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Thermal stability of sodium nitrate microcapsules for high-temperature thermal energy storage

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ABSTRACT

The $NaNO_3$ microcapsules (MCP-$NaNO_3$-2) with good thermal stability were prepared by twice repeating the process of microencapsulation. The thermal stability of MCP-$NaNO_3$-2 was tested by thermal cycles and high-temperature heating in the furnace. The thermal properties, such as latent heat, melting point, supercooling degree, were determined by thermogravimetric analyzer (TG) and differential scanning calorimetry (DSC). The microcapsule morphologies were observed by optical microscope and scanning electron microscope. After 80 thermal cycles mainly between 250 and 350 °C, the latent heat of MCP-$NaNO_3$-2 only had a small reduction of about 3.6%, the melting point of MCP-$NaNO_3$-2 only decreased by about 1 °C, and the supercooling degree of MCP-$NaNO_3$-2 slightly fluctuated within about 2 °C. Additionally, the thermal properties of the MCP-$NaNO_3$-2 heated for 5 h at 350, 450, 500, and 550 °C showed that the latent heat of MCP-$NaNO_3$-2 was relatively stable until 500 °C, from 136.1 to 130.3 J/g, but sharply decreased to 110.2 J/g at 550 °C. It is concluded that MCP-$NaNO_3$-2 has good thermal stability in thermal cycles and at the high temperature up to 500 °C and has a good potential for high-temperature thermal energy storage.

1. Introduction

Nitrate salts are important and widely used as high-temperature phase change materials for thermal energy storage in the solar thermal power plants [1–5], waste heat recovery systems and industrial processes [6–9]. Commercial solar thermal plants which concentrate the sun's energy to produce steam and electricity mainly use nitrate-based melts as a heat transfer fluid or for thermal energy storage. Molten salts consisting of $NaNO_3$ and KNO_3 (60–40 wt%, m.p. 238 °C, Solar Salt) have been used successfully as a thermal energy collection and storage fluid in a large-scale solar central receiver demonstration system in the solar power plants [10].

In practical application, the thermal stability is a significant performance parameter for all kinds of phase change materials such as alloys [11], fatty acids [12–14], inorganic salts [15,16], paraffin wax [17,18]. There are also many studies on the thermal stability of nitrate salts. Bauer et al.[19] reported that $NaNO_3$ was thermally stable at 350 °C in air at atmospheric pressure, and mass variations of $NaNO_3$ during the 2600 h test at 350 °C were monitored four times and found to be smaller than ± 0.05%. Wang et al. [20] investigated the thermal stability of the $LiNO_3$–$NaNO_3$–KNO_3 ternary salt system, and found that the weight change of the ternary salt system is minimal below 435 °C. Olivares et al. [21] further investigated the thermal stability of the $LiNO_3$–$NaNO_3$–KNO_3 ternary salt system in different blanket gas atmospheres of argon, nitrogen, oxygen and air by simultaneous differential scanning calorimetry, thermogravimetry and mass spectrometry (DSC/TG-MS). The thermal stability of the ternary salt system was measured by the gases evolving from the melt. Evolution of the main gaseous species NO was detected at 325 °C in an atmosphere of argon, at 425 °C in an atmosphere of nitrogen, at 475 °C in an atmosphere of air and at 540 °C in an atmosphere of oxygen, demonstrating the favourable effect of pO_2 on the reversible nitrite/nitrate equilibrium.

Molten nitrate salts have high corrosivity to the encapsulating materials. The microencapsulation is an effective method to solving the corrosive issue, and meanwhile increasing the surface area for heat transfer between phase change materials and environment [22]. $NaNO_3$ microcapsules, with the melting point of 306 °C, have been successfully prepared using perhydropolysilazane (PHPS) as the shell material through a novel method of solvent extraction combined with ultrasonic dispersion for the first time, and their microstructures and thermal properties such as latent heat, melting point, supercooling degree have been investigated in detail [23]. In general, phase change materials microcapsules are required to have good thermal stability to ensure an intact structure for thermal energy storages. The thermal stability of $NaNO_3$ microcapsules need to be further studied to obtain the microcapsules with good thermal stability.

