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Using silicagel industrial wastes to synthesize polyethylene glycol/silica-hydroxyl form-stable phase change materials for thermal energy storage applications

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ABSTRACT

Polyethylene glycol form-stable phase change materials (PEG FSPCMs) have received much attention in recent years for thermal energy storage applications due to their remarkable thermal properties. However, the conventional synthesis of PEG FSPCMs usually employed chemical grade regents as starting materials, which is unlikely suitable for large-scale industrial preparation of PCMs. In the present work, silicagel industrial wastes were employed as starting materials for the first time to synthesize a polyethylene glycol/silica-hydroxyl compound (PEG/SHC) form-stable phase change material using a facile sol-gel method. The morphology and chemical compatibility were characterized using scanning electron microscopy (SEM), fourier transform infrared spectroscopy (FT-IR) and X-ray diffraction (XRD). The thermal energy storage performance was evaluated using differential scanning calorimetry (DSC), thermogravimetric analysis (TGA), thermal constants analysis, respectively. The results indicated that the PEG was encapsulated in the SHC matrix through a physical interaction, and the weight fraction of PEG in the FSPCM could be as high as 80% with no significant leaking liquid observed. The thermal energy storage capacity in this FSPCM was found to be (59.38–132.4) J/g and (63.56–133.4) J/g in the melting and crystallization process, respectively, as the loaded PEG weight fraction ranging from 50% to 80%. The thermal conductivity of the FSPCM enhanced by the SHC matrix was determined to be as high as 30% compared with that of the pure PEG. Additionally, the FSPCM synthesized in this method could maintain a stable thermal property during the heating/cooling cycles. On the basis of these results, it was demonstrated that the sol-gel method developed in this work could not only obtain PEG based FSPCMs with good performance for thermal energy storage, but also propose an effective way of producing economic benefits by reusing silicagel industrial wastes.

1. Introduction

With the depletion of fossil resources in the earth, the effective utilization and rational management of nonrenewable resources have become the urgent demand of the development of human society. On the other hand, the continuous increase of industrial waste has also been a serious threat currently to human living environment, and therefore developing techniques for the industrial waste recycling is vital to the construction of social ecological balances. Most importantly, the exploiture and application of new techniques or methods for the energy resources utilization and management on the basis of industrial waste would be more significant and impressive for constructing green and energy-saving societies.

Thermal energy storage using phase change materials (PCMs) has intrigued a great deal of interests in recent years due to its potential applications in the fields of intelligent temperature control design [1] , indoor thermal fluctuation reduction [2], solar cooling technology [3], heat management on electronic devices [4], thermal energy collection in thermosolar industry [5] and so on. The PCMs involved in this energy-saving technology are capable of storing/releasing thermal energy during the phase transition process at almost constant temperatures with the involved latent heats absorbed/released, which are generally several times larger than those commonly used in sensible heat storage materials [6,7].

As for the PCMs currently studied, polyethylene glycol (PEG) based materials have received much attention because of their large heat

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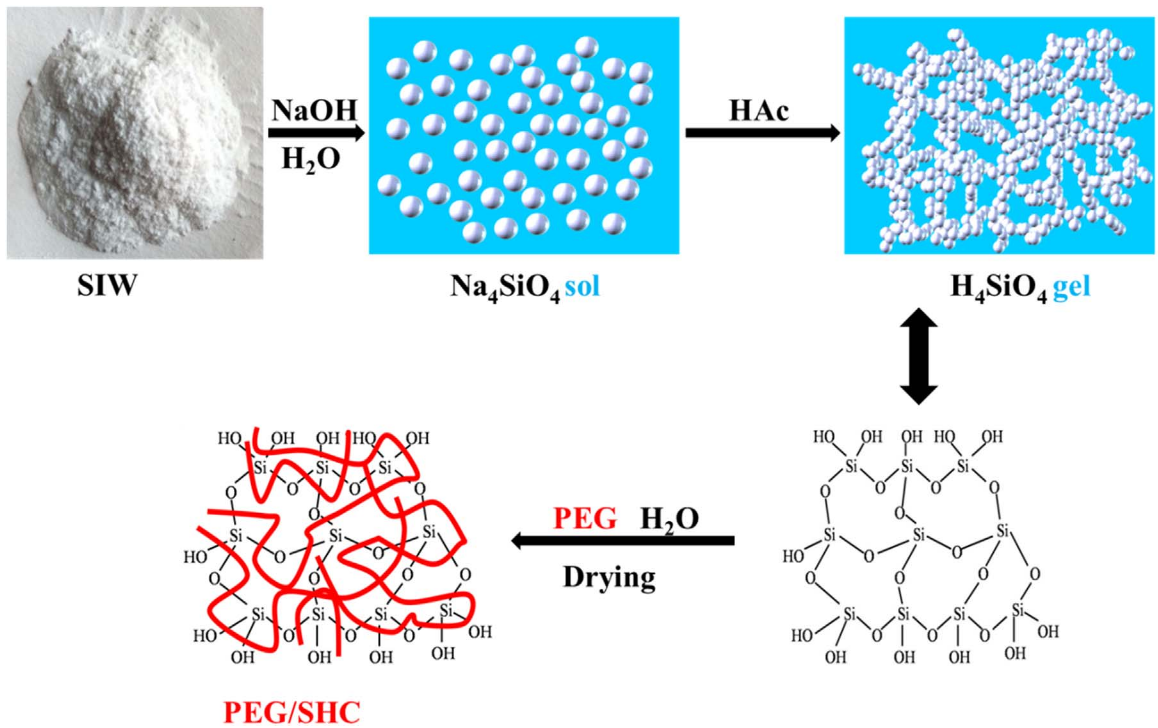

