Composite and Microencapsulated Phase Change Materials: A Brief Review

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Abstract

Phase change materials (PCMs) play a valuable part in thermal management solutions. The immense benefits of PCMs towards energy savings have increased its market demand in all developing and developed economies. Emerging progress in the properties of PCMs can overcome numerous limitations of conventional heat storage systems, such as low thermal conductivity, thermal stability, only energy changing model, etc. The combination of the composite material with Micro-Encapsulated Phase Change Materials (MEPCM) was utilised by employing a low-cost, small-scale procedure to exploit the better thermal transport features of the hybridized PCMs. Composite and microencapsulated PCMs offer high thermal conductivity, thermal stability and avoid leakages during phase transition due to their high latent heat storage properties. Shape-stabilized composite PCMs have been showcasing admirable thermal performance and effective encapsulation for Thermal Energy Storage (TES) applications. Many research articles have been published on evaluating different TES systems. This review aims to serve as a consistent, reliable, and helpful reference for future research on eco-friendly and energy-efficient TES containing PCMs.

Keywords. Microencapsulation, Phase Change Materials (PCM), Composites, Thermal Energy Storage (TES), Thermal Stability

1. INTRODUCTION

The increase in temperature has a detrimental effect on the routine activities on earth, and in some cases, due to the drop of the average temperature, there is a huge need for supplemental energy. In order to compensate for the fluctuating temperatures and stabilize the condition for specific applications, a high volume of investment is also required [1].

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The PCM is a good energy packing material to achieve obtainable heat energy that is kept or available in excess. These TES methods are eco-friendly, and their capacity to store heat and the extensive use of temperature-controlled packing in industries such as bio-medical, pharmaceuticals, and food and beverage are encouraging their implementation [2]. TES is a simple yet effective way to decrease energy consumption and optimise its utilization. In recent years, PCMs have found application in many industries such as solar dryers in agricultural industries, electronic industries, solar cooling, solar power plant, photovoltaic electricity generation system, waste heat recovery systems, domestic hot water, and building envelopes. [3]. Most of the studies focused on the upper volumetric TES capabilities with minimal consideration given to the semi-permanent escape features. In the indirect incorporation method, a leakage problem may occur, and the PCM would be incompatible with PU [4].

This article provides a detailed review of composite PCM from the outlook of synthesis procedures, microencapsulation of PCM, thermal stability, and thermal conductivity. Thus, this review can benefit new research by highlighting the limitations, challenges, and gap that needs to be bridged. The review paves the way for expanding the prospects and applications of composite PCMs.

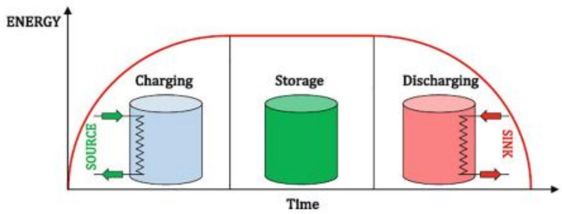

Fig 1.1: Thermal Energy storage stages [5].

2. Phase Change Materials

2.1. Composite PCMs

PCMs are incapable of efficiently storing and releasing thermal energy. Providentially, composite PCMs comprising photothermal materials can respond rapidly to light and actively meet the necessities in an exact environment [6]. In polyurethane foam, the TES capacity is improved by integrating a fatty acid ester-based PCM for latent heat storage. The PU– PCM composite material improved heat absorption capacity by 34% compared to the PU rigid foam. The composite materials demonstrated the buffering function in the case of temperature variations by improving the heat sinks. The PU- PCM composite rises in density and thermal conductivity [7].

2.2. Microencapsulated PCMs

Microencapsulation is a method used to present a core material as PCM (energy-storage) and a shell material as organic or inorganic polymers. It retains the thermo-

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mechanical performance, avoids PCM from leakages, improves the protection from the environment, and it widens the surface area for heat transfer. The heat transfer features of the MEPCM will be affected by the encapsulation ratio. It specifies the efficiency of the PCM inside the shell, and it is calculated by following relation [8].

$$E.R. = \frac{(\Delta H)_{mpcm}}{(\Delta H)_{pcm}} \times 100 \quad (1)$$

where $(\Delta H)_{mpcm}$ and $(\Delta H)_{pcm}$ is the latent heat of the MEPCM and the PCM respectively. The encapsulation will depend upon the shell material width, wherein the encapsulation ratio lowers for thicker shell material [9]. Various methods of microencapsulation have been developed and well evaluated by researchers. Regarding the low thermal conductivity of PCMs, several matrices, such as compacted graphite matrix, thin aluminum sheets, honeycomb-like shapes, have been used with low thermal conducting paraffin to improve the thermal conductivity [10].

