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Preparation, heat transfer and flow properties of microencapsulated phase change materials for thermal energy storage

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ABSTRACT

Microencapsulated phase change material (MPCM) is one of the most practical materials to enhance the energy efficiency for thermal energy storage. The microencapsulation technique is used to solve the leakage and volume change problems of pure phase change material (PCM). The MPCM slurry has become a novel heat transfer fluid in heat transfer and heat storage systems. In recent decades, the microencapsulation methods have been widely studied and proposed in many fields such as building, textile, food storage, solar and thermal energy storage, etc. The MPCM and its slurry prepared by these methods are widely investigated and put into practice. Based on these findings and applications, the different microencapsulation methods are characterized in this work. Next, the flow characteristics and basic thermal properties of this novel slurry are introduced in classification. At last the heat transfer problems under different situations are reviewed and analyzed. The future trend of the microencapsulation in thermal energy applications is presented.

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1. Introduction

In order to satisfy the global energy demand and alleviate the associated environmental problems, phase change materials (PCMs) for thermal energy storage have attracted much attention to various applications. In various energy systems, they can both be used as thermal storage medium and heat transfer fluid [1]. PCMs can be selected from n-alkane, bromoalkane, fatty acids, glycol, salt hydrates and metals [2–4]. They can also exist on the form of eutectics as PCMs.

However, conventional PCMs suffer from the leakage problem and significant subcooling phenomenon during its phase change process, thus it limits their application as thermal storage materials. Normally the thermal conductivity of the common organic PCM is very low, thus it is an obstacle for heat transfer. The PCMs are modified by encapsulation techniques including microencapsulation technique and shape stabilization technique to solve these problems. Both encapsulation technologies have advantages and disadvantages. The products with microencapsulation technique can be served as more than a heat storage material but also as a heat transfer fluid, which facilitates the heat exchange between the storage medium and charge/discharge outlet [1,5,6]. Other kinds of phase change fluids include ice slurry, phase change emulsion and clathrate hydrate slurry. However, microencapsulated phase change material (MPCM) slurry is the most commonly proposed kind among the all types of the slurry to solve both the problems peculiar to organic and inorganic kinds of the slurry. On the other hand, the MPCM slurry can increase the heat transfer area and thermal conductivity of phase change materials. A detailed introduction of different kinds of microencapsulation technique was presented in Reference [7]. Potential shell materials used in the encapsulation for thermal energy storage applications are elaborately listed by Jacob and Bruno [8].

The objective of this work is to help better understand the composition of the MPCM materials and the working mechanism of the MPCM slurry as functional thermal fluid. Thus in the future thermal control engineering design, a new pathway is to be taken into account. They are presented in this order: Firstly, the formations of the MPCM, namely the microencapsulation preparation methods, are classified and summarized. Next, the heat transfer and flow characteristic research results are studied. The features of the MPCM properties and the establishment of models for the MPCM slurry are summarized. Based on the summary and analysis of major experimental results, characterizations of thermal and hydrodynamic properties for the MPCM slurry are made in this work, including the properties, heat transfer characteristics, stability and applications. In this study, each property is reviewed with its specific model and application regions. Basic evolution trends are also compared with other kinds of the PCMs that are available in literature, so as to reveal the basic information of possible ways for future breakthroughs. In the final part, the future directions of the MPCM in thermal energy storage applications are also presented.

2. Preparation methods of microencapsulated phase change materials

Microencapsulation is a process of coating a core material with a layer of film at the size of below 1000 μm, known as a microcapsule. The core material and the shell material can both be organic and inorganic. Phase change materials are widely used as core materials for thermal energy storage. The shell material is built to protect the PCMs from leakage and contact against the environment. The microencapsulation methods have been studied in various fields such as medical science [9] and food storage [10,11]. The products with microencapsulation technique have new chemical and physical properties. The MPCMs for thermal energy storage can be prepared using chemical, physico–chemical, physico–mechanical or chemical–mechanical methods. These methods contain four categories of encapsulation technique, each includes several preparation methods.

2.1. Chemical methods

Chemical methods with different approaches are introduced and the properties of the prepared microencapsulated PCMs in different articles are listed in Table 1. The organic or inorganic materials can be used as shell material or the precursor to build the shell. The microencapsulation of the PCM decreases the heat storage ability, but the heat transfer properties are not subsequently weakened, which would be also discussed in this paper.

2.1.1. Suspension–like polymerization

This method involves two kinds of disperse systems: suspension and emulsion. Ma et al. [13] used emulsion polymerization method to prepare a series of microencapsulated PCMs with acrylate–based polymer shells and binary core materials. The suspension polymerization system involves two phases: the dispersed (discontinuous) phase containing the reagents of core materials and monomers with initiator to prompt the reaction; the continuous phase including reactant of shell materials and solvent. And the suspension polymerization process can be described as follows: (i) the dispersed phase is mixed under stirring to obtain homogeneous oil solution; (ii) the solution is then added into the continuous phase at a constant temperature to form an oil/water emulsion; (iii) the oil/water emulsion is further homogenized with an emulsifier (iv) the stable emulsion is stirred at a higher constant temperature for some time to help the polymerization reaction; (v) the resultant microencapsulated PCMs are filtered, washed and dried. An emulsion polymerization microencapsulation process is shown in Fig. 1 [2].

Konuklu et al. [4] synthesized a series of microcapsules containing four kinds of n-alkanes, using an emulsion polymerization with poly (styrene–co–ethylacrylate) as shell material. Unlike the preparation process of Ma's, the dispersed phase contains the reactant of shell materials and cross linker while the continuous phase contains the core materials and the solvent. And the initiator of the chemical reaction was added into the homogenized