International Journal of Thermal Sciences 50 (2011) 2205–2219

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

journal homepage: www.elsevier.com/locate/ijts

Experimental study on charging and discharging periods of water in a latent heat storage unit

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A R T I C L E I N F O

Article history:
Received 15 October 2010
Received in revised form
10 June 2011
Accepted 18 June 2011
Available online 30 July 2011

Keywords:
Phase change
Solidification
Melting
Latent heat
Thermal energy storage

A B S T R A C T

This study is focused on investigation of the natural convection and the parametric (*flow and design*) effects on charging and discharging periods of water in a shell-and-tube type latent heat thermal energy storage unit. An electronic ice thickness measurement method is used to monitor the solid–liquid interface variations during phase change and this method is validated by the comparisons of visual and temperature data. Experiments are carried out for different values of heat transfer fluid (HTF) flow rates and inlet temperatures. Three different tube materials and two different shell diameters are also tested. A control volume approach is utilized on the experimental data for the determination of the total stored/rejected energies. Experimental results indicate that, for both solidification and melting processes, natural convection becomes the dominant heat transfer mechanism after a short heat conduction dominated period. In addition, inlet temperature of HTF, thermal conductivity of the tube material and the diameter of shell have considerable effects on the storage capability of the system, for charging period. For discharging period, the inlet temperature of HTF is more effective on rejected energy in comparison with the flow rate, for selected parameters.

1. Introduction

Thermal energy storage (TES) is a key technology in providing a balance between energy supply and demand for heating and cooling systems. In both sensible heat TES (SHTES) and latent heat TES (LHTES), by shifting the load from limited and expensive time period to a wide and cheaper time period, numerous economical and environmental advantages can be achieved [1]. In comparison to the SHTES, LHTES has an additional advantage of having a high-energy storage density during phase change process within a narrow temperature range.

Solidification and melting phenomena have great importance in the design of LHTES systems. Investigations on solid–liquid (*charging*) and liquid–solid (*discharging*) processes have been carried out for many decades and detailed reviews on phase change literature have been conducted by many researchers [1–4]. Investigations on phase change generally focus on one of the following two purposes: (1) The natural convection effects and asymmetric solidification/melting formations in a system, and (2) Effects of several design and flow parameters of the HTF on the overall energetic/exergetic performances of the storage system.

The influence of natural convection during phase change inside circular cylinder and spherical capsules was investigated for inward and outward directions, under various Rayleigh and Stefan numbers. Ho and Viskanta [5] carried out experimental and numerical investigation for inward melting of *n*-octadecane inside a cylindrical capsule. Webb et al. [6] studied the inward melting of unfixed ice in a horizontal cylindrical capsule. Bathelt and Viskanta [7] studied the melting phenomenon around cylindrical tube numerically and experimentally. Ho and Chen [8] presented the time wise melting profiles around a cylindrical tube, for different values of initial and tube temperatures. Ismail and da Silva [9] developed a numerical method to simulate melting period of phase change material (PCM) around a cylinder, in the presence of natural convection. Khodadadi and Zhang [10] and Tan et al. [11] represented the effects of buoyancy-driven convection on melting of PCM inside a spherical capsule. These studies [5–11] briefly indicate that, in the early stages of the phase change, heat transfer mechanism is driven by conduction with a symmetrical solid–liquid interface. After buoyancy effects appear, the interface and local Nusselt number variations around the tube (or *capsule*) become asymmetric and the natural convection effect becomes dominant.

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doi:10.1016/j.ijthermalsci.2011.06.010