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Thermal Conductivity Enhancement of Novel Phase Change Materials with Graphene Nanoplatelets: A Comparative Study

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Abstract

The main goal of this research is to enhance the thermal conductivity of a commercial phase change material (PCM) (CR+28) by incorporating graphene nanoparticles (GNP). The PCM was standardized to have a latent heat of 180 kJ/kg, a specific heat of 2.1 - 1.5 kJ/kg.K, and thermal conductivity of 0.5 - 1.1 W/m.K. 10 g of GNP was added to the PCM for group 1, while the standard PCM was used for group 2. There were 20 samples in each group, and the sample size calculation was done using a G-power of 80%, $\alpha = 0.05$ per set, resulting in a total sample size of 40. The 10 g GNP in PCM showed high thermal conductivity, which was 5.35% more than the standard PCM without GNP. Statistical analysis showed a significant difference in the mean-variance of thermal conductivity between group 1 and group 2, with a p-value of 0.001 ($p < 0.05$). Based on the findings of this study, it can be concluded that adding 10g of GNP to the PCM significantly improves its thermal conductivity.

Keywords

Thermal conductivity, Graphene nanoparticles, Energy storage, Nanoparticles, Waste heat recovery, Solidification, Phase change material

Introduction

The thermal conductivity of a material is determined by its ability to transfer heat through its atomic or molecular structure. Nanoparticles can enhance the thermal conductivity of a material by providing additional pathways for heat transfer through the material. In addition, nanoparticles can also increase the surface area of a material, which can increase the number of photon scattering events and further enhance thermal conductivity [1]. The size and shape of the nanoparticles can also play a role in enhancing thermal conductivity, with smaller particles and particles with high aspect ratios being more effective [2]. This investigation is planned to improve the novel PCMs thermal conductivity with the addition of nanoparticles. Heat dissipation and electrical engines, waste heat recovery, building conditions, computer cooling, and in-vehicle thermal comfort are the principal uses of PCMs [3].

Recently, there are 1105 publications and nearly 869 papers published based on the thermal conductivity of nanoparticles in novel PCMs, respectively, according to Google Scholar and Science Direct. The rate of heat transmission is increased as a result of the higher thermal conductivity of nano enhanced PCM in contrast to that of conventional PCM [4]. To increase the heat conductivity of paraffin wax in comparison to the base material, nanoparticles dispersed in it as a PCM have been investigated [5]. A phase transition material with porous ceramic has been studied with nanoparticle addition to improve thermal conductivity [6].

It has been noticed that limited studies have been done on enhancement of thermal conductivity in PCM. This study investigated the enhancement of novel PCM of thermal conductivity by adding GNP. The main goal of adding GNP to a commercial PCM (CR+28) is to improve its thermal conductivity and enhance its thermal energy storage and release capabilities. This could have important implications for a wide range of applications, including thermal management in electronics, building insulation, and solar energy storage, among others. The study has been conducted to compare the thermal conductivity of PCM and PCM with GNP.

Materials and Method

The sample preparation and novel PCM sample encapsulation were carried out by the Institute of Mechanical Engineering, Saveetha Industries, Saveetha School of Engineering, and Saveetha Institute of Medical and Technical Sciences, Chennai (Tamil Nadu, India). PCM and PCM with GNP were the two groups that contributed to this study to determine thermal conductivity. PCM type of salt hydrate and PCM with GNP samples were utilized in the research to compare the thermal conductivity properties. A total of 40 experiments were carried out on each sample or group to examine the thermal conductivity by injecting GNP nanoparticles, with one repeat in each group for the purpose of comparison. G-power was found to be 80% after samples on each set of 20 sizes were taken.

PCM types of salt hydrate were considered as a group 1 (Control) at the melting temperature range from 26 - 28 °C and thermal conductivity at 0.5 - 1.1 W/mK. 20 sample bottles are taken for this group 1. PCM poured into the sample bottle for each 20 samples in 20 bottles. After pouring, keep it at one place to determine thermal conductivity.

PCM with 10 g of GNP is considered as group 2 (Experimental). 20 sample bottles are taken for this group 2. PCM was poured into the 20 sample bottles for each one before adding GNP into it. After pouring, 10 g of GNP was added into the 20 sample bottles which already had PCM. Eventually, group 2 was ready to compare with group 1.

At first, a 20 g PCM type of salt hydrate was taken and put into the sample bottle which is 30 ml capacity. 10 g of GNP is added into sample bottles which already have PCM. Shake the sample bottle after pouring GNP into it. By the sonication method, both GNP and PCM were mixed and sonification was done for 20 min and made into sample bottles perfectly [7, 8]. To analyze the PCM sustainable with GNP of thermal conductivity as well as normal PCM by using kd2 pro thermal analysis at 30 °C room temperature in figure 1.

The process is repeated for every 20 samples per group. Similarly, repeat this process at 10 °C and 20 °C temperature for 20 samples per group and note the temperature values to measure thermal conductivity. The thermal conductivity values of all 20 samples of group 1 are entered in table 1 (2nd column) and the values of all 20 samples of group 2 are entered in table 2 (3rd column).

Figure 1: Measurement of thermal conductivity.

Table 1: Thermal conductivity of PCM without GNP (Base) and with GNP.

Sample Number	Base PCM	Nanoparticle PCM
1	0.531	0.586
2	0.548	0.592
3	0.532	0.587
4	0.527	0.581
5	0.544	0.588
6	0.534	0.579
7	0.526	0.576
8	0.53	0.583
9	0.545	0.589
10	0.539	0.573
11	0.546	0.574
12	0.533	0.585
13	0.536	0.58
14	0.527	0.591
15	0.535	0.586
16	0.539	0.577
17	0.531	0.585
18	0.533	0.582
19	0.528	0.588
20	0.538	0.572

Statistical analysis

IBM created the statistical program Statistical Package for the Social Sciences (SPSS) for data administration, data analysis, mathematical modeling, etc. The T-test is carried out on the thermal conductivity measurement produced for the research samples using the SPSS. The statistical program (SPSS) is used to perform the descriptive table, as well as the Bonferroni studies. Stir speed and the percentage of reinforcement weight are independent variables in this study, whereas thermal conductivity is the dependent variable. The study also offers the standard deviation, significance, and mean statistics [1].

Results

The thermal conductivity of phase transition materials with and without GNP is shown in table 1 for both types of materials. Table 2 displays the group statistics for PCM with GNP and PCM without GNP of thermal conductivity. Table 3 shows the results of the independent samples test for thermal conductivity. Table 4 compares the descriptive of thermal conductivity for PCMs with and without GNP. The result is that the thermal conductivity is noted in the tables of the two groups.

Discussion

The data show that the GNP in PCM sustainably improves thermal conductivity more significantly than the standard PCM without GNP. To simplify the process, the descriptive table results also show us the mean, standard deviation, standard error, etc. to make the steps easier to understand [9]. It makes it possible to quickly calculate thermal conductivity for analysis. Previously, the study on the titanium nanoparticle with PCM provided 9.6% of thermal conductivity increase compared to the base material.

Another study on the use of NePCM with thermal enhancement to promote phase transition materials nano-enhanced PCM in Jirawattanapanit et al. [10]. This study demonstrates that 6% of NePCM is beneficial for lowering the heat sink base temperature; all NePCM-equipped configurations together lower the heat sink base temperature [11]. With the use of nanoparticles, this inquiry is intended to increase the thermal conductivity of the sustainable PCM [1]. These PCMs are employed as materials for thermal energy latent heat storage [2]. To increase heat conductivity, nanoparticles have been added to a porous ceramic phase transition [6].

But, in our research, in figure 2, 5.35% more thermal conductivity was observed than the standard PCM without GNP and also got a significant value around p = 0.001 which is ($p < 0.05$). As an outcome, PCM is generated with a substantially high thermal conductivity by addition of GNP.

Future research aims to keep objects and materials cold by shielding them from sunshine and high temperatures, as well as by using cooling telephones, switch boxes, and clothing [12]. In any application where the storing and releasing of thermal energy is necessary, PCMs are the best choice. So, novel PCM has an ability to change the material phases from one phase of solid into liquid phase and limitation which includes limited phase change temperature, cost and availability, phase transition, degradation, and temperature [13].

Table 2: Group statistics of thermal conductivity in PCM without GNP (Base) and with GNP.

Group		N	Mean	Std. deviation	Std. error mean
Thermal conductivity	PCM without GNP	20	0.5351	0.006672	0.001492
	PCM with GNP	20	0.5827	0.006018	0.001346

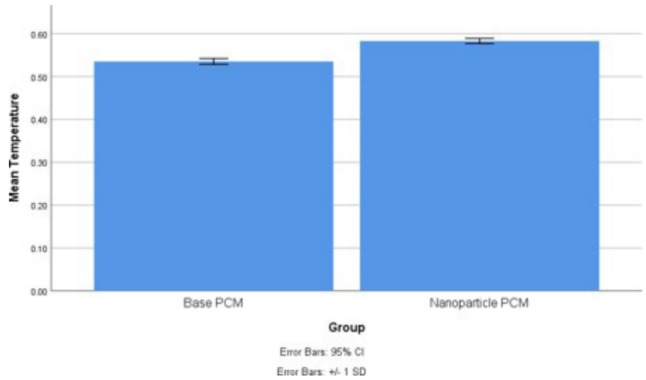

Figure 2: Mean thermal conductivity with and without GNP. The mean value shows that the thermal conductivity of PCM with GNP had a maximum value of 5.35% more than the standard PCM (Base) with +/-1 standard deviation. X-axis denotes base and nanoparticle PCM and Y-axis denotes mean temperature.

Table 3: Independent samples test of thermal conductivity in PCM without GNP (Base) and with GNP.

		Levene's test for equality of variances		T-test for equality of means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean difference	Std. error difference	95% CI of the difference	
									Lower	Upper
Thermal conductivity	Equal variance assumed	0.131	0.001	-23.69	38	0.001	-0.0476	0.00200	-0.051	-0.0435
	Equal variance not assumed			-23.69	37.6	0.001	-0.0476	0.0020	-0.051	-0.0435

Table 4: Descriptives of thermal conductivity as PCM without GNP (Base) and with GNP.

	N	Mean	Std deviation	Std error	95% CI for mean		Minimum	Maximum
					Lower	Upper		
PCM without GNP	20	0.53510	0.00667	0.00149	0.53198	0.53822	0.526	0.548
PCM with GNP	20	0.58270	0.00601	0.00134	0.57988	0.58552	0.572	0.592
Total	20	0.55890	0.02490	0.00393	0.55093	0.56687	0.526	0.592

Conclusion

Innovative encapsulating technology boosts the thermal conductivity of PCM within the constraints of this investigation (GNP). In comparison to PCM without GNP, 10 g of GNP increased thermal conductivity by over 5.35%. The PCM thermal conductivity with 10 g of GNP was significantly influenced by a unique encapsulation approach. The space industry, photovoltaic electricity systems, solar cooling, and PCM with GNP may all use PCM due to its improved heat conductivity.

Acknowledgements

None.

Conflict of Interest

None.

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