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# Preparation and thermal properties of polyethylene glycol/expanded graphite as novel form-stable phase change material for indoor energy saving

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ABSTRACT

Phase change material (PCM) is a new kind of material for energy storage; its thermal properties are key factors in determining the application areas and the actual effect. The polyethylene glycol (PEG)/expanded graphite (EG) composite was prepared as a novel form-stable PCM by vacuum impregnation in this study. Nitrogen adsorption test indicated that EG belonged to materials in mesoporous scale with developed porous structure and prodigious adsorbility. The PEG/EG PCM owned excellent sealing performance and remarkable thermal storage capacity. The phase change temperatures and latent heats of the PEG/EG PCM were in range of 18.89–25.93 °C and 97.56–98.59 $J \cdot g^{-1}$ respectively. TGA and thermal performance manifested that the PEG/EG PCM presented good thermal stability and EG performed favorable conductivity and improved the thermal storage efficiency. The obtained PCMs were suitable for indoor energy saving and thermal comfort improvement.



## 1. Introduction

Thermal storage material, especially those using latent heat to store energy, has attracted unprecedented concern due to the growing challenges of energy crisis and climate change [1]. Phase change material (PCM) with higher thermal storage densities and nearly isothermal process, has been widely used in aerospace, military affairs, medical treatment, textile and successfully applied in building materials area [2–4]. Among the investigated PCMs, organic solid-liquid PCMs are more attractive, which includes paraffin, alkyl esters, fatty acids, polyethylene glycol and its derivatives. However, PCM is sensitive to ambient temperature or pressure in the practical application, which leads to liquid leakage problem. Normally, PCM is packaged in the skeleton to avoid this problem [5]. Polymers and microcapsule are used as skeletons to coat PCM. However, during the composite process, these skeletons would be riskily ruptured or sunken so that PCM would flow away from the skeleton and losing thermal storage ability [6]. Form-stable encapsulation of PCM has been regarded as a hot issue in recent years. Many researchers aim to construct porosity material adsorption system, which can effectively solve the liquid leakage problem and protect PCM from external problems. Lately, researchers have successfully manufactured stearic acid/EG PCM and it showed that EG improved the thermal conductivity and stability of stearic acid/EG composites [7]. Compared with other porous materials, EG has good adsorption capacity, but less impurity, less surface free radicals, stable performance, low cost and easy preparation [8]. It is obvious that porous materials give an encapsulation to PCM by using developed pore structure. If the PCM could be applied into indoor building or decorative materials, the novel various of functional composites could provide thermostat and thermal energy conservation properties, and improve the indoor thermal comfort [9,10].

The aim of this study was to prepare a thermostable PEG/EG PCM for indoor energy saving application. The pore structure of EG, packing capability and thermal properties of PEG/EG PCM were investigated respectively. According to results, PEG/EG PCM exhibited good sealing performance and remarkable thermal storage capacity, which were beneficial for energy saving. This provides a development direction for the building and household adornment materials.

## 2. Materials and methods

### 2.1. Materials and sample preparation

#### 2.1.1. Materials

PEG (AR, the average molecular weight is 800 g/mol) was purchased from Shanghai Macklin Biochemical Co., Ltd. (Shanghai,

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China) and stored at room temperature hermetically. Expandable flake graphite (80 meshes) was supplied by Jinrilai graphite Co., Ltd. (Qingdao, China).

### 2.1.2. Preparation of PEG/EG PCM

Through high-temperature expansion at 800 °C for 60 s, the over-dried flake graphite was developed into EG and cooled down naturally in a desiccator. PEG was configured as 20% anhydrous ethanol solution which was blended with EG by spray at mass ratios of 6:1(PCM1), 7:1(PCM2), 8:1(PCM3), 9:1(PCM4), 10:1 (PCM5) and 11:1(PCM6), respectively. The samples were put in a vacuum oven at 85 °C for 12 h under pressure of −0.1 MPa. After the vacuum adsorption process, the PEG/EG PCMs were constructed (Fig. 1(a)). The liquid leakage tests were proceeded to ensure the packing capability.

## 2.2. Measurement

EG porosity was measured by nitrogen adsorption test at 150 °C (Autosorb-iQ, USA) using BET formula to calculate the specific surface [11]. The morphologies and microstructures were observed by a Scanning Electron Microscope (JSM-7001F, Japan). Differential Scanning Calorimeter (DSC Q2000) and Thermogravimetric Analyzer (TGA Q50) were to characterize thermal properties of samples. Curves of weight loss and derivative weight loss (DTG) were also plotted and analyzed. Thermal storage efficiency testing was carried out by a measurement machine in Fig. 1(b).

