Design of electric heating phase change thermal storage device and numerical simulation research on heat transfer characteristics

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Introduction

The low-valley electric energy storage and clean heating technology cannot only effectively balance the grid load, improve the efficiency and utilization of the grid, but also use cheap electricity price policy realizes low-cost operation of distributed heating, little dependence on infrastructure, small footprint, low operating cost, high degree of automation, safety and reliability, and other significant features. It is a research hotspot in the field of clean heating technology[1-2] .

In this paper, a baffle-type electric heating phase-change heat storage device is designed to convert electrical energy into thermal energy and use CPCM to realize energy storage and release. The device stores low-priced electricity during the trough period and provides it to users during the peak period of electricity consumption.，It has the characteristics of high energy storage density, small device size, and easy maintenance and installation. The approximate isothermal characteristics of the CPCM in the phase-change process are also conducive to the stable output of heat energy of the system, and it has broad application prospects.

Pcm is the heat storage carrier of the phase change heat storage device, and the selection of the matching pcm is the key to the success of the device design. According to the "Code for Heating, Ventilation and Air-conditioning Design of Civil Buildings GB50736-2012", paraffin wax is selected as the heat storage medium in this paper. its phase transition temperature is between 47° C and 64° C, which is in line with residential heating temperature and has low cost, but the thermal conductivity of pure paraffin wax is low. Some scholars have proposed that adding a certain amount of expanded graphite can greatly increase the thermal conductivity and significantly reduce the charging/exothermic time. The thermal performance of the composite CPCM is shown in Tab.1:

Table 1. CPCM thermal properties parameters

Material name		Paraffin\Expanded Graphite
Density	kg/m^3	882
Specific heat	j/kgk	3395
Thermal Conductivity	w/mk	0.49
Viscosity	kg/ms	0.00324
Pure Solvent Melting heat	J/kg	203000
phase-change temperature	K	337.16

Device structure design

Some scholars have used electric heat storage for heating earlier. Han et al.[3] numerically demonstrated three-cylindrical containers using FLUENT software. The statistical findings revealed that the shield and tube configuration achieved a shorter time to melt for the same mass of PCM and heat transfer surface area. Zivkovic [4] conducted a mathematical model，the results show that under the same volume and heat transfer area, the melting time of pcm in a rectangular container is about half of the melting time of a cylindrical container.

Based on the above research, this paper designs a baffle-type electric heating phase change heat storage device. The device uses expanded graphite as the matrix and paraffin wax as the phase change heat storage medium. In order to maintain the shape of the CPCM and prevent its leakage, the CPCM needs to be encapsulated. The device uses an electric heating plate to directly heat the CPCM, and then the CPCM transfers the heat to the fluid. The heat storage plates are arranged alternately and fixed inside the water tank and separated by rectangular channels, water flows through the channels.Fig.1 is shown The model diagram.

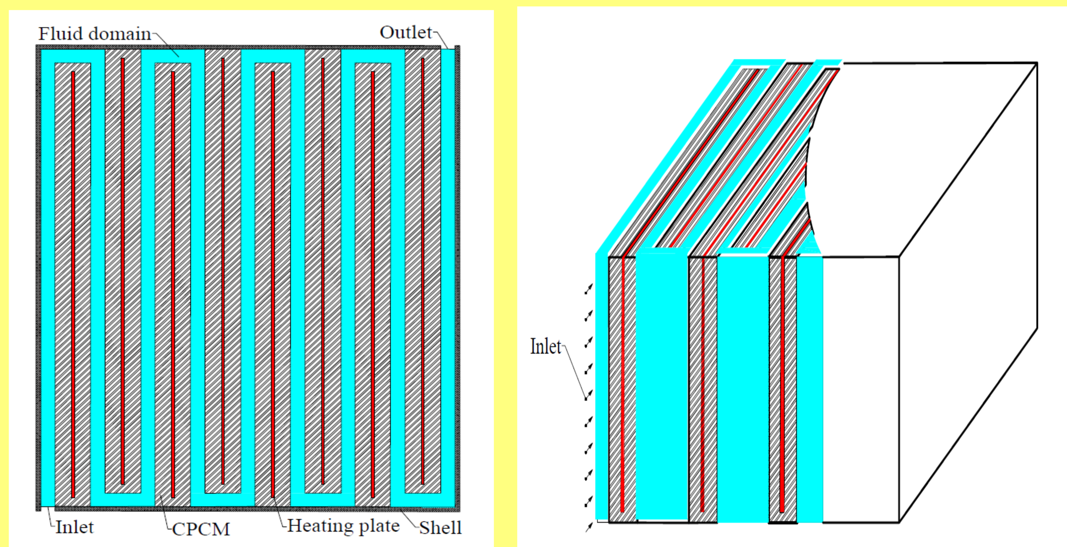

Fig. 1. Three-dimensional schematic diagram and cross-sectional schematic diagram of the device.

