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Heat transfer performance enhancement of paraffin/expanded perlite phase change composites with graphene nano-platelets

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Abstract

The efficiency of latent heat thermal energy storage systems is often limited by the low thermal conductivity of phase change materials (PCMs), which limits the heat transfer rate and energy storage efficiency. Therefore, this study investigates the performance enhancement of form-stable PCMs with the addition of exfoliated graphene nano-platelets (xGnP) as a heat transfer promoter. Experimental research was carried out on fabrication, characterization and testing the properties of paraffin/EP/xGnP composite PCMs. It was shown that the xGnP particles formed an interconnecting network inside the open pores of EP, which remarkably improved the thermal properties and thermal energy storage/retrieval properties of composite PCMs. For instance, in comparison with paraffin/EP composites, addition of 1% of xGnP increased the thermal conductivity by up to 49%. Thermal energy storage/release test also revealed that the paraffin/EP/xGnP composites reduced the heat storage/ release duration by up to 33%, compared to paraffin/EP composite PCM. The enhancement of thermal properties and thermal energy storage rate of paraffin/EP/xGnP composites is a promising way to achieve high energy storage efficiency in numerous latent heat thermal energy storage applications such as solar energy storage and energy conservation in buildings.

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Keywords: Phase change materials (PCMs); exfoliated graphene nano-platelets (xGnP); heat transfer rate; energy storage

1. Introduction

With the increasing gap between global supply and demand of energy, energy storage becomes as an intermediate step to facilitate clean, versatile and efficient use of energy. Among the various energy storage technologies, latent heat thermal energy storage (LHTES) with the utilization of phase change materials (PCMs) can provide attractive solutions to the problems of energy storage and conservation. This is due to

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the obvious merits of PCMs such as very high volumetric heat capacity and small temperature variation during the thermal energy storage process.

However, a typical but most significant drawback which affect the thermal storage performance of PCMs in thermal energy storage system is the low thermal conductivity of most organic PCMs. Furthermore, in a latent heat thermal energy storage system, the major cost is associated with the heat transfer technology that employs to achieve large amount of heat charge/discharge rates in order to achieve high efficiency. Therefore, heat transfer enhancement in TES applications is a key point in terms of both energy and economic aspects. The common approaches including usage of extended surfaces, integrating high conductive fillers and fabrication of micro-encapsulated PCMs have been employed to enhance the heat transfer performance of PCM in TES applications. The versatile technology among the abovementioned methods is enhancing the thermal conductivity of PCMs with the addition of high conductivity fillers. Nevertheless, TES system also requires large amounts of latent heat of fusion. The addition of thermal conductive fillers will reduce the latent heat of fusion because the promoter is not engaged in phase change operation. Therefore, there is a need for compromising between the thermal conductivity and latent heat and hence, filler materials with high conductivity and larger specific surface area will be the best choice.

Among the studied PCMs, organic solid-liquid PCMs (i.e. paraffin and fatty acids) are considered as promising candidates due to its sharp melting temperature, large volumetric heat capacity and little or no super-cooling effects [1]. However, pure PCMs limit its applications in many fields due to the leakage problem [2]. Therefore, form-stable PCMs have been introduced to overcome the leakage issues. Form-stable PCMs are fabricated by impregnating functional PCM into porous supporting materials in the presence of atmospheric or vacuum pressure. The supporting materials are expected to provide a mechanical strength to the composite as well as to prevent the leakage of liquid PCM during the phase change process [3].

carbon based conductive fillers including expanded graphite, carbon nanotube (CNT) and graphene materials are widely studied and utilized as thermal conductive filler materials. For instance, Karaipekli and Sarı [4] studied the heat transfer performance of Capric–myristic acid/expanded perlite composite with the dispersion of expanded graphite (EG). The results revealed that the thermal conductivity of composite PCM was enhanced by 58% with the addition of 10 wt% of EG. Xu and Li [5] fabricated paraffin/diatomite/ MWCNT (multi walled carbon nanotubes) form-stable composite PCM for the application of thermal energy storage cementitious composites. The authors claimed that, compared to paraffin/diatomite composite PCM, the use of MWCNT has clear beneficial effects for improving thermal conductivity, and heat storage/release rates. the addition of 0.26% of MWCNT in the composite PCM resulted in thermal conductivity increment of 43%.

