



Characterization of Composite PCM (Paraffin/Expanded Graphite) for Solar PV Cooling Application

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Abstract. This study develops a composite phase change material (PCM) for the use of solar photovoltaic thermal management. The composite PCMs utilized in this study were paraffin wax (FRW-52) as the base PCM and expanded graphite (EG) as the filler to the PCM. The composite PCM was synthesized by melting paraffin wax and incorporating expanded graphite via mechanical agitation and ultrasonic homogenization. The material was analyzed by differential scanning calorimetry (DSC), scanning electron microscopy (SEM), and thermal conductivity tests to assess phase transition behavior, thermal stability, morphology, and heat transfer properties. SEM pictures indicate that expanded graphite, utilized as a filler, showed excellent adsorption with paraffin, resulting in a uniform and homogeneous composite material. The thermal conductivity from the composite PCM was about ~ 48.02 W/m.K. These values show a significant increase compared to the values of base PCM (paraffin $k = 0.2 - 0.3$ W/m.K). The latent heat was about 152.39 J/g, and the specific heat was about 22.41 J/g $^{\circ}$ C. Furthermore, SEM images show that EG mixed into paraffin wax blends well and becomes homogeneous; DSC results indicate that this mixture does not form new compounds, so the characteristic properties of paraffin as a PCM are preserved.

Keywords: Paraffin, Phase Change Material, Photovoltaic, Thermal Management

1 Introduction

Solar photovoltaic technology is a highly potential renewable energy solution for supporting low-carbon electricity generation. Their application in building structures, public services, educational facilities, and tourism infrastructure is becoming progressively significant, especially in tropical areas. As solar irradiance rises, a substantial fraction of absorbed solar energy is transformed into heat instead of electricity. The accumulation of heat increases the photovoltaic surface temperature while decreasing voltage output, power generation, and electrical efficiency (Bayrak et al., 2025). To address this issue, various techniques for cooling solar PV surfaces have been developed, which are classified as active and passive cooling. Passive cooling often utilizes phase-change materials (PCMs). Numerous investigations have been carried out, including the application of organic phase change materials on

monocrystalline solar panels, leading to a decrease in panel temperature and an enhancement in efficiency (Waqas et al., 2019; Xu et al., 2023).

Organic phase transition materials possess many limitations, including poor thermal conductivity and susceptibility to leakage during the melting phase (Cui et al., 2022). A range of methods has been employed to overcome these constraints, including the integration of conductive fillers—like metals and carbon—into organic PCMs that augment thermal conductivity, boost power production, and elevate solar photovoltaic efficiency (Han et al., 2025; Sun et al., 2025; Due et al., 2026; Rajamony et al., 2025). Several recent studies have shown that expanded graphite as a PCM reinforcing material yields excellent thermal characteristics in electric vehicle battery cooling systems (Li et al., 2021; Zhang et al., 2024). However, this approach has not yet been widely applied to solar PV cooling systems, particularly those designed for buildings.

The majority of investigations have been limited to laboratory or controlled environments, despite the growing number of studies on PCM-based passive cooling for PV systems. The performance of photovoltaic (PV) systems is substantially affected by high solar irradiance, fluctuating wind speeds, and elevated humidity, with only a limited number of studies concentrating on actual outdoor tropical conditions. Research on the performance testing of solar PV systems with passive cooling systems enhanced by conductive fillers in tropical regions has not yet been extensively conducted. This study proposes a passive solar PV cooling system based on a paraffin PCM composite with expanded graphite filler, and performance testing was conducted directly in a tropical region (South Bali). The novelty of this research is the development of paraffin-based PCM composites with expanded graphite as a conductive filler. The approach involves a comprehensive analysis of material-system characteristics, including thermal properties (latent heat, thermal conductivity) and morphology using a scanning electron microscope (SEM). In addition to its technical contribution to the PV thermal management, this particular setting also underlines the relevance of the solution to the sustainable development of the green tourism in the tropical regions.

