NUMERICAL ANALYSIS OF THERMAL STORAGE AND RELEASE PERFORMANCE OF MECHANICAL THERMAL STORAGE BASED ON 2-D THERMAL CONDUCTIVITY DIFFERENTIAL EQUATION

by

Hao LI *

School of Mathematics and Statistics, Suzhou University, Suzhou, Anhui, China

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In order to understand the numerical analysis of the thermal storage and release performance of mechanical heat storage materials, the author proposes a study on the numerical analysis of the thermal storage and release performance of mechanical heat storage materials based on 2-D thermal conductivity differential equations. The author first studied the phenomenon of iron resistance in the sleeve on the overall heat storage performance of the magnesium brick, and made two conclusions about the number of magnets in the sleeve brick. Second, ANSYS is used to model the exothermic process of mechanical heat storage, analyze the temperature distribution, flow field distribution, heat transfer coefficient of heat storage under different conditions, and compare the experimental results. Finally, the experiment shows that the addition of the sleeve does not affect the overall heat storage performance of the magnetic brick, which can extend the service life of the resistance metal and provides some support for the expansion of the use of the heat storage material of the magnetic brick. By using the numerical calculation method to calculate the error, it can be seen that the error between the numerical simulation and experimental results is less than 16, and the experimental results are consistent with the experimental results. The ability to store and release heat of a heat storage facility depends largely on its size structure, and the heat storage and release ability of a small heat storage facility is better than that of a large heat storage facility. For heat storage materials with high thermal conductivity, their heat transfer coefficient will increase with increasing temperature, but the increase is not significant. For thermal accumulators with low thermal conductivity, their heat transfer coefficient will decrease with increasing temperature.

Key words*: mechanical heat storage, numerical analysis,
2-D thermal conductivity*

Introduction

In the existing energy structure, thermal energy is one of the most important energy sources. However, most of the energy sources, such as solar energy, geothermal energy and industrial waste heat and waste heat, are intermittent and unstable, and in many cases people cannot reasonably use energy. We use appropriate energy storage methods and specific devices to store temporarily unused energy through certain energy storage materials, and the method of reusing it when needed is called energy storage technology. The storage of heat is basically divided into two types, namely sensible heat storage and phase change heat storage. Sensible heat storage is the process of storing thermal energy by heating a thermal storage material to

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* Author's e-mail: cszlihao@163.com

increase its temperature. Phase change heat storage is the use of the melting heat generated during the phase change of thermal storage materials to store thermal energy. The thermal storage medium that utilizes solid-liquid phase change latent heat storage is often referred to as phase change material. Compared with sensible heat storage, phase change heat storage has the advantages of simple device, small volume, high heat storage density, approximate isothermal heat storage (release) process, and easy process control. Therefore, it has become the most practical development potential, widely used, and important heat storage method [1].

The use of heating devices can control energy consumption and demand, which is a necessary measure to improve energy efficiency. In recent years, it has become a research hot spot due to its high temperature retention rate, low weight of the heating device, and high heat absorption and emission efficiency of the heat transfer stage. Those, by developing highly efficient phase thermal storage, energy storage technology will bring economic, environmental and social benefits.

The principle of operation of the machine is to heat the body before sending air to the body to heat the body. When the air temperature reaches 100 °C, the heat inside the heating system rises to a certain pressure and is pumped into the gas heating system. During this process, the gas continues to increase the temperature of the star in the gas. When it reaches a certain level, the oil expands and flows upwards, and part of the hot stars enters the interior of the heat storage facility by heating. The other part of the heat goes to the interior of the body to be electrically heated and ultimately to keep warm. In addition, the mechanical heating device has excellent heat resistance, so the heat generated during the heating process can be removed quickly [2].

