Serbian Tribology Society

SERBIATRIB '25

19th International Conference on Tribology

Faculty of Engineering University of Kragujevac

Kragujevac, Serbia, 14 – 16 May 2025

IMPACT OF GRAPHENE ON THE PROPERTIES OF PHASE CHANGE MATERIAL

Kapilan NATESAN[1, *], Sriram MUKUNDA[1], Vidhya P[3], Shivarishika K[4]

[1,2] Nitte Meenakshi Institute of Technology, Yelahanka, Bangalore, India

[3] Government First Grade College, Bangarpet, India

[4] M.S. Ramaiah Institute of Technology, Bangalore, India

*Corresponding author: kapil_krecmech@yahoo.com

Abstract: The Phase change materials (PCMs) have the unique ability to store and release large amounts of heat within a relatively small temperature range due to their latent heat properties. The PCMs are used in solar power system, textile industry, buildings etc. The paraffin wax was one of the cheapest PCM and used in thermal energy storage applications. However, its drawback is its low thermal conductivity which affects the heat transfer. Hence, in this work, we have used graphene which has higher thermal conductivity to enhance the thermal conductivity of the paraffin wax. The graphene of various concentration such as 0.25, 0.5, 0.75 and 1.00 % were added to the paraffin wax. The results show improvement in thermal properties of the paraffin wax offers a promising solution for enhancing heat transfer in thermal management systems and heat exchangers. The thermal conductivity of the paraffin wax improved significantly with the addition of graphene and higher thermal conductivity was observed with the graphene dosage of 1%. Additionally, the melting temperature of the paraffin wax has reduced significantly with graphene addition. Also, the graphene addition resulted in faster melting and solidification rates due to and enhanced the overall thermal performance of the paraffin wax.

Keywords: Phase change materials, paraffin wax, property, graphene.

1. INTRODUCTION

The Phase change materials (PCMs) are a class of materials that exhibit the remarkable ability to store and release thermal energy during phase transitions. The PCMs have gained much important in recent years because of their storage ability to store higher energy in a compact and efficient manner. The PCM materials can undergo a physical transformation from one phase to another, such as from solid to liquid or vice versa, while absorbing or releasing a large amount of heat in the process. This unique property makes PCMs invaluable in various applications ranging from energy storage and thermal management to temperature regulation and building insulation. [1, 2].

The PCM has a high energy storage capacity; however, its temperature remains constant during the phase transition, resulting in a stable material temperature throughout the process, which is crucial for applications requiring stable thermal environments, such as electronics, green buildings, and transportation. This constant-temperature property makes PCMs particularly effective for temperature regulation.

The selection of a suitable PCM is primarily depend upon by its phase transition enthalpy and the temperature at which the phase change occurs as these properties determine the material's ability to store and release thermal energy efficiently [3]. The PCMs offer several advantages over conventional energy storage materials. One of the key benefits is their high energy storage density compared to materials like water or concrete, meaning a smaller volume or mass of PCM can store a substantial amount of energy. The PCM is available in a wide range of types, each tailored to specific applications depending on their properties which play a crucial role in determining their suitability for different thermal energy storage or temperature regulation needs. Advanced PCMs, including eutectic mixtures and composite materials, are engineered to improve specific characteristics, such as enhancing thermal conductivity or mitigating supercooling [4,5]. The applications of PCMs are diverse and expanding rapidly. The PCMs also play a vital role in electronics cooling, absorbing and dissipating heat generated by devices, which helps prevent overheating and extends the lifespan of electronic components In the construction industry, PCMs are integrated into building materials like floor, ceiling, walls, ceilings etc to minimise heat gain and temperature control [6]. In recent years, microencapsulated PCM is getting attention and popular among researchers. The microencapsulation of PCMs offers an effective solution to challenges such as volume change, phase separation and leakage during phase transitions as this technique not only enhances the structural stability of PCMs but is also one of the most widely adopted methods to improve the overall efficiency and reliability of thermal energy storage systems [7].