Fig. 1. Synthesis process of PEG/SHC FSPCMs.

storage capacity, adjustable phase change temperature varied with different molecular weights, stable chemical property, no toxicity and relatively reasonable price [8–11]. However, the liquid phase leakage and low thermal conductivity of PEG have greatly hindered its practical applications in thermal energy storage fields [12–14]. To overcome these obstacles, the synthesis technique called form-stable PCMs (FSPCMs) preparation has been proposed by embedding PCMs into some supporting materials, including expanded graphite [15], diatomite [16], cellulose [17], bentonite [18] , graphite [19] and so on. The supporting materials could not only prevent the liquid phase leakage by encapsulating PCMs in materials, but also significantly improve the thermal conductivities by providing a three-dimensional inorganic structure in the entire FSPCMs [20]. Among the numerous supporting materials, silica-hydroxyl compounds (SHCs) are of interest due to their excellent encapsulation capacity and relatively high thermal conductivity compared to the pure PEG [21,22]. Consequently, the design and synthesis of PEG/SHCs based FSPCMs have become one of the frontier research topics in developing new PCMs for thermal energy storage applications.

Tang et al. synthesized PEG/SiO_2/MWCNT and PEG/SiO_2 doped Cu using tetraethoxyl silane (TEOS) as starting materials to obtained FSPCMs [23,24]. Qian et al. prepared co-crystallized poly (ethylene glycol) composites utilizing TEOS as supporting matrix precursor [1]. Yang et al. prepared PEG/SiO_2 composites with TEOS as the silica framework precursor [25]. Fang et al. prepared microencapsulated octadecane with silica shell by using sol-gel method with methyl triethoxysilane [26]. In these synthesis strategies for PEG based FSPCMs, the chemical grade TEOS or methyl triethoxysilane were generally employed as starting materials to obtain the prerequisite silica precursor. However, these conventional regents used as the resources for SHC is unlikely suitable for large-scale industrial preparation of FSPCMs due to their high cost, chemical toxicity and complicated reaction conditions involved in the synthetic process [27]. It is worth noting that Qian et al. developed a temperature-assisted so-gel method for preparation of a green shape-stabilized composite PCM of PEG/SiO_2 with enhanced thermal performance using the “hazardous waste” oil shale ash produced in the oil shale processing [21]. Although the synthesis process employed in their work seems a little complicated and the silica extraction efficiency is relatively low, the waste oil shale ash used in this work instead of the chemical grade regents provides an innovative technique of low cost synthesis of PEG based FSPCMs using industrial wastes.

In this work, we have presented a facile sol-gel method of synthesizing PEG/SHC FSPCMs using silicagel industrial wastes provided by a silicagel production plant for the first time. This sol-gel method involved only sodium hydroxide and acetic acid as coreagents without any other surfactants or coagulants needed in the conventional sol-gel preparation process. Moreover, the sample morphology, chemical structure, crystal phase and thermal stability of the as prepared PEG/SHC FSPCMs have been characterized using scanning electron microscopy (SEM), fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD) and thermogravimetric analysis (TGA) techniques, respectively. The thermal property and conductivity of the PEG/SHC FSPCM have been determined using a differential scanning calorimeter (DSC) and thermal constants analyzer, respectively. The results indicate that the PEG/SHC FSPCMs prepared based on the silicagel industrial wastes behave a good thermal property, enhanced thermal conductivity and stable cycle performance comparable to those synthesized using the conventional sol-gel method.

2. Experimental

2.1. Materials

The silicagel industrial wastes, a kind of amorphous byproduct from an enterprise of silica gel producer in Tangshan city, China, mainly contains silica, denoted by SIW. Polyethylene glycol with an average molecular weight of 1500 (PEG1500), was purchased from Haian Petroleum Chemical Factory, Jiangsu province, China. Sodium hydroxide (NaOH, AR,) and glacial acetic acid (HAc, AR,) were provided by Sinopharm Chemical Reagent Co., Ltd., China and Tianjing Fuyu Fine Chemical Co., Ltd., China, respectively. All of these starting materials were used as received in the flowing PCM synthesis process.