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Applied Thermal Engineering 25 (2005) 1488–1502
APPLIED THERMAL ENGINEERING
www.elsevier.com/locate/apthermeng

Total solidification time of a liquid phase change material enclosed in cylindrical/spherical containers

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Received 14 April 2004; accepted 8 October 2004
Available online 16 December 2004

Abstract

This study investigates the inward solidification problem of a phase change material (PCM) encapsulated in a cylindrical/spherical container with a third kind of boundary condition. The governing dimensionless equations of the problem and boundary conditions are formulated and solved numerically by using enthalpy method with control volume approach. The problem is solved many times for different values of the affecting parameters and data sets are obtained for dimensionless total solidification time of the PCM. These data sets are then used to derive correlations which express the dimensionless total solidification time of the PCM in terms of Stefan Number, Biot Number and Superheat Parameter.

Keywords: Phase change; Latent heat energy storage; Inward solidification in cylindrical and spherical region

1. Introduction

Cool storage systems remove heat from a thermal storage medium during the periods of low cooling demand and use this cool energy when it is needed. For that purpose, latent heat systems are more attractive than sensible ones due to their large storage capacities and constant charge and discharge temperatures. One of most popular latent heat storage systems is the encapsulated

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1359-4311/$ - see front matter
doi:10.1016/j.applthermaleng.2004.10.005

Nomenclature

Bi	Biot number $\left(=\frac{hr_0}{k_s}\right)$
c_p	specific heat (j/kgK)
C^*	dimensionless specific heat $\left(=\frac{c_{p_l}}{c_{p_s}}\right)$
C^+	dimensionless specific heat $\left(=\frac{c_{p_l}}{c_{p_s}}\right)$
h	convective heat transfer coefficient (W/m^{2}K)
H	enthalpy (j/kg)
H^*	dimensionless enthalpy $\left(=\frac{H}{c_{p_s}(T_{\text{initial}}-T_\infty)}\right)$
i	nodal point
k	thermal conductivity (W/mK)
K^*	dimensionless thermal conductivity $\left(=\frac{k_l}{k_s};1\right)$
K^+	dimensionless thermal conductivity $\left(=\frac{k_l}{k_s}\right)$
L	latent heat of solidification (j/kg)
N	total grid number inside the container
r_0	radius of the spherical or cylindrical container (m)
R	dimensionless radial position $\left(=\frac{r}{r_0}\right)$
Ste	Stefan number $\left(=\frac{c_{p_s}(T_{\text{initial}}-T_\infty)}{L}\right)$
T_{initial}	initial temperature of PCM (°C)
T_m	phase change temperature (°C)
T_∞	coolant fluid temperature (°C)
$V^*_{e_i}$	dimensionless volume of the control volume
V^*_s	dimensionless volume of the solid part in the control volume
V^*_l	dimensionless volume of the liquid part in the control volume
X	dimensionless linear interpolation factor

Greek symbols

α	thermal diffusivity (m^2/s)
ΔR	dimensionless radial distance between grid points
$\Delta\tau$	dimensionless time step
θ	dimensionless temperature $\left(=\frac{T-T_\infty}{T_{\text{initial}}-T_\infty}\right)$
θ_m	superheat parameter $\left(=\frac{T_m-T_\infty}{T_{\text{initial}}-T_\infty}\right)$