The primary source of paraffin wax (PW), an organic substance that is colorless, odorless, and chemically based, is petroleum waste. It is a combination of hydrocarbons with a melting point that typically ranges from below freezing to over 100 degrees Celsius. The number of carbon atoms in the crystal structure is the primary criterion used to classify PW. The paraffin, also referred to as pure alkanes, is a gaseous substance with one to four carbon atoms at ambient temperature. At normal temperature, paraffin with five to seventeen carbon atoms is typically liquid; paraffin with more than seventeen is a wax. Saturated hydrocarbons make up solid waxes, which are inherently linear, isobranched, or cycloalkanes [8]. The PW is widely utilized across various applications due to its distinctive thermal and chemical properties due to its ability to absorb and release substantial amounts of thermal energy during phase transitions makes it a popular choice as a PCM. During periods of excess energy production, PW melts and stores thermal energy; this stored heat is later released as the wax solidifies, helping to meet increased energy demand or compensate for fluctuations in renewable energy availability. It has low melting point (47 to 65°C), low reactivity and chemical inertness enhance its safety and compatibility with a wide range of materials, minimizing the risk of undesirable chemical interactions [9].

The solidification of the PCM can be reduced using radial fins with turbulence promoters which also increases the interface velocity; however, fin parameters have to be optimised to get better performance [10]. The microencapsulation of PCMs is used to minimise PW leakage during its transition (from solid to liquid phase) and this type of PCMs are preferred in recent years, however its thermophysical properties has to be enhanced [11].

1.1 Literature Review

The PCM has a greater energy storage capacity because it retains energy in the form of latent heat [12]. The heat transfer characteristics of the PCM are enhanced by the addition of nanoparticles (NPs) which have higher thermal conductivity. The addition of copper NPs in the PCM greatly improves the thermal conductivity [13]. When the liquid phase is heated, a temperature gradient develops between the heated surface and the surrounding liquid, which can impede or reduce the efficiency of heat transfer. As a result, the layer of PCM loses thermal energy. It is essential to transfer this heat to the colder surface until solidification occurs [14]. It is reported that the PCM integrated with heat pipe provides a cooling load of about 87% within the specified power range, however it is necessary to design various typologies [15].

Various methods are used to improve the thermal conductivity of PCM; however, these methods should be cheap and environmentally friendly. It is suggested that adding NPs is one of the methods [16]. The use of titanium oxide (TiO2) as additive enhances its thermal properties and it is suggested that the PCM added with TiO2 can be used in solar PV/T applications [17].

The aluminium oxide (Al2O3) and multi wall carbon nanotubes (MWCNTs) also used to enhance the properties of PW. The results revealed enhancement in the thermal properties of the PCM added with these materials [18]. A study was carried out to use PW as the PCM for the thermal battery [19]. A study was conducted to improve the thermal performance of energy storage in a hydronic system by integrating evacuated tubes into a hot water tank. The findings indicated that the system achieved optimal thermal performance under warm weather conditions [20]. It is reported that the graphene oxide and single walled carbon nanotubes (SWCNT) also can be used for the improvement of thermal properties of the PCM. The obtained findings show the addition of SWCNT NPs with dosage 10% enhances the melting point [21]. The results of a study indicate that adding Fe_2O_3 NPs at any dosage enhances both the density as well as viscosity, however the thermal conductivity of PW is enhanced [22]. A numerical investigation was conducted on the melting of PW dispersed with Al_2O_3, Copper Oxide (CuO), and Zinc Oxide (ZnO) using ANSYS. The results indicate that dispersing NPs in small dosage causes enhancement in rate of heat transfer among the NPs tested, the Al_2O_3 showed slightly better thermal performance compared to other NPs [23]. A study investigates the influence of Al_2O_3 NPs concentrations, the impact of activated wall orientation and hot wall temperature on the melting process and thermal energy storage performance. The computed results demonstrate that these parameters significantly impact both the melting rate and the amount of stored energy. The findings indicate a greater enhancement in performance when the enclosure is filled with a 1 vol% NP dosage and heated from the bottom. However, increasing the NP dosage beyond 1 vol% leads to diminishing returns [24].

The purpose of this work is to improve the characteristics of PW by adding graphene (G), with an emphasis on dosage optimization. We aim to determine the optimal concentration of G that optimizes PW's performance through meticulous investigation, thereby enhancing its efficacy as a phase transition material.