Numerical simulation

HEAT RELEASE PROCESS

Use fluent to solve by numerical simulation method, mesh the entire calculation area through fluent meshing, open the energy equation, continuity equation and solidification and melting model in fluent, set the material properties, CPCM needs to be set in the material panel, tab.1 is CPCM thermophysical parameters. In the iterative process. the convection term in the equation system adopts the two-up style, velocity and pressure are coupled. The boundary conditions are given CPCM initial temperature is 348.15K, the inlet water temperature is 318.15K，and the given water flow velocity is 0.005m/s. Because the thickness of the phase change unit has a greater influence on the heat release time, then simulates the heat release performance of 6,8, 10, and 12 phase change units under 4 working conditions when the heat storage volume and heating flow are constant.

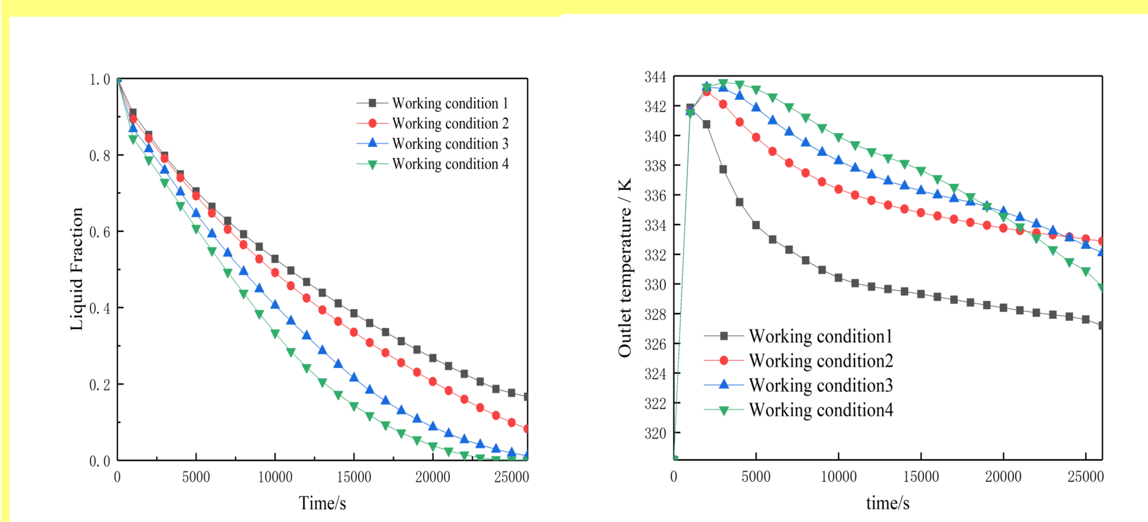

Fig. 2. Change curve of liquid phase rate(a) and outlet temperature(b) diagram of phase change unit under 4 working conditions

It can be seen from the figure that the outlet water temperature presents a trend of first rising and then falling. After comparison, working condition 2 is selected, which not only has the longest heat storage time, the overall outlet temperature fluctuation is small, but also consumes less materials under the premise of meeting the heating requirements.

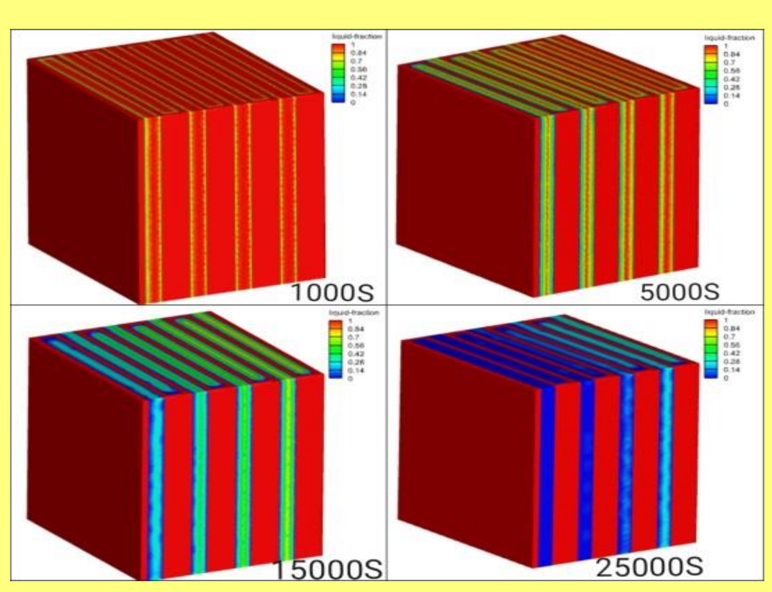

Fig. 3. Cloud chart of liquid fraction distribution at 4 moments

It can be seen from Figure 3 that the phase change process between different heat storage plates is quite different, and the heat release at the entrance ends early, and the heat storage unit near the exit still has some CPCM is not solidified, and there is a "dead zone" in the center of the heat storage plate. The heat release efficiency of the heat storage device is calculated to be 90.08%. Although there is a "dead zone", due to the structural characteristics of the device itself, the heat storage plates are staggered to increase the disturbance between the fluids, and at the same time, the heat exchange area is increased, so that the heat release efficiency of the device is high.