2 Methodology

2.1 Materials

This study utilized paraffin wax (FRW-52) and expanded graphite (EG) as materials. Paraffin wax was chosen as the base phase change material due to its favorable latent heat storage properties, consistent chemical behavior, and optimum melting temperature for low-temperature thermal management. Expanded graphite is used as a conductive filler to enhance thermal conductivity within the PCM matrix. Expanded graphite used in this study is made from graphite powder with heat treatments. The graphite powder continued dried in a furnace at 100°C for a duration of 10 hours, resulting in expandable graphite. The expandable graphite was then heated to 800°C for 60 seconds to produce expanded graphite (EG).

2.2 Composite PCM preparation

Firstly, paraffin wax was heated using a hot plate stirrer until it completely melted. The

melting temperature was sustained at approximately 80°C and the stirrer rotation at about 500 rpm to ensure complete liquefaction. Expanded graphite then gradually poured into the liquid paraffin while stirring continuously, and the rotation increased to about 850 rpm. The purpose of continuous stirring was to disperse expanded graphite as uniformly as possible within the PCM matrix. The schematic of composite PCM synthesis is shown in Figure 1.

From the previous research of Septiadi et al., (2022) , the proportion of mass of expanded graphite was 20 wt%, providing the best thermal conductivity enhancement and good mass stability with the total density of the composite PCM set to 600 kg/m³; therefore, the total density of the mixture in this study was determined to be 600 kg/m³, with an EG mass fraction relative to paraffin of 20 wt%. The detailed composition of composite PCM is shown in table 1. The composite PCM results shown in figure 2.

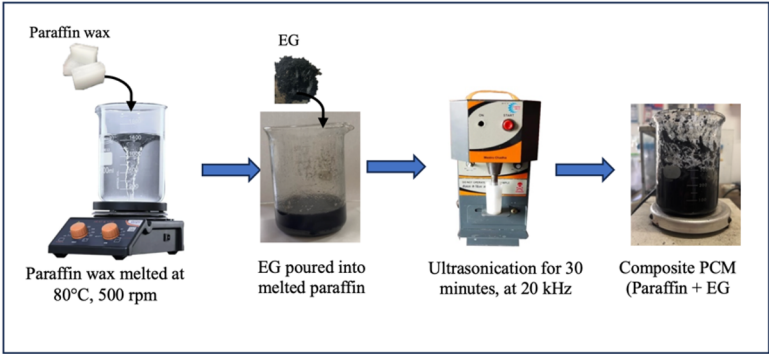


Figure 1. Schematic of Composite PCM Preparation

The EG mass fraction can be calculated using equation (1).

$$EG\;fraction = \frac{m_{EG}}{m_{EG}+m_{PW}} \times 100\% \tag{1}$$

where m_{EG} is the mass of expanded graphite and m_{PW} is the mass of paraffin wax.

Table 1. Composite PCM’s Composition

PCM	Paraffin wax (gram)	EG (gram)	Total (gram)
PCM 1	5,467	0	5,467
PCM 2	4,373	1,093	5,467



Figure 2. Composite PCM samples

2.3 Characterization methods

Differential Scanning Calorimetry (DSC). DSC analysis was used to determine the melting temperature, solidification temperature, and latent heat of the composite PCM. The latent heat and specific heat of composite PCM is measured using the equation (2) and (3)

$$h = \frac{\text{Area}}{m} \quad (2)$$

$$C_p = \frac{\ddot{Q}}{m \cdot \beta} \quad (3)$$

where h is the latent heat (J/g), Area is the peak height (mJ), and m is the sample mass (g). C_p is the specific heat, $\ddot{Q}$ is the heat flow (mW), and β is the heating rate ($^{\circ}\text{C}/\text{min}$).

