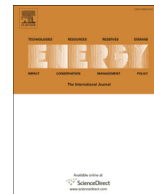




Contents lists available at ScienceDirect

Energy

journal homepage: [www.elsevier.com/locate/energy](http://www.elsevier.com/locate/energy)

## Activated carbon derived from peat soil as a framework for the preparation of shape-stabilized phase change material

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### ARTICLE INFO

#### Article history:

Received 5 September 2014

Received in revised form

15 January 2015

Accepted 17 January 2015

Available online xxx

#### Keywords:

Phase change material

Activated carbon

Thermal energy storage

n-Octadecane

Shape-stabilized phase change materials

### ABSTRACT

This work focuses on the preparation of AC (activated carbon) through a physical activation method using peat soil as a precursor, followed by the use of the AC as an inorganic framework for the preparation of SPCM (shape-stabilized phase change material). The SPCM, composed of n-octadecane as the core and AC pores as a framework, was fabricated by a simple impregnation method, with the mass fraction of n-octadecane varying from 10 to 90 wt.%. The AC has a specific surface area of 893 m<sup>2</sup> g<sup>-1</sup> and an average pore size of 22 Å. The field emission scanning electron microscope images and nitrogen gas adsorption-desorption isotherms shows that the n-octadecane was actually encapsulated into the AC pores. The melting and freezing temperatures of the composite PCM (phase change material) were 30.9 °C and 24.1 °C, respectively, and its corresponding latent heat values were 95.4 Jg<sup>-1</sup> and 99.6 Jg<sup>-1</sup>, respectively. The composite shows a good thermal reliability, even after 1000 melting/freezing cycles. The present research provided a new SPCM material for thermal energy storage as well as some new insights into the design of composite PCM by tailoring the pore structure of AC derived from peat soil, a natural resource.

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### 1. Introduction

PCMs (phase change materials) are TES (thermal energy storage) materials that are widely used for energy storage and temperature control applications. PCMs have attracted great interest in many fields due to their high energy storage density and ability to store energy at a nearly constant temperature. Their applications include intelligent buildings [1], intelligent textiles [2], temperature-control greenhouses [3], solar heating systems [4,5], biomedical and biological carrying systems [6], and thermal insulation [7], among others.

PCMs can be grouped into three types based on their phase transition: solid–liquid, solid–gas and liquid–gas. However, solid–liquid PCMs are most preferred because of their smaller variation in volume compared with solid–gas or liquid–gas PCMs [8]. Paraffin wax, such as n-octadecane, n-nonadecane and n-hexadecane, is an attractive solid–liquid organic PCM candidate, as it's melting and freezing points are within the human comfort

temperature zone and it has a high latent heat storage capacity. Other advantages offered by paraffin wax are freezing without much subcooling, the ability to melt congruently, self-nucleating properties, compatibility with conventional construction materials, lack of segregation, chemical stability, safety and non-reactivity [9,10]. However, despite its many desirable properties, paraffin wax suffers from poor thermal conductivity [8,11], which leads to low heat exchange. Paraffin wax also experiences large volume changes during phase change processes, which cause leakage if it is directly incorporated into building materials [12]. The latter problem limits its application in energy storage materials.

In the past few decades, the use of supporting materials to remedy undesirable properties of PCMs has been extensively developed. The supporting materials used consisting of organic materials based polymers [13–15] or inorganic porous materials [16,17]. For supporting material based inorganic porous materials, PCM is encapsulated into their pore structures, while supporting material based on polymer, PCM is encapsulated into their polymer networks [18]. The composites were then known as SPCMs (shape-stabilized phase change materials). The purposes of converting PCM into SPCM are to overcome liquid leakage and low thermal

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conductivity problems. SPCM can be defined as a new material which has ability to keep the shape of PCM as in a solid state even when the temperature of PCM is over a melting point of PCM (melting state) [19]. SPCMs can be prepared by either physical methods, such as impregnation, adsorption and blending, or chemical methods, such as graft copolymerization and sol gel processes [20,21]. The method used depends on the types of supporting material.

Many organic polymer materials can be used as supporting materials, such as poly-(ethylene oxide) [22], high-density polyethylene [23–25] and ethylene propylene diene terpolymer plastic [26]. However, some polymers may release poisonous gases, such as formaldehyde, which causes health and environmental problems. Therefore, inorganic porous materials such as expanded graphite [8,27], carbon nanotubes [28], activated carbon [29,30], graphene oxide [31,32], SiO<sub>2</sub> composites [33,34], expanded perlite [35,36], activated montmorillonite [37], etc. are more preferred as supporting material compared to supporting material-based polymers. These materials are attractive because of their high surface-area-to-volume ratio, porous structure, excellent thermal stability, non-poisonous character and inertness. However, most of them are expensive and difficult to synthesize especially expanded graphite, carbon nanotube and graphene oxide, thus not economical to be used, particularly for building applications.