2.3. Thermal energy storage (TES)

The effective utilization of both organic and inorganic PCMs as TES is influenced by the thermal conductivity which describes these materials. The phase transition of PCM is crucial in latent heat energy storage by solid-liquid transition. In the phase change composite material, the energy stored/ liberated is dependent on the molecular interaction. The energy is released by the response between moisture and dehydrated salt [11].

The energy storage density of SHS material, like rock, is concerning 5, or 7 times fewer than the storage density of paraffin or sodium sulfate decahydrate PCM. During the heating process, the PCM will absorb energy, and when the surrounding temperature lowers, the PCM will release energy in the form of solid-liquid phase change, wherein latent heat storage is the most effective method for TES. Coconut coir fiber reinforced PCM composite material was used in making envelopes, which can also be used as a TES material. Henceforth, the addition of carbon fibers to these systems demonstrates a combined effect on improving the heat transfer abilities [12].

2.4. Thermal conductivity of PCMs

The solid state PCM have the low thermal conductivity when compared to PCM and MEPCM foam composite material. The degree of positioning of the MEPCM in the foam matrix and the improper spreading of PCM to the foam matrix will affect the heat transfer rate. Conductive particles are joined to bridge the gap for the discontinuous heat flow path. The chemical belongings of the PCM are not affected when supportive materials are added, they offer a ceaseless design with a decent way for-heat transfer [13]. The G foam composite with P-wax is ascribed to high thermal conductivity of the G- foam matrix which permit the rapid heat transfer throughout P-wax. In the solid phase the thermal conductivity is somewhat decreases with increasing temperature.

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Addition of EG to the CPCM was significantly improved the thermal conductivity when the EG content is higher. The inorganic PCM, calcium chloride hexahydrate was encapsulated with EG to attain 14 times higher the thermal conductivity [14].

Thermal properties of CPCM determined by impregnation method

S. No	PCM	Melting temperature (^{0}C)	Freezing temperature (^{0}C)	Enthalpy (kJ/kg)	Thermal conductivity (Wm^{-1} K^{-1})	Application	Ref.
1.	Polyethylene glycol	60.4	37.9	164.9	-	Energy storage	1
2.	Polyethylene glycol	57.5	34.8	142.6	0.45	TES	3
3.	Polyethylene glycol	63.5	34.7	160.7	0.79	Microelectronic device	4
4.	Polyethylene glycol	60.2	41.6	136.8	4.764	Energy conversion and storage	6
5.	Paraffin	36.4	35.5	157.4	-	TES	8

Table 2.1 Thermal properties of CPCM

2.5. Thermal stability of PCM

The thermal stability accounts for the strength, leak resistance, and thermal degradation of the PCM. These characteristics determine the nature of application of thermal energy-storage systems made of composite PCMs. Paraffin is the most familiar PCM used to reduce temperature variations in various applications. They are utilized in applications that require non-corrosive systems, wherein small volume variations in the phase change process are handled with good thermal stability. The thermal stability of diatomite/ paraffin exhibited steadiness up to 95˚C. Composite PCMs generally have good thermal stability [15].

3. Recent applications and advancements of CPCM

The CPCMs are also used in some high technology fields like Aeronautics Space Administration, and smart drug delivery. In the medical field, CPCMs like 1-tetradecanol are filled into hollow mesoporous CuS_2 by impregnation and are used to eliminate the tumor and multimodal cancer treatments. In the building application, the shape stabilized PCM with supporting materials can be used, and it is utilized in the different parts like interior and exterior walls, ceiling, roof, and floor [16].

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4. Conclusion

To conclude, a brief review has been showed on the thermal features of recently explored composite PCM directed on the thermal attributes of composite PCMs. As of now, different investigations have been conducted to synthesis shape-stabilized organic composite PCMs. The synthesized PCMs, their performance, design, and overall system have been observed to provide a several useful applications.

In the composite PCM the thermal physical characteristics like thermal stability, thermal conductivity is suitable for integrated TES material. The addition of composite PCM is the incorporation of composites in porous material to prevent leakages during the phase transformation. Thermal characterization of the composites revealed that the temperature of melting and freezing point of the composite was not affected with properties of the incorporated material, but had a negative effect on the latent heat storage capacity in all cases.

