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Melting and solidification heat transfer characteristics of phase change material in a latent heat storage vessel: Effect of perforated partition plate

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ABSTRACT

Recently, latent heat thermal energy storage system has gained attentions in order to utilize the middle temperature factory waste heat (100–200 °C). The purpose of this study is to develop heat storage system with a latent heat storage material for using the middle temperature heat. In this study, the direct contact melting and solidification behavior between heat transfer fluid (oil) and erythritol (PCM) were visualized in order to investigate the characteristics of heat storage and release at difference flow rate of oil (1.0–4.0 kg/min) and the effects of perforated partition plate. In this direct contact method, if the packed height of erythritol increases due to porous solidification, erythritol may be flowed out from a vessel with oil. So to control the packed erythritol height, the effect of a perforated partition plate in the vessel was investigated. As a result, it is found that since the bubbles of PCM are broken by the perforated partition plate, it prevents that the solidified height of PCM increases.

1. Introduction

Recently, the focusing the difference of electric power consumption during day and night, the researches of heat saving have been performed. Effective ways of heat storage techniques are needed for recovery and utilization of various alternative energy sources such as factory waste heat, solar energy and off-peak electricity. Latent-heat thermal-energy storage system has the advantage of performing the charge and discharge function at nearly constant temperature and has a large storage capacity.

Generally, a multi-tube heat exchanger is used in a conventional latent heat storage system. On the other hand, the direct contact method has good points such as rapidly heat exchange compared with the other type like a shell and tube type. So, the direct contact method has been investigating. It was experimentally investigated about a spray-tower type direct contact heat exchange using the PCM (tetradecane) in a low temperature regions and air [1]. Also, it was observed phase change process using overall heat transfer coefficient during the melting and solidification process. And, it was compared with the result of numerical analysis [2]. The direct contact melting of hydrocarbon mixtures of tetradecane and hexadecane binary mixture, and pentadecane and octadecane binary mixture were investigated experimentally [3]. In addition, during the solidification process, direct heat exchanging behavior of a sodium thiosulphate pentahydrate with a heat transfer oil has been investigated [4]. Effects of the flow rate of the heat transfer oil and the volume of the storage medium on the heat transfer coefficient were also considered. As shown above, more reference about direct contact type using PCM at low temperature region has been reported. In this study, our purpose is to develop heat storage system with a latent heat storage material for using the middle temperature waste heat (100–200 °C) from factories [5]. In order to use a commercially available cylindrical container as the direct heat exchanger with packed PCM and heat transfer oil, it was investigated thermal and flow behaviors in a container for recovering industrial waste heat at middle temperature [6]. The study was investigated the fundamental melting and solidification behaviors of PCM by using two dimensional roundly sliced model. But, the oil flowed only in the central part, which did not contribute to the release and storage of the PCM neat both ends of the flow. Also, during solidification process, the inlet oil flow obstructed by formation and growth of the solidified PCM amounts in the bottom inlet pipes. Thereby the flow rate of oil reduces by blocking several flow paths.

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Nomenclature

Q	mass transfer area effective, (m^2)
Cp	specific heat, kJ/(kg K)
f	flow rate of oil, (kg/min)
t	time, (min)
T	temperature, (°C)
ΔT	temperature difference, (°C)
L	latent heat, (kJ/kg)
m	weight of erythritol, (kg)

Subscripts

M	melting process
S	solidification process
oil	heat transfer fluid
PCM	phase change material
m	melting point
0	start time
f	finish time
th	theoretical
ts	test section

