Computer Assisted design and performance analysis of fin type phase change hot water storage tank

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Abstract. The numerical simulation of the fin-type phase-change hot water storage tank is carried out and the influence of different fin height and number of fins on the heat storage characteristics of paraffin wax/expanded graphite is explored by using ANSYS software in this paper. The results indicate that during the heat storage process, the closer to the copper tube and the fins, the faster the temperature change rate. The higher the fin height, the faster the temperature change rate at the same measuring point. At the same time, the increase in the number of fins is not positively correlated with the temperature rate of each measuring point.

Keywords: Paraffin wax/expanded graphite; phase change heat storage; Fluent simulation; temperature change rate.

1. Introduction
During the phase change process, lots of heat is stored by phase change heat storage and temperature is almost constant, but the thermal conductivity of general phase change materials is poor. N N Wang, Y W Sun and Y W Cao [1-3] researched the utilization efficiency of hot water storage tanks with different phase change materials. The simplest and most economical way to enhance heat exchange is increasing the heat exchange area. X N Song, G X Jiang, D G Lin and W C Jin [4-7] have numerically studied the heat transfer effect of PCM under different fin height and fin space. A phase change hot water storage tank based on spherical packaging is numerically studied by X Tan et al. [8]. Additionally, Z Wei [9] further numerically studied the influence of the spiral groove heat storage ball on the heat transfer effect. The influence of different inclination angles on the heat release characteristics of the round-shaped phase change hot water storage tank was experimentally determined by A G Li [10]. Ul Hasnain Fakhar et al. and Fekadu Birlie et al. [11, 12] studied the effect of the number of fins and the inclination angle of the fins on the melting rate of phase change materials. Asgari M. et al. and Z H Chen et al. [13, 14] studied the influence of branched fins with different thicknesses and lengths on the thermal conductivity of phase change materials.

In summary, domestic and foreign scholars have used the numerical research to study the influence factors of the water tank structure, phase change material and fins on the phase change hot water storage tank. In this paper, paraffin wax/expanded graphite is used as the phase change material, and the numerical simulation method is used to explore the temperature change of the phase change material heat storage/release process under the conditions of different fin heights and fin spacing, so as to provide theoretical support for the performance optimization of the phase change hot water storage tank.
2. Model establishment

2.1. Physical model

In this paper, the research object is a phase change heat storage unit extracted from a fin type phase change hot water storage tank. The flowing medium in the inner tube, which is a 25mm heat exchange copper tube, is water. The outer tube is a 50mm straight round tube made of aluminum, filled with paraffin/expanded graphite as a composite phase change material between the inner and outer tubes. The tube is 600mm long, and the heat storage unit is placed horizontally. Figure 1 shows the physical model of the thermal storage unit and its cross-sectional model.

Figure 1. Physical model and cross-sectional model of heat storage unit.

2.2. Mathematical model

In the process of phase-change heat, the temperature and physical parameters of the phase-change material will change over time. It is more complicated to establish a phase-change heat storage model. Therefore, in order to simplify the calculation, the following assumptions are made:

1. Paraffin wax/expanded graphite phase change materials are identical;
2. Liquid phase paraffin wax is an incompressible Newtonian fluid with an unsteady state and laminar flow, and its density conforms to Boussinesq assumption;
3. The outer surface of the hot water storage tank is insulated from the outside, no heat dissipation;
4. The thermophysical parameters of paraffin have nothing to do with temperature changes and they are constant. The thermophysical parameters of paraffin wax in the solid-liquid coexistence zone have a linear relationship with temperature changes.

Based on the idea above, the continuity equation, momentum equation and energy equation of the phase change material can be obtained.

