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Preparation, characterization and thermal properties of dodecanol/cement as novel form-stable composite phase change material

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ABSTRACT

This research was aimed at preparing novel form-stable composite phase change material (PCM) for thermal heat storage application in buildings. Dodecanol was incorporated into cement through vacuum impregnation technique. The microstructure, chemical compatibility, thermal properties, thermal stability and reliability were determined by environmental scanning electron microcope (ESEM), Fourier transformation infrared spectrum analysis (FT-IR), differential scanning calorimetry (DSC), thermal gravimetric analyzer (TGA) and thermal cycling test. Test results showed that the maximum mass fraction of dodecanol retained in cement without seepage was 9%. This composite was characterized as form-stable composite. FT-IR results indicated that the form-stable composite is chemically stable. The melting temperature and latent heat of the form-stable composite were found to be 21.06 °C and 18.39 J/g. TGA and thermal cycling test results revealed that the form-stable composite is thermally stable and reliable. It can therefore be concluded that the prepared form-stable composite is a potential candidate for thermal energy storage application in buildings. With the help of an example it is shown that the 2 storey residential building has the capacity to store 2448 MJ of thermal energy. This, in turn, will have significant impact in reducing the energy consumption of buildings.

1. Introduction

The increase in energy demand arising from rapid economic growth worldwide have resulted in several energy concerns such as supply difficulties, exhaustion of energy resources, climate change and environment pollution [1]. The building and industrial sectors are the dominant energy consumers around the world with a total of 28 percent share to the overall energy consumption [2]. Moreover, in recent years the energy demand for buildings have increased very rapidly due to population growth, enhancement of building services and thermal comfort levels, and the rise in time for people spending inside buildings [3]. Therefore, improving the energy efficiency of buildings would help in resolving energy shortage and environmental pollution issues that the world is facing.

Thermal energy storage is a simple and effective technique to enhance the energy efficiency of buildings. It can be accomplished either using sensible heat storage or latent heat storage or reversible chemical reaction heat storage. Among these methods, latent heat storage utilizing PCM is most promising technique because of its advantages of high energy storage density and small temperature change from storage to retrieval. PCM works on the principle that as the temperature increases, the material store energy by changing its phase from solid to liquid and vice versa with in a defined temperature change. Similarly, when the temperature decreases, PCM releases heat by changing its phase from liquid to solid.

Most of the early work in latent heat storage was carried out using inorganic PCMs because they have high heat of fusion, good thermal conductivity, non-flammable and are cheap [4]. However, they have some undesirable features for example most of them are corrosive to most metals, undergo super cooling and phase decomposition [5]. The utilization of organic PCM as heat storage is known for long time. They are generally chemically stable, do not suffer from super cooling, non-corrosive, non-toxic and have high latent heat of fusion. Hawes et al. [4] carried out investigation on the use and stability of organic PCMs including butyl stearate, 1-dodecanol, polyethylene glycol, 1-tetradeconal, paraffin and dimethyl sulfoxide in concrete. Modified PCM concrete showed good thermal storage characteristics. Sari and Karaipekli [6] prepared form-stable composite PCM by incorporating palmitic

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acid into expanded graphite. The carrier was able to successfully retain 80% by mass without seepage of PCM from the composite. The composite sustained 3000 cycles of melting and freezing and hence testified the thermal and chemical reliability of the composite. The thermal conductivity of the composite was improved by incorporating different mass fraction of expanded graphite into the composite. Based on the test results, the form-stable composite showed considerable latent heat energy storage potential. Karaman et al. [7] prepared form-stable composite PCM by incorporating polyethylene glycol in diatomite. Polyethylene glycol was retained by 50% weight into the pores of diatomite without leakage. Based on the test results, it was concluded that the novel form-stable composite can be utilized for energy storage applications such as in wallboards. Chen et al. [8] prepared *n*-octadecane/molecular sieve 5A as form-stable composite for thermal energy storage in buildings. According to the authors, molecular sieve can improve thermal stability of the composites due to the synergistic effect between *n*-octadecane and molecular sieve 5A.

This research utilized dodecanol, which has high latent heat storage and melting temperature in the human comfort zone (16–26 °C), as PCM into cement through vacuum impregnation technique. The purpose was to develop novel form-stable composite PCM having excellent heat transfer control in terms of thermal storage, thermal stability and reliability, physical and chemical compatibility. The possible chemical and physical interaction between cement and PCM were evaluated through FT-IR analysis while the thermal properties, thermal stability and reliability of the composite were determined using differential scanning calorimetry, thermal gravimetric analyzer and thermal cycling test.