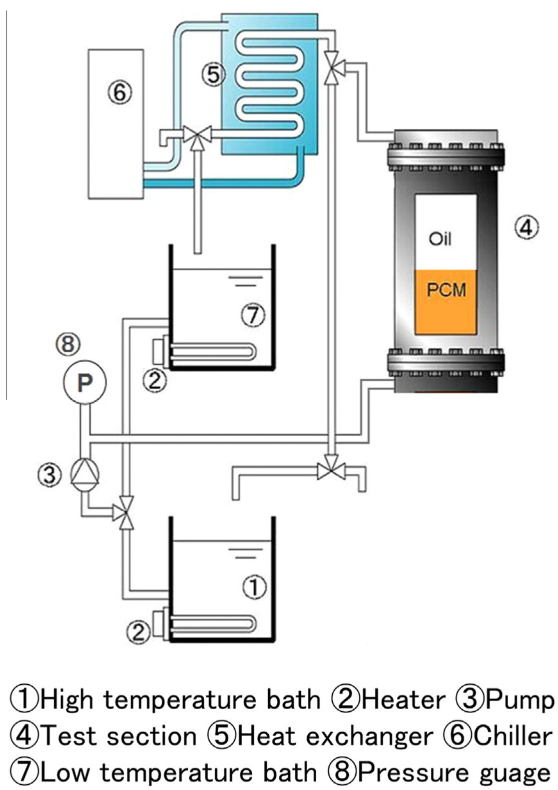

Fig. 1. A schematic diagram of experimental apparatus.

In previous study of author [7], it was observed the melting and solidification behaviors of PCM (erythritol) also, it was investigated the influence of packed height of PCM (erythritol) and changed of flow rate of oil in the melting and solidification process. But during the solidification process, oil flows through the nozzle plate, oil droplet are coated by the solidified PCM, after it forms porous zone with time. As a result, the packed height of PCM increases by increasing porous zone. In this direct contact method, if the packed height of erythritol increases, it cannot charge a lot of erythritol and erythritol may be flowed out from a vessel with oil. So, this experiment was investigated the effect of installing two type perforated partition plate in the vessel to control the packed PCM height of formed oil droplet broken by surface of perforated partition plate and improved performance to the thermal conductivity.

Table 1
Physical properties of heat transfer fluid and erythritol [9,10].

Property	Erythritol	Heat transfer fluid (silicon oil)
Latent heat (kJ/kg)	340 [9]	–
Melting point (°C)	119 [9]	–
Firing point (°C)	–	318 [10]
Density (kg/m^3)	1480 (at 20 °C) [9] 1300 (at 140 °C)	960 [10]
Specific heat (kJ/(kg K))	1.38 (at 20 °C) [9] 2.77 (at 140 °C)	1.48 [10]

2. Experimental apparatus

The experimental system consisted of a heat storage vessel of 100 × 300 × 500 mm (width × length × height), high and low temperature baths (heating capacity: 2 kW), a heat exchanger, a chiller (cooling capacity: 4.5 kW), a pressure gauge (measuring range: 5 kPa–100 MPa, accuracy: ±0.05%), a digital camera, a pump (SANWA PUMP, MMH21), and K-type thermocouples and a data logger to obtain measured temperature data, as shown in Fig. 1. Fig. 2 shows the details of the heat storage vessel. Oil flows through a

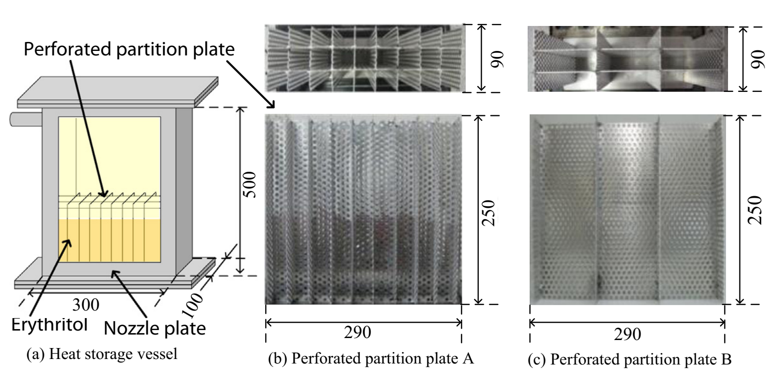

Fig. 2. Detail diagrams of heat storage vessel.