Continuity equation:
\[
\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u)}{\partial x} + \frac{\partial (\rho v)}{\partial y} + \frac{\partial (\rho w)}{\partial z} = 0
\]  

Momentum equation:
\[
\rho \frac{\partial u}{\partial t} + \rho \left[ \frac{\partial (\mu u)}{\partial x} + \frac{\partial (\mu v)}{\partial y} + \frac{\partial (\mu w)}{\partial z} \right] = -\frac{\partial p}{\partial x} + \mu \nabla^2 u + \frac{(1-\beta)^2}{\beta^2 + \omega} A_m \mu
\]  
\[
\rho \frac{\partial v}{\partial t} + \rho \left[ \frac{\partial (\mu u)}{\partial x} + \frac{\partial (\mu v)}{\partial y} + \frac{\partial (\mu w)}{\partial z} \right] = -\frac{\partial p}{\partial y} + \mu \nabla^2 u + \frac{(1-\beta)^2}{\beta^2 + \omega} A_m \mu - \rho g \alpha (T - T_0)
\]
\[
\rho \frac{\partial \omega}{\partial t} + \rho \left[ \frac{\partial (\rho \mu)}{\partial x} + \frac{\partial (\rho v \omega)}{\partial y} + \frac{\partial (\rho w \omega)}{\partial z} \right] = -\frac{\partial p}{\partial z} + \mu \nabla^2 \omega + \frac{(1-\beta)^2}{\beta^2 + \omega} A_m \mu
\]  

(4)

Energy equation:

\[
\frac{\partial H}{\partial t} \rho C_p \left( \mu \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} + \omega \frac{\partial T}{\partial z} \right) = \lambda \nabla^2 T
\]  

(5)

3. Phase transition process simulation

3.1. Boundary condition setting

Copper pipe wall surface:

\[ T_w = C \]  

(6)

Thermal insulation on the outer surface of the phase change hot water storage tank:

\[ \frac{\partial T}{\partial x} |_{x=0,x=L} = 0 \]  

(7)

3.2. Parameter settings

Define the physical parameters of the heat storage unit material, set the boundary conditions, and determine the calculation step as 1s. The physical parameters of paraffin/expanded graphite phase change materials are shown in Table 1.

**Table 1. Physical parameters of paraffin wax/expanded graphite phase change material.**

| Parameter                     | Numerical value |
|-------------------------------|-----------------|
| Density(kg/m³)                | 760             |
| Specific heat capacity(J/kg·K) | 2100            |
| Thermal Conductivity(w/(m·K)) | 0.25            |
| Latent heat of phase change(kJ/kg) | 170            |
| Viscosity coefficient(kg/(m·s)) | 0.00324        |
| Solidus temperature(K)       | 324.15          |
| Liquidus temperature(K)      | 330.15          |

4. Simulation results and analysis

In the heat storage process of the phase change material, set the hot water inlet temperature to 80°C, the paraffin/expanded graphite initial temperature to 20°C. In addition, the cold water inlet flow rate is 1.768m/s (0.5m³/h). Three measuring points L1, L2 and L3 are selected for comparison. The distance between the three measuring points is 4mm. The location of the three measuring points is shown in Figure 2.
4.1. Liquid phase rate of heat storage process of phase change material
The liquid phase rate of the phase change material storage/discharge process under different fin height and fin numbers is shown in Figure 3. In the early stage of the heat storage process, the liquid phase ratio of the phase change material is not changed under different conditions because the solidus temperature of paraffin wax/expanded graphite is 51°C, while the initial temperature of the phase change material is 20°C. The material continuously accumulates heat until the temperature reaches 51°C, and the liquid phase ratio begins to increase. The solid and liquid coexist state until the liquid phase ratio reaches 1. It can be seen from these figures that the higher the height and the greater the number of fins, the longer the heat storage time of the phase change material in the heat storage unit, and the more heat storage.