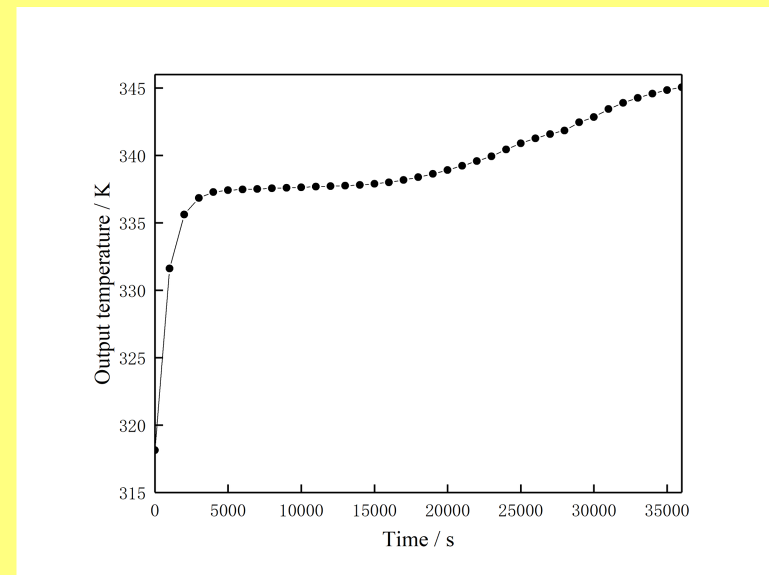

Fig. 4. Outlet temperature of heat storage process

HEAT STORAGE PROCESS

It can be seen from Fig.4 that the outlet water temperature rises first. During 3000S-15000S, the temperature is maintained at about 337.16K, and then slowly rises. It can be seen from Fig.5 that the liquid phase velocity is basically stable after 30000S. At this time, the liquid phase ratio of each phase change unit is basically close to 1, and the liquid phase ratio values are respectively: 0.835, 0.848, 0.891, 0.928, 0.965, 0.992, 0.999, 1.000, and the heat storage efficiency can be calculated as 93.2%. In short, the device has the characteristics of high heat storage efficiency and small outlet temperature fluctuations.

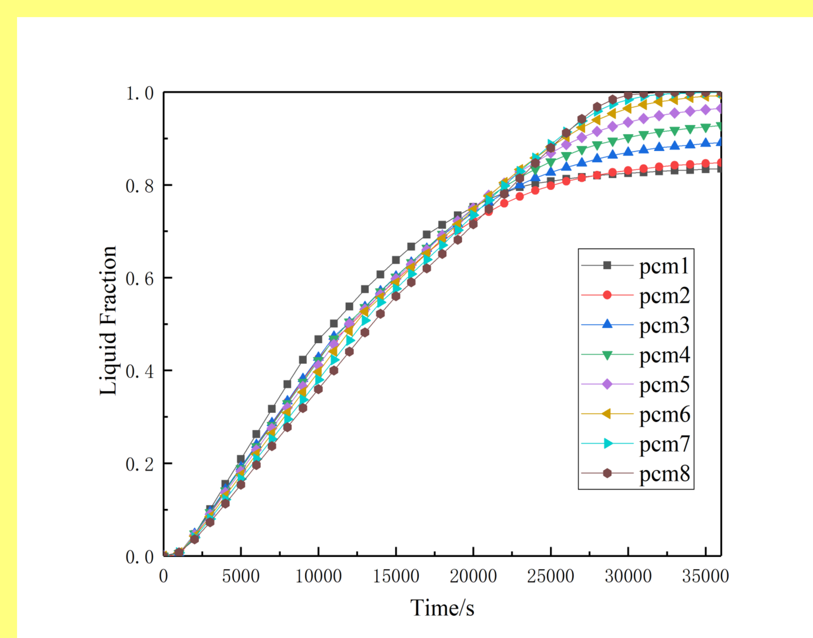

Fig. 5. Liquid Fraction of each pcm

Conclusions

The main conclusions drawn from all these work are:

- It is best when the number of the best phase change units is 8;
- The staggered placement of the heat storage plates increases disturbance of the fluid, and at the same time increases the heat exchange area, so that the heat release efficiency is as high as 90.08%;
- The simulation results show that the heat storage efficiency is 93.2%. In general, the device has the characteristics of high heat storage/release efficiency and small outlet temperature fluctuations. It is suitable for non-central heating users, which can reduce user costs and make full use of power resources.

References

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