Thermal conductivity test. The thermal conductivity test was used to analyze the thermal conductivity improvement of the composite PCM during the incorporation of EG as conductive filler. The thermal conductivity of composite PCM is calculated using the equation (4).

$$k = \frac{Q}{A \frac{\Delta T}{\Delta L}} \quad (4)$$

where k is the thermal conductivity (W/m.K), Q is the heat rate (W). A is the area (m^2), ΔT is the temperature gradient, and ΔL is the sample thickness (m).

Scanning electron microscope (SEM). SEM photograph was used to determine the morphology of the composite PCM. This was used to analyze the homogenization adsorption of EG into the paraffin matrix.

3 Result and Discussion

3.1 Result

DSC Test Results. The DSC test of composite PCM was measured using the PerkinElmer STA 6000 Simultaneous Thermal Analyzer. The results of the DSC test were shown in Table 2.

Table 2. DSC Test Results of Composite PCM

No	Parameters	Unit	Composite PCM (Pa/EG)
1	Sample mass	gram	8.418
2	Onset temperature	°C	53.9
3	Peak temperature	°C	53.78
4	Peak height	mW	13.876
5	Area	mJ	1282.93
6	Heat rate	°C/min	10
7	Heat flow	mW	31

The latent heat of composite PCM calculated using equation 5.

$$h = \frac{1282.93}{8.418}$$
$$h = 152.39 \text{ J/g} \tag{5}$$

The specific heat of composite PCM is calculated using equation 6:

$$C_p = \frac{31.5}{8.418 \cdot 0.167}$$
$$C_p = 22.41 \text{ J/g} \cdot ^\circ\text{C} \tag{6}$$

Thermal Conductivity Test Results. The thermal conductivity of composite PCM was measured using Linear Heat Conduction TD 1002A. The test was conducted three times, and ΔT was calculated based on the average of the three tests. The results shown in Table 3.

Table 3. Average test results of thermal conductivity test

Parameters	Values	Unit
Q	10	W
A	0.0007065	m ²
ΔT	5.90	K
Δx	0.02	m

The thermal conductivity measured from equation 7.

$$k = \frac{10}{0.0007065 \frac{5.9}{0.02}}.$$

$$k = 48.02 \text{ W/m.K} \quad (7)$$

SEM photograph. The SEM photograph of the composite PCM is shown in Figure 3.

