



Integration of form-stable paraffin/nanosilica phase change material composites into vacuum insulation panels for thermal energy storage

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HIGHLIGHTS

- Innovative phase change material integrated vacuum insulation panel was developed.
- The PCM integrated VIP has both low thermal conductivity and high thermal mass.
- Containing PCM composites in VIPs prevents any leakage.

ARTICLE INFO

Article history:

Received 2 March 2015

Received in revised form 6 September 2015

Accepted 7 September 2015

Keywords:

Phase change material

Vacuum insulation panel

Nano silica

Thermal energy storage

ABSTRACT

We investigated the integration of form-stable paraffin/nanosilica composites into vacuum insulation panels (VIPs) to improve the thermal mass. In total, six form-stable paraffin/nanosilica composites were produced by absorbing paraffin in different types of nanosilica with different surface characters, hydrophobic and hydrophilic. In view of cost, a phase change material (PCM) composite prepared by hydrophilic precipitated silica was chosen to produce the PCM-integrated VIPs. The microstructure and phase change behaviour of the PCM composites were investigated. The thermal mass of the PCM-integrated VIPs was found to be improved. With integration of PCM the thermal conductivity of the VIPs was increased, although it was still very low compared to normal foam insulations.

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1. Introduction

The incorporation of PCMs in building components may help reduce indoor temperature oscillations, since PCMs have the ability to store a large amount of latent heat within the small temperature range associated with a phase change. Extensive research into the application of PCMs in buildings to achieve latent heat storage has been conducted over the past several decades; examples of these works can be found in Refs. [1–3].

The latent heat, or thermal energy storage, of PCMs can be utilized in buildings in many different forms. In these utilizations, PCM-enhanced building envelopes such as wallboards, floors and ceiling boards that are impregnated with PCM have been proven successful [4]. PCMs have also been impregnated into thermal insulation materials to achieve greater thermal mass. Researchers [5,6] have studied rigid polyurethane foams incorporated with PCMs, which can be incorporated with or without microencapsula-

tion. Kosny et al. [7,8] studied the performance of fibrous insulation material incorporated with microencapsulated PCMs. The results indicated that the PCM-enhanced fibre insulation had excellent potential for successful application because of its ability to reduce energy consumption for space conditioning and to reduce peak loads [8]. It is expected that these types of dynamic insulation material will widely contribute to the objective of reducing energy use in buildings [8,9].

In these applications, however, microencapsulated PCMs have been preferred due to the potential leakage problem, which is one of the basic problems with the use of solid-to-liquid PCMs in insulation material or building material. In solid-to-liquid PCMs, the PCM exists in the solid phase below the melting point and in the liquid phase above the melting point. Certain problems, such as leakage, are associated with the presence of a liquid-phase PCM. To overcome the leakage problem, PCM must be contained properly. Microencapsulation is one method to contain PCM in very thin polymer shell, making micro-sized particles. Yet the procedure is complex and expensive, which makes wide application of microencapsulated PCMs less practicable.

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Compared to microencapsulated PCMs, the form-stable PCM composites was much easier to produce. Numerous works have been conducted to develop form-stable PCM composites by absorbing PCMs in granular porous particles, including expanded perlite [10,11], diatomite [12,13], nano silica [14], and expanded graphite [15,16]. Fabrications of the composites have attracted more attentions, while applications of these PCM composites have been limited. In earlier works [17,18] by the authors, in case of no preventions, PCM leakage of paraffin/diatomite composites was observed when the composites were mixed with cement and water. Since the prevention [17,18] is a physical method, it is still in doubt that the leakage would not happen during whole service life of the composites. To the best knowledge of authors, there is no perfect way to prevent PCM leakage of the composites, especially when the PCM composites contact with moisture.

In this study, we investigated the integration of form-stable PCM composites into Vacuum insulation panels (VIPs), in the expectation that the integration of PCM could improve the thermal mass of VIPs. Particularly, leakage of the PCM would not be a problem since the composites are form-stable and completely sealed within the VIP envelope.