In light of building energy conservation and management, a number of form-stable PCMs have been fabricated in the past, using organic functional PCMs. However, the incompatibility issues between composite PCM and cementitious materials (i.e. leakage issues) resulted in the feasibility of only few form-stable PCMs in cementitious composites. For instance, Xu and Li developed paraffin/diatomite composite PCM with the phase transition temperature of 41.1°C, making ideal solution to building exterior applications. Ramakrishnan et al. [6] developed a novel composite PCM based on paraffin and hydrophobic expanded perlite which is reported as highly compatible with most construction materials such as cement and gypsum. In this study, we investigate the heat transfer performance enhancement of paraffin/hydrophobic EP composite PCM by integrating exfoliated graphene nanoplatelets (xGnP) into composite PCMs. Then the micro-morphology characterization and thermal properties was determined using scanning electron microscopy (SEM) and thermal conductivity analyser techniques. Finally, thermal energy storage performance of developed composite PCM was studied using a self-designed heat storage/release testing setup.

2. Materials and methods

2.1. Materials

A commercial grade paraffin (RT27 from Rubitherm®-Germany) and hydrophobic expanded perlite (EP) (supplied by Filchem Australia Pty Ltd) were used to fabricate the form-stable PCM. The xGnP® (purchased from XG Sciences, Inc.) used in this study, has a specific surface area of 750 m²/g, and particle diameter and thickness ranging from 1-2 μm and 1-5 nm respectively.

2.2. Preparation and characterization of paraffin/EP/xGnP

The paraffin/EP/xGnP composite PCM was fabricated by vacuum impregnation method, where composition of materials is designed as 49.5% paraffin, 49.5% EP and 1% xGnP. The fabrication process of composite PCM is as follows. First, xGnP was dispersed in acetone by using an ultrasonic probe sonicator. After the sonication for 30 minutes, EP was added and then xGnP/EP/acetone mix was undergone vigorous stirring for 2 hours using a magnetic stirrer equipment. After the uniform mixing of xGnP/EP, dry mixture was obtained by over-drying process. The dry mixture of xGnP/EP was then mixed with paraffin at an ambient temperature of 60°C and vacuum pressure to impregnate paraffin into the pores of EP. Finally, paraffin/EP/xGnP composite PCM was obtained after cooling down to room temperature.

2.3. Tests on fabricated composite PCM

In order to study the effect of xGnP on the characterization and properties of form-stable composite PCMs, experimental investigations were carried out on paraffin/EP and paraffin/EP/xGnP composite PCMs. Micro-morphology characteristics of composites were observed using a scanning electron microscopy (SEM, ZEISS Supra 40 VP). The thermal properties of paraffin/EP and paraffin/EP/xGnP were determined using a TCi thermal conductivity analyzer. The TCi developed by C-Therm Technologies Ltd., is a device that measures the thermal conductivity of a small sample by the modified transient plane source (MTPS) method. The composite PCMs were compressed into solid disc samples with the diameter of 25.4 mm and thickness of 5 mm with a manually controlled hydraulic pressure machine. Finally, the heat transfer performance enhancement of composite PCMs with the addition of xGnP was studied by using the self-designed heat storage/release test setup shown in Fig. 1. In this test, approximately, 20 g of composite PCM powder was filled in a glass tube with its opening sealed. Two water baths at temperatures of 40°C and 10°C were used for heating and cooling processes, respectively. The temperature at the midpoint of the specimen was measured and recorded using a k-type thermocouple, a data-logger and a computer.