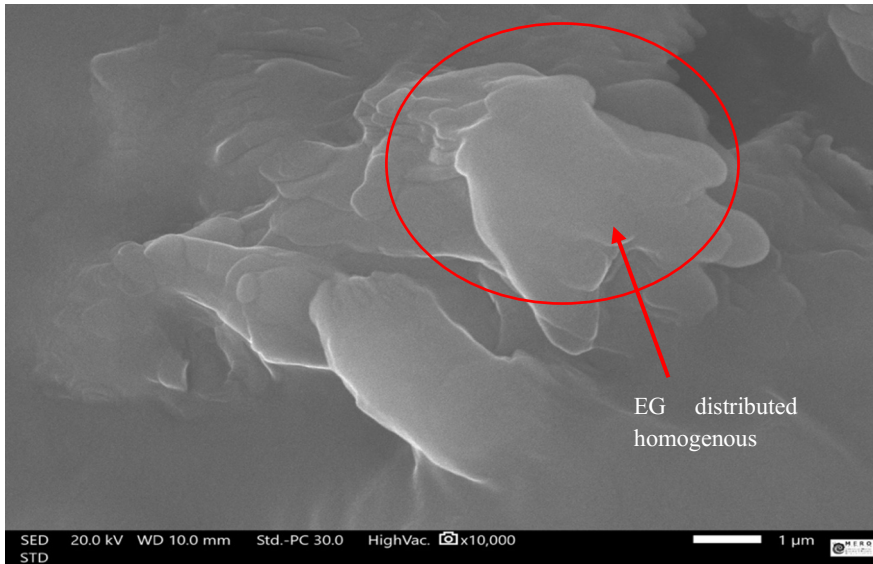


Figure 3. SEM Photograph of Composite PC

3.2 Discussion

Thermal Characteristics of Composite PCM. Figure 4 shows the results of the DSC test of composite PCM. DSC analysis of the paraffin–expanded graphite (EG) composite showed that the samples exhibited a major endothermic peak in the range of 55–58 °C. This peak is characteristic of the paraffin melting transition, during which latent energy is absorbed to disrupt the crystalline order of long-chain hydrocarbons. The melting onset temperature of the samples (approximately 52–54 °C) indicates that the addition of EG filler does not alter the fundamental crystalline structure of the paraffin. The melting point (T_m) of the PCM composite shows a very narrow range, specifically around 56.81–57.87. The change in T_m is very small ($< \pm 1$ °C), indicating that EG is thermally inert with respect to paraffin. These results are consistent with previous studies showing a slight change in T_m (~1–3°C) in different types of PCM composites with the addition of EG filler or a combination of AlN and EG (Dagdevir

et al., 2025; Nguyen et al., 2023). These phenomena show the thermal stability of composite PCM utilizing paraffin and the expanded graphite as filler.

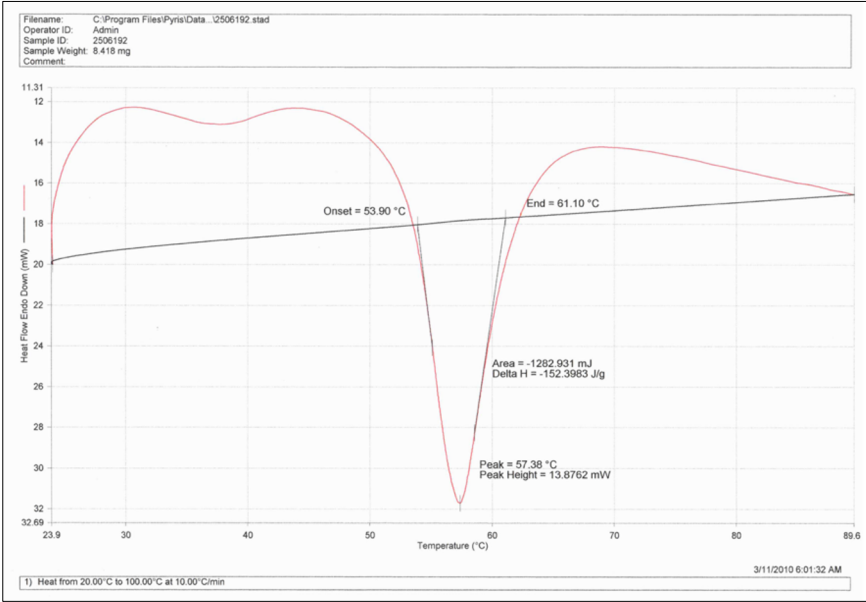


Figure 4. DSC Test Results of Composite PCM

The latent heat of the composite PCM was about ~ 152.39 J/g. This was slightly below the PCM paraffin latent heat values ($\sim 180 - 190$ J/g). This occurs due to a decrease in the PCM fraction in the mixture. These results are consistent with a previous study showing that conductive fillers not only enhance thermal conductivity but also maintain the enthalpy of transition and a stable peak shape in the DSC results of PCM composites (He et al., 2018).

The specific heat of composite PCM was about 22.41 J/g $\cdot^{\circ}\text{C}$. This value is much higher than the specific heat capacity of paraffin ($\sim 2 - 2.8$ J/g $\cdot^{\circ}\text{C}$). This demonstrates the effectiveness of expanded graphite filler in enhancing the specific heat capacity of PCM composites. This is consistent with previous research by Nguyen et al. (2023), which showed that the addition of high-conductivity inorganic fillers not only improves heat conduction but also increases the sensible heat storage capacity of PCM composites.

