Applied Thermal Engineering 42 (2012) 49–57

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

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

Fluid flow and heat transfer in a latent thermal energy unit with different phase change material (PCM) cavity volume fractions

Wei-Biao Ye [a,*], Dong-Sheng Zhu [a,b], Nan Wang [a]

[a] Key Lab. of Enhanced Heat Transfer and Energy Conservation, Ministry of Education, School of Chemistry and Chemical Engineering, South China University of Technology, Guangzhou 510640, PR China

[b] School of Mechanical and Power Engineering, East China University of Science and Technology, Shanghai 200237, PR China

ARTICLE INFO

Article history:
Received 14 August 2011
Accepted 5 March 2012
Available online 11 March 2012

Keywords:
Latent thermal energy unit
PCM cavity volume fractions
Conjugate heat transfer
CFD analysis

ABSTRACT

In present work, the effects of different cavity volume fractions of phase change material (PCM) on fluid flow and heat transfer behavior in a latent thermal unit are studied numerically. The commercial Computational Fluid Dynamics (CFD) package, Fluent, is used for the numerical solution based on transient conjugate heat transfer. The numerical results have been verified and validated against numerical and experimental data available in published literature. The volume expansion ratio, the time of complete thermal storage, heat flux, liquid fraction, velocity and temperature fields are investigated for the range of PCM cavity volume fractions (ϕ_{max}) from 35% to 95%. It is noted that a vortex (as a heat transfer enhancer) is present near the heating plate wall for the PCM cavity volume equal to 85%. It is found that the volume expansion ratio decreases as ϕ_{max} increasing, whereas the time for complete energy storage increases. Further, the correlations of the volume expansion ratio and the time of complete thermal storage are developed as a function of $\phi_{max.}$ The detailed knowledge regarding interface heat transfer rate provides a deeper understanding the heat transfer mechanisms.

1. Introduction

Latent heat thermal energy storage (LHTES) has become a particularly attractive technique in energy saving using the melting enthalpy of phase change materials (PCM) [1]. The PCM are used to balance temporary temperature alternations and to store energy in several practical application areas, from electronics to the automobile industry and also buildings [1,2]. The major advantages of using PCM in latent thermal unit are their large heat storage capacity and their isothermal behavior during storage/release process [3]. Further, it is necessary to store energy due to the temporary phase shift between energy generation and consumption that may offer significant savings energy in the aforementioned products.

LHTES requires a relatively smaller container volume for a given energy compared with a conventional sensible heat energy storage system. Many geometries of the PCM container are proposed for these systems to enhance heat transfer rates between the PCM and heat transfer fluid (HTF). In these geometries, PCM are typically placed in rectangular/slab containers [4–9], cylindrical [10–13]/shell and tube [14,15], and spherical capsules [16–18]. The shell and tube system is the most intensely analyzed LHTES (accounting for more than 70%) due to the fact that most engineering systems employ cylindrical pipes and also heat loss from the shell and tube system is minimal. The rectangular and cylindrical containers are commonly employed as PCM containers [19]. However, other different finned types have been became a main topic in research [20–22]. Additionally, the melting process in plate-fin geometry is similar to that in rectangular [23].

Volumetric expansion of PCM inside a container is a critical problem that exists in reality due to a large density difference in the solid and liquid PCM, and needs to be considered during the thermal storage process. Further, natural convection is caused by the density variation inside the liquid due to the temperature differences. Khodadadi and Zhang [16] computationally studied the effect of buoyancy-driven convection on constrained melting of low-Prandtl number PCM within spherical containers by finite volume method. However, density change of PCM was neglected except the liquid phase which drives natural convection in the melting process by invoked the Boussinesq approximation in the body force terms. Lacroix and Benmadda [23] researched numerically natural convection-dominated melting of *n*-octadecane heated from a finned vertical wall. A small air gap was maintained

* Corresponding author. Tel./fax: +86 20 87114568.
E-mail addresses: ye.weibiao@mail.scut.edu.cn, weibiaoye@foxmail.com (W.-B. Ye), cedshzhu@scut.edu.cn (D.-S. Zhu).

1359-4311/$ – see front matter Crown Copyright © 2012 Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.applthermaleng.2012.03.002