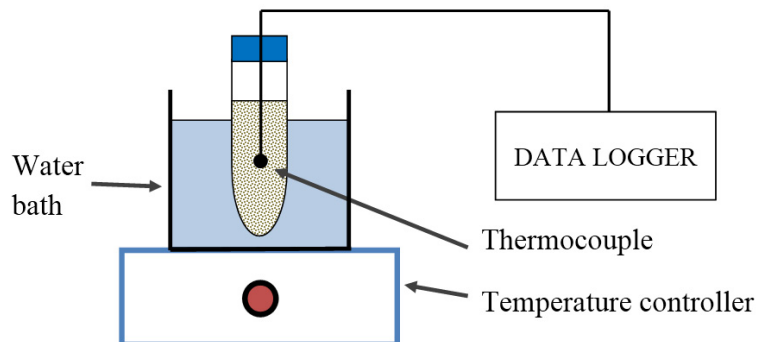


Fig. 1. Schematic diagram of heat storage/release performance test

3. Results and discussions

3.1. Morphology characterization of paraffin/EP/xGnP

Fig. 2 shows the SEM images of undispersed xGnP, EP/xGnP paraffin/EP and paraffin/EP/xGnP mixture. Fig. 2(a) shows the undispersed xGnP before ultrasonic dispersion treatment. Fig. 2(b) shows EP/xGnP dry powder before fabricating composite PCM, where xGnP particles are connecting the interporous network of EP. Such high conductive connecting networks are expected to improve the heat transfer performance of paraffin. In addition, as shown in Fig. 2(c) and Fig. 2(d), well dispersed xGnP particles are found to be partially submerged into the paraffin of composite PCM (in comparison with Fig. 2(c)), resulting in the enhancement of thermal conductivity of pure paraffin, as expected.

3.2. Thermal properties of composite PCMs

The thermal enhancement with the addition of xGnP, as measured by thermal conductivity is depicted in Fig. 3. It can be clearly seen from figure that in comparison with paraffin/EP composite PCM, addition of xGnP significantly boosted the thermal conductivity with the increase level as high as 49%. This increment is expected to eliminate the poor heat transfer performance of composite PCMs in light of the application in solar energy storage and building energy conservation. More precisely, inadequate heat transfer performance in building integrated PCMs resulted in poor solidification at night which will eventually reduce the effective energy storage for the next thermal cycle, as reported in previous studies [7, 8]. However, embedding high conductive fillers such as graphene nano-platelets increase the heat transfer performance of PCMs so that the energy storage/retrieval process is accelerated.

3.1. Heat transfer performance enhancement of paraffin/EP with xGnP

The addition of graphene nano-platelets in the heat transfer performance enhancement can be observed from heat storage release test results as shown in Fig. 4. It can be seen from figure that paraffin/EP and paraffin/EP/xGnP both composite PCMs have a decreasing rate of heat storage during the temperature rate of 25-30°C, due to phase change process. However, in comparison with paraffin/EP composite PCM, paraffin/EP/xGnP had obvious faster heat storage/retrieval rates. For instance, during the heating process, the time required for the temperature rise from 25°C to 30°C is 720 s and 480 s, respectively for paraffin/EP and paraffin/EP/xGnP composites. Similarly, relevant time requirement for cooling from 27°C to 23°C were 780 s and 540 s respectively. This indicates a reduction in heat storage/release time of approximately 33%.

4. Conclusions

In this study, effect of exfoliated graphene nano-platelets (xGnP) on the heat transfer performance enhancement of paraffin/EP form-stable PCM was investigated. Experimental investigations were carried out to study the fabrication, characterization and testing the properties of paraffin/EP/xGnP form-stable PCM composites. The experimental results demonstrated that the thermal properties and thermal energy storage performance of paraffin/EP/xGnP composites were remarkably improved in comparison with paraffin/EP composites. The micro-morphology characterization with scanning electron microscopy (SEM) test revealed that the nano-sized xGnP particles are formed an interconnecting network inside the pores of EP and partially embedded with paraffin. Compared to paraffin/EP composites, addition of 1% of xGnP can bring obvious beneficial effects on thermal conductivity and heat storage/release performance. This is particularly demonstrated by the enhancement of thermal conductivity by up to 49% and reducing the heat storage/retrieval duration by up to 33%.

