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Numerical Simulation and Experimental Study on the Exothermic Characteristics of Thermal Storage Brick Based on ANSYS Analysis

Zhao Di, Wang Qimin, Liu Jitang

Abstract— This paper studies the effect of heat storage bricks added to ceramic bushings on the internal resistance wire to protect the heat release characteristics of the heat storage bricks added to the casing. Numerical simulation and heat storage through ANSYS The brick exothermic experiment was verified. The results show that the regenerative bricks with ceramic casing have no influence on the heat release characteristics, which plays a good role in promoting the service life of the regenerative bricks and saving energy.

Key words— **Heat storage brick; Exotherm; Numerical simulation.**

I. INTRODUCTION

As far as the current energy development status is concerned, with the rapid development of clean energy such as hydropower, wind power and nuclear power, and the serious environmental pollution in the coal industry, electric heat storage boilers are widely favored, but they are affected by the difference between the power system and the electricity consumption in various regions. The large limit, the peak-to-valley difference of power supply increases year by year, and the solid electric heat storage technology is an effective method to solve the peak-to-valley difference of power consumption. It is an effective way to "cut the peak and fill the valley" by vigorously promoting the heat storage device operating in the low valley period [1]. The greenhouse gas emissions caused by small and medium-sized coal-fired boilers, NOx, SO_2 dust pollution is a major challenge to achieve the 19th "winning the blue sky defense war" concept. "Coal to electricity", the use of low valley electricity storage, is important to reduce operating costs and balance grid load. By using the structural combination of the refractory material and the heat insulating material, the heat storage body can achieve less heat dissipation and heat storage stability [2]. Among them, magnesia bricks have a large proportion of heat storage. However, when the regenerator is in operation, the regenerator unit will be in a high temperature state for a long time regardless of the storage and heat release operation. Since the material of the regenerator brick is composed of a heat storage material with good thermal conductivity, it is long. Under high temperature conditions, the insulation performance is lowered, and the heat source resistance wire connected with a certain mode generates a "fuse short circuit" phenomenon, which reduces the service life of the resistance wire and affects the storage and heat release process of the heat storage body. Therefore, it is necessary to rationally optimize the phenomenon that the heating wire and the heat storage brick are heated for too long and are easily melted, and a feasible solution is adopted.

In this experiment, the insulated high-alumina ceramic tube is embedded on the external resistance wire, and the resistance wire and the heat storage brick are “isolated”, which reduces the probability of the resistance wire “fuse”. This paper studies the effect of the casing on the exothermic performance of the magnesia brick. The numerical simulation of the heat dissipation process of the brick body reaching a certain temperature is carried out and compared with the experiment. It will promote the use of magnesia brick regenerators. The research results in this paper have certain guiding significance for environmental protection and energy utilization.

II. EXPERIMENTAL DEVICE AND EXPERIMENTAL METHOD

The storage and heat release test bench of the solid electric regenerator is composed of a circulating fan, a resistance wire, a duct, a heat storage brick, and a heat preservation tube heat exchange device. The schematic diagram of the system of the solid electric regenerator system is shown in Fig. 1. The working principle is that the electric resistance wire is connected with constant current, the regenerator brick is heated, the circulation fan is turned off, and the heating period of the regenerator is set to 10 h. When the temperature rises to a certain temperature, the circulating fan is started, and the air flows through the heat storage body through the air passage and performs air convection heat exchange with the heat storage body, and the hot air is finally exchanged into the heat exchange device to heat the water. The middle part of the regenerator is composed of a heat storage grid, surrounded by an insulation layer, and the wind passages are on both sides. The schematic diagram of the structure is shown in Fig. 2, wherein the heat storage bricks shown in Fig. 3 are arranged in the lattice body, and the heat storage is arranged. The body is made up of several pieces of 200 mm × 200 mm × 90 mm magnesia bricks. The electric resistance wire is heated by constant current under constant power. The electric resistance wire transfers heat to the ceramic tube which is internally set. The ceramic tube transfers heat to the ceramic. The air film between the tube and the regenerator is transferred to the regenerative brick through the air film.