References

[1] Shahid, U. B., & Abdala, A. (2021). A critical review of phase change material composite performance through Figure-of-Merit analysis: Graphene vs Boron Nitride. Energy Storage Materials, 34, 365-387.

[2] Nie, B., Chen, J., Du, Z., Li, Y., Zhang, T., Cong, L., ... & Ding, Y. (2021). Thermal performance enhancement of a phase change material (PCM) based portable box for cold chain applications. Journal of Energy Storage, 40, 102707.

[3] Piselli, C., Castaldo, V. L., & Pisello, A. L. (2019). How to enhance thermal energy storage effect of PCM in roofs with varying solar reflectance: Experimental and numerical assessment of a new roof system for passive cooling in different climate conditions. *Solar Energy*, *192*, 106-119.

[4] Al-Jethelah, M., Ebadi, S., Venkateshwar, K., Tasnim, S. H., Mahmud, S., & Dutta, A. (2019). Charging nanoparticle enhanced bio-based PCM in open cell metallic foams: An experimental investigation. *Applied Thermal Engineering*, *148*, 1029-1042.

[5] Ma, T., Yang, H., Zhang, Y., Lu, L., & Wang, X. (2015). Using phase change materials in photovoltaic systems for thermal regulation and electrical efficiency improvement: a review and outlook. *Renewable and Sustainable Energy Reviews*, *43*, 1273-1284.

[6] Subramanian, M., Hoang, A. T., Kalidasan, B., Nižetić, S., Solomon, J. M., Balasubramanian, D, Nguyen, X. P. (2021). A technical review on composite phase change material based secondary assisted battery thermal management system for electric vehicles. Journal of Cleaner Production, 322, 129079.

e-ISBN: 9788770229647 https://doi.org/10.13052/rp-9788770229647.033

[7] Ohayon-Lavi, A., Lavi, A., Alatawna, A., Ruse, E., Ziskind, G., & Regev, O. (2021). Graphite-based shape-stabilized composites for phase change material applications. Renewable Energy, 167, 580-590.

[8] Yousefi, A., Tang, W., Khavarian, M., & Fang, C. (2021). Development of novel form-stable phase change material (PCM) composite using recycled expanded glass for thermal energy storage in cementitious composite. Renewable Energy, 175, 14-28.

[9] Zou, D., Liu, X., He, R., Zhu, S., Bao, J., Guo, J., ... & Wang, B. (2019). Preparation of a novel composite phase change material (PCM) and its locally enhanced heat transfer for power battery module. Energy Conversion and Management, 180, 1196-1202.

[10] Rathore, Pushpendra Kumar Singh, and Shailendra Kumar Shukla. "Enhanced thermophysical properties of organic PCM through shape stabilization for thermal energy storage in buildings: A state of the art review." Energy and Buildings 236 (2021): 110799.

[11] Ren, S., Li, J., Huang, K., Bai, Y., & Wang, C. (2021). Effect of composite orders of graphene oxide on thermal properties of Na2HPO4• 12H2O/expanded vermiculite composite phase change materials. *Journal of Energy Storage*, *41*, 102980.

[12] Luo, J., Zou, D., Wang, Y., Wang, S., & Huang, L. (2022). Battery thermal management systems (BTMs) based on phase change material (PCM): A comprehensive review. Chemical Engineering Journal, 430, 132741.

[13] Amaral, C., Pinto, S. C., Silva, T., Mohseni, F., Amaral, J. S., Amaral, V. S., & Vicente, R. (2020). Development of polyurethane foam incorporating phase change material for thermal energy storage. *Journal of Energy Storage*, *28*, 101177.

[14] Liu, H., Wang, X., & Wu, D. (2019). Innovative design of microencapsulated phase change materials for thermal energy storage and versatile applications: a review. *Sustainable Energy & Fuels*, *3*(5), 1091-1149.

[15] Shao, Y. W., Hu, W. W., Gao, M. H., Xiao, Y. Y., Huang, T., Zhang, N., ... & Wang, Y. (2021). Flexible MXene-coated melamine foam-based phase change material composites for integrated solar-thermal energy conversion/storage, shape memory and thermal therapy functions. Composites Part A: Applied Science and Manufacturing, 143, 106291.

[16] Wang, Z., Zhu, S., Zhao, X., Huang, L., & Zou, D. (2022). Preparation and thermal performance of a novel alloy microencapsulated phase change material (MEPCM)/ceramic composite. International Journal of Thermal Sciences, 176, 107478.

e-ISBN: 9788770229647 https://doi.org/10.13052/rp-9788770229647.033