The thermal conductivity of composite PCM (paraffin/EG) was about ~ 48.02 W/m $\cdot\text{K}$. This was much higher than the thermal conductivity of paraffin as the base PCM, which was about $0.2 - 0.3$ W/m. K. This verifies that EG significantly contributes to the development of efficient thermal percolation pathways, aligning with the results of studies by Nguyen et al. (2023) and Wang et al. (2023), which indicated that EG can enhance the conductivity of PCM by over 20 times via the creation of a graphite-sheet-based conductive network.

Morphology of Composite PCM. From figure 3 SEM photograph of composite PCM. The results show that at 10,000x magnification, the EG clusters in the PCM composite mixture are distributed homogeneously. This indicates that the dispersion technique using ultrasonication in PCM composites successfully produced a more homogeneous mixture with little to no agglomeration. These dispersion results are consistent with a study (Williams & Peterson, 2021) that demonstrated an improvement in the thermal characteristics of paraffin-based PCMs reinforced with Al_2O_3 nanoparticles using ultrasonication.

Overall analysis of composite PCM characteristics. The findings of this study suggest that EG dispersion, shape stability, thermal stability, and energy storage performance are interrelated throughout various parameters.

EG may function efficiently as a thermal conductivity enhancing substance, porous filler, and structural stabilizer due to ultrasonication. The paraffin/EG PCM composites developed in this study indicate high thermal stability, consistent phase transitions, and improved thermal conductivity, making them ideal for highly complex thermal management systems, such as solar photovoltaic cooling, which necessitate reliable performance during prolonged operation and under substantial loads.

4 Conclusion

The study successfully developed and analyzed a paraffin wax/expanded graphite (Paraffin/EG) composite phase change material (PCM) for the passive control of temperature of photovoltaic (PV) systems in tropical environments. The integration of expanded graphite markedly improved the thermal efficiency of the basic PCM while maintaining its phase transition properties. Differential scanning calorimetry (DSC) investigations showed that the composite phase change material (PCM) maintained a consistent melting temperature suitable for photovoltaic cooling, with a latent heat of 152.39 J/g and a specific heat capacity of 22.41 J/g·°C. The results demonstrate that the integration of expanded graphite did not negatively impact the thermal energy storage capacity of paraffin.

Thermal conductivity investigations indicated a significant enhancement relative to pure paraffin, attaining around 48.02 W/m·K. This significant improvement is due to the creation of highly conductive thermal networks by an enhanced graphite network, enabling enhanced heat transfer within the composite material. Furthermore, SEM analysis validated a uniform distribution of expanded graphite within the paraffin matrix with negligible agglomeration, indicating that the employed melting–stirring–ultrasonication technique effectively yielded a structurally stable composite PCM.

The proposed composite shows competitive thermal conductivity and retains advantageous latent heat storage properties compared to previously reported PCM-based solar cooling materials. These findings underscore the crucial function of expanded graphite to enhance thermal conductivity, heat absorption capacity, and structural integrity, which are vital attributes for passive photovoltaic thermal management.