When the regenerator is heated, the temperature is controlled by a thermocouple, and a thermocouple is installed inside the device for temperature measurement. The measurement points are shown in Fig. 4.The heat storage brick body converts the electric energy into heat energy for storage, uses the circulating fan during the heating period, performs air convection heat exchange on the heat storage body, and passes the heat stored in the heat storage device through the air to supply heat to the required users.

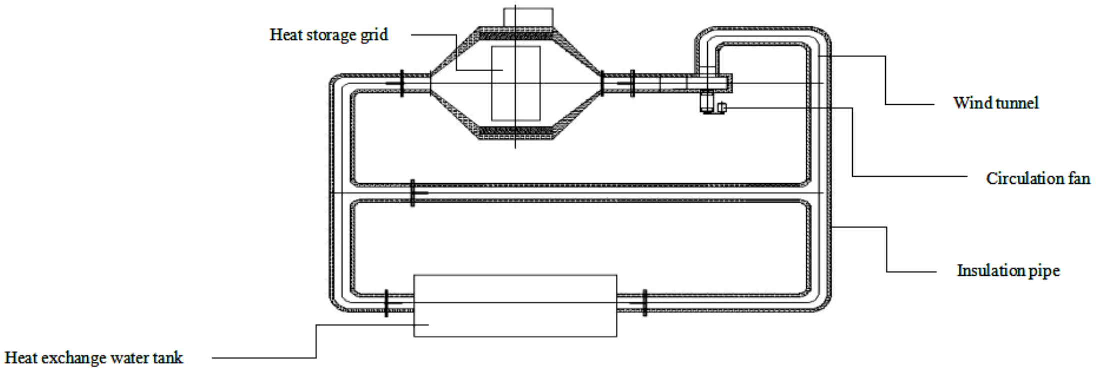


Fig.1. Solid electric regenerator system device diagram

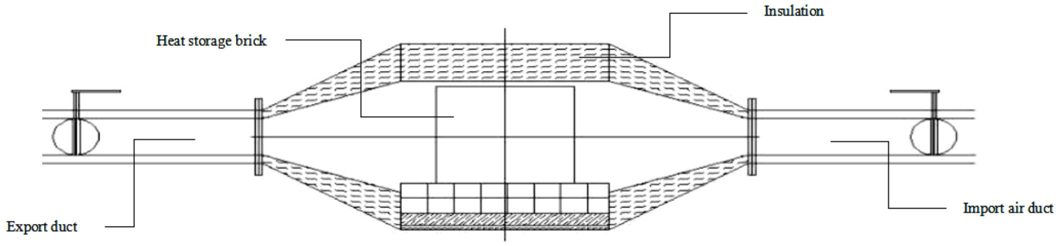


Fig.2. Heat storage structure diagram

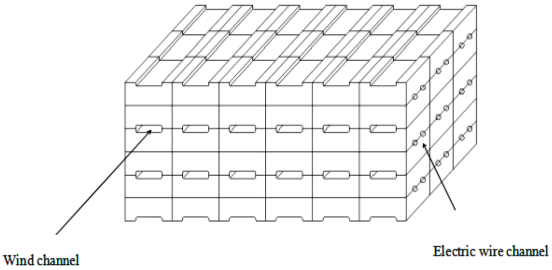


Fig.3. Three-dimensional model of heat storage brick

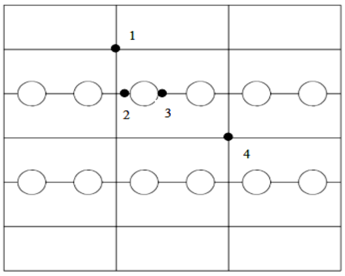


Fig.4.Temperature measuring point layout

III. EXPERIMENTAL DEVICE TEMPERATURE SIMULATION AND EXPERIMENT

A. Temperature simulation

（1）Setting of physical property parameters of heat storage materials

Since the heat storage brick requires the brick material to have a very high heat capacity, the heat capacity depends on the specific heat capacity and thermal conductivity of the material [3-4]. The physical properties of the heat storage material are shown in Table 1.

