thermal conductivity of PW composites relative to MW composites.

The impact of graphene nanofiller on the thermal conductivity of PCM (49 per cent sodium carbonate and 51 per cent lithium carbonate eutectic composition) was studied [14]. They reported that the thermal conductivity of PCM increased by 51 % with only 1.25 weight percent of graphene added to the composite. The thermal conductivity of composite expanded perlite (ExP)/n-eicosane ($C_{20}$) using carbon nanotubes as an innovative type of composite form-stable PCM (F-SCPCM) was classified and improved [15]. By incorporating CNTs at a mass fraction of 1 wt. %, the thermal conductivity of the composite PCM increased by 113.3 %. In contrast, the overall melting and freezing times of composite PCMs containing 1 % CNTs have been drastically reduced as a result of enhanced thermal conductivity.

The effect of $MnO_2$ nanowires and nanotubes on the thermal conductivity of PCM (paraffin wax, myristic acid (MA), palmitic acid (PA), and stearic acid (SA)) composites was investigated [16]. The addition of $MnO_2$ nanowires and nanotubes has enhanced thermal conductivity of PCM nanocomposites by 377.16 %. The influence of $Al_2O_3$, $SiO_2$, hydrophobic $SiO_2$ and $TiO_2$ nanoparticles on the thermal conductivity of the phenol-water PCM system was investigated [17]. In the case of $TiO_2$, they observed that the improvement in thermal conductivity peaked at a certain concentration (3 wt. %) and then declined. In addition, they discovered that 0.02 and 0.04 wt. % of carbon black nano powder (CBNP) improved thermal conductivity by 44.7 % and 45.9 %, 41.7 %, and 45.3 % for PCMs packed with 4 % $Al_2O_3$ and 3 % $SiO_2$, respectively.

The influence of MgO and MWCNT on thermal conductivity, supercooling, latent fusion heat, stability, and water based PCM ($BaCl_2.2H_2O$) energy storage was tested [18]. At the same concentration, the thermal conductivity of PCM increased by 6 percent for MWCNTs and 17 % for MgO nanoparticles. The effect of nano-sheets of ultrathin graphite on the thermal conductivity of stearic acid (composite phase change material) was investigated [19]. They observed that the thermal conductivity of ultrathin graphite nano sheets was 10.08 times that of pure SA.

The effect of nickel powder (Ni) on the thermal conductivity of phase change material was studied [20]. They observed an increase in thermal conductivity with an increase in nickel nanopowder mass fraction and a decrease in solidification and melting times with increasing nickel powder concentrations. An experiment was conducted to determine how nanoparticles affect the thermal conductivity of phase-change material (paraffin wax) [21]. As observed by the researchers, the addition of nanodiamonds to paraffin wax increased the thermal conductivity of microcapsules by fifty percent. On the other hand, they stated that nano-diamonds enhanced the thermal properties of PCMs.

A microencapsulated PCM (micro-PCM) with a boron nitride (BN) reinforced melamine-formaldehyde shell for thermal conductivity improvement via an in-situ polymerization process was synthesised [22]. The thermal conductivity of the microcapsules increased as the concentration of the highly thermally conductive BN increased. The impact of multi-walled carbon nanotubes (MWCNTs) on the thermal conductivity of a phase-change material (N-octadecane) was examined [23]. The addition of 1 wt. % MWCNTs improved the thermal conductivity of a 10 wt. % nano-emulsion by 4.32. In addition, they concluded that nano-PCM was used as energy storage and heat transfer fluids in thermal system implementations to an excessive degree.

An examination of previous investigations reveals that there are few studies on the relationship between $SiO_2$ nanoparticles and thermal conductivity of PCM, which include them. In this paper, we used $Na_2S_2O_3 \cdot 5H_2O$, $Zn(NO_3)$ $6H_2O$ and paraffin wax as a PCMs with a wide range of mass fractions and $SiO_2$ nanoparticles as a supporting material to construct nano-PCMs.

## EXPERIMENTAL

### Materials preparation used in the experiment

Sodium thiosulphate pentahydrate ($Na_2S_2O_3.5H_2O$), zinc nitrate hexahydrate, $Zn(NO_3)_2.6H_2O$, paraffin wax (or petroleum wax) and $SiO_2$ nanoparticles (20-30 nm), produced by SRL India, were used in the study. At the boiling point of liquid PCM, $SiO_2$ nanoparticles were added. The mixture was then agitated with a mechanical stirrer at 1000 rpm for 30 minutes, before being sonicated in an ultra-probe sonicator. This ensured that the $SiO_2$ particles were dispersed uniformly in the liquid PCM.