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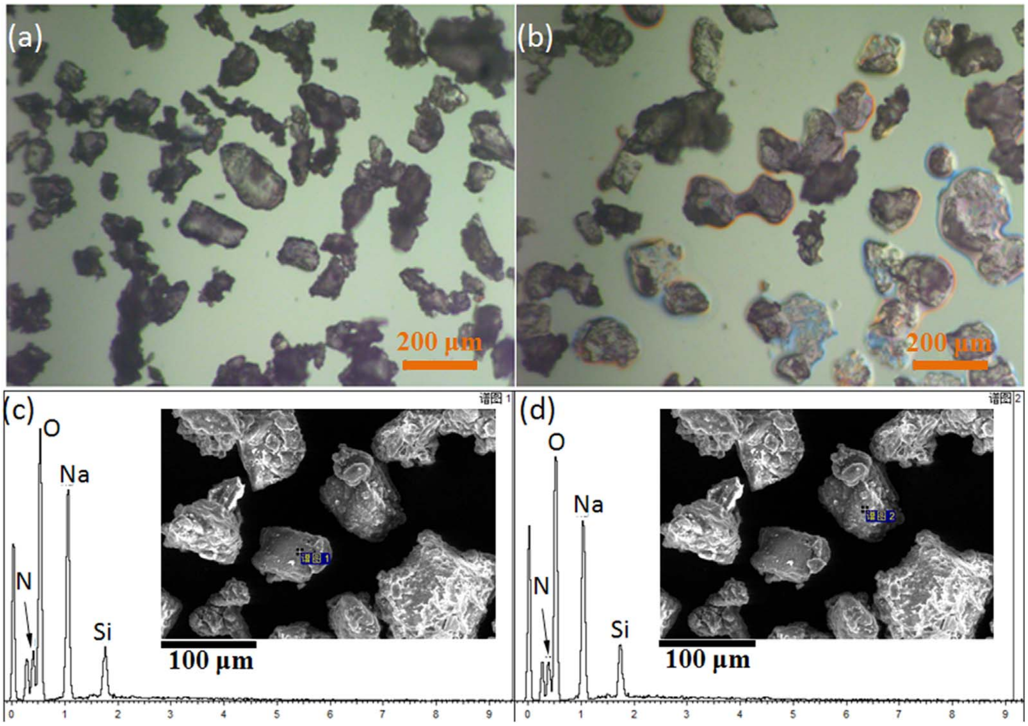

Fig. 1. Optical micrograph images and EDS results of MCP-$NaNO_3$-1 before and after 5 thermal cycles, (a) before thermal cycles, (b) after thermal cycles, (c), (d) EDS results before thermal cycles.

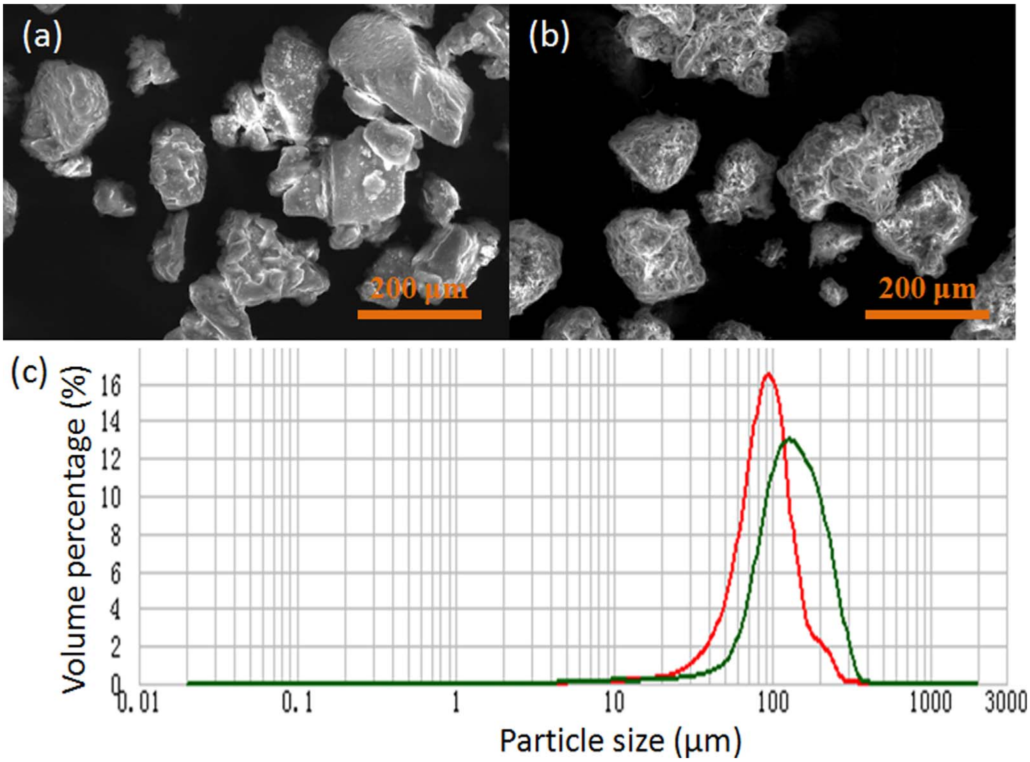

Fig. 2. SEM images and particle size distribution of MCP-$NaNO_3$-1 and MCP-$NaNO_3$-2, (a) MCP-$NaNO_3$-1, (b) MCP-$NaNO_3$-2, (c) particle size distribution.

In the present work, the thermal stability of $NaNO_3$ microcapsules was improved by twice repeating the process of microencapsulation. The latent heat, melting point, supercooling and microstructures of $NaNO_3$ microcapsules after 80 thermal cycles mainly between 250 and 350 °C were determined to show the thermal stability of $NaNO_3$ microcapsules in thermal cycles. In addition, the $NaNO_3$ microcapsules