Table 1. Thermal storage material physical properties

Heat storage material	Magnesium oxide
Melting point/℃	1600
Density/Kg·m-3	2900
Specific heat capacity/J·Kg-1·℃-1	1000
Thermal Conductivity/W·m-1·K-1	2.7
Monolithic heat storage brick volume/m3	0.0028075

\ *（2）Control equations and numerical calculations of experimental processes*

During the heating process in which the heat storage brick is heated at an initial temperature, the electric resistance wire is heated at a constant current under a constant current. And the outer wall surface is set to be adiabatic. The experimental model shows that the heat storage process in the heat storage brick is a three-dimensional unsteady heat conduction problem with an internal heat source. During the heat release process, the air at the magnesium brick air duct convects the wall surface of the magnesium brick. The heat transfer, combined with the conditions of this experiment, uses the continuous equation of the incompressible turbulent mean motion, the momentum equation and the empirical formula of the energy equation for mathematical description. The following is the governing equation for this experiment.

According to the mathematical description, the differential equation of heat conduction is derived as follows:Take the $dxdydz$ micro-element,According to the law of conservation of energy, the increment of the energy of the micro-element in the unit time $cm\frac{\partial t}{\partial \tau} = c_p \rho dxdydz \frac{\partial t}{\partial \tau}$ .Unit heat, the heat generated by the heat source in the micro-element is $\dot{\phi} dxdydz$, and the law of conservation of energy is [5]:

$$\frac{\partial t}{\partial \tau} = a\nabla^2 t + \frac{Q}{c_p \rho} \tag{1}$$

$$\nabla^2 t = \frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} + \frac{\partial^2 t}{\partial z^2} \tag{2}$$

$$a = \frac{\lambda}{c_p \rho} \tag{3}$$

In the middle: t—Magnesia brick temperature;
τ—time;
a—Temperature coefficient;
x—The distance from the surface to the inside of the length of the magnesia brick;
y—The distance from the surface to the inside of the height direction of the magnesia brick;
z—The distance from the surface to the inside of the width direction of the magnesia brick;
λ—Thermal conductivity of magnesia brick;
ρ—Density of magnesia brick;
c_p—Specific heat capacity of magnesia brick;
Q—Heating power of the resistance wire;

The continuous equation for the instantaneous value of turbulence is [6]:

$$\frac{\partial \overline{\rho}}{\partial t} + \frac{\partial}{\partial x_i}\left(\overline{\rho}\,\overline{u_i} + \overline{\rho' u_i'}\right) = 0 \tag{4}$$

In combination with the motion of the incompressible turbulent fluid, the divergence of the average velocity and the divergence of the pulsation velocity are both zero.

$$\begin{gathered} \frac{\partial \overline{u_i}}{\partial x_i} = 0 \\ \frac{\partial u_i'}{\partial x_i} = 0 \end{gathered} \tag{5}$$

For the incompressible turbulence mean equation:

$$\frac{\partial}{\partial t}\left(\rho \overline{u_i}\right) + \frac{\partial}{\partial x_j}\left(\rho \overline{u_i}\,\overline{u_j}\right) = \rho F_i - \frac{\partial \overline{p}}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\overline{\tau_{ij}} * - \rho \overline{u_i' u_j'}\right) \tag{6}$$

$$\left[\overline{\tau}_{ij} *\right] = 2\mu\left[\overline{D}\right] + \lambda \nabla \overline{\vec{V}}\left[I\right] \tag{7}$$

$$[\overline{D}] = \left[\frac{\partial \overline{u_j}}{\partial x_i} + \frac{\partial \overline{u_i}}{\partial x_j}\right] \qquad \nabla \cdot \vec{\overline{V}} = \frac{\partial \overline{u_j}}{\partial x_j} \tag{8}$$

