



Thermal conductivity enhancement of recycled high density polyethylene as a storage media for latent heat thermal energy storage



C. Yang^a, M.E. Navarro^{b,*}, B. Zhao^a, G. Leng^b, G. Xu^a, L. Wang^a, Y. Jin^a, Y. Ding^b

^a Smart Grid Research Institute, China State Grid, Beijing, China

^b BCES Birmingham Centre of Energy Storage, University of Birmingham, United Kingdom

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ABSTRACT

In the context of reducing CO₂ emissions and balancing energy supply and demand across the electricity grid, energy storage has become an important topic. Therefore, new energy policies are looking for more efficient and environmental friendly technologies. The aim of this research is to assist in the implementation of the renewable energies technologies and to improve the energy efficiency in well-known and established processes by recovering and storing heat. Moreover, the use of a recycled material as a storage media for thermal energy storage applications shows a more sustainable use of resources reducing at the same time the overall cost.

In this research a novel composite, a recycled high density polyethylene (HDPE)/graphite(Cg) mixture, for medium temperature thermal energy storage application has been formulated and characterized. One common characteristic of polymers is their low thermal conductivities. This causes a slow thermal response when the PCM is used in high power applications. In this study the thermal conductivity properties of the HDPE/Cg were enhanced by the optimization of its manufacturing process and composition. Graphite content was added in different mass fractions into the PCM, and thermal properties were measured by means of Thermogravimetric analysis (TGA), Differential scanning calorimetry (DSC) and Laser Flash Analysis (LFA). The experimental results showed that the thermal conductivities are improved by the higher mass fraction of graphite. When the graphite content was in the ratio of 20 wt%, the thermal conductivity of the PCM increased from 0.51 W m⁻¹ K⁻¹ up to 1.31 W m⁻¹ K⁻¹. The secondary electron microscopy confirms a good homogeneity of the manufacturing process. Further chemical stability analysis was performed by means of charging and discharging processes. The cycled samples present good thermal property reliability at temperatures up to 250 °C.

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1. Introduction

Thermal energy storage (TES) is an expanding field which aims to assist in the implementation of the renewable energies technologies and to improve the energy efficiency in well-known and established processes by recovering and storing heat. Latent heat thermal energy storage (LHTES) is a technology that uses the energy absorbed or released during the phase change of a material. This material is called phase change material (PCM) [1]. The main properties for TES materials are density, specific heat capacity, latent heat in phase change materials (PCMs), thermal conductivity and cycling stability, as well as availability and costs. The efficient use of energy using PCM as thermal energy storage (TES) materials has attracted a great interest in both industrial and

domestic applications [2–4]. PCMs can be classified depending on their chemical nature as organic (paraffin, non-paraffin compounds), inorganic (salt hydrate or metals) and eutectics (organic–organic, inorganic–inorganic, organic–inorganic) [1].

1.1. Organic

- Paraffin are non-corrosive, chemically inert and stable below 500 °C, show little volume changes on melting and have low vapor pressure in the melt form, therefore are one of the more utilized PCM, however, they present low thermal conductivity, are non-compatible with the plastic container and flammable. These adverse properties can be improved and solved by encapsulating the paraffin in a suitable container [5].
- Non-paraffin: non-paraffin organic PCM comprises those materials who contain functional groups such as alcohol and fatty acids or polymers.

* Corresponding author.

E-mail address: h.navarro@bham.ac.uk (M.E. Navarro).

1.2. Inorganic

- Salt hydrates: have been extensively studied for their use in LHTES systems. They present a high latent heat of fusion per unit volume, a higher thermal conductivity than paraffin's and small volume changes on melting also compatible with plastics, non-flammables, but are slightly toxic, present supercooling and nucleation problems and corrosive to most metals [6,7].
- Metals have a high heat of fusion per unit volume, present higher thermal conductivities than other PCMs and a relatively low vapor pressure. Nevertheless, they require more complex engineering systems.

1.3. Eutectics

- Eutectics are mixtures in which both components change their phase simultaneously at a temperature below their melting temperature when they exist separately. They present sharp melting point and no segregation during the phase change [8].