1.2 Materials and methodology

One inexpensive material that is frequently used as a PCM is PW. Its reduced TC, however, may make it more difficult to distribute heat evenly and may cause cooling processes to lag. In order to overcome this restriction, G was added as an additive to PW in order to increase its TC and benefit from its better thermal characteristics. The G of dosages such as 0.25, 0.5%, 0.75, and 1% by weight, were considered and added to the PW and a study was carried out, how different G dosages affects the PW’s TC.

Figure 1 illustrates the PW, while Figure 2 presents the G and the SEM image of the G is displayed in Figure 3.

Figure 1. photo of PW

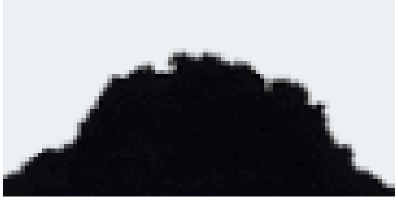

Figure 2. photo of Graphene (G)

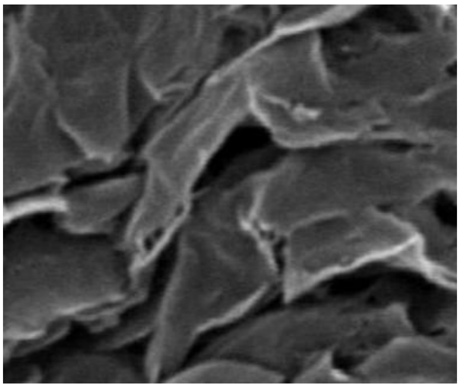

Figure 3. Graphene's SEM image

2. EXPERIMENTAL SETUP

To accomplish consistent mixing of G and PW, an ultrasonicator was used and is shown in the figure 4. First, the PW was heated to 70 degree C using water bath and added with 0.25% graphene and sonicated for 20 minutes. The solution was mixed, then allowed to cool, which produced a consistent dispersion of G throughout the PW. This process was followed in a similar manner for G dosages of 0.5%, 0.75%, and 1% by weight. After that, samples of the synthesized PW were gathered for various assays at different doses of graphene. The ultrasonicator utilized in this investigation to effectively mix G and PW and provide consistent characteristics among the samples.

Figure 4. Ultra sonicator used in this work

Figure 5 illustrates the PW with various G dosages and the samples were collected. The tests were performed to understand the impact of G on its heat transfer properties.

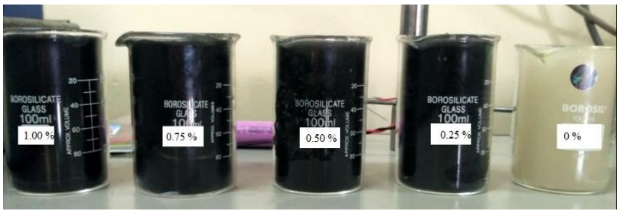

Figure 5. PW with different dosages of graphene

2.1 Results and discussion

Incorporating G into PW can significantly impact its properties. The G, a two-dimensional carbon material recognized for its outstanding mechanical and thermal characteristics, alters the behavior of PW in several ways.

Table 1. Properties of PW and Graphene

Properties of PW	
Property	Value
Thermal conductivity	0.179 W/mK
Density	901 kg/m^3
Melting point	60 ºC
Freezing point	51 ºC
Properties of Graphene	
Property	Value
Thermal conductivity (W/mK)	
Thickness	5 to 9 nm
Density	0.01 g/cm^3
Surface area	60 to 200 m^2/g
Size	10 µm
Purity	99 %
Odour	Odourless

The PCMs are characterized by their thermal conductivity (TC), which is a critical component in determining successful heat transmission and is shown in figure 7. Although PW is known for having a low TC, adding G, which has a high TC, can greatly enhance the composite material's thermal performance. This improvement is especially helpful in applications like thermal management systems where effective heat transport is crucial. The amount of G supplied has a direct impact on how much the PCM improves in terms of heat conductivity; significant improvements are shown at 1% dose. The increased heat conductivity with higher doses of G make the material more useful for a variety of purposes.