In the formula: $\frac{\partial}{\partial t}\left(\rho \overline{u_i}\right)$ is the local rate of change of the average momentum component; $\frac{\partial}{\partial x_j}\left(\rho \overline{u_i}\,\overline{u_j}\right)$ is the divergence of the average momentum flux; ρF_i is the average mass force component; $\frac{\partial \overline{p}}{\partial x_i}$ is the average pressure gradient; $\frac{\partial}{\partial x_j}\left(\overline{\tau_{ij}} *\right)$ is the divergence of the average viscous stress; $\frac{\partial}{\partial x_j}\left(-\rho \overline{u'_i u'_j}\right)$ is the divergence of the mean of the momentum flux pulsation.

The average energy equation of incompressible turbulent fluid in terms of enthalpy is:

$$\frac{\partial \rho \overline{h}}{\partial t} + \frac{\partial\left(\rho \overline{h}\,\overline{u_j}\right)}{\partial x_j} = \frac{\partial \overline{p}}{\partial t} + \overline{u_j}\frac{\partial \overline{p}}{\partial x_j} + \overline{u'_j \frac{\partial p'}{\partial x_j}} + \overline{\tau *_{ij}}\frac{\partial \overline{u_i}}{\partial x_j} + \overline{\tau *'_{ij}\frac{\partial u'_i}{\partial x_j}} + \frac{\partial}{\partial x_j}\left(-\rho \overline{h' u'_j} - \overline{q_j}\right) \tag{9}$$

Among them $\overline{\tau *'_{ij}\, u'_i}$ is a time average value of the pulsating viscous stress corresponding to the power of the pulsation speed. $-\rho \overline{h' u'_j}$ is the average value of the turbulent pulsation caused by the total turbulent flux and the static pulsating flux,and $\overline{u'_j \frac{\partial p'}{\partial x_j}}$ is a part of the pulsating pressure work caused by the pulsation speed.

Due to the technical application in actual engineering, the periodicity of heat storage and heat release of the heat storage brick, the temperature of the regenerator is set to 600~800 ℃. Since this experiment only studies the heat release problem of the regenerator, The initial environment during the exothermic process was chosen to be 667℃ at room temperature. In the calculation process, the time step is 360s, and the heat release time is 10h. Since the heat storage brick is adjusted after the heat storage, the electric power is heated at a power of 5043 W, and the relevant parameters are calculated for one of the bricks:

$$\text{Heat flux density q=}\frac{P}{S} = \frac{5043}{90 \times 2 \times 2 \times 3.14 \times 0.025 \times 0.2} \text{=892.25 w/m}^2 \tag{10}$$

Due to the addition of high-aluminum ceramic material, but the heat flow rate is unchanged, the heat exchange area changes, and the heat flow density changes.

$$\text{Heat flow Q=892.25×3.14×0.025×0.2=14.008 w} \tag{11}$$

$$\text{Changed heat flux density q=}\frac{14.008}{3.14 \times 0.02 \times 0.2} \text{=1115.3 w/m}^2 \tag{12}$$

Since the device Re is 40,000 ~ 160,000, it is forced convection heat transfer under turbulent flow. The fluid flow point is disordered under turbulent flow conditions, so the effect of natural convection due to temperature diff erence on the entire flow state is extremely weak and negligible. So the expression for the calculation formula is [7]:

$$\mathrm{Nu}=f（\mathrm{Re}，\mathrm{Pr}） \qquad （13）$$

The exact experimental formula is:

$$\mathrm{Nu}=0.023\mathrm{Re}^{0.8}\mathrm{Pr}^{0.4}=\frac{\alpha d}{\lambda} \qquad （14）$$

When the temperature is t=100°C, it is obtained by looking up the table.

$$\mathrm{Pr}=0.69，\lambda=3.19\times10^{-2}\mathrm{w/(m\cdot c)}，r=\frac{2A}{L}=29.69\mathrm{mm}，d=59.38\mathrm{mm}$$