### Thermal conductivity measurement

The KD2 Pro is a portable thermal property measuring device. The structure of the stand holds the needle sensor. Using a water bath with a temperature controller to maintain the temperature of a teat sample (Fig. 1). We can measure thermal conductivity with a 5 % margin of error.

### Processes involved in the experiment

Thermal conductivity is determined for $Na_2S_2O_3.5H_2O$, Paraffin wax and $Zn(NO_3)_2.6H_2O$ using thermal analyzer and water bath. The water bath with temperature controller is used for heating of PCMs, and subsequently the thermal conductivity is measured at the specific temperature by thermal analyzer at every state of distinct concentration of $SiO_2$ nanoparticles. 26.4 g of Paraffin Wax, 54.7 g of $Na_2S_2O_3.5H_2O$ and 60.6 g of $Zn(NO_3)_2.6H_2O$ of varied concentration of $SiO_2$ nanoparticles (0.02, 0.04, 0.06, 0.08 and 0.1 volume fractions) at every stage is adequately charged into borosilicate glass such that the PCMs are filled up to the brim of the glass. The thermal conductivity is measured at eight different temperatures with the interval of 5°C from the melting point of $Na_2S_2O_3.5H_2O$ and $Zn(NO_3)_2.6H_2O$, each of four readings forward and backward from the melting temperature. Similarly, four readings of **k** forward and four backward is measured for Paraffin Wax. The melting point of Paraffin Wax,

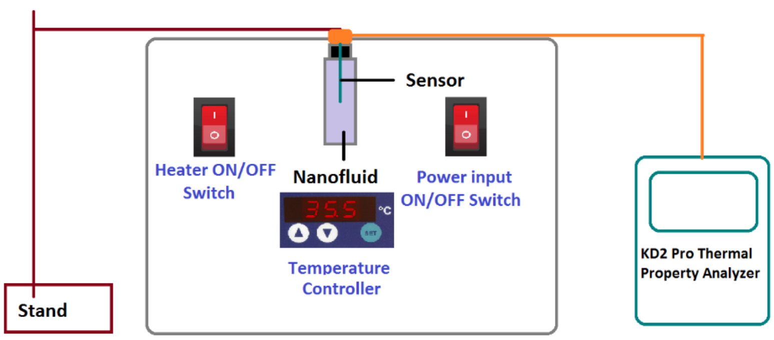


Fig. 1 Experimental set-up for measuring thermal conductivity.

Table 1. Materials required for 50 mL of $SiO_2$ nano-PCMs.

| $SiO_2$, volume fraction | $SiO_2$ (grams) | (A) parffin wax, g | (B) $Na_2S_2O_3.5H_2O$, g | (C) $Zn(NO_3)_2.6H_2O$, g |
|---|---|---|---|---|
| 0.02 | 2.3 | 44.1 | 78.4 | 95.5 |
| 0.04 | 4.6 | 43.2 | 76.8 | 93.6 |
| 0.06 | 6.8 | 42.3 | 75.2 | 91.6 |
| 0.08 | 9.1 | 41.4 | 73.6 | 89.7 |
| 0.1 | 11.3 | 40.5 | 72 | 87.7 |

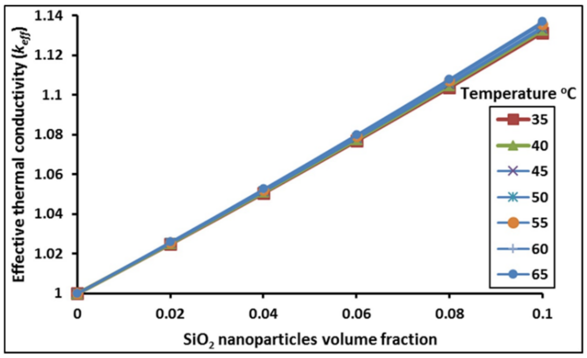


Fig. 2. Effect of nanoparticle concentration on thermal conductivity of $SiO_2$/Paraffin Wax nano-PCM.

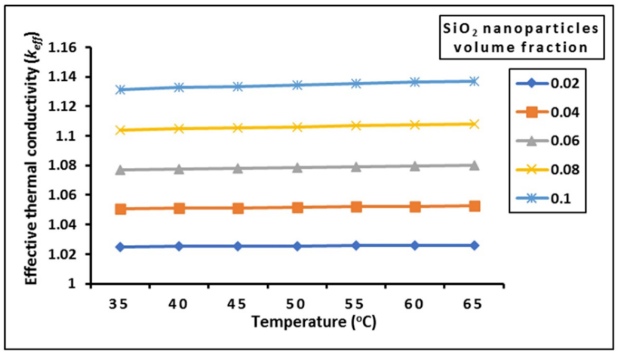


Fig. 3. Effect of temperature on thermal conductivity of $SiO_2$/Paraffin Wax nano-PCM.

