International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 241

SIMULTANEOUS CHARGING AND DISCHARGING PERFORMANCE OF A LATENT ENERGY STORAGE SYSTEM

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ABSTRