Study of Thermal Transport Properties of Carbon Based NFPCM (Graphene) For Space Cooling Applications

A. Sathishkumar¹, Hasan Mohammed, Namit Saxena and M. Cheralathan¹

Department of Mechanical Engineering, SRM Institute of Science and Technology, Kattankulathur, Chennai 603 203, Tamil Nadu, India.

Email: cheralam@srmist.edu.in

Abstract

This examination is planned to research the hardening conduct of water scattered with Graphene nano particles in a circular holder during cementing. The examinations were directed with unadulterated water and nanofluid stage change materials (NFPCMs) with GNP mass grouping of 0.35 %, 0.7 % and 1.05 %. The NFPCM was set up by scattering graphene nanoparticles and a nucleating specialist in the base PCM (stage change material). Nanoparticle’s (GNP) go about as a nucleating specialist to help the quick development of precious stones in cementing processes. The expansion of GNPs came about with an apparent decrease in the sub cooling of water from -12 ºC to -2.5 ºC alongside decrease of 25 % in cementing time attributable to its high warm conductivity and bigger explicit surface region. The expansion of the Nucleating operator lessens the serious situation of sub-cooling in the PCM, all things considered, which improves the exhibition of evaporator in a refrigeration framework. In addition, NFPCM with upgraded heat move rate and without sub-cooling can be valuable in numerous CTES (Cool Thermal Energy Storage) applications. The beginning of hardening progressed on account of NFPCM because of higher cooling rate in the sub cooling district for some random driving potential. The quickened method of vitality charging happened during 78 % of all out cementing time.

1. Introduction

In the cutting-edge world, with the movement in development power is needed in each field for operational purposes, close by which the prerequisite for its amassing has in like manner extended. This need has driven specialists to accumulate essentialness from new sources including both fossil and phony to encourage the force and energy usage need around the planet. However, close by social occasion, accumulating of this force is also significant and it serves various applications in different fields. The hidden expansive use of Fossil forces, Natural Gas, Petroleum have caused a lessening in its availability in view of which humankind has been constrained to use substitute focal points for power creation, sensible use of the open resources and Energy Storage Systems with higher efficiency. Power can be put away in different structures by various techniques, some giving momentary energy stockpiling while others are fit for mass power stockpiling. One significant goal of capacity includes the transformation of power from structures which are progressively hard to the ones increasingly efficient and helpful. Thermal energy storage systems are a very old concept in olden times, caves systems were filled with block ice cut from frozen lakes and rivers, the ice then keeps the cave system cool and undergoes phase change in the process. Thermal energy storage systems can work in the form of backup...
to refrigeration plants in times of power shortages, they can be used to increase the efficiency of existing air-conditioning plants [1]. These setups require diverting a part of cooling during the off-peak hours into a cold energy reservoir that can be tapped into when required. The cool thermal energy is stored in the form of latent heat of fusion [2].

Phase Change Materials (PCM) as the name states are materials that can change their phase at various temperatures with a special quality of High Heat of Fusion, which make them equipped for putting away and delivering energy at a specific characterized temperature. [3].

DI water is thought to be of great interest for it to act as a PCM, but due to there not being interstitial sites for crystallization freezing takes 3-4% longer. Chandrasekaran, et al. [4] played out the examination to improve heat move attributes of De Ionized water based CuO nano-fluid Phase Change Material in a round case throughout hardening for vitality effective cold warm stockpiling framework. Solidification qualities of water based NFPCM and scattering CuO nanoparticles and an accelerating specialist in the main blended PCM. Nearness of CuO nanoparticles in water diminished hardening span impressively by 35% and 33.3%. Upgrading heat move rate because of synergistic impact of nucleating specialist and nanoparticles. Kumaresan et al. [5] performed research on Phase Change Materials based nano-fluids for vitality proficient and cool warm stockpiling framework. This current examination presents the hardening conduct of De Ionized water hinged nanofluid stage change material exemplified in a round holder. The nano-fluid stage change material is set up by scattering the multi divider carbon nanotubes with volume divisions of 0.15, 0.3, 1.0. 0.45 and 0.6% respectively in water as the base stage change material. The upgraded warm vehicle traits of the Nano Fluid Phase-Change Material are exceptionally valuable to work the cool warm vitality stockpiling (CTES) framework at greater working temperature of the optional refrigerant. It is anticipated that a possible vitality sparing capability of around 6e9% in the Cool Thermal energy Stockpiling utilizing the Nano-Fluid PCMs Sathishkumar et al. [6] performed research on Phase-Change Materials hinged nano- fluids for vitality proficient and cool warm stockpiling framework. This current investigation presents the hardening conduct of De Ionized water-based nano-fluid stage change material epitomized in a round tank. The base liquid is DI water. Thermal conductivity improvement of 11.7% and 56% was watched Shortened. the cementing length of the Nano-Fluid Phase Change Material by 25% and 20.6% than that of base Phase-Change Material at the encompassing shower temperature of - 12⁰c and - 9 ⁰c, separately. Braga et al. [7] research helped understand the sort of control utilized on mass stockpiling in tank heat exchangers, full scale exemplification and smaller scale epitome. The weight drop because of embodiment was audited and the successful methods of warm conductivity upgrade procedures are examined. Different regulation strategies like Shell type, empty circles, pressed bed, miniaturized scale epitome alongside different analyses and examinations were arranged and recorded. Around 50 related articles were evaluated on PCM advancement. (Chan et al. [8] reported an examination on execution of Nano PCM with water as base Phase-Change material blended with 50 nanometre Al203 in a circular container was done. The channel temperature & volume stream pace of warmth move liquid (HTF) (Aqua- ethylene glycol arrangement is utilized as a Heat Transfer Fluid) are changed to keep up the case divider temperature consistent at a temperature go from 4⁰ C to 10⁰ C individually. The volume portion convergence of the nano-particles in the utilized Phase-Change Material in the examination spans from .5% to 2%. Eames et al. [9] worked out the analysis on the dynamic conduct of single circular warm (ice) stockpiling components. Three glass circles of radii of 4.07, 3.5 and 3.135 cm were picked for this examination. A streaming water–glycol arrangement throughout a scope of temperature shifting somewhere in the range of 4.5 and 12°C (during discharging) and somewhere in the range of −9.5 and −4.4°C (during charging) was utilized as a warmth move liquid. Several fascinating outcomes have been gotten from this investigation. Ismail et al. [10] researched on the delayed consequences of a numerical report on the glow move during the strategy of solidifying of water inside a round compartment. The directing states of the issue and related breaking point conditions were nitty gritty and clarified using a constrained differentiation approach and a moving framework plot. The prototype was additionally employed used to look into the consequences of dimensions and material of the shell, starting temperature of the stage.
change material and the outside temperature of the round case on the established mass segment and the perfect open door for the all solidifying. Bedecarrats et al. [3] worked out the examination on the investigation of a mechanical procedure of vitality stockpiling usable for cooling or refrigeration, investigating a test equipment which is a container with a lessened size, stacked up with aimlessly dispersed business handles, set in a refrigeration annulus. The handles are round holders in which stage change materials (PCM) are exemplified.

2. Materials and methods

2.1 Selection and Preparation of Nano fluid phase change material.

The determination of the PCM relies upon the heat properties like high explicit heat, high idle warmth of combination per unit, high warm conductivity is fundamental for better thermal execution and heat transfer. Explicit prerequisites relying upon the circumstance like synthetic properties. The PCM ought to have the option to support stage change under cyclic thermal loading. Contemplating this DI Water is chosen with a Thermal Conductivity of 0.608 W/mK for the exploration.

The nanoparticles should help improve the heat conductivity of the DI water, and assists with the crystallization during freezing unavoidably lessening the time taken for freezing and basically the force required. Taking the different heat properties and components into thought for the cooling energy framework application, Graphene Nanoplatelets (GNP) have been chosen for the exploration.

The properties of GNP is listed in Table 1.

| Table 1 Specifications of GNP. | Graphene Nano Powder 99% |
|------------------------------|--------------------------|
| Product Name | Graphene Nano Powder 99% |
| Formula | C |
| Molecular Weight | 12.01gm/Mol |
| Supplier | Platonic Nanotubes |
| Particle Size (Bet) | < 10 Nm |
| Appearance | Powder |
| X-Ray Diffraction | Conforms |

2.1.1 Preparation of Nano fluid phase change material

Nanofluid stage change materials (NFPCM) planning comprises of a couple of successive advances when utilizing it as a working liquid in any CTES framework. NFPCM is simply not a blend of the nanoparticles and base PCM. The best possible blending, sonication of the nanoparticles is required to yield the best outcomes. The two essential strategies for planning NFPCMs are given beneath: -

- Single-step method: Direct evaporation and condensation is carried out on the nano particle in the base fluid to produce nanofluids.
- Two-step method: In this method, the nanoparticles are obtained by different methods and then are dispersed into the base liquid with dispersants.

Two stage techniques are normally favoured as changing the nanoparticles with various base PCMs builds the extent of study. A determined measure of the surfactant SDBS is blended in with a known volume of base PCM which is DI water. The volume of base PCM taken is 90% of the total volume encased inside the ball. The blend is then mixed for 15-20 minutes utilizing an attractive stirrer.
Surfactants are mixes which diminish the surface pressure or the durable power between the fluid and strong. Surfactants may go about as cleansers, wetting operators, frothing specialists and dispersants. The graphene nanoparticles are then scattered in the above blend and the arrangement is mixed for another 30 mins. To get even scattering of the nanoparticles, the arrangement was ultra-sonicated for 30 mins at a recurrence of 40 KHz.

![Figure 1. Steps involved in the preparation of NFPCM.](image)

CNTs are hydrophobic, and powerless to collection and precipitation in water and along these lines the characteristic packaging of the cylinders brought about by solid Van der Waals powers, non-receptive surface properties, uncommonly enormous explicit surface regions, and perspective proportions make the blend harder.

![Figure 2. SEM image of NFPCMs: (a) 0.35 of wt. % of GNP (b) 0.7 of wt. % of GNP (c) 1.05 of wt. % of GNP](image)
These scanning electron microscope photos help to determine the dispersion of the GNP, in the prepared PCM. The thermophysical properties enthalpy, specific heat (Cp), density (ρ), was measured it with the differential scanning calorimetric (DSC) analysis.

2.2 Experimental setup

![Experimental setup of solidification testing rig.](image)

2.2.1 Encapsulation of the spherical capsule with RTD’s

The round ball used to hold the nanofluid was comprised of Low-Density Polyethylene having an external breadth of 75mm and a thickness of which was 2.5 mm. The circular ball used to hold the nanofluid was comprised of Low-Density Polyethylene having an external width of 75mm and a thickness of which was 2.5 mm. The opening was amplified enough to permit an away from of the three RTD sensors without a moment’s delay. The PCM ball was loaded up with the arrangement. RTD sensors immediately. The PCM ball was filled with the solution. RTD sensors were used to measure the temperature inside the spherical capsule. For this, 3 RTDs were placed on a support wire. The support wire was first passed through a hole made in the cap of the spherical capsule. The RTD and the support wire made of steel were insulated using the polytetrafluoroethylene tape. The placement of the RTDs were done a gap of 10 mm from the first sensor. The RTD sensors were secured with the help of electrical tape. The back ends of the sensor wire are required to be labelled so that there is no confusion while attaching the cable to different channels. The centre RTD is labelled as RTD 1 and the following 2 RTDs at intervals of 10 mm from previous, labelled as RTD 2 and RTD 3.

2.3 Volume calculation of nanofluid in NFPCM capsule

*Volume calculation of nano fluid in spherical capsule*

\[
\text{diameter of the spherical capsule} = 75\text{mm} \\
\text{thickness of the spherical capsule} = 2.5\text{mm}
\]
radius of the spherical capsule = 36.25mm

\[
\text{volume of spherical capsule} = \frac{4}{3} \times \pi r^3
\]

\[
= \frac{4}{3} \times \pi \times 0.03625^3
\]

\[
= 1.995 \times 10^{-4} m^3
\]

90% volume of nano fluid filled in spherical capsule = \(1.810 \times 10^{-4} m^3 = 180 \text{ml approx.}\)

![Diagram showing RTD's within the sphere](image)

**Figure 4.** This shows the placement of RTD’s within the sphere, for proper measurement of the thermal characteristics of the NFPCM.

3. Results and Discussion

3.1 Measurement of Density

The density of both the water and NFPCM are estimated at air temperature by gauging a fluid example in a standard volumetric cup (Class An) of 25 ml and 50 ml, utilizing a high precision electronic parity (± 0.002 g) with isolated space compartment. The methodology is rehashed multiple times to accomplish greater precision. We can draw the conclusion from ‘Table 2’ the percentage of increasing
the density is maximum for 1.05 wt. % of GNP. Also, minimal changes in the density does not affect the stability of the NFPCM.

\[
\text{Density } \rho = \frac{M_t - M_{fl}}{M_{fl}}
\]

Where, \( M_t \) = mass of flask and NFPCM
\( M_{fl} \) = mass of the flask

\[
\text{percentage increase of density} = \frac{(\rho_{NFPCM} - \rho_{PCM})}{(\rho_{PCM})}
\]

### Table 2 Density Measurement of different NFPCMs.

| SPECIMEN | COMPOSITION       | \( M_t \) (kg) | \( M_{fl} \) (kg) | \( P \) (kg m\(^3\)) | \% of increase in density |
|----------|------------------|---------------|----------------|----------------|--------------------------|
| S1       | De Ionized water | 0.0528        | 0.0280         | 990            | -                        |
| S2       | 0.35%            | 0.0528        | 0.0280         | 991            | 0.30                     |
| S3       | 0.7%             | 0.0530        | 0.0280         | 993            | 0.81                     |
| S4       | 1.05%            | 0.0530        | 0.0280         | 1002           | 1.14                     |

### 3.2 Variation of transient temperature with time for both DI water and NFPCMs

Figure 5 shows the time temperature history for the DI water at three different radial locations for the surrounding bath temperature of -9 C. It was observed that the total mass of the DI water got solidified within 7000 seconds including sub-cooling. Figure 6 depicted that the variation of solidification time for the NFPCMs with respect to the concentrations of the GNPs. The NFPCM with higher mass concentration of GNP shows the maximum reduction in the over all solidification time as compared with DI water. The incorporation of Graphene Nano Particles likewise abbreviated the solidification time of the Nano-fluid PCM by 20.6 % than that of PCM without the addition of nano particles at the encompassing temperature of - 9 °C. Due to the addition of maximum concentration GNP with DI water results in the reducing the need for subcooling substantially. The similar pattern of solidification and sub-cooling behaviour was observed for addition of different nano-particles has been reported in various research articles.

The time temperature history for the DI water at three different radial locations for the surrounding bath temperature of -9 C shows in Figure 7. It was observed that the total mass of the DI water got solidified within 5400 seconds including sub-cooling. Figure 8 depicted that the variation of solidification time for the NFPCMs with respect to the concentrations of the GNPs. The NFPCM with higher mass concentration of GNP shows the maximum reduction in the overall solidification time as compared with DI water. The incorporation of Graphene Nano Particles likewise abbreviated the solidification time of the Nano-fluid PCM by 25 % than that of PCM without the addition of nano-particles at the encompassing temperature of - 12 °C. The subcooling was eliminated completely for the addition of 0.75 wt. % GNP with DI water.
Figure 5. Variation of transient temperature of DI water in all three radial locations ($T_{\text{surr}} = -9$ °C).

Figure 6. Variation of transient temperature of DI water at -9°C for different NFPCMs.
Figure 7. Variation of transient temperature of DI water at -12 °C in all three radial locations.

Figure 8. Variation of transient temperature of DI water at -9 °C for different NFPCMs.
3.3 Enthalpy Measurement

Figure 9 – 10 shows that the DSC analysis for DI water for both melting and freezing conditions. Here the area under the curve represents the enthalpy generated. The peak represents the highest and the lowest temperature achieved during freezing and melting and the end signifies the temperature at which melting or freezing is completed. For DI water, we can see that the area under the curve and the peak temperatures are lowest which shows that is generating the lowest enthalpy and also it is taking the most amount of time to reach their final states of melting and freezing showing no significant amount energy saved. Figure 9 shows that the DI water start to freeze at -17.8 °C and ends at -26.1 °C. Also, the peak heat rejection takes place at -22.2 °C. The total amount of heat removed from the DI water at the rate of 247 J/g. However, the melting starts at -0.4 °C and end at 18.2 °C at the heat addition rate of 280 J/g.

![Figure 9. DSC analysis – Enthalpy of DI water for both freezing and melting.](image1)

![Figure 10. DSC analysis – Enthalpy of NFPCM (0.35 wt. %) for both freezing and melting.](image2)
Figure 11. DSC analysis – Enthalpy of NFPCM (0.7 wt. %) for both freezing and melting.

Figure 12. DSC analysis – Enthalpy of NFPCM (1.05 wt. %) for both freezing and melting.

Figures 11 and 12 show that the NFPCMs start to freeze around -18 °C and ends at -21 °C. Also, the peak heat rejection takes place around -21.2 °C. The total amount of heat addition got enhanced from 247 J/g to 323 J/g. The improvement in the heat absorption area got achieved due to the increase in the thermal transport properties of the DI water by adding high conductive solid particles in nano-size.

4 Conclusions

A progression of examinations was carried out on hardening attributes of De Ionized water based nano fluid Phase-Change Material with a nucleating operator and the accompanying ends was made dependent on the trial outcomes.
- The existence of higher conductive Graphene Nano Particles went about as the nucleating specialist to start the cementing of the NFPCM ahead of time to that of the base PCM through significant decrease in the level of subcooling. The incorporation of Graphene Nano Particles likewise abbreviated the solidification time of the Nano-fluid PCM by 25 % and 20.6 % than that of PCM without the addition of nano particles at the encompassing temperature of - 12 °C and - 9 °C individually.
- The subcooling behaviour of the DI water got reduced substantially with the addition of GNP in maximum concentration.
- It was reported that the addition of high conductivity low density nanoparticles will not improve the density of the base fluid appreciably.
- Because of increase in different convergences of nano into the base pcm conductivity increments and cementing time is influenced. The thermal conductivity of PCM gets upgraded by utilization of nano particles.
- The charging time was diminished by 20-25 % in every one of the setups at individual conditions. The solidifying time was recorded to be different for each thermal exchange surface utilized.
- The escalated freezing was acknowledged for the initial 25% of the solidification duration throughout which fifty percentage of the mass settled in base PCM and Nano-Fluid PCM.

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References

[1] Sathishkumar A, Cheralathan M. Influence of thermal transport properties of NEPCM for cool thermal energy storage system. Journal of Thermal Analysis and Calorimetry. 2020 Oct 29:1-2.
[2] Kumaresan V, Chandrasekaran P, Nanda M, Maini AK, Velraj R. Role of PCM based nanofluids for energy efficient cool thermal storage system. International Journal of Refrigeration. 2013 Sep 1;36(6):1641-7.
[3] Sharma RK, Ganesan P, Tyagi VV. Long-term thermal and chemical reliability study of different organic phase change materials for thermal energy storage applications. Journal of Thermal Analysis and Calorimetry. 2016 Jun 1;124(3):1357-66.
[4] Chandrasekaran P, Cheralathan M, Kumaresan V, Velraj R. Enhanced heat transfer characteristics of water based copper oxide nanofluid PCM (phase change material) in a spherical capsule during solidification for energy efficient cool thermal storage system. Energy. 2014 Aug 1;72:636-42.
[5] Kumaresan V, Chandrasekaran P, Nanda M, Maini AK, Velraj R. Role of PCM based nanofluids for energy efficient cool thermal storage system. International Journal of Refrigeration. 2013 Sep 1;36(6):1641-7.
[6] Sathishkumar A, Kumaresan V, Velraj R. Solidification characteristics of water based graphene nanofluid PCM in a spherical capsule for cool thermal energy storage applications. International Journal of Refrigeration. 2016 Jun 1;66:73-83.
[7] Braga SL, Guzmán JJ, Pacheco HG. A study of cooling rate of the supercooled water inside of cylindrical capsules. international journal of refrigeration. 2009 Aug 1;32(5):953-9.
[8] Chan CW, Tan FL. Solidification inside a sphere—an experimental study. International communications in heat and mass transfer. 2006 Mar 1;33(3):335-41.
[9] Eames IW, Adref KT. Freezing and melting of water in spherical enclosures of the type used in thermal (ice) storage systems. Applied thermal engineering. 2002 May 1;22(7):733-45.
[10] Ismail KA, Henriquez JR, Da Silva TM. A parametric study on ice formation inside a spherical capsule. International Journal of thermal sciences. 2003 Sep 1;42(9):881-7.

[11] Bedecarrats JP, Castaing-Lasvignottes J, Strub F, Dumas JP. Study of a phase change energy storage using spherical capsules. Part I: Experimental results. Energy Conversion and Management. 2009 Oct 1;50(10):2527-36.