VIPs are among the most promising building insulation materials in the early stages of commercialization. VIPs have an insulation performance which normally ranges from 0.004 W/m K in pristine condition to a typical 0.008 W/m K after 25 years of ageing. This is 5–10 times better, depending on ageing, than the traditional insulation used in buildings today. Therefore, VIPs enable the use of highly insulated construction for walls, roofs and floors, especially in the refurbishment of older buildings where space is often limited [19]. However, VIPs and organic foams, including Expanded Polystyrene (EPS), Extruded Polystyrene (EPS), and Polyurethane (PU), do not have enough thermal mass, which is helpful for improving thermal performance of building envelopes [8].

A VIP is fabricated by containing evacuated open porous material inside a multilayer envelope, as shown in Fig. 1 [20]. The main components of a VIP are inner core, barrier envelope, getters and desiccants. As shown in Fig. 1, the core is fabricated from porous material of suitable pore size. Its function is to maintain the

vacuum below a minimum critical level and to physically support the VIP envelope. The envelope works as an air- and vapour-tight barrier and is the most important component of the VIP [21]. Small size porous materials such as open porous foams, powders and fibres can be employed as the core in VIPs. Commonly, fumed silica, silica aerogels and expanded perlite individually or in a mixture form are used in VIP cores.

Six form-stable PCM composites were produced, in this study, by absorbing PCMs in hydrophilic and hydrophobic nanosilicas, namely fumed silica, precipitated silica and silica aerogel. The hydrophilic precipitated silica/paraffin composite was chosen to produce PCM-integrated VIPs in view of cost. The thermal behaviour of the PCM-integrated VIPs was then tested through a simulated hot-box test. The optimum PCM content in the PCM-integrated VIP was determined according to thermal behaviour investigations.

It was found that the PCM integrated VIPs developed in this study have both low thermal conductivity and high thermal mass by virtue of VIPs and PCMs. The potential applications of PCM integrated VIPs in buildings could also save construction and labour costs without the need to install PCM and insulation separately.

2. Materials

The PCM used in this study was RT21 from Rubitherm®, a liquid consisting of saturated hydrocarbons with the molecular formula C_nH_{2n+2} . The basic properties of RT21 are shown in Table 1. The melting point of RT21 ranges from 18 to 23 °C, close to comfortable ambient temperature.

Six different types of nanosilica were used as supporting materials to produce the form-stable PCM composites. Hydrophilic fumed silica (FS1) was purchased from Chengqixin (Shenzhen) Co. Ltd. Hydrophilic precipitated silica (PS1) was purchased from Tuoyi (Guangzhou) Co. Ltd. Hydrophobic fumed silica (FS2) and precipitated silica (PS2) were supplied by Evonik Degussa (China) Co. Ltd. Hydrophilic and hydrophobic silica aerogel, SA1 and SA2, were purchased from Guangdong Alison Hi-Tech Co. Ltd. The details of these six supporting materials are shown in Table 2.

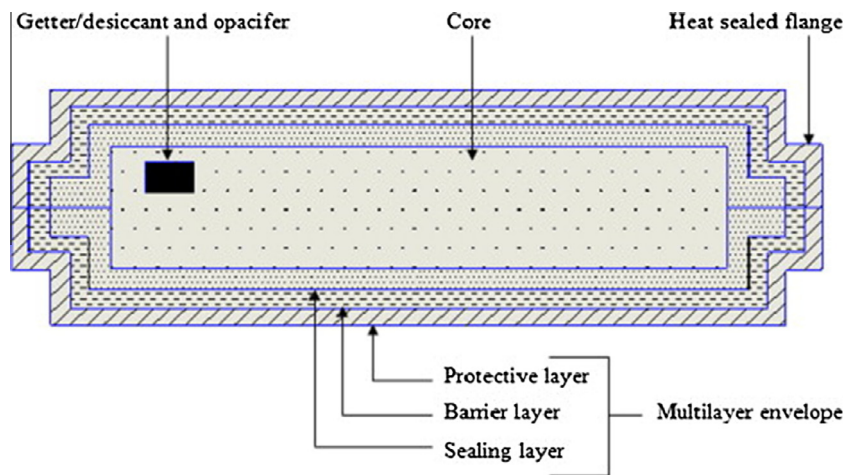


Fig. 1. Schematic of a VIP [20].

Table 1
Properties of RT21.

Material	Melting temp. (°C)	Heat storage capacity (kJ/kg)	Bulk density-liquid (kg/L)	Bulk density-solid (kg/L)	Thermal conductivity (for both phases) (W/m K)
RT21	18–23	160	0.77	0.88	0.2

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