Numerical Simulation and Analysis Of PCM on Phase Change Process Consider Natural Convection Influence

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Abstract-A phenomenon of heat energy storage and release in phase change materials (PCM) which used in building retaining structure has been investigated. In the reality process of phase change, liquid phase has two ways of heat exchange: pure heat conduction and natural convection. To analyze the reality melting and solidification of PCM , set up the PCM heat transfer model which considering liquid-phase natural convection in this paper and exploit CFD software to carry out numerical simulation. The result shows that the influence of natural convection has mainly something about circumfluence generated by liquid phase, the direction of circumfluence which is opposite when heat and cool, the circumfluence intensity enhances as the height of phase interface increase.

Keywords -Energy storage, Phase change materials, Natural convection, Numerical simulation.

I   INTRODUCTION

As the process of phase change along with conduction and convection, so that the solving of phase change heat transferred problem more complex, almost of time we use numerical simulation. When study the problem of phase change, consider the density of phase change materials change small, we often neglect the influence of natural convection. However, in the actual phase change process, because of temperature (which bring out natural convection) exist all the time, and as the proportion of liquid-phase increase gradually, the influence of natural convection increase, it make the movement of solid and liquid-phase surface complex. [1-2] This article set the PCM heat transfer model which considering liquid-phase natural convection under the phase change, and use Fluent software numerical simulation to discuss and analyze the influent regular of storage and generate heat.

II   MODEL ESTABLISHMENT

The study for simulation of storage and generate heat when phase change materials in the test tube. To simplify the analysis, the assumption that specific heat of solid-liquid phase, thermal conductivity is a constant, phase change temperature is fixed value [3]. The equations are:

$$\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u)}{\partial x} + \frac{\partial (\rho v)}{\partial y} = 0 \tag{1}$$

$$\frac{\partial (\rho u)}{\partial t} + u\frac{\partial (\rho u)}{\partial x} + v\frac{\partial (\rho u)}{\partial y} = \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) - \frac{\partial p}{\partial x} + S_u \tag{2}$$

$$\frac{\partial (\rho v)}{\partial t} + u\frac{\partial (\rho v)}{\partial x} + v\frac{\partial (\rho v)}{\partial y} = \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) - \frac{\partial p}{\partial x} + S_v \tag{3}$$

$$\frac{\partial (\rho H)}{\partial t} + u\frac{\partial (\rho H)}{\partial x} + v\frac{\partial (\rho H)}{\partial y} = \frac{\lambda}{c_p}\left(\frac{\partial^2 H}{\partial x^2} + \frac{\partial^2 H}{\partial y^2}\right) + S_h \tag{4}$$

Here the density is expressed by:
$$\rho = \rho_{ref}\left[1 - \beta\left(T - T_{ref}\right)\right]$$

The source terms are expressed by:

$$S_u = \frac{(1 - f_1)^2}{f_1^3 + \varepsilon} A_{mush} u$$

$$S_v = \frac{(1 - f_1)^2}{f_1^3 + \varepsilon} A_{mush} v + \frac{\rho_{ref} g \beta(h - h_{ref})}{c_p}$$

$$S_h = \frac{\rho}{c_p}\frac{\partial (\Delta h)}{\partial t}$$

Here:

t——time, s

β——expansion coefficient, K^{-1}

μ——dynamical viscosity, $(N \cdot s)/m^2$

u, v——:r-direction velocity, z-direction velocity, m/s

f_1——the proportion of liquid

c_p——specific heat in setting pressure, $KJ/(Kg \cdot K)$

λ——conductivity coefficient, $w/(m \cdot k)$

T_{ref}——base temperature, K

ρ_{ref}——corresponding density with Tref, Kg/m^3

ε——a number below 0.00001, avoid division by zero

A_{mush} ——continuous number of indistinct region（$10^4 \sim 10^7$）

specific enthalpy:

$H = h + \Delta H$

h ——specific enthalpy of apparent heat，J / Kg

$h = h_{ref} + \int_{T_{ref}}^{T} c_p dT$

h_{ref} ——datum enthalpy（initial enthalpy）

ΔH ——specific enthalpy of latent heat，J / Kg

$\Delta H = f_1 L$

L ——phase change of latent heat，J / Kg

$f_1 = \begin{cases} 0 & T < T_{melt} \\ 1 & T > T_{melt} \end{cases}$

The boundary conditions:

$T_{(x,y,t)} |_{x=R} = T_{hot} (T_{cold})$

$\frac{\partial T}{\partial y} |_{y=l} = 0$

The initial conditions：

$T_{(x,y,t)} |_{t=0} = T$

The same temperature in whole region （melt: $T < T_{melt}$，solidification: $T > T_{melt}$，T_{melt} is phase change temperature.

III SIMULATION ANALYSIS

As the model is axisymmetric, check the half of physical model which diameter is 2cm, and the elevation is 6cm to simulate. See Figure 1.

