Simulation Analysis of Thermal Storage Process of Phase Change Energy Storage Materials

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Abstract. In order to solve the difficult problem of phase change heat transfer, a numerical model is used to establish a mathematical model for the phase change material. Numerical simulation of heat storage and release process of phase change heat exchanger based on Fluent software. The simple experiment is carried out to verify that the phase change energy storage heat exchanger has better heat transfer characteristics than the ordinary heat exchanger, and provides a theoretical basis for the application of phase change energy storage materials to practical engineering.

1. Introduction
The phase change is the change of the physical state of matter, such as the process of water freezing, in which there is a large amount of latent heat in the material. The phase change process is also accompanied by a large amount of energy conversion, which can accelerate the transfer or storage of excess heat and re-release it when needed to obtain applicable heat energy. This is the basic principle of phase change energy storage.

![Figure 1. Basic principle of phase change energy storage](image-url)
The phase change heat transfer problem cannot be accurately expressed by mathematics. It is more reasonable to use the combination of physical and mathematical equations.

At present, the research work on phase change materials mainly focuses on the phase change mechanism of materials, latent heat of phase change, heat transfer, etc., while the research on heat transfer equipment is not long [1-4]. In order to truly realize the engineering application of heat storage technology, research on phase change energy storage heat transfer equipment must be carried out. The use of phase change energy storage technology to optimize the radiator can improve the energy utilization rate, can store the discontinuous and unstable heat in the actual project, release it in the required time, and solve the contradiction between heat dissipation and heat supply [5]. Therefore, the research on the heat storage and release process of the phase change energy storage heat exchanger can provide theoretical support for the application in practical engineering.

2. Phase change microcapsule heat transfer model
In this paper, the phase change energy storage heat exchanger of concentric casing is taken as an example to numerically solve the energy storage characteristics of the phase change material, and the internal temperature field and solid-liquid distribution of the material in the phase change heat storage process are obtained.

2.1. Phase change heat transfer physical model
Figure 2 shows the physical heat transfer model of the phase change heat exchanger. It consists of three parts: the outer casing, the phase change material and the heat exchange tube. The phase change material is encapsulated between the outer casing and the heat exchange tube. The heat exchange process is a high temperature fluid flowing through the heat exchanger heat exchanger tube, the phase change material is melted to absorb heat and stored, during which the hot fluid and the heat exchange tube undergo convective heat transfer, and the heat exchange tube and the phase change material heat exchange mode For heat conduction, which ignores the loss of phase change material to the outside [6].

![Figure 2. Basic principle of phase change energy storage](image)

2.2. Phase change heat transfer mathematical model
The Solidification/Melting model in fluent software can be used to calculate the mathematical model of the phase transition process. When calculating, the phase change material is regarded as a porous medium. When the solid-liquid ratio is 0, the material is solid phase, the flow rate is 0; When the ratio is 1, the material is liquid, and the flow velocity of the fluid can be obtained by the momentum equation; when the flow ratio is between 0-1, the flow rate is a function of the liquid fraction [7].

Its two-dimensional governing equation is:
\[
\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial t} (\rho u) + \frac{\partial}{\partial r} \left( \rho \frac{u}{r} \right) = S_m \quad (1)
\]

Where \( \rho \) is the material density, \( u \) is the axial flow velocity, \( \nu \) is the radial viscosity, \( S_m \) is the mass of the sparse phase added to the continuous phase, and \( r \) is the radial coordinate.

Momentum equation:

\[
\frac{\partial}{\partial t} \left( \rho u \right) + \frac{1}{r} \frac{\partial}{\partial r} \left( r \rho u \nu \right) + \frac{1}{r} \frac{\partial}{\partial r} \left( r \rho u u \right) = -\frac{\partial p}{\partial x} + \frac{1}{r} \frac{\partial}{\partial r} \left[ r \mu \left( \frac{\partial u}{\partial x} - \frac{2}{3} \left( \nabla \nu \right) \right) \right] + \frac{1}{r} \frac{\partial}{\partial r} \left[ r \mu \left( \frac{\partial u}{\partial x} + \frac{\partial u}{\partial x} \right) \right] + F_x, \quad (2)
\]

\[
\frac{\partial}{\partial t} \left( \rho u \right) + \frac{1}{r} \frac{\partial}{\partial r} \left( r \rho u \nu \right) + \frac{1}{r} \frac{\partial}{\partial r} \left( r \rho u u \right) = -\frac{\partial p}{\partial x} + \frac{1}{r} \frac{\partial}{\partial r} \left[ r \mu \left( \frac{\partial u}{\partial x} + \frac{\partial u}{\partial x} \right) \right] + \frac{1}{r} \frac{\partial}{\partial r} \left[ r \mu \left( \frac{\partial u}{\partial x} - \frac{2}{3} \left( \nabla \nu \right) \right) \right] - 2 \mu \frac{\nu}{r^2} + 2 \mu \frac{\nu}{r^2} + \frac{\partial}{\partial x} \left( \frac{\nu}{r^2} \right) + \rho \frac{w^2}{r} + F_r, \quad (3)
\]