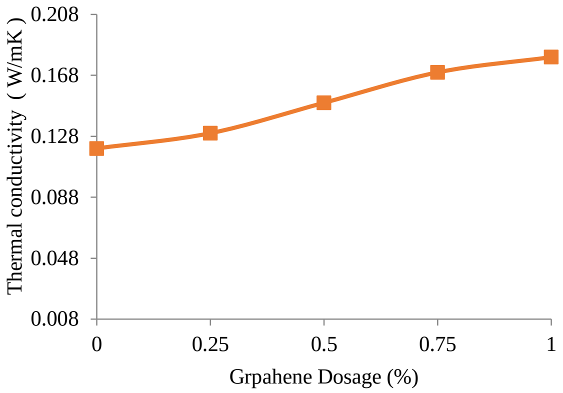

Figure 6. Influence of G addition on the TC's of PW

One important feature affecting PW's usage as a PCM is its melting point, particularly when the substance is changing from a solid to a liquid. Although PW normally has a high melting temperature, adding G may change this characteristic. When incorporated, G's remarkable TC and stability can change how PW melts. Its exceptional heat transfer qualities raise the composite's overall TC and encourage more effective heat transfer, which could have an effect on the melting process. Furthermore, the composite can withstand higher temperatures before decomposition or deterioration happens due to graphene's thermal durability, which could raise the melting point or postpone the start of thermal breakdown.

However, depending on variables like G concentration, the quality of its dispersion within the wax matrix, and the interactions between G and wax molecules, the precise effect of G on the melting temperature of PW may differ. The kind and purity of the PW utilized are two other factors that affect melting behavior. Notably, the dosage of G has a substantial impact on the melting temperature; PW tends to melt at a lower temperature as G concentration rises. The melting temperature is significantly lowered at 1% G dose in comparison to other levels, but only somewhat at 0.25% and 0.50% dosages. The melting temperature fluctuations at different dose levels of G are shown in Figure 8.

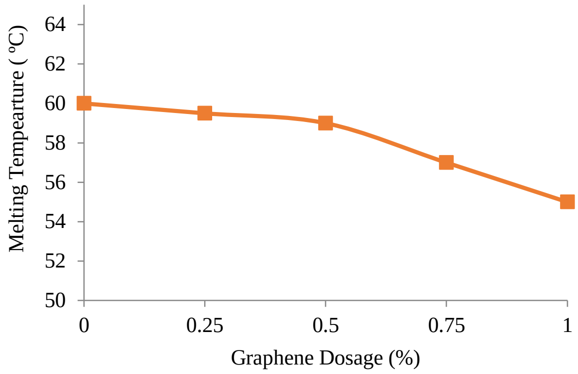

Figure 7. Influence of G addition on the melting temperature of PW

The total density of the composite material may decrease as a result of G being mixed with PW. However, a number of variables, such as the concentration of G and its dispersion within the wax matrix, affect how much of an increase there is. The addition of G results in a lighter component, reducing the composite's density. Nevertheless, the resulting density decrease could not be very large if the G concentration is low in relation to the PW. As a two-dimensional material with a high aspect ratio, G can considerably improve the characteristics of the composite, even at modest concentrations, without leading to a considerable increase in density.

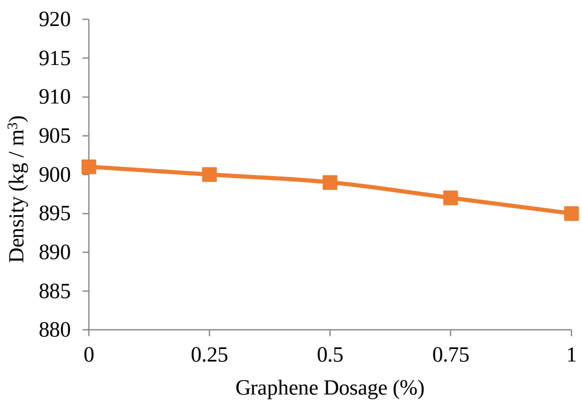

Figure 8. Influence of G addition on the density of PW

It is essential to understand the precise concentration of G and how it was dispersed throughout the wax matrix in order to provide an appropriate assessment of the density changes. The density of the composite is also influenced by variables like the G's size and shape. Significantly, a tiny and deemed insignificant change in the density of PW has been noted with different G dosage levels. The density variations corresponding to various doses of G are depicted in Figure 8.