Figure1. Physical model

Fluent's own pre-processing software gambit set up model and divide network. In this paper, the model meet the conditions of mappable, refine mesh around, wall-1 border is adiabatic surface, other border outside. Wall-2 is heating (cooling) surface. Simulation of working conditions can be seen in table 1, thermal properties of the phase change materials as shown in table 2.

At above simulated conditions of the melting and solidification process, the simulation results are shown in Figure 2 and Figure3.

From the phase change graph simulation results of Figure.2,we can see that the liquid-phase (the red part) is large in the upper than in the lower, that is phase change materials melt fast at in the upper, it described that the natural convection in the melting process is to accelerate the speed of melting; On the contrary, the role in cooling process is to slow down solidification,seen Figure.3.

The interface of solid-liquid phase is not parallel with heating surface, it curved gradually from the top, inward when it melting, outward when it solidify. Because of natural convection effect, phase change so fast in the top region, isotherm tilted on the top in phase change process [4].

In fact, in gravity, because of heterogeneous temperature field, heterogeneous density generates buoyancy force, which leads to generate natural convection in the liquid-region of phase change materials. At this moment, it show the phase interface cured in the top through simulation, because in the initial stage of phase transition, liquid-phase is more less, and the influence of natural convection is not so strong. The primary way of transferring heat is heat conduction. The interface of solid-liquid phase almost parallel to heating surface, with the liquid phase increased, the influence of natural convection is much stronger. The way of heat transfer turn to natural convection from heat conduction. When it melting, liquid phase change materials which close to the heated wall is heated to high temperatures, small density, under the role of buoyancy move up [5]. The upper container is shocked by heat flow and the speed of melting is accelerated so the solid-liquid interface appears bent. The higher position, the faster speed, bending is more obvious.

From the velocity distribution of Figure. 2 and Figure. 3, it is obvious to know that when it melts, the circumfluent direction is anticlockwise. Flow velocity of phase change material which approaches to heat surface rise upward. Heat flow when it rises to the top of the container rebounded. Higher temperature flow rush to solid interface, which cause phase interface in the top region to be inflexed. The impact of the heat flow in this region lead to the increase of velocity melted in phase change materials and the increase of temperature grads. The heat of liquid is transferred to phase change materials of solid/liquid interface. Liquid phase is cooled so that the temperature velocity and density decrease until reach the bottom. Liquid phase impact on the heat surface, and the temperature grads in this region also increase. The direction of circumfluence is clockwise when it solidity, which is contrary to melt. The internal liquid phase, which is high temperature, rise until the top region under the influence of buoyancy. Velocity vector of the top region points to the solid/liquid interface, which lead phase change material of higher temperature to impact on the phase interface, and the temperature grads decreased. It can reduce the solid velocity of phase change materials in this place. So the phase surface of top region excursed outward a little.

IV SUMMARIES

From the study on the simulation of PCM melting and solidification, we can know:

(1) It is proved that liquid phase region in the process of phase change, which to be dealt with natural convection model, approach reality.

(2) The influence of natural convection has mainly something about circumfluence generated by liquid phase, the direction of circumfluence which is opposite when heat and cool.The circumfluence intensity, as the height of phase interface increase, enhances. It lead to solid/liquid phase interface inflect from the top gradually, when it melt, and it inflect outward when it solidity. The phenomenon, phase change is faster and isothermal incline in the top region.

ACKNOWLEDGMENTS

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TABLE I. SIMULATED PARAMETER

	wall-1	wall-2
melting	adiabatic	constant wall temperature boundary conditions： t_w：32℃、35℃、38℃、41℃、44℃
solidification	adiabatic	constant wall temperature boundary conditions： t_w：10℃、5℃

TABLE II. PCM'S THERMAL PARAMETERS

Density	kg/m^3	**1510**
Thermal conductivity	$W/(m·K)$	0.8
Constant pressure heat capacity	$kJ/(kg·K)$	solid：1.43 liquid：2.31
Phase change temperature	℃	29
Phase change latent heat	kJ/kg	188
Thermal expansion	$1/k$	$5×10^{-4}$
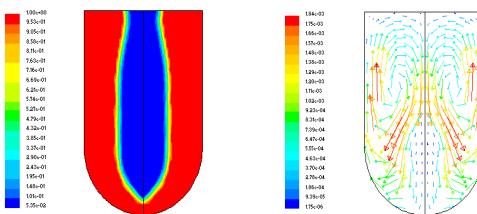
(a) phase change graph   (b) velocity distribution

Figure 2. Melting simulation graph of heating temperature 41 ℃, time 1000s

(a) phase change graph   (b) velocity distribution
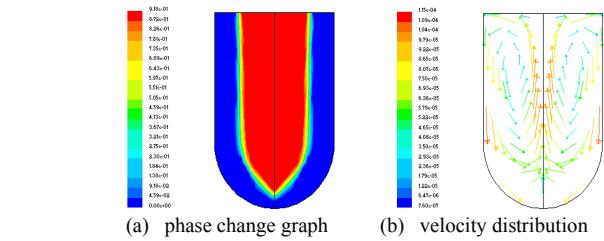
Figure 3. Solidification simulation graph of cooling temperature 10 ℃, time 500s