In the formula: \( \mu \) is the dynamic viscosity coefficient, \( p \) is the static pressure, \( \nabla \) is the Laplacian operator, \( F_x \) is the axial volume force, \( F_r \) is the radial volume force, and \( w \) is the rotational flow rate.

Energy equation:

\[
\frac{\partial}{\partial t} \left( \rho h - p - \frac{\rho u^2}{2} \right) + \frac{\partial}{\partial x} \left( \rho u E + up \right) = \frac{\partial}{\partial x} \left( k \frac{\partial T}{\partial x} - \sum hJ + u \tau + S_h \right) \quad (4)
\]

In the formula: \( J \) is the diffusion flux, \( k \) is the effective thermal conductivity, \( h \) is enthalpy, \( \tau \) is the stress tensor, and \( S_h \) is the chemical reaction heat.

3. Fluent-based heat exchanger performance test

Using Geometry in Fluent to build a model. Construct a set of concentric circles on the coordinate system of XOY. The dimensions are as shown in the figure below. The extension length is 1000mm, and the four concentric cylinders are given from inner to outer: inner fluid; inner pipe; pcm; outer pipe. The mesh module is used to mesh the model.

![Figure 3. Meshing](image)

3.1. Parameter Settings

The simulated material is a regenerative paraffin phase change material with a phase transition temperature of 494-511k, a latent heat of phase change of 161000J/kg, a viscosity of 0.001372kg/m·s. The temperature of the internal fluid in the tube is 300k, the setting step is 1s for a long time, and the calculation time is 100s, which is calculated twice.
3.2. Analysis of results

The results module is solved by the results module to obtain the liquid fraction at 100s and the liquid fraction at 200s (Figure 4 Shown), temperature cloud map and mass fraction cloud map (Figure 5 shown).

Simulation results: The iterative calculation curve shows that the calculation results of the phase change material finite element analysis are convergent, and Figure 4 respectively shows that the liquid fractions at 0.6s for 200s are 0.69 and 0.5 respectively, which fully indicates the phase change material continuously releases and transfers heat in the simulation calculation.

![Figure 4. Calculation results](image)

![Figure 5. Contours](image)

4. Experimental verification

In the experiment, a square groove is used instead of the circular concentric pipe in the simulation, and the phase change material is filled into the interlayer. The inner and outer layers are designed with stainless steel to prevent rust from affecting the heat transfer rate. The experimental equipment is shown in Figure 12.

![Figure 6. Experimental device](image)

The temperature sensor is installed on the upper end of the inner and outer sides, and the external heat flow is difficult. The fluid heating method is adopted. The material temperature is 20°C, the heating temperature is 70°C the heating time is 5400s, and the initial temperature is changed to 10°C, 20°C, 30°C,
40°C, the experimental results are shown below (A is the outside temperature of the box, and B is the temperature inside the box.):

The experimental result generation curve is shown in the following figure: the heat dissipation rate of the outer side of the box body is faster than that of the inner side of the box body, and the heat transfer effect is better, which is basically consistent with the good heat exchange effect of the fluid in the tube in the above simulation. Changing the initial temperature does not change the heat transfer effect of the phase change material and the heat transfer rate of the joint inside the box does not change significantly. It can be shown that the temperature difference is not to accelerate heat transfer. Power. The experimental results, combined with the above simulation of flent, can be concluded that the energy storage characteristics of the phase change material can accelerate the heat exchange rate between the inner and outer sides.

5. Conclusion
Through the numerical solution method and image display method of fluent, reducing the energy storage process of phase change materials. Through simulation and experimental verification, it can be concluded that during the process of heat storage and release, the solid-liquid phase distribution is stepped, and the temperature also changes stepwise; the temperature difference does not change during phase change heat storage. The rate of heat transfer, but the change in temperature affects the presence of the solid-liquidus phase of the phase change material.

In this paper, fluent simulation and experimental verification are used to simulate and verify the heat transfer process of phase change materials in phase change energy storage tubes under the influence of
natural convection. The obtained values and conclusions can be studied for phase change materials. And the application provides a theoretical basis to optimize the use of phase change materials in practical engineering.

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