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Performance enhancement of a latent heat thermal energy storage system using curved-slab containers

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ABSTRACT

In order to realize an inexpensive and high capacity thermal energy storage (TES) system, we propose a new compact slab type container which has an arc outer configuration for promoting the appearance of close contact melting. Transient 2D numerical melting simulation of a solid phase change material (PCM) in a container is performed by the enthalpy-porosity approach. The simulated result quantitatively elucidated the experimental melting process from the beginning to the end. The TES system is composed of curved-slab containers filled with PCM subjected to convective boundary conditions where heat transfer fluid flows between the containers. The performance enhancement of the latent heat TES system was analyzed, and this system shows a large amount of storage capacity with higher efficiency.

1. Introduction

Phase change problems are encountered extensively in nature and in a wide variety of technologically important processes. Such processes include thermal energy storage, melting of ice, crystal growth, and thermal control of electronic equipment using PCMs. Thermal energy storage (TES) has recently attracted increased interest in relation to thermal applications, such as water heating, waste heat utilization, cooling and air-conditioning. In particular, TES systems play an important role in providing enormous potential for facilitating energy savings and reducing environmental impact. Indeed, TES appears to provide one of the most advantageous solutions for correcting the gap that often occurs between the supply and demand of energy. TES is a term widely used to describe the storage used for both the heating and cooling of energy. It deals with the storing of energy by cooling, heating, melting, and solidifying a substance, and the energy becomes available as heat when the process is reversed [1].

Recently, Regin et al. [2] reviewed the development of available latent heat thermal energy storage technologies. Different aspects of storage such as material, encapsulation, heat transfer, applications and new PCM technology innovation have been examined. High storage density of PCM such as paraffin wax at small temperature changes (50–100 °C) can be a significant advantage in solar applications and utilization of waste heat. In spite of these desirable properties of paraffin, its low thermal conductivity (≈ 0.2 W/(m K)) is its major drawback, which decreases the rates of heat stored and released during melting and crystallization processes. In the TES system, both heat charging and discharging processes using spherical capsules have been investigated for enhancement of large latent heat storage due to its low volume to heat transfer surface area ratio and easy packing into the storage system [2–6]. Assis et al. [6] explored numerically and experimentally the melting of a solid PCM in spherical capsules. The solid PCM would sink to the bottom of sphere due to gravity during melting. The enthalpy-porosity method clarifies the sedimentation of a solid PCM, and the appearance of close motion of the solid PCM is accompanied by generation of liquid at the melting interface. This liquid is squeezed through a narrow gap between the melting surface and the capsule wall to the space above the solid PCM. Until now, a large number of papers have pointed out that the effect of solid phase sedimentation and appearance of close contact melting are significant for melting the solid PCM [7]. Koizumi [8] showed the limited results of an experimental study of constrained melting of PCM (three thin copper plates inserted at right angles in a spherical capsule) and unconstrained melting of PCM within a spherical capsule placed in an upwardly directed heated flow. But it is difficult for a spherical capsule to be subjected to close contact melting from the beginning to the end, and furthermore it is expensive for a large number of capsules to be filled with PCM.

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