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Fatty acids as phase change materials: A review

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ABSTRACT

Fatty acids as phase change materials have attracted much attention for their various applications in building energy efficiency, solar heating systems and air-conditioning systems. After summarizing the basic characteristics of fatty acids, eutectic mixtures of fatty acids and fatty acid esters, as well as the preparation and characteristics of fatty acid composites as phase change materials (PCMs), this paper analyzes the thermal reliability and stability of fatty acids as PCMs and their heat transfer characteristics in a unit which is followed by an introduction to the energy storage systems of three kinds of fatty acids as PCMs. Besides, it also points out the future research direction of fatty acids as PCMs as a solution of the insufficiency and flaws of current researches.

Contents

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1. Introduction

In recent years, with the rapid economic development, energy shortage and environmental issues have become increasingly serious. Therefore, it is an important topic to improve energy utilization efficiency and protect environment. Energy storage is an essential method to match the thermal energy supply and demand in time or space. Latent heat thermal energy storage (LHTES) can achieve a higher energy storage density, a smaller size of the system and a narrower temperature range during the melting and freezing process of phase change materials (PCMs). PCMs have attracted much attention for their various applications in building energy efficiency, solar heating systems and air-conditioning systems [1–4].

At present, a large number of inorganic, organic and their mixtures PCMs have been studied. Among all investigated PCMs, fatty acids have many superior properties, including proper melting temperature range, high heat capacity, congruent melting, little or no supercooling during phase transition, lower vapor pressure, non-toxic, non-corrosive to metal containers, good chemical and thermal stability, low cost, non-flammability and small volume change [5–10]. In the researches of the fatty acids as PCMs, it is found that, two or more fatty acids can be mixed to form the eutectic mixture with a lower phase change temperature. It is also found that fatty acids esters can be synthesized via esterification reaction, and fatty acid composite PCMs also can be prepared through different ways. These fatty acids derivatives have enriched the application of fatty acids.

In this paper, a review of the literatures on the thermal properties, derivatives, composites, applications, and limitations of fatty acids as PCM is presented.

2. Fatty acids as PCMs

2.1. Pure fatty acids

Phase change temperature and latent heat are the two basic parameters of phase change matertials (PCMs); therefore, many researchers have tested the two parameters of fatty acids as PCMs. This paper summarizes the test results of the phase change temperature and latent heat of fatty acids as PCMs as indicated in Table 1. Since the phase change temperature and latent heat of PCMs tend to be influenced by individual experimental conditions such as temperature, purity, and the accuracy of analytical instruments etc., literature data in Table 1 are slightly different from each other [5]. In the literature reviewed, almost no research has been done about the unsaturated acids as PCMs or the chemical structure of saturated and unsaturated acids and the influence of chemical structure on thermal properties. Besides, the research on fatty acids as PCMs is mainly on the phase change temperature and latent heat, thermal conductivity, heat transfer behavior of saturated acids with the carbon number of 10–18. In general, it is easy to find that, the phase change temperature and latent heat of saturated fatty acids are increasing with the increase of the carbon chain length. Besides, the application of fatty acids as PCMs is influenced by other physical and thermal properties of fatty acids as PCMs such as their density, specific heat and thermal conductivity listed in Table 2.

2.2. Eutectic mixtures of binary fatty acids

The eutectic temperature is the lowest melting temperature of a mixture of two or more components, and such mixture is a eutectic mixture which features the same stability of a single component. The eutectic mixtures of fatty acids as PCMs have expanded the phase change temperature range and thus the engineering application of fatty acids as PCMs. The properties of fatty acids as PCMs are listed in Table 3 as a summary of public literatures.

Generally, a eutectic mixture of fatty acids is prepared by slowly cooling down uniformly mixed two kinds of fatty acids melted with different proportions. The mass ratio, phase change temperature and latent heat of the eutectic mixture are obtained via the differential scanning calorimeter (DSC) test. Considering the complexity of obtaining the mass ratio via experiments, Zhang et al. [36] analyzed a (quasi) eutectic based on the "second law of thermodynamics" and "phase equilibrium theory", and obtained the relation between the melting temperature, latent heat and component physical properties of the (quasi) eutectic, providing a theoretical guidance for predicting the melting temperature and latent heat and determining the optimal mass ratio of eutectic mixtures such as the eutectic mixtures of fatty acids. For a binary mixture with balanced phase change medium, the formulas for calculating the liquidus are shown below:

$$\begin{cases} -H_A(T_m-T_A)/T_A+RT_m\ln(1-X_A)+G_{A,\,ex}=0 \\ -H_B(T_m-T_B)/T_B+RT_m\ln(1-X_B)+G_{B,\,ex}=0 \end{cases} \quad (1)$$

In particular, for fatty acids, $G_{A,\,ex}=G_{B,\,ex}=0$ is a very good approximation, therefore, the liquidus formula of component i is as below:

$$T_m=[1/T_i-R\ln X_i/H_i]^{-1} \quad (i=\mathrm{A},\ \mathrm{B}) \quad (2)$$

where T_m is the melting temperature of the mixture, K; T_i, the melting temperature of the ith component, K; X_i, the mole fraction of the ith component; H_i, the latent heat of the ith component, J mol^{-1}; and R, gas constant, 8.315 J mol^{-1} K^{-1}. By virtue of the formula above, the phase diagram of a binary eutectic can be drawn, and corresponding eutectic points can be determined.

The formula for calculating the melting enthalpy of a (quasi) eutectic is shown below:

$$H_m=T_m\sum_{i=1}^{n}[X_iH_i/T_i+X_i(C_{PLi}-C_{PSi})\ln(T_m/T_i)] \quad (3)$$

where H_m is the latent heat of the mixture, J mol^{-1}; C_{PLi}, the specific heat at constant pressure of the ith component in the liquid state, and C_{PSi} the specific heat at constant pressure of the ith component in the solid state.

If the molecular weight of every component is big enough, Eq. (3) can be simplified as Eq. (4). The error of the formula for latent heat is rather small due to ignoring the sensible heat. As for the long-chain organic compounds, the error is less than 4%.

$$H_m=T_m\sum_{i=1}^{n}(X_iH_i/T_i) \quad (4)$$

With the same formula above, Yuan et al. [37] verified the mass ratio, melting temperature and melting enthalpy of the binary eutectic mixture mentioned in literature [19], and predicted the phase change temperature and phase change enthalpy of 15 eutectic mixtures of fatty acids via theoretical calculation. The calculation results show that the calculated values agree well with those of the previous experimental values. For the 15 eutectic mixtures of fatty acids, the minimum and maximum melting temperatures are 10.2 and 51.5 °C respectively, and the minimum and maximum latent heat values are 138.6 and 187.5 J/g respectively. The eutectic mixtures of fatty acids are