3. CONCLUSION

The PW is a readily available material commonly used across a wide range of applications. It possesses a high latent heat storage capacity, allowing it to absorb and release substantial amounts of thermal energy during phase transitions, which facilitates effective heat storage and release. Additionally, PW demonstrates excellent thermal stability, resisting degradation or decomposition over numerous phase change cycles. It can endure repeated heating and cooling without substantial loss of performance. Moreover, PW is non-toxic and non-hazardous, ensuring its safety for various uses. However, its relatively low TC can limit its effectiveness as the PCM. To address this issue, this study incorporates graphene as an additive to enhance the TC of PW. The results indicate that the addition of G significantly improves TC, with a 1% weight dosage of G yielding the most favourable results for enhanced heat transfer.

ORCID iDs

Kapilan NATESAN 0000-0002-5351-0341
Sriram MUKUNDA 0000-0002-5416-5375
Vidhya P
Shivarishika K

REFERENCES

[1] Vrajesh P Panchamiya, "A review on phase change materials: Development, Types, and Applications", J. Phys.: Conf. Ser. 2426 012033, 2023.

[2] Muhammad Saqib, Rafal Andrzejczyk, "A review of phase change materials and heat enhancement methodologies", *Energy and envrionment*, Vol. 12, Issue3, e467, 2023.

[3] Ao-Shuang Yang, Tian-Yu Cai, Li Su, Yong-Sheng Li, Fang-Fang He, Quan-Ping Zhang, Yuan-Lin Zhou, Ren He, Kai Zhang, Wen-Bin Yang , „Review on organic phase change materials for sustainable energy storage", *Sustainable Energy Fuels*, vol. 6, pp. 5045-5071, 2022.

[4] Rubel, R.I., Akram, M.W., Alam, M.M. "Phase Change Materials in High Heat Storage Application: A Review". *Arab J Sci Eng* vol 49, pp. 14533–14551, 2024.

[5] Ismail, K. A. R., Lino, F. A. M., Teggar, M., Arıcı, M., Machado, P. L. O., Alves, T. A., De Paula, A. C. O., and Benhorma, A.A "Comprehensive Review on Phase Change Materials and Applications in Buildings and Components", *ASME Open J. Engineering,* 1 01104, 2022.

[6] Muhammad Saqib, Rafal Andrzejczyk, "A review of phase change materials and heat enhancement methodologies", *Energy and envrionment,* Vol 12, Issue3, e467, 2023.

[7] Patil, Jayesh R., Mahanwar, Prakash A., Sundaramoorthy, Elamaran and Mundhe, Gajanan S.. "A review of the thermal storage of phase change material, morphology, synthesis methods, characterization, and applications of microencapsulated phase change material" *Journal of Polymer Engineering*, vol. 43, no. 4, pp. 354-375, 2023.

[8] Qudama Al-Yasiri, Márta Szabó, "Paraffin As a Phase Change Material to Improve Building Performance: An Overview of Applications and Thermal Conductivity Enhancement Techniques, Renew". *Energy Environ. Sustain*. Vol. 6, 38, 2021.

[9] Reza Vakhshouri, A. "Paraffin as Phase Change Material". IntechOpen. 2020. doi: 10.5772/intechopen.90487

[10] Giulia Righetti, Luca Doretti, Claudio Zilio, Giovanni A. Longo, Simone Mancin, "Experimental investigation of phase change of medium/high temperature paraffin wax embedded in 3D periodic structure", *International Journal of Thermofluids*, Vol 5–6, 100035, 2020.