$Na_2S_2O_3.5H_2O$ and $Zn(NO_3)_2.6H_2O$ are 52°C, 36°C and 48°C respectively. Thermal conductivity of paraffin wax is calculated at temperatures in the range from 35°C to 65°C, for $Na_2S_2O_3.5H_2O$ from 30°C to 65°C, and for $Zn(NO_3)_2.6H_2O$ from 20°C to 55°C. Each measurement was repeated a total of three times, and the average of the three measurements was used for further analysis.

Supposing A, B and C to be Paraffin Wax, $Na_2S_2O_3.5H_2O$ and $Zn(NO_3)_2.6H_2O$, Table 1 is formulated. This Table exhibits the different concentration of nanoparticle incorporation in A, B and C, respectively. The resultant readings of three different PCMs of distinct concentration of $SiO_2$ nanoparticles at different temperatures are documented and the graph is plotted to analyze the results.

## RESULTS AND DISCUSSION

### Efficiency of the thermal conductivity of $SiO_2$/Paraffin Wax nano-PCM

The impact of nanoparticle concentration on the thermal conductivity of $SiO_2$/Paraffin Wax nano-PCM: Fig. 2 shows the results for effective thermal conductivity, $k_{eff}$ of the $SiO_2$/Paraffin Wax nano-PCM at various temperatures. $k_{eff}$ is the ratio of thermal conductivity of the nano-PCM to the base material - Paraffin Wax at the same temperature.

From Fig. 2 it is seen that the $k_{eff}$ values are more than 1, showing that nano-PCM has a higher thermal conductivity than reference material (PCM). An improvement in thermal conductivity was found with increasing temperature and nano-PCM concentration. In the study's range of conditions, however, raising the nano-PCM concentration had a greater impact on the enhancement than did temperature rise. Enhancement in $k_{eff}$ varies between 2.5 and 13.7 % for $SiO_2$/Paraffin Wax nano-PCM.

### Effect of temperature on thermal conductivity of $SiO_2$ /Paraffin Wax nano-PCM

Fig. 3 illustrates the results for $k_{eff}$ of the $SiO_2$/ Paraffin Wax nano-PCM at varying nanoparticle concentrations.

The enhancement of nano-PCM $SiO_2$/Paraffin Wax

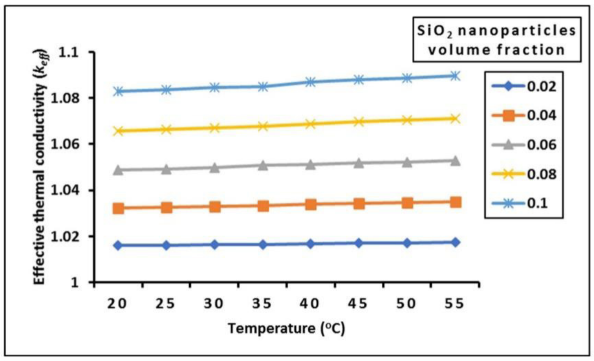


Fig. 4. Effect of temperature on thermal conductivity of $SiO_2/Zn(NO_3)_2.6H_2O$ nano-PCM.

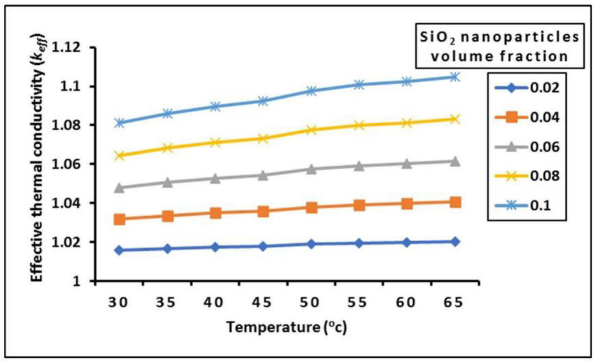


Fig. 5 Effect of temperature on thermal conductivity $SiO_2$/ Sodium thiosulphate pentahydrate nano-PCM.

nano-PCM was shown to increase as its temperature rises. In the range of study conditions, however, increasing the $SiO_2$/Paraffin Wax nano-PCM concentration has a greater impact on the enhancement than raising the temperature. $SiO_2$/Paraffin Wax nano-PCM exhibits an increase in effective heat conductivity ($k_{eff}$) between 2.5 % and 4.6 %. At a temperature of 65°C and a volume fraction of 0.1 of $SiO_2$/Paraffin Wax nano-PCM, the maximum increase of 13.7 % was found.