Organic phase change material generally do not present supercooling neither phase segregation, they are less corrosive than salt hydrates stable when they are cycled, present a low toxicity and low cost [9]. However, their low thermal conductivity restricts their applications. In some applications the thermal energy must be absorbed or released at a very fast rate. However, most PCMs have a low thermal conductivity [10], resulting on an underuse of the PCM because it partially melt, profiting only the sensible heat of the material. Instead, if you want to use all the latent heat of the PCM, the low thermal conductivity of the materials slows down the charge/discharge process [11]. In order to solve this, several methods have been proposed for increasing the thermal conductivity of PCMs: adding conductive structures (extended surfaces like fins and annular substructures) [12–16], impregnating a porous matrix (impregnation) [17] or dispersing a high conductivity particles within the PCM (mixing) [18]. Despite the insertion of thermal conductivity enhancers means the worsening of the energy density the TES material store [19–21] the reduction of the rate of heat storage and extraction during the melting and solidification cycles allows the use of these technologies in applications such as thermal electronic management [22] and industrial processes [23].

Among organic materials, recycled High density polyethylene (HDPE) as a PCM present good thermal properties, chemical stability and low price. It has a high degree of crystallinity, is a non-polar thermoplastic resin, nontoxic, odorless with a density between 0.941 and 0.960 g cm⁻³. It has a good chemical stability, with a melting point above 125 °C. Conventional HDPE presents a latent heat between 210 and 180 J g⁻¹ [24]. However, its thermal conductivity is around 0.3 W m⁻¹ K⁻¹ [25]. HDPE has been extensively studied as a material for the encapsulation of PCM, rather than a thermal energy storage material [26].

In recent years, using carbon materials to improve the thermal performance of PCM has received great attention because it has a high thermal conductivity and corrosion resistance, high temperature resistance, good self-lubricating. Several studies report the use of carbon as an expanded graphite (EG), with a thermal conductivity of expanded 300 W m⁻¹ K⁻¹ [27] and also as a carbon fiber [28–30]. Sari [31] prepared a paraffin/HDPE composite energy storage material, 77 wt% wax and 3 wt% graphite flakes obtaining a 24% thermal conductivity enhancement. Xiao et al [32] enhanced the thermal conductivity of a waxes/styrene – butadiene – styrene (SBS) copolymer composite by adding graphite improving the thermal performance by shortening the charge/discharge process 47% and 34%. Sari et al. [33] studied the effect on the thermal conductivity of a paraffin wax when it is mixed with expanded graphite. The results showed that when the mass

fraction of exfoliated graphite was 2%, 4%, 7% and 10% the thermal conductivity was 0.40 W m⁻¹ K⁻¹, 0.52 W m⁻¹ K⁻¹, 0.68 W m⁻¹ K⁻¹ and 0.82 W m⁻¹ K⁻¹ respectively. Zhang et al. [34] studied the addition of several additives, different oxides and graphite, obtaining a thermal conductivity enhancement higher when graphite was mixed with the PCM/HDPE of 221% with 20% graphite.

The aim of this study is to increase the thermal conductivity of a recycled polymer, high density polyethylene (HDPE), for low temperature TES applications due to its poor thermal conductivity. Several compositions with different amounts of thermal conductivity enhancer materials have been formulated. The main properties related to thermal energy storage applications have been characterized: melting point, latent heat, specific heat capacity, thermal conductivity and thermal performance. The results showed that as expected, when the energy density of the composite decreased, the melting point remains around the recycled raw material. Furthermore, the thermal conductivity is enhanced significantly as well as the charge/discharge time.

2. Materials

The materials used in this research have been purchased from two different sources. As the PCM material it has been purchased a recycled HDPE polymer from Polyplastic Pellets. HDPE has a melting point of 130 °C, a latent heat of fusion of 164 kJ/kg and a density of 0.954 kg m⁻³ [35,36]. The polymer was presented in pellet form with a diameter around 5 mm with 1 mm thickness. The thermal conductivity enhancer is commercial graphite in flaked form, from Sigma Aldrich. According to the specifications, the graphite flakes have a density of 1.9 g cm⁻³.

3. Experimental

In order to design and study the properties of the composite HDPE/Cg it has been prepared using several compositions with several contents of Cg, as can be seen in Table 1.

The composite formulation starts with the grinding of the polymer, as it is sold as pellets to a particle size lower than 1 mm. The grinding process is done by means of a rotor mill (Retsch) and a sieve size of 1 mm. After the grinding process the graphite is added in the correct amount for each composition and mixed by means of a rotating mixer until the mixture is homogeneous. Then the mixture is placed into round molds (50 mm and 13 mm diameter) and heated at a temperature higher than the melting point, 150 °C for 30 min. After that the mixtures were hot pressed in order to remove the air trapped in the viscous structure. The molds were let cool down at room temperature. The resulting 50 mm composites can be seen in Fig. 1.

Table 1
HDPE/Cg composition in % (w/w).

Sample	HDPE	Graphite
H1	100	0
H2	99	1
H3	96	4
H4	90	10
H5	85	15
H6	80	20

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