[11] Zhijuan Chang, Kai Wang, Xuehong Wu, Gao Lei, Qiangwei Wang, He Liu, Yanling

Wang, Qi Zhang, “Review on the preparation and performance of paraffin-based phase change microcapsules for heat storage“, *Journal of Energy Storage*, Vol 46, 103840, 2022.
[12] K. Chintakrinda, R.D. Weinstein, A.S. Fleischer, “A direct comparison of three different material enhancement methods on the transient thermal response of paraffin phase change material exposed to high heat fluxes“, *Int. J. Therm. Sci*., vol. 50, pp. 1639–1647, 2011.
[13] X. Ma, M. Sheikholeslam, M. Jafaryar, A. Shafeee, T. Nguyen-Thoi, Z. Li, “Solidification inside a clean energy storage unit utilizing phase change material with copper oxide nanoparticles”, *Journal of Cleaner Production*, 245, 118888. 2020.
[14] Q. Zhang, Y. Rao, Y. Jiao, L. Li, Y. Li, and L. Jin, “Preparation and Performance of Composite Building Materials with Phase Change Material for Thermal Storage“, *Energy Procedia*, 143, pp. 125-130, 2017.
[15] Castell, C. Solé, “Design of latent heat storage systems using phase change materials (PCMs)“, Advances in Thermal Energy Storage Systems, *Woodhead Publishing Limited*, pp. 285–305, 2015.
[16] Z.A. Qureshi, H.M. Ali, S. Khushnood, “Recent advances on thermal conductivity enhancement of phase change materials for energy storage system: a review“, *Int. J.Heat Mass Transf*. 127, pp. 838–856, 2018.
[17] Hussein M. Maghrabie, Khaled Elsaid, Enas Taha Sayed, Ali Radwan, Ahmed G. Abo-Khalil, Hegazy Rezk, Mohammad Ali Abdelkareem, A.G. Olabi, “Phase change materials based on nanoparticles for enhancing the performance of solar photovoltaic panels: A review“, *Journal of Energy Storage*, vol 48, 103937, 2022.
[18] Muhammad Aqib, Azhar Hussain, Hafiz Muhammad Ali, Ammar Naseer, Furqan Jamil, “Experimental case studies of the effect of Al2O3 and MWCNTs nanoparticles on heating and cooling of PCM“, *Case Studies in Thermal Engineering*, Vol 22, 100753, 2020.
[19] Dinesh Kumar Saini, Chandrashekara M., “Enhancing paraffin wax based thermal battery performance with water: Fabrication and experimental analysis“, *International Communications in Heat and Mass Transfer*, Vol 152, 107276, 2024.
[20] Malkawi DS, Rabady RI, Malkawi MS, Al Rabadi SJ. “Application of Paraffin-Based Phase Change Materials for the Amelioration of Thermal Energy Storage in Hydronic Systems“. *Energies*. Vol 16, pp. 120-126, 2023. https://doi.org/10.3390/en16010126
[21] Waqas, Hassan, Hasan, Md. Jahid, Naqvi, Syed Muhammad Raza Shah, Liu, Dong, Muhammad, Taseer, Eldin, Sayed M. and Kang, Can. "Enhancing the performance of thermal energy storage by adding nano-particles with paraffin phase change materials" *Nanotechnology Reviews*, vol. 13, no. 1, pp. 20230180. 2024, https://doi.org/10.1515/ntrev-2023-0180
[22] Chaichan MT, Mahdi MT, Kazem HA, Al-Waeli AHA, Fayad MA, Al-Amiery AA, Isahak WNRW, Kadhum AAH, Takriff MS. “Modified Nano-Fe2O3-Paraffin Wax for Efficient Photovoltaic/Thermal System in Severe Weather Conditions“. *Sustainability*. vol 14(19), 12015, 2022. https://doi.org/10.3390/su141912015
[23] M. Auriemma and A. Iazzetta, vNumerical Analysis of Melting of Paraffin Wax with Al2 O3 , ZnO and CuO Nanoparticles in Rectangular Enclosure“, *Indian Journal of Science and Technology*, vol 9, Issue: 3, pp. 1-8, 2016.
[24] Müslüm Arıcı, Ensar Tütüncü, Miraç Kan, Hasan Karabay, “Melting of nanoparticle-enhanced paraffin wax in a rectangular enclosure with partially active walls“, *International Journal of Heat and Mass Transfer*, vol 104, pp 7-17, 2017.