AC shows a promising inorganic porous material which can be used to encapsulate PCM. It is due to their properties which are abundant, chemically stable, high surface area, rich with pores, favorable pore size distribution, low density, easy to prepare, and cheap [38]. The surface area, pore diameter and surface chemistry of AC could also be easily engineered depending on the type of activation method and carbon precursor used. However, the pore structure of AC with similar pore size distribution, network-inner connection, functional groups on the internal surface and geometrical shape are difficult to obtain. Therefore, the phase change behavior of PCM in pores of AC is complicated thus make them difficult to study. These encourage us to synthesis AC from peat soil as one of the supporting material-based AC for the preparation of TES material based on PCM.

AC has attracted increasing attention in many areas of science, engineering and technological applications due to its special chemical, physical and electrical properties. AC is composed of blocks of thin, imperfect graphene layers randomly bound in a three-dimensional network, whereby the free spaces within the blocks are known as pores [39]. AC is composed of short-range ordered micrographite at the nanometer scale that is formed by the stacking of nano-sized graphitic sheets [40].

The encapsulation of PCMs into AC pores by adsorption to yield a shell framework is a potential means to control the volume changes of the PCMs during the phase change processes, increase the heat transfer area and protect the PCM from its external environment during its application [41]. The low thermal conductivity of PCM can also be slightly increase using AC, as supporting materials, which can affect the overall thermal conductivity of the PCM [31].

AC can be produced from a variety of industrial and agricultural wastes, such as bamboo [42], coconut shells [38], rice husks [43], industrial waste lignin [44], pineapple peels [45], corncobs [46], oil palm waste [47], durian shells [48], nut shell (almond, hazelnut, walnut, pistachio and macadamia shells) [49,50], fruit stones (apricot stone, cherry stones and grape seed) [51–53], cattail [54], tobacco stems [55], waste tea [56], waste tires [57], waste sludge [58] and lather waste [59]. The preparation of AC from industrial and agricultural carbonaceous-based waste materials can reduce the discharge of waste matter into the environment. In addition, alternative resources, such as coal-based materials [38], can also be used as precursors for producing AC. Unfortunately, research on the

utilization of peat soil as carbonaceous material for AC production is still lacking.

In this study, we demonstrate the production of AC from peat soil using physical activation. The pores of PSAC (peat soil activated carbon) were used as a framework for the preparation of SSOAC (shape-stabilized n-octadecane/PSAC) composite. The PSAC has multiple pores with a high-inner surface area, which allows it to be easily saturated with the melted n-octadecane. In addition, the PSAC used in this study can improve the thermal stability and thermal conductivity of the PCM composites due to the synergistic effect between the n-octadecane and PSAC. Therefore, the SSOAC composite can be applied in building energy conservation, heat recovery systems for thermal energy storage, transportation industries, electronic devices, etc. In general, this effort is anticipated to inspire new application of AC produced from low-cost resources as a promising supporting material for TES-based latent heat PCM technology.

## 2. Materials and methods

### 2.1. Materials

The peat soil sample used in this study was collected from Sabak Bernam, Selangor of Malaysia. The 30–90 cm deep layer relative to the surface of the peat soil was collected from the site. It was then oven dried at 60 °C for 48 h. The sample was ground and sieved through a 0.5 mm sieve and then used as a precursor for AC production. n-Octadecane (Sigma–Aldrich, Co., USA) was employed as a PCM (phase change material). Absolute ethanol (R&M Chemicals, UK) was used for the preparation of n-octadecane solutions.

### 2.2. Preparation of activated carbon from peat soil

AC has been prepared from peat soil using a simple physical activation method by heat treatment under an atmospheric environment. The dried peat soil samples were placed in a porcelain cup with a lid and carbonized at 800 °C in a box furnace for 7 h. The heating rate was 5 °C min<sup>-1</sup>, starting from room temperature. Carbonization was conducted to remove low-boiling-point and low-melting-point organic compounds while retaining carbon with a high porosity and surface area. After carbonization, the resulting carbons were activated under atmospheric pressure at 500 °C. Lastly, the samples were stored in a desiccator for further use and characterization.

### 2.3. Preparation of shape-stabilized n-octadecane/PSAC composite

A SSOAC composite was prepared by a simple impregnation method. The n-octadecane was melted by heating above its melting temperature and then dissolved in 30 mL of absolute ethanol. PSAC was added into the n-octadecane solution and the solution was then stirred at 600 rpm for 4 h. The mixture was oven dried at 80 °C for 48 h or until all of the excess ethanol was evaporated. The n-octadecane content in the composite PCM was varied from 10 to 90 wt.% (Table 1). The preparation of SSOAC composites (Table 1) were repeated two times.

**Table 1**

n-Octadecane and PSAC compositions used for the preparation of the SSOAC composites.

n-Octadecane/PSAC (wt.%)	n-Octadecane (g)	PSAC (g)	Labels
10	0.2	2	PCM-1
30	0.6	2	PCM-2
50	1.0	2	PCM-3
70	1.4	2	PCM-4
90	1.8	2	PCM-5

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