References

- Bayrak, F., Gönül, A. & Camci, M. (2025). Thermal management of photovoltaic panels using configurations of spray cooling systems. *Applied Thermal Engineering*, 274. <https://doi.org/10.1016/j.applthermaleng.2025.126656>
- Cui, W., Si, T., Li, X., Li, X., Lu, L., Ma, T. & Wang, Q. (2022). Heat transfer analysis of phase change material composited with metal foam-fin hybrid structure in inclination container by numerical simulation and artificial neural network. *Energy Reports*, 8, 10203–10218. <https://doi.org/10.1016/j.egyr.2022.07.178>
- Dagdevir, T., Lin, X., Caliskan, U. & Ding, Y. (2025). A novel hybrid battery thermal management system using a wavy minichannel and a composite phase change material. *International Journal of Heat and Mass Transfer*, 251. <https://doi.org/10.1016/j.ijheatmasstransfer.2025.127397>
- Du, T., Xu, Y., Ma, H., Li, Y., Li, Z. & Wang, C. (2026). Performance assessment of photovoltaic/thermal module coupled PEM electrolyzer hydrogen production system based on nanofluids and composite phase change materials. *Applied Energy*, 402. <https://doi.org/10.1016/j.apenergy.2025.126990>
- Han, M., Jiao, K., Lu, L., Jin, Z., Ma, T. & Wang, Q. (2025). PEG-based solid-solid phase change materials for passive cooling of solar photovoltaic panels. *Applied Energy*, 394. <https://doi.org/10.1016/j.apenergy.2025.126190>
- He, L., Wang, H., Zhu, H., Gu, Y., Li, X. & Mao, X. (2018). Thermal properties of PEG/graphene nanoplatelets (GNPs) composite phase change materials with enhanced thermal conductivity and photo-thermal performance. *Applied Sciences (Switzerland)*, 8(12). <https://doi.org/10.3390/app8122613>
- Li, X., Li, H., Kong, X. & Yang, H. (2021). Characterization and experimental investigation of composite phase change materials based on aluminum nitride/expanded graphite. *Journal of Energy Storage*, 35. <https://doi.org/10.1016/j.est.2021.102326>
- Nguyen, G. T., Ly, T. N., Tran, N. T., Tuan, H. N. A., Hieu, N. H. & Bui, T. H. (2023). Glutaric acid/expanded graphite composites as highly efficient shape-stabilized phase change materials at medium-temperature. *Journal of Energy Storage*, 63. <https://doi.org/10.1016/j.est.2023.107038>
- Rajamony, R. K., Pandey, A. K., Sofiah, A. G. N., Paw, J. K. S., Suraparaju, S. K., Fatehmulla, A., Chopra, K., Samykano, M. & Farade, R. A. (2025). Experimental Investigation of Carbon-Based Nano-Enhanced Phase Change Materials Assimilated Photovoltaic Thermal System: Energy, Exergy and Environmental Assessment. *Journal of the Taiwan Institute of Chemical Engineers*, 167. <https://doi.org/10.1016/j.jtice.2024.105835>
- Septiadi, W. N., Alim, M. & Adi, M. N. P. (2022). The application of battery thermal management system based on heat pipes and phase change materials in the electric bike. *Journal of Energy Storage*, 56. <https://doi.org/10.1016/j.est.2022.106014>
- Sun, A., Sun, Y., Zhao, J. & Song, X. (2025). Characterization, experimental study and optimization of the performance of photovoltaic panel integrated with form-stable phase

- change materials and conductive ZnO/MnO₂ nanoparticles. *Solar Energy Materials and Solar Cells*, 292. <https://doi.org/10.1016/j.solmat.2025.113752>
- Wang, H., Rao, Z., Li, L. & Liao, S. (2023). A novel composite phase change material of high-density polyethylene/D-mannitol/expanded graphite for medium-temperature thermal energy storage: Characterization and thermal properties. *Journal of Energy Storage*, 60. <https://doi.org/10.1016/j.est.2022.106603>
- Waqas, A., Ji, J., Bahadar, A., Xu, L., Zeshan & Modjinou, M. (2019). Thermal management of conventional photovoltaic module using phase change materials—An experimental investigation. *Energy Exploration and Exploitation*, 37(5), 1516–1540. <https://doi.org/10.1177/0144598718795697>
- Williams, J. D. & Peterson, G. P. (2021). A review of thermal property enhancements of low-temperature Nano-enhanced phase change materials. *Nanomaterials*, 11(10). <https://doi.org/10.3390/nano11102578>
- Xu, Z., Kong, Q., Qu, H. & Wang, C. (2023). Cooling characteristics of solar photovoltaic panels based on phase change materials. *Case Studies in Thermal Engineering*, 41. <https://doi.org/10.1016/j.csite.2022.102667>
- Zhang, X., Yuan, J., Fu, Y., Nie, R. & Kong, X. (2024). Study on the potential of multi-performance enhanced phase change materials in battery thermal management. *Applied Thermal Engineering*, 246. <https://doi.org/10.1016/j.applthermaleng.2024.122932>

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