By calculation, it can be calculated that when Re=40000, $\alpha=51.18\ \mathrm{w/(m^2\cdot ℃)}$

when Re=160000, $\alpha=155.136\mathrm{w/(m^2\cdot ℃)}$

B. Numerical Simulation

Since the heat accumulator is made up of several blocks of heat storage bricks according to a certain structure, each brick body has the same heat during storage and heat release, so it can be regarded as a part of the heat storage body, so one piece is taken. The modeling and analysis of the bricks shows that the process belongs to the non-steady state heat conduction with internal heat source. Since the boundary conditions of this experiment are the second type of boundary conditions and the wall heat flux density is constant. Therefore, the thermal conductivity, density, and specific heat capacity are all constant [8].The Ansys Workbench Geometry was used to model the monolithic regenerative bricks in three dimensions, and then imported into the Transient Thermal finite element software to simulate the temperature of the monolithic regenerator bricks. Since this experiment only studies the exothermic characteristics of the regenerator bricks, the simulation parameters are as follows. 2 is shown. The temperature distribution results of the heat storage brick device after 10 h of heat release at 5043 W were obtained. The simulation results are shown in Figure 5. It can be seen from the figure that during the exothermic process, the temperature of each point in the magnesia brick changes continuously with time. The temperature of the magnesia brick differs greatly from the ambient temperature at the beginning, and the temperature decline trend is obvious. With the increase of time, the temperature of the magnesia brick and The ambient temperature slowly approaches and the temperature decline is small. Finally, the steady state is achieved and the heat dissipation is relatively uniform. Because this experiment only studies the exothermic process of the regenerative bricks, when the heat is released, the load is changed under closed conditions, and the constant current power is reduced. Therefore, the heat flux density of the regenerative bricks becomes smaller, and the temperature decreases in the numerical simulation of the exothermic heat.

Table 2. Numerical simulation parameters of magnesia brick exotherm

Parameter name	Numerical value	Unit
Magnesia brick density	2900	$\mathrm{Kg\cdot m^{-3}}$
Magnesium brick specific heat capacity	1000	$\mathrm{J \bullet Kg^{-1}\cdot ℃^{-1}}$
Magnesium brick thermal conductivity	2.7	$\mathrm{W\cdot m^{-1}\cdot K^{-1}}$
Ceramic thermal conductivity	200	$\mathrm{W\cdot m^{-1}\cdot K^{-1}}$

Air thermal conductivity	0.0714	W·m^{-1}·K^{-1}
Air convection heat transfer coefficient	137	w/(m^2 • ℃)
Exothermic time	10	h
Time Step	360	s
Heat flux during heat release	5043	w/m^2