## 3. Results and discussion

By BET analysis, EG showed a high specific surface area which was 134.48 $m^2 \cdot g^{-1}$. This is highly beneficial for PCMs adsorption. EG possesses mesoporous structure with the pore sizes concentrated on the 1–10 nm range (Fig. 2(b)). According to the hysteresis loop of adsorption/desorption isotherm, the distance between the closed point on the upper and lower end of the hysteresis loop was wide. This indicated EG possesses a wide mesoporous aperture distribution. Therefore, EG possessed powerful adsorption ability, which was advantageous for PCM to prepare phase change functional material.

EG had a lamellar, puff and porous structure (Fig. 2(a)), which was benefit for PEG adsorption. In previous research, EG performed a preferable absorptivity of absorbing stearic acid and the absorption capacity had reached 90% [7]. Liquid PEG was filled up the pores of EG under vacuum by air pressure and pore syphoning. PEG/EG PCM had a relatively smooth surface in PCM4 and PCM6. For PCM6, little superfluous PEG on the surface of EG was visible.

The leakage tests were carried out at 155 °C for 3 h. PEG would enter into the macro pores firstly then permeate into mesoporous under the effect of negative pressure and gradually fill up mesoporous of EG during adsorption process. When the PEG mass frac-

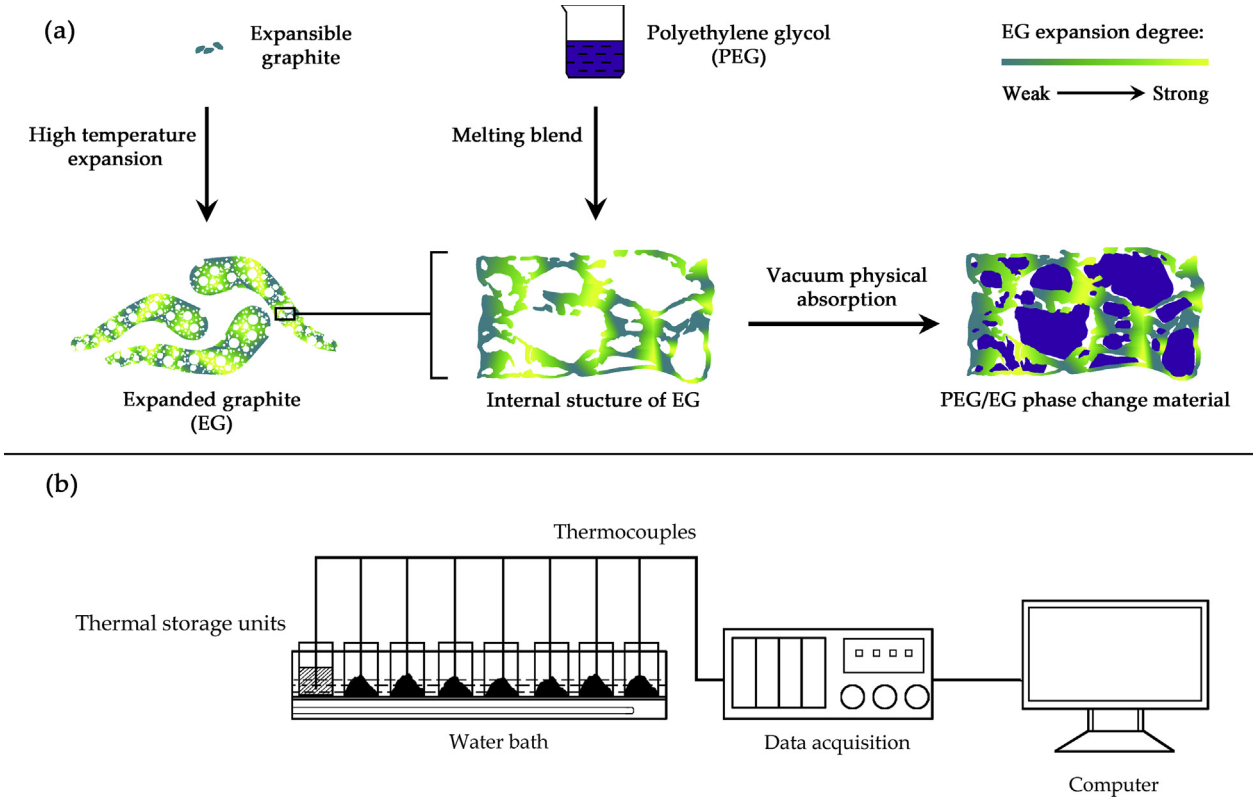


**Fig. 1.** (a) The synthetic route of PEG/EG PCM; (b) the schematic of the temperature measurement system.