Literature review

Thermal energy is one of the most important energy sources in human life and production. It is not only the carrier of energy conversion process, but also the medium for energy storage, and also the carrier of heat. At present, people mainly use thermal storage materials for storage and release of thermal energy. Mechanical thermal storage materials, as a new type of thermal storage technology, have the advantages of simple structure, high heat exchange efficiency, and uniform heat transfer. Therefore, it has been widely used in thermal storage systems. In terms of materials, due to the main component of the thermal storage body being graphite, which has a high thermal conductivity, the selected thermal conductivity model is: In the process of solving the thermal conductivity differential equation, it is necessary to determine the boundary conditions within each region, and divide each region during the solving process. Among them, when dividing the heat storage body into grids, it is necessary to ensure that the geometric shape of each area is consistent, and the distance between grid units is as small as possible. In order to improve computational accuracy, it is necessary to perform grid subdivision on each region. In practical applications, due to measurement conditions that cannot fully meet the conditions for measuring each region, in order to reduce calculation time and improve calculation accuracy, it is necessary to divide each region into different grid units.

In the manufacturing sector, thermal energy is often used in production, and the storage and utilization of thermal energy is an important link. A heating device is a type of heat transfer device that absorbs or releases heat by heating or cooling gases or liquids. Heat storage materials are usually made of ceramics, metals, and fillers, and the ability to store heat is determined by the thermal conductivity of the material. The higher the thermal conductivity of the heat storage material, the greater its ability to store and release heat. On the contrary, less heat storage and release. Different researchers have proposed different versions of heat storage devices. However, due to the small size of the heat storage body, it is difficult to use the correct mathematical model to study the manufacturing process, so few researchers have studied the physical equipment of the body heat storage. Domestic and foreign researchers have conducted extensive research on the theoretical and experimental aspects of phase change heating equipment. Massatt [3] numerical modelling and experimental research on the heat storage and release properties of floor heating systems using multi-phase heat exchangers and their impact on the internal thermal environment. Wang *et al.* [4] to design experiments on the heat storage and exchange performance of plate-type phase-shift heat exchangers, to study the thermal performance of plate-type phase-shift heat exchangers with different operations, and to propose valid theoretical models for plate-type heat storage and exchange performance. type phase change heat storage heating .

Solid-state electric heaters are a good way to address the biggest differences in energy consumption, including silver-magnesium bricks for heat dissipation. Supporting heating devices that run less time can be a good way to *shave the peaks and fill the valleys*. However, because the heater is in a temperature state for a long time during operation, the insulation performance of the heat storage brick will decrease in terms of temperature for a long time, and the phenomenon of *fire melting and short circuit* will occur. formed in heat to protect the metal connected in some way, and will reduce the life of the metal resistance and affect the heat storage process. Therefore, it is necessary to improve the design of resistance wire and heat storage brick.

The author’s research on the effect of coatings on the thermal storage and storage performance of magnesium bricks provides clear support for expanding the use of magnesium bricks as heat storage materials. In addition, numerical modelling of heat transfer properties of heat storage bricks with ceramic tubes has important guidelines for environmental protection and energy use [5, 6].

Methods

Thermal conductivity differential equation

Before analyzing the system, it is first necessary to conduct numerical simulations. Therefore, it is necessary to first establish the thermal conductivity differential equation of the system, and use the finite element calculation software ANSYS to numerically simulate the system based on existing experimental results:

- Firstly, use the APDL language in ANSYS software to write a program and establish a finite element model.
- Divide the grid, set material parameters and boundary conditions.
- Calculate and analyze using FLUENT software.
- Perform numerical solutions.
- Output results.

In the calculation process, the heat storage body is divided into three regions: high temperature region, middle lower temperature region, and low temperature region. The heat conduction differential equation is solved in each region obtain the temperature distribution inside the system.

Numerical simulation of heat storage device

Setting of temperature load

During the heating of the heat storage brick, the metal resistance is heated with constant power and constant current, and the outer wall is installed as an insulator. In engineering practice, the starting ambient temperature is chosen to be 20 °C due to the heating and discharge operation time in the heat storage brick. During the calculation, the first stage is 365 seconds, and the warm-up time is 12 hours.