2. Experimental investigation

2.1. Materials selection and characterization

Phase change material properties would have direct impact on the human comfort level. According to the literature [5,9], it should possess desirable thermal, physical, kinetic and chemical properties. Ideally, PCM should have high storage density, good heat transfer, small volume change, low vapor pressure, no super cooling, long term chemical stability, non-toxic, non-flammable and self-nucleating behavior [5,9]. In addition, for building applications its phase change temperatures should be in between 16 and 26 °C [10,11]. Hawes et al. [12,13] also pointed out economic considerations as one of the criteria for selection of PCM. Based on these criterions, some of the organic PCMs are enlisted in Table 1. Among them, dodecanol and *n*-octadecane are in the human comfort zone and they also have high latent heat capacity. However, the cost of 100 ml of *n*-octadecane (in China) is around RMB 280 while the cost of docecanol is around RMB10. In addition, dodecanol is one of the most highly polar of the PCM. According to Hawes et al. [14], when docecanol contracts on freezing it may cause greater retention of PCM in smaller pores of the carrier. Therefore, dodecanol, having phase change temperature in the human comfort zone, possessing high latent heat capacity and from economic point of view was selected as PCM for this research. Cement, which is the widely used construction material, was used as carrier for PCM. It was sieved through 150 μm sieve and dried at 105 °C for 24 h before use. The chemical composition of cement analyzed by X-ray fluorescence (XRF) technique is given in Table 2.

Table 1
Oraganic PCMs.

PCM	Melting point (°C)	Latent heat capacity (J/g)	References
Butyl stearate	19	140	[13]
Dodecanol	21.69	205.4	This research
1-Tetradecanol	38	205	[13]
n-Octadecane	28.12	236	[34]
Palmitic acid	61.70	194.45	[6]
Polyethylene glycol	33.32	143.16	[7]
Stearic acid	59.9	177.84	[35]

2.2. Preparation of form-stable composite PCM

The form-stable composite PCM was prepared using vacuum impregnation technique. For convenience, Sari and Karaipekli setup [6] was modified (Fig. 1). Cement with different mass fractions of

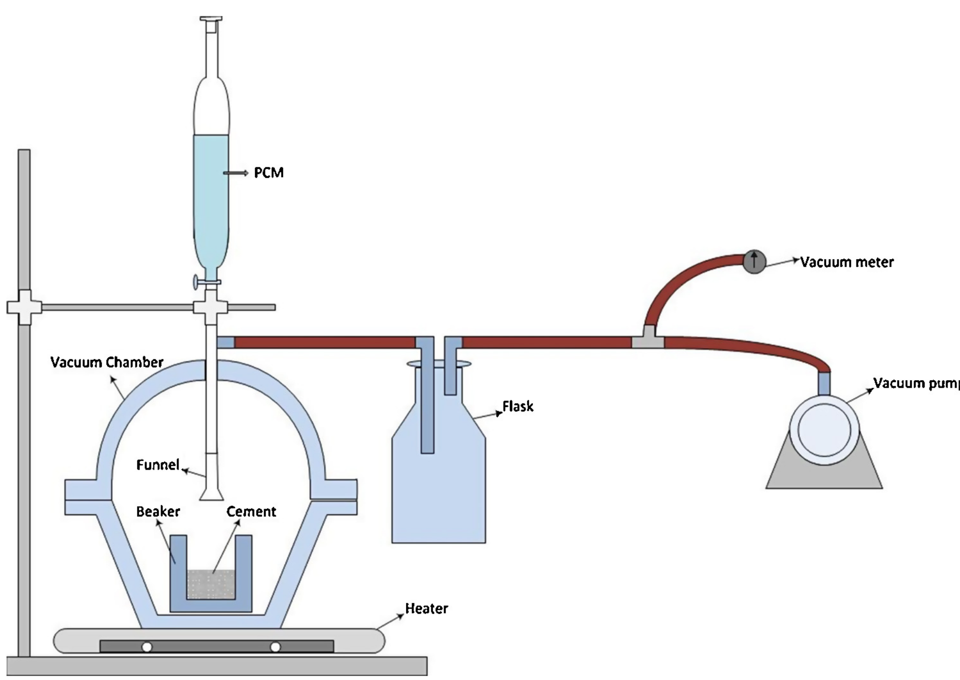

Fig. 1. Schematic of vacuum impregnation system.