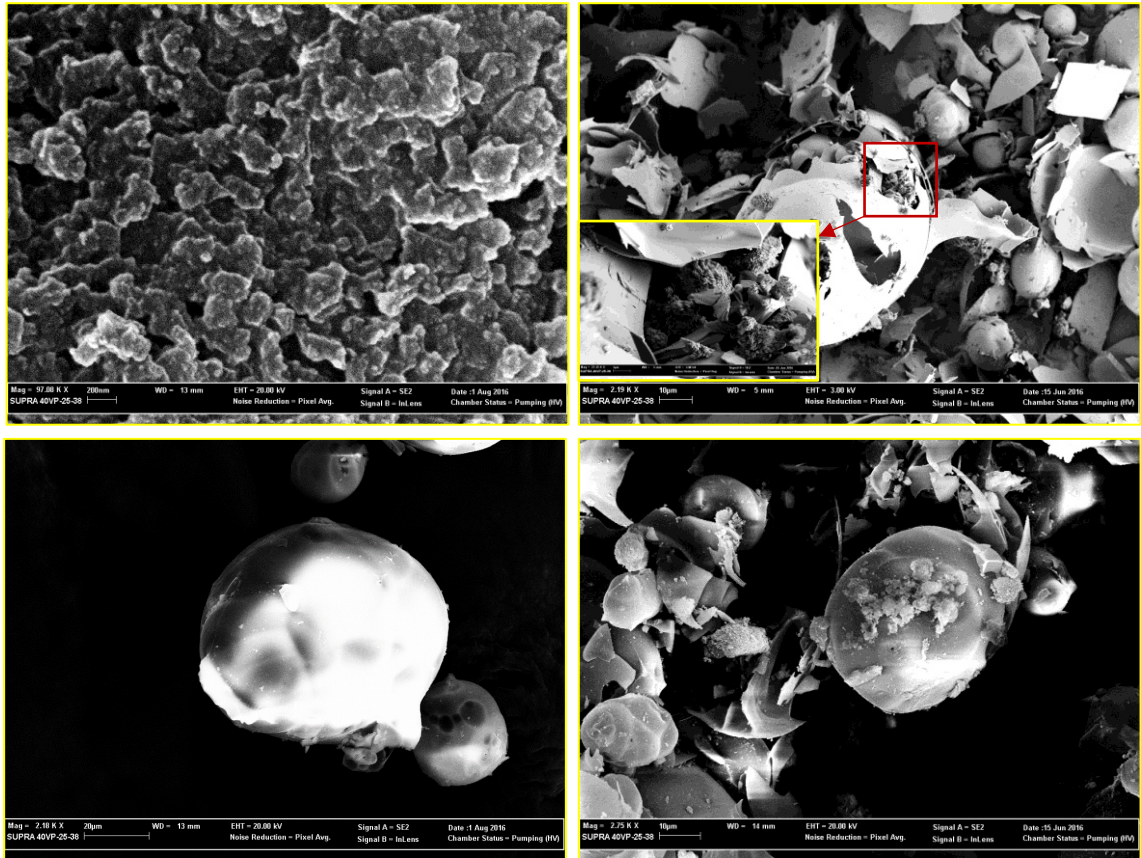


Fig. 2. SEM morphologies of fabricated composite PCMs (a) xGnP (b) EP/xGnP (c) paraffin/EP (d) paraffin/EP/xGnP

