Simulation and Analysis of Fuel Tank Heat Exchanger Based on Phase Change Material

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Abstract. A replaceable heat exchanger plate fuel tank is designed for the heat dissipation problem of the fuel tank. The oil temperature curve of the fuel tank without the heat exchanger plate and the heat exchanger plate is simulated and analyzed. It is proved that the phase change material heat exchanger plate can reduce the equilibrium temperature of the fuel tank. The latent heat and phase transition temperature of the phase change material were changed, and the influence of the properties of the phase change material on the oil temperature change of the fuel tank was simulated.

1. Introduction
The increase in the oil temperature of the hydraulic system not only increases the leakage of the hydraulic system, but also reduces the volumetric efficiency and changes the performance of the control element [1, 2]. Therefore, the heat dissipation of the hydraulic system is of great significance to the normal operation of the hydraulic system [3]. In this paper, the fuel tank of the replaceable heat exchanger plate based on phase change material is proposed, which utilizes the advantages of large latent heat of phase change material and high heat storage density, and the heat generated in the hydraulic system is taken away, so that the system can work longer in the specified temperature range.

2. Phase change heat transfer physical model
FLUENT uses the enthalpy-porosity formula instead of the obvious solid-liquid interface, and regards the liquid-solid mixing zone porosity of the phase transition as the region where the liquid region is a porous medium, and the paste phase region is the liquid phase ratio $\beta$ at 0-1. In the area between the simulations, it is assumed that the paste phase region is a porous medium in the solidified material whose porosity is decreasing from 1 to 0. When the material is completely solidified, the porosity becomes 0, and the flow velocity is also lowered to zero [4].

The concept of liquid phase rate $\beta$ is introduced in the melt solidification model in the FLUENT software. Define the liquid phase rate as:

$$
\beta = \begin{cases} 
0, & T \leq T_s \\
\frac{T - T_s}{T_i - T_s}, & T_s < T < T_i \\
1, & T \geq T_i 
\end{cases}
$$
When the liquid phase ratio is $0 < \beta < 1$, the phase change material can be regarded as a liquid solid phase blurred region, the liquid solid phase blurred region is regarded as a porous medium, and the porous region is a ratio of liquid. When the solidus of the material $T_s$ is equal to the liquidus of the material $T_l$, only the solid phase and the liquid phase are separated during the phase transition, and other relationships between the liquid phase rate $\beta$ and the temperature $T$ are not considered here.

3. Fluent-based fuel tank model and simulation

3.1. Modelling

The model is shown in Figure 1, where the heating module is the heat generated in the simulated hydraulic circuit; the fluid module is the hydraulic oil; the fan module is the fan surface added in the heating module to provide power for the flow of the liquid, simulating oil circulation in a hydraulic circuit[5]; the heat exchanger plate is inserted into the heat exchange plate filled with the phase change material, and the structural parameters of the heat exchange plate are shown in Figure 2, and the heat exchange plate is packaged with an aluminum plate, and the phase change material is filled inside. The way the heat exchanger plate is inserted into the fuel tank is shown in Figure 3.

![Figure 1. Fuel tank model grid diagram](image1)

![Figure 2. Heat exchanger plate structure](image2)
3.2. Fuel tank simulation without heat exchanger

After the divided mesh is introduced into the fluent and the boundary conditions are set, the transient analysis is performed, and the starting temperature of the loop is set to 300K. The simulation temperature distribution cloud diagram is shown in Figure 4. The temperature of the hydraulic oil is transferred from the inner layer to the outer layer layer by layer. The temperature near the wall surface is 3-5K higher than the temperature inside the tank.

Set the temperature monitoring point, as shown in Figure 4 in the cross position. The monitoring point temperature change is shown in Figure 5. In the fuel tank, the temperature of the oil gradually rises, and the rate of rise gradually becomes slower. When the temperature is 4500s, the temperature of the monitoring point does not change and stabilizes at 343.5K.
3.3. Fuel tank simulation without heat exchanger

Three heat exchanger plates were inserted into the outer layer of the tank, and the grid was divided and simulated. The temperature change at the monitoring point is shown in Figure 6. At 1250s, when the oil temperature reaches 327K, the temperature rise of the oil is obviously slowed down. This is because the phase change material in the heat exchange plate reaches the phase transition temperature and begins to undergo phase change to absorb a large amount of heat. When 2400s, the temperature reaches 335K, then the temperature rise of the oil temperature increases. This is because the phase transition of the heat exchanger plate is completed, and the heat storage cannot be continued. The heat dissipated in the oil is reduced compared with the phase change phase, and the temperature is increased. When the temperature reaches 4500s, at this time, the oil temperature is 340.4K, the oil absorption and heat dissipation reach a dynamic balance, and the oil temperature does not change any more. Compared with the non-heat exchanger tank, the equilibrium temperature drops by 3.1K. It is proved that adding a phase change hot plate is beneficial to the heat dissipation of the hydraulic oil tank.

![Figure 6. Oil change curve in fuel tank with heat exchanger plate](image)

4. Analysis of the influence of material properties

4.1. Analysis of the influence of latent heat

In this paper, three phase change materials with phase change latent heat of 100000 j/kg, 180000 j/kg and 300000 j/kg were set up to analyze the effect of latent heat on the heat dissipation of phase change materials. The results show that the longer the latent heat, the longer the phase transition time, and the longer the system temperature is near the phase transition temperature. After the phase change, the rate of temperature rise is basically the same, the time for the system to reach the heat balance is prolonged, and the heat balance temperature of the system does not change substantially.
4.2. Analysis of the influence of phase transition temperature

In this paper, three different phase transition temperatures of 318-320K, 323-325K and 328-330K are set, and the other thermal properties are unchanged. The influence of phase transition temperature on the heat dissipation effect is analyzed. The temperature change at the monitoring point is shown in the Figure 8. The results show that the lower the phase transition temperature, the faster the system temperature rises after the phase transition is completed. This is because the phase transition temperature is low and the temperature difference between the external environment is small, which is not conducive to the outward transfer of heat, and the phase transition temperature is high, the oil temperature difference with the heat exchanger plate is getting smaller and smaller. At the same time, the temperature difference between the heat exchanger plate and the external environment is getting larger and larger, so that the absorbed heat is reduced, the heat released is increased, and the temperature rises slowly, and the system reaches the heat balance for a long time. It can be seen from Figure 8 that the system with a phase transition temperature of 318-320K has reached thermal equilibrium at 4500s, and the system with phase transition temperature of 328-330K is considered to achieve thermal equilibrium at 5100s. However, the equilibrium temperature of the system basically does not change.
5. Conclusion
According to the heat dissipation problem of the fuel tank, the heat exchanger oil tank is designed. The position of the heat exchanger plate is equivalent to inserting the partition in the fuel tank. Conducive to the flow disturbance of the oil, enhance heat transfer. After the heat exchanger plate is inserted, the phase change material absorbs a large amount of heat through the latent heat process, and the temperature in the oil tank is lowered. Compared with the non-heat exchanger plate, the equilibrium temperature of the oil is reduced by 3.1K.

The phase change material with latent heat and high phase transition temperature can extend the time that the system reaches the heat balance, and has no obvious influence on the temperature of the heat balance. Phase change materials are rarely used in hydraulic heat dissipation systems. The research of this topic provides a reference for material selection and structural design.

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