**The impact of nanoparticle concentration on the thermal conductivity of $SiO_2/Zn(NO_3)_2.6H_2O$ nano-PCM**

Fig. 4 depicts the results for effective thermal conductivity, $k_{eff}$ (where effective thermal conductivity, $k_{eff}$ is the ratio of thermal conductivity of the nano-PCM to the base PCM (Zinc nitrate hexahydrate) at the same temperature) of the $SiO_2/Zn(NO_3)_2.6H_2O$ nano-PCM at various temperatures.

From the graph below, it can be seen that the $k_{eff}$ values are more than 1, showing that nano-PCM has a higher thermal conductivity than reference material (PCM). The enhancement is found to grow as temperature and nano-PCM concentration rise. In the study's range of settings, however, raising the nano-PCM concentration had a greater impact on the enhancement than increasing the temperature. Enhancement in $k_{eff}$ is between 1.6 and 9 % for $Zn(NO_3)_2.6H_2O$ nano-PCM, respectively. At 55°C fluid temperature and 0.1 volume fraction, $SiO_2$/ $Zn(NO_3)_2.6H_2O$ nano-PCM exhibited a 9 % increase in performance.

As the temperature of nano-PCM rises, it is discovered that the enhancement rises as well. In the study's range of settings, however, raising the nano-PCM concentration had a greater impact on the enhancement than increasing the temperature. For $SiO_2$/ $Zn(NO_3)_2.6H_2O$ nano-PCM, the increase in effective thermal conductivity ($k_{eff}$) is between 8.1 % and 8.4 %. At 55°C fluid temperature and 0.1 volume fraction, $SiO_2/Zn(NO_3)_2.6H_2O$ nano-PCM showed the greatest improvement of 8.4 %.

**Efficient thermal conductivity of $SiO_2$/Sodium thiosulfate pentahydrate nano-PCM**

Using the KD2 Pro thermal properties analyzer, thermal conductivity measurements were conducted at different temperatures (30, 35, 40, 45, 50, 55, 60, and 65°C) for $SiO_2$/Sodium thiosulphate pentahydrate nano-PCM with five different nanoparticle concentrations (0.02, 0.04, 0.06, 0.08 and 0.1 volume fractions). Each measurement was repeated a total of three times, and the average of the last three measurements was used for further analysis.

Fig. 5 displays the results for effective thermal conductivity, $k_{eff}$ (where effective thermal conductivity, $k_{eff}$ is the ratio of thermal conductivity of the nano-PCM to the base PCM (Sodium thiosulphate pentahydrate) at the same temperature) of the $SiO_2$/Sodium thiosulphate pentahydrate nano-PCM at various temperatures.

The effective thermal conductivity values in the following figures are more than one, suggesting that the thermal conductivity of nano-PCM is greater than that of the standard material (PCM). Temperature and concentration of nano-PCM have been discovered to increase the enhancement. However, under the parameters of the investigation, raising the nano-PCM concentration has a greater impact on the enhancement than increasing the temperature. The increase in effective thermal conductivity ($k_{eff}$) for $SiO_2$/Sodium thiosulphate pentahydrate nano-PCM ranges from 1.57 to 10.5 %. $SiO_2$/Sodium thiosulfate pentahydrate nano-PCM showed the greatest improvement at 65°C fluid temperature and 0.1 volume fraction, with an increase of 10.5 %.

## CONCLUSIONS

The effective thermal conductivity of three types of $SiO_2$ nano-PCM at various temperatures and nanoparticle concentrations (0.02, 0.04, 0.06, 0.08 and 0.1 volume fractions) was determined in this study.

The effective thermal conductivity of nano-PCMs increases with increasing concentration and temperature for $SiO_2$/Paraffin Wax nano-PCM, $SiO_2$/Zinc nitrate hexahydrate nano-PCM, and $SiO_2$/Sodium thiosulphate pentahydrate nano-PCM. Effective thermal conductivity for a given nano-PCM increases linearly with concentration and temperature.

However, increasing the concentration of the nano-PCM has a more pronounced effect on the enhancement than increasing the temperature. When compared to the reference material, the effective thermal conductivity ($k_{eff}$) of $SiO_2$/Paraffin Wax nano-PCM increased by 13.7 %. When compared to reference material, the effective thermal conductivity ($k_{eff}$) of $SiO_2$/Zinc nitrate hexahydrate nano-PCM increased by 9 %. When $SiO_2$ / Sodium thiosulphate pentahydrate nano-PCM was compared to reference material, the effective thermal conductivity ($k_{eff}$) increased by 10.5 percent.

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