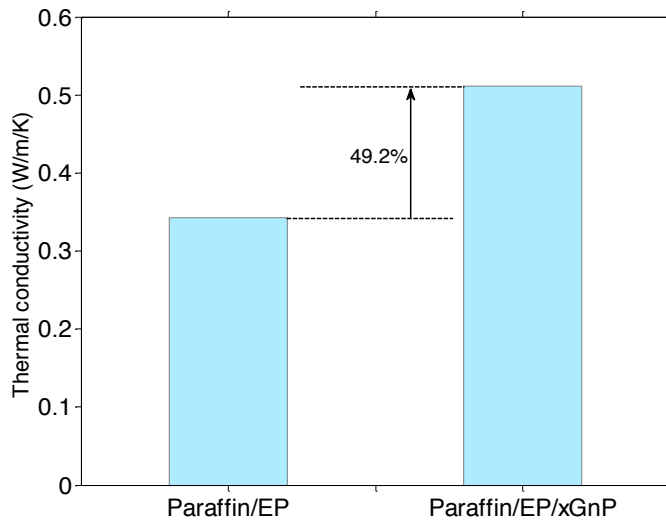


Fig. 3. Thermal conductivities of paraffin/EP and paraffin/EP/xGnP composites

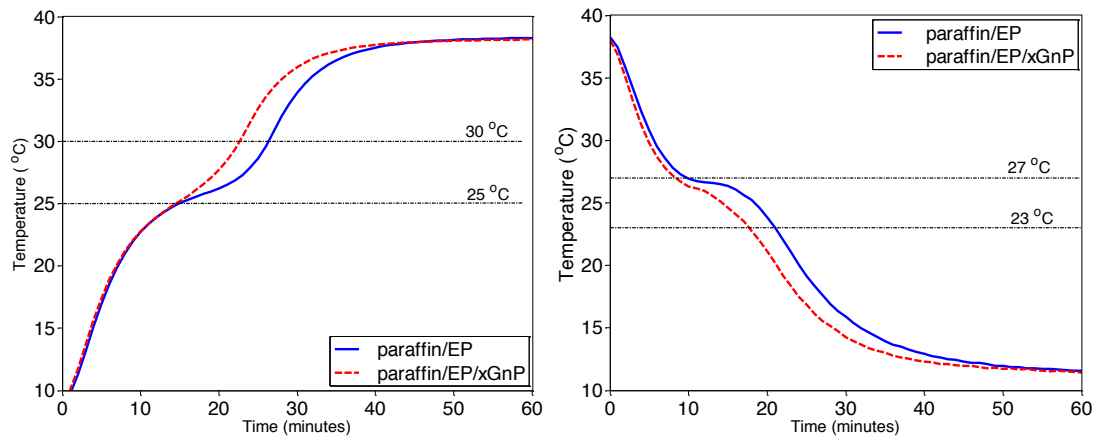


Fig. 4. Heat storage/release performance test (a) heating process (b) cooling process

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References

1. Jiao, C., B. Ji, and D. Fang, *Preparation and properties of lauric acid–stearic acid/expanded perlite composite as phase change materials for thermal energy storage*. Materials Letters, 2012. **67**(1): p. 352-354.
2. Liu, C., et al., *A novel PCM of lauric–myristic–stearic acid/expanded graphite composite for thermal energy storage*. Materials Letters, 2014. **120**: p. 43-46.
3. Sun, D., L. Wang, and C. Li, *Preparation and thermal properties of paraffin/expanded perlite composite as form-stable phase change material*. Materials Letters, 2013. **108**: p. 247-249.
4. Karaipekli, A. and A. Sari, *Capric–myristic acid/expanded perlite composite as form-stable phase change material for latent heat thermal energy storage*. Renewable Energy, 2008. **33**(12): p. 2599-2605.
5. Xu, B. and Z. Li, *Paraffin/diatomite/multi-wall carbon nanotubes composite phase change material tailor-made for thermal energy storage cement-based composites*. Energy, 2014. **72**(0): p. 371-380.
6. Ramakrishnan, S., et al., *A novel paraffin/expanded perlite composite phase change material for prevention of PCM leakage in cementitious composites*. Applied Energy, 2015. **157**: p. 85-94.
7. Ramakrishnan, S., et al., *Thermal performance of buildings integrated with phase change materials to reduce heat stress risks during extreme heatwave events*. Applied Energy, 2016.
8. Ramakrishnan, S., et al., *Parametric analysis for performance enhancement of phase change materials in naturally ventilated buildings*. Energy and Buildings, 2016. **124**: p. 35-45.