The electric power of heating the thermal storage brick is 12997 W, and the heat flux density of a brick:

$$q=\frac{p}{s}=\frac{12997}{90\times3\times3\times3.15\times0.026\times0.3}=2299.37\ \left[\mathrm{Wm^{-2}}\right] \tag{1}$$

Due to the addition of high alumina ceramic materials and the constant heat flux, the heat transfer area changes, resulting in a change in heat flux density. The heat flow rate:

$$q=2299.37\times3.15\times0.026\times0.3=36.2\ [\mathrm{W}] \tag{2}$$

Setting of thermal convection

The Re of this device is 40000~160000, so it belongs to forced convection heat transfer in hot air condition. Due to the non-uniformity of the flow expression in the fast flow, the natural-convection characteristic caused by the temperature difference of all flow states is less strong and can be neglected:

$$\mathrm{Nu}=f(\mathrm{Re},\mathrm{Pr}) \tag{3}$$

The exact experimental equation:

$$\mathrm{Nu}=0.024\,\mathrm{Re}^{0.8},\ \mathrm{Pr}^{0.4}=\frac{\alpha d}{\lambda} \tag{4}$$

Take the qualitative temperature $t = 100$ °C and refer to:

$$\begin{gathered}\mathrm{Pr}=0.68\\ \lambda=\frac{2A}{L}\cdot10^{-2}\,[\mathrm{Wm^{-1}{}^\circ C^{-1}}]\\ r=\frac{2A}{L}=29.65\ [\mathrm{mm}]\\ d=59.27\ [\mathrm{mm}]\end{gathered} \tag{5}$$

The calculation shows that Re = 40010, α = 51.19 W/m^2°C. At Re = 160020, α = 155.137 W/m^2°C.

Numerical simulation

In the heating system, according to some standards, there are many heating bricks, so each brick has the same heat in the heating process, so take one of the bricks. Experiments show that the system is unstable when heated. As an internal heating material, thermal conductivity, density, and specific capacity depend on constant temperature [7]. The material, therefore, the thermal conductivity, density and specific heat capacity are determined by making two models of the heat storage brick using ANSYS, entering the TransientThermal finite element software, and measuring the temperature from the heat storage brick.

The thermal storage brick device is heated with 12997 W power for 12 hours. During the heating process, the temperature of each case in the magnesium brick continues to change over time. After the casing surface temperature increases, the surface temperature inside the magnesium brick first increases, and then heat is transferred from the inside to the outside. Because this experiment only studies the heat storage process of thermal storage bricks, there will be very little heat loss under closed conditions, so the convective heat transfer coefficient of thermal storage bricks is extremely small and will not be considered in the numerical simulation of thermal storage temporarily.

After the thermal storage brick is heated with constant power at its initial temperature, the resistance wires inserted in the parallel holes begin to transfer heat outward. At this time, the ceramic tube next to the resistance wire first contacts the high heat flow, causing the temperature to rise. Then, the heat passes through the tiny air film between the ceramic tube and the magnesium brick body, and is ultimately transferred to the magnesium brick body. Due to the fact that this experiment is a 3-D non-stationary heat conduction problem, during the non-stationary heat conduction process of heating up the magnesium brick, heat enters from the wall surface adjacent to the resistance wire and ceramic tube, and is continuously absorbed along the way, causing the entire temperature of the magnesium brick to rise and ultimately stabilizing the temperature at each point. Since the thermal conductivity of the selected magnesia brick and the heat required to raise the temperature of the object per unit volume by 1 °C are fixed values, the Thermal diffusivity will not change during the numerical simulation of the magnesia brick [8].

Experiments

Experimental equipment and methods

The solid electric heat storage experimental platform is composed of high aluminum ceramic tubes, resistance wires, air ducts, heat storage bricks, and insulation pipes. The system device is shown in fig. 1. When the thermal storage brick is heated at a constant power and reaches a certain temperature, the circulating fan is started. The air exchanges heat with the thermal storage body through the air duct, and then flows into the heat exchanger to heat water for use by the user. The heat storage body is stacked with several magnesium bricks. The resistance metal is heated by constant current and transfers heat to the tube. The heat pipe then transfers the heat between the ceramic pipe and the heat storage body to the air film, which then passes through the air film to the brick body. When heating the heat storage device, a thermocouple is installed to measure the temperature. Heat storage bricks convert and store electrical energy into thermal energy. During heating, a circulation fan is used to transfer the heat stored in the heat storage device from the air to the consumer [9].

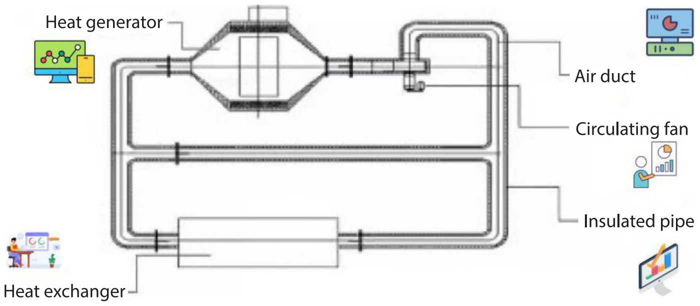

Figure 1. Solid state electric heat storage system device

In order to verify the accuracy of ANSYS simulation and the actual performance of the heat storage facility, the heat storage heating device was used as a blank brick heating test, and the magnesium bricks were sealed in the heat storage. At the beginning of the test, turn off the circulation fan, carefully put an insulating layer on the upper end of the heating element, turn off the power supply, electrical equipment, fire, and electric chimney. When the surface temperature of the brick is 20 °C, the electric heating wire heats the metal resistance placed in the channel with a constant power of 12997 W. At this time, the initial temperature of measurement Point 1 of the heat storage brick is 22.3 °C, the temperature of measurement Point 2 is 25.8 °C, the temperature of measurement Point 3 is 42.4 °C, and the initial temperature of measurement Point 4. 22.6 °C. A data set was recorded every 1 hour and the experiment was stopped after heating the brick for 12 hours.

The following figures shows the individual comparison curve between the experimental temperature and the simulation temperature at the measurement Points 1-4. Through the comparison of curves and experimental data, it can be seen that the resistance wire starts heating at time $t = 0$, and after heating for 12 hours, the temperature of each point in the thermal storage brick tends to be uniform. The change in indicators 1 and 4 is equal to two straight lines from the beginning to the end. Figures 2 and 3 at the beginning of heating, the temperature at measurement Points 2 and 3 suddenly increases. Because the measurement Points 2 and 3 are on the hot spot, while the Points 1 and 4 are far from the hot spot, and the generated heat is from

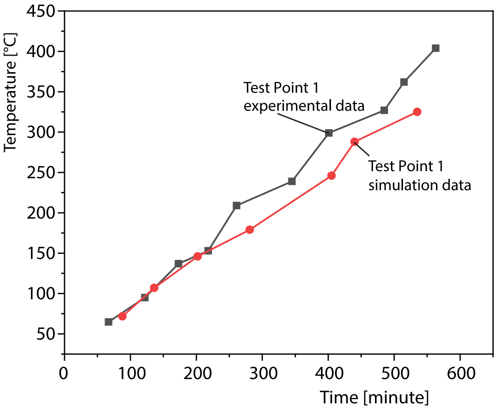

Figure 2. The curves of experimental temperature and simulated temperature at measuring Point 1 are compared separately

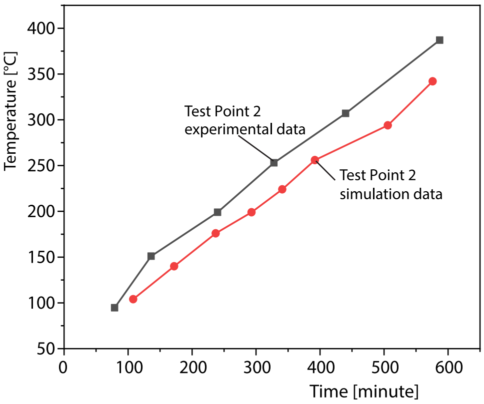

Figure 3. The curves of experimental temperature and simulated temperature at measuring Point 2 are compared separately

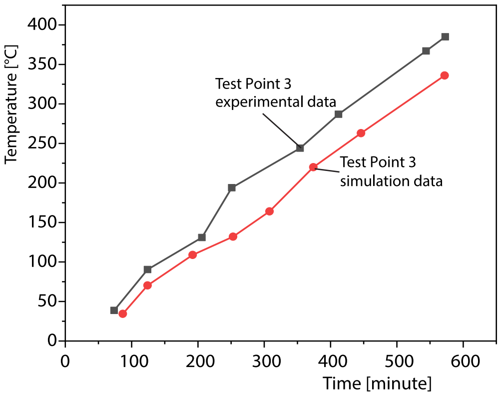

Figure 4. The curves of experimental temperature and simulated temperature at measuring Point 3 are compared separately

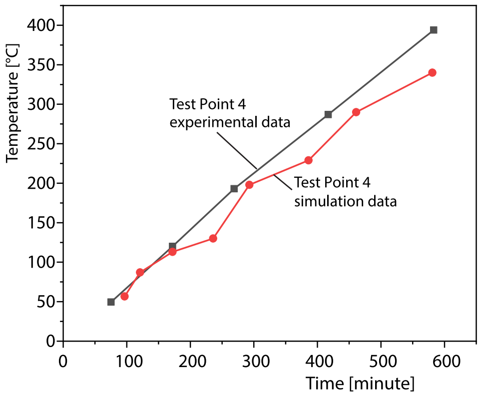

Figure 5. The curves of experimental temperature and simulated temperature at measuring Point 4 are compared separately

inside. In figs. 4 and 5, the heat generated when the brick is heated at constant power from time $t = 0$ is different from the initial temperature of the brick. Therefore, the unsteady temperature change curve of measurement Points 2 and 3 increases, and the final temperature of measurement Points 2 and 3 is higher than that of measurement Points 1 and 4.

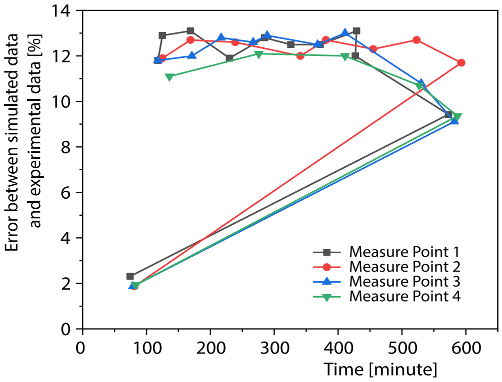

Figure 6. Comparison of error between simulated data and experimental data

After heating the magnesium brick for 12 hours, the error curves of measurement Points 1-4 are shown in fig. 6.

As shown in fig. 6, initially the simulated value is the same as the experimental value, so the error is zero. To analyze the overall performance of the heat storage facility, the average temperature, maximum temperature difference, heat storage and release rate are calculated for each location of the heat storage patch. In order to evaluate the average temperature, maximum temperature difference, heat input and output rate of different regions, calculate the heat accumulation of each region, compare and analyze their average and maximum temperature using numerical methods. When heating with constant power, the heat increases, and the experimental and simulated values increase significantly. After heating for 1 hour, the error reaches a relatively stable state. After heating for 12 hours, the error values of measurement Points 2 and 3 are relatively consistent, and measurement Points 2 and 3 are distributed on both sides of the same heat source hole, with stable heat variation [10]. The error values of measurement Points 1 and 4 are relatively small compared to measurement Points 2 and 3. This is because measurement Points 1 and 4 are far from the heat source, and the heat is relatively stable when it reaches measurement Points 1 and 4. The simulated values are not significantly different from the experimental values. By using numerical analysis methods to calculate the error, it can be seen that the error between the numerical simulation results and the experimental results is less than 16%, and the simulation results tend to be consistent with the experimental results. Therefore, the model and method for numerical simulation analysis are correct .

Conclusions

The author uses a two-step heating process with different ANSYS equations to test the exothermic process of heat storage devices. During its validation, the feasibility and accuracy of the numerical simulation model were confirmed by comparing the experimental results with the experimental results. At the same time, by analyzing the average temperature, maximum temperature difference, heat input and output rate of each region, the following conclusions were drawn.

- The thermal storage process of heat storage brick is numerically modeled using ANSYS finite element solution method. The temperature distribution of the heating brick is obtained from many factors. The error between the simulation value and the experimental value is less than 15, and the experimental results are consistent with the experimental results. This ensures that the simulation code has advantages such as speed, high performance and accuracy.
- The addition of casing does not have a significant effect on the overall thermal performance of the magnetic brick, and has a positive effect on the protection and *insulation* of the rejected metal. This provides clear support for expanding the use of magnesium brick heat storage products.

- When the heating system is in the storage area, the temperature is lower, so the heat output is faster.
- Heat output is faster when the heating system is in the storage area.

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