4.2. Temperature change of phase change material in heat storage process at different time.
Figure 4 shows the temperature change cloud diagram of the phase change heat storage process. As time goes by, the heat of the hot water through the heat exchange tube is absorbed by the phase change...
material. At first, only the temperature of the phase change material around the heat exchange tube and the fins rises, and then, along the heat exchange tube and the rib, the heat of the sheet is transferred to the surroundings, and the temperature also gradually increases from the heat transfer tube to the surroundings. The temperature contour is roughly the same as the shape of the heat transfer tube. After 1000s, the temperature of most phase change materials rises and the phase change occurs. The energy is stored gradually from solid to liquid. After 1500s, compared with 1000s, it can be seen that the temperature change of the phase change material slows down. This is because the main heat storage method of the composite phase change material is sensible heat storage at this time. The heat is transformed into latent heat storage, and the temperature change is small.

![Temperature distribution cloud diagram of phase change material heat storage process at different times.](image)

**Figure 4.** Temperature distribution cloud diagram of phase change material heat storage process at different times.

4.3. The effect of fin height on the heat storage process

The temperature distribution cloud diagram of the phase change material heat storage process is shown in Figure 5 when the number of fins is \( n = 4, n = 6, \) and \( n = 8 \) and the time is the same 1000s. It can be seen from the figure that adding fins can increase the heat exchange area. The fins and the copper tube are
the places where the temperature is highest. Therefore, as the height of the fins increases, the volume of the phase change material temperature reaching the liquidus temperature increases and the more heat is absorbed from the hot water.

![Figure 5. Temperature distribution cloud diagram of phase change material under different fin heights (1000s).](image)

It can be seen from Figure 6 that the measuring point L1 closest to the copper tube and the fin has the fastest rate of temperature rise, reaching the highest temperature, and the phase state changes from solid to liquid, measuring point L2 is the second, and measuring point L3 has the slowest rate of temperature rise and the lowest temperature. From the temperature curves in the figure below, it can be seen that the slope of the curve, that is, the temperature rise rate, gradually slows down, indicating that the phase change material has changed from sensible heat storage to latent heat storage. It can be seen that the distance from the fins and the copper tube is inversely related to the temperature rise rate, and the fins can effectively enhance the heat transfer efficiency. The process and cost permitting, the higher the fin, the better the heat transfer effect.
4.4. **The influence of the number of fins on the heat storage process**

Figure 7 shows the temperature distribution cloud diagram of the heat storage process of the phase change material when the number of fins is $n=4$, $n=6$ and $n=8$ respectively and the time is the same 1000s. It can be seen from the figure that adding fins can increase the heat exchange area and the fins and the copper tube are the places where the temperature is highest. Therefore, as the height of the fin increases, the volume of the phase change material that reaches the liquidus temperature increases, and more heat is absorbed from the hot water.
It can be seen from Figure 8 that although the number of fins of the phase change heat storage unit is different, the temperature rise rate decreases from the measuring point L1 to the measuring point L3, and the speed of the measuring point L2 is closer to the measuring point L1. The measuring point L3 is much smaller than the rate of measuring point L1. This shows that the temperature rise rate of the phase change material in the same heat storage unit is mainly related to the height of the fins, that is, the longer the distance from the copper tube and the fins, the slower the temperature rise rate. The slope of each curve gradually decreases, which shows that the temperature growth rate gradually slows down as time goes on.
5. Conclusion
The temperature changes at different locations with different heights of fins and the number of fins are explored by this article. The main conclusions are as follows.

(1) It takes a certain time for the liquid phase rate of the phase change material to change, because it takes a certain time for the phase change material to reach the solid/liquid line temperature when it accumulates/releases heat before the phase change can occur;

(2) The farther away from the copper tube and fins, the slower the temperature change rate. The higher the fin height, the faster the temperature change rate at the same measuring point, the higher the temperature reached within the same time, the better the heat transfer effect, but the increase of the ribs will also increase the production cost and the difficulty of the manufacturing process;

Figure 8. Temperature change curves at each measuring point of phase change material under different number of fins.
(3) The increase in the number of fins is not positively related to the temperature rate of each measuring point, but the greater the number of fins, the less time it takes for all phase change materials to complete the accumulation/discharge process.

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