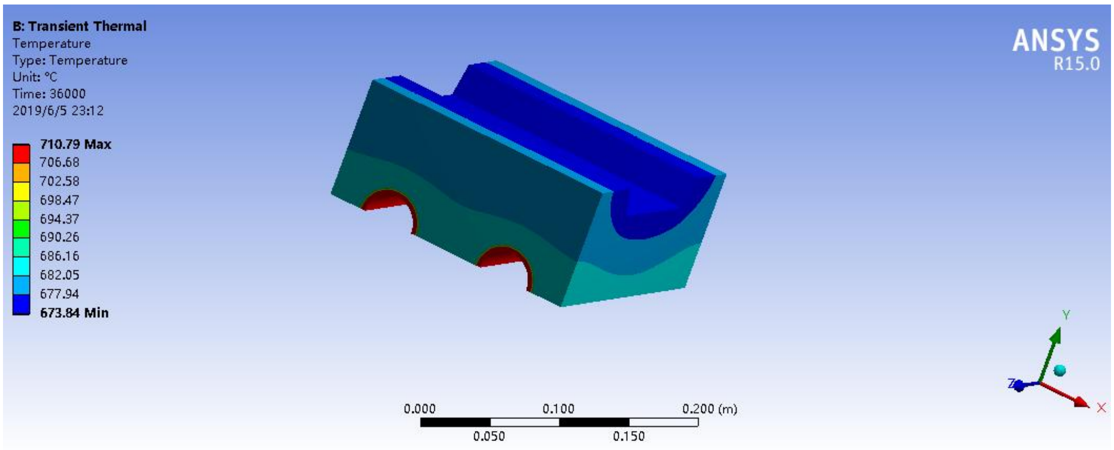
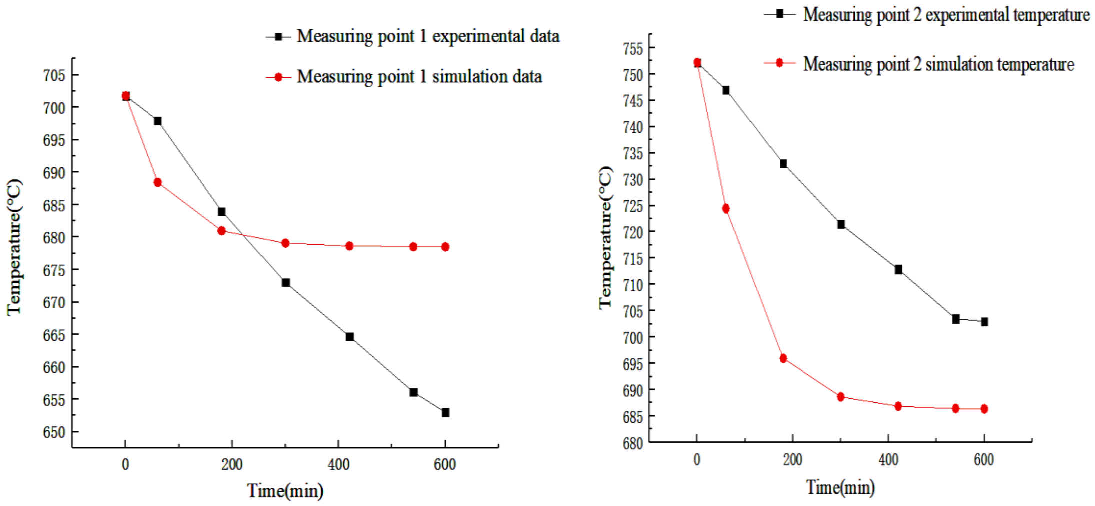


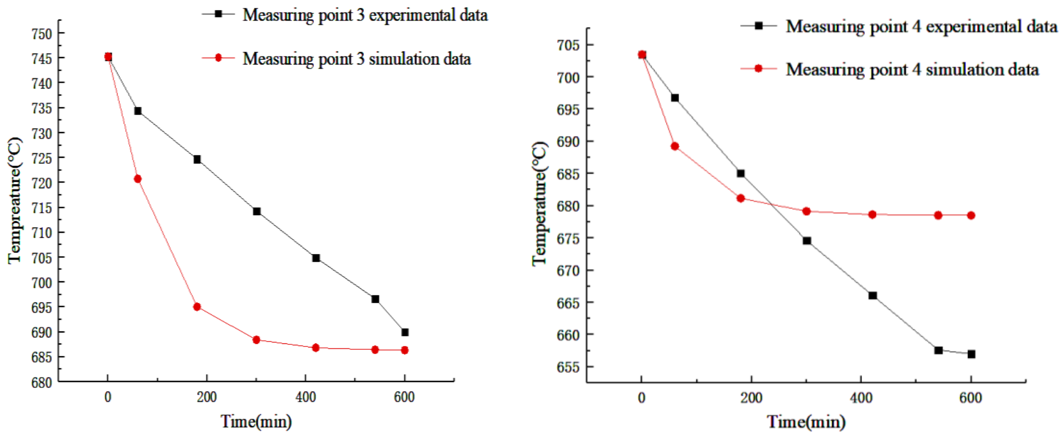
Fig.5. Temperature distribution after magnesia bricks exotherm for 10 h

IV. EXPERIMENTAL PROCEDURE

In order to verify the accuracy of ANSYS numerical simulation and verify the actual performance of the exothermic characteristics of the experimental magnesia brick, the solid electric regenerator furnace device (Fig. 1) was used to carry out the hollow furnace brick heating experiment, and the magnesium brick of Fig. 3 was closed and heated. At 8:00 am on the day of the experiment, according to the thermocouple, when the ambient temperature of the upper surface of the brick is 20, the solid heat storage device is heated at a constant power of 12996 w.



(a) (b)



(c) **(d)**

Fig.6.Magnesium brick exothermic 10 h experiment and numerical simulation comparison curve

At this time, the tuyere valve connected to the circulation fan passage is closed. The temperature of the regenerative brick is 22.2 from the measuring point 1, the initial temperature is 25.6 , the initial temperature is 42.3, and the initial temperature is 42.5. The load is up to 5043 w. At this time, the circulating fan and the air duct valve connected with the circulating fan are opened to carry out the convective heat exchange between the brick body and the air. After the heat release for 10 h, the temperature of the measuring point 1 of the brick body is 647.5, and the temperature of the measuring point 2 is 693.6, the temperature of the measuring point 3 is 687.2, and the temperature of the measuring point 4 is 647.9.According to the curve, the trend of the measuring point 1 and the measuring point 4, the measuring point 2 and the measuring point 3 are about the same. According to the distribution map of the measuring point, the connecting point of the measuring point 1 and the side point 4 and the heat source are symmetrically arranged at the center. 2 and the measuring point 3 and the heat source are axisymmetric, the distance between the two measuring points and the heat source is equal, the comparison curve measuring point 1 and the measuring point 4, the temperature difference between the measuring point 2 and the measuring point 3 is almost the same with time, and then It shows that the exothermic process of the magnesia brick in this experiment is uniform and stable inside the brick body. It can be seen from the curves of measuring point 1 and measuring point 4 that both of them are located relatively far away from the heat source. At 300~600 min, the experimental results show that the ambient temperature is quite different from the real brick body temperature due to the longer exothermic time. Therefore, the numerical simulation cooling trend is gradually stable. The measuring point 2 and the measuring point 3 are distributed at the heat source. The numerical simulation temperature setting value is unchanged, the initial temperature is higher, and the drop is more obvious. Therefore, the numerical simulation slows down at 0~200min. It can be seen from the comparison calculation that the error between the numerical simulation result and the experimental result is not more than 10%, which indicates that the numerical simulation result is correct.

V. CONCLUSION

(1) The ANSYS finite element method is used to simulate the exothermic process of solid heat storage bricks, and the temperature distribution of the regenerator bricks under different measuring points is obtained. The simulation results are consistent with the experimental results. The numerical simulation value and the experimental

measurement value are less than 10%. The results of numerical simulation have the advantages of high speed, high efficiency and good accuracy.

(2) The addition of the casing has no significant influence on the overall heat release performance of the magnesia brick. For the protection of the resistance wire, the "isolation" control of the resistance wire has a certain effect, which has certain advancement for further expanding the use of the magnesia brick regenerator effect.

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AUTHOR BIOGRAPHY

Zhao Di, born in 1996, Shenyang Institute of Engineering, Energy and Power Engineering, Currently studying for graduate students.

Wang Qimin, born in 1971, Tsinghua University, Energy and Power Engineering, Ph.D. Currently, Dean of the School of Energy and Power Engineering, Shenyang Institute of Engineering. Research direction: research mechanism of biomass boiler, low temperature pyrolysis gasification of domestic garbage.

Liu Jitang,born in 1965, Northeastern University, Thermal Engineering, Associate Professor.Currently,Teacher of the School of Energy and Power Engineering, Shenyang Institute of Engineering. Research direction: theoretical research and application technology development in the field of thermal engineering.