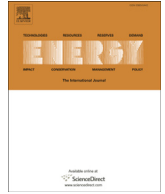




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## Thermophysical properties and thermal characteristics of phase change emulsion for thermal energy storage media

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### ABSTRACT

A great deal of attention has been paid to energy saving devices in place of conventional air-cooled and water-cooled devices. The thermal energy storage system that uses the latent heat of a PCM (phase change material) for air-conditioning or heating has recently become popular because it does not require high electric power and it saves energy. An emulsion dispersed nano-size particles of phase change material is produced. We discuss with the thermophysical properties, the stability of emulsion, and the heat transport characteristics as a thermal functional fluid. The testing emulsion, which has nano-size particles as the discrete phase, is produced with a  $D$ -phase emulsification method. The diameter of discrete phase in the emulsion is measured for evaluation of the long-term stability of emulsion. In addition, the DSC (differential scanning calorimetry) curve of emulsion is determined. Thermophysical properties such as viscosity and thermal conductivity of emulsions were studied in this work, and was compared with that of the base fluid. The results reveal that the emulsion with the  $D$ -phase emulsification method has the superior stability. From the differential thermal analysis, the DSC curve of present emulsion indicates a discontinuous change at the phase change temperature of phase change material due to its latent heat.

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### 1. Introduction

A dispersed system which contains phase change materials for the dispersed phase attracts increasing attentions as one kind of thermal storage media [1–4]. A microcapsule system [5–8] has a reputation as a thermofunctional fluid. However, the microcapsule fluid has a bunch of very real problems such as a lack of long-term stability and durability for the practical usage of thermal storage devices.

An emulsion is a type of dispersed system [9]. In the emulsion, one of two liquids which will not mix with each other is dispersed as particles (the dispersed phase) in the other (the continuous phase). Especially, the emulsion which contains nano-size phase change materials for the dispersed phase has great advantages

against other type of phase change materials. For instance, the nanoemulsion indicates a low viscosity, a high fluidity, and a long-term stability comparison with the microemulsion [10]. Furthermore, its heat transport characteristics as a thermofunctional fluid is superior to a single phase fluid system [11–15].

The aim of our research group is to propose more sophisticated latent heat storage technologies and new thermofunctional fluids. As part of that effort, we have replaced the dispersed phase in emulsions with alkane-based phase change materials, and by reducing the size of those materials to nano-size, we have developed phase change emulsions and also examined the thermal properties and stability of these emulsions [16].

On the other hand, a diverse variety of techniques for preparing emulsions have been proposed in the field of cosmetics science, but these techniques have not been described based on their long-term stability and convenience from the perspective of use as thermofunctional fluids, and that research amounts to nothing more than selecting preparation techniques which have empirically been

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## Nomenclature

### Abbreviations

TD	tetradecane
HD	hexadecane
OD	octadecane

### Roman letter symbols

n	empirical shape factor
T	temperature, °C

### Greek letters

$\beta$	sphericity
$\eta$	viscosity, Pa s
$\phi$	volume fraction
$\lambda$	thermal conductivity, W m <sup>-1</sup> K <sup>-1</sup>
$\psi$	mass fraction

### Subscripts

e	emulsion
in	inlet
out	outlet
p	dispersed particle in emulsion
w	water

successful in many cases. There, in this research, an emulsion was prepared using the D-phase emulsification method, which is easy and requires little energy compared to the phase inversion emulsification method which has previously been the most common technique for emulsion preparation [17–19]. Then the stability of that emulsion was evaluated, and its thermal properties were measured. Heat storage and radiation characteristics were also experimentally examined.

## 2. Phase change emulsion

Generally speaking, emulsion preparation methods can be divided into two types: mechanical techniques and surface chemistry techniques. With mechanical techniques, the dispersed particles are reduced to microparticles using a homogenizer with high shearing force or high pressure, and this technique is suitable for large-scale mass production. With surface chemistry techniques, on the other hand, the HLB value (hydrophilic–lipophilic balance) of the emulsifier (surfactant) is adjusted, and emulsification is achieved by obtaining the D-phase, which is a surfactant associate, through adjustment of the temperature or adding an additive. This method does not require large-scale equipment, and energy consumption for producing the emulsion can be reduced. In this research, the emulsion was prepared using a surface chemistry technique called the D-phase emulsification method, and the particle size distribution and characteristics of the obtained emulsion were examined. Also, the emulsion which was the subject of this research was the O/W type in which the continuous phase is water. The D-phase emulsification method is a technique developed by Sagitani et al. [20]. With this method, an emulsion is produced by adding water-soluble polyalcohol to a nonionic surfactant, oil and water system, adjusting the HLB value, and obtaining a D-phase and O/D gel. The details of the preparation procedure are given in the references [10], but since energy consumed in emulsion production can be reduced because the method requires no heating or cooling

as with the PIT method, and no great mechanical force for agitation, it was thought to be suitable for the application which was the subject of this research. Furthermore, the method can use a water-soluble surfactant with a comparatively wide range of HLB values, and thus the impact on the environment is low and the amount which can be prepared at one time is larger than with the PIT method.

Fig. 1 shows an overview of the method of emulsion production. For the detailed procedure of D-phase emulsification and information on characteristics of the produced emulsion, please refer our previous study [16]. The D-phase emulsification needs the following steps: preparing surfactant–polyalcohol water solution with surfactant; formation of clear gel emulsion; formation of oil-in-water emulsion. For process of making this O/W emulsion, the addition of polyalcohol water to the usual emulsion components (oil, water, and surfactant) is necessary since the addition of polyalcohol water changes the liquid crystalline phase to the surfactant isotropic solution.

Fig. 2 shows the phase diagram of emulsification process of the D-phase emulsification method. The mixture rates are indicated by taking each vertex as 100mass%, and the opposing side as 0mass%. For example, a solution at point A in the diagram indicates a blend of a mixed liquid of polyalcohol water (50mass%) and surfactant (50mass%). Moving along the arrow from point (a) to point (b) means that oil is added until it accounts for approximately 80mass% of the mixed liquid. In the D-phase emulsification method, the first step is formation of an O/D gel emulsion by dispersing an oil phase (photo (b) in Fig. 3) into a solution containing water, polyalcohol and surfactant (point A). This is then made into an O/W solution by diluting the gel emulsion with water (point C). Photographs of the appearance at points (a), (b) and (c) in Fig. 2 are shown, respectively, in Fig. 3 (a), (b) and (c). For preparing an emulsion using the D-phase emulsification method in this research, polyoxyethylene sorbitan monooleate (HLB value 15.0) was selected as the nonionic surfactant. This surfactant is highly hydrophilic, and thus the cloud point which indicates hydrophobicity as the temperature rises is not near the ordinary use temperature and it is thought that the emulsion can be kept in a stable condition even through repeated cycles of heating and cooling. Regarding the substances used as emulsion materials in this research, purified water was used as the continuous phase. Polyoxyethylene sorbitan monooleate (C<sub>64</sub>H<sub>124</sub>O<sub>26</sub>) was used as the surfactant, and 1,3-Butane diol (C<sub>4</sub>H<sub>10</sub>O<sub>2</sub>) and ethylene glycol (C<sub>2</sub>H<sub>6</sub>O<sub>2</sub>) were adopted as the polyalcohol. In addition, tetradecane (C<sub>14</sub>H<sub>30</sub>, melting point 5.9 °C), hexadecane (C<sub>16</sub>H<sub>34</sub>, melting point 18.2 °C), and octadecane (C<sub>18</sub>H<sub>38</sub>, melting point 27.0 °C) as the dispersed phase which are the phase change materials. In this experiment, an emulsion blended

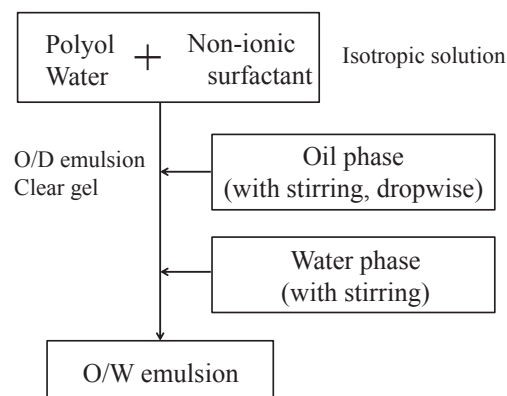


Fig. 1. Process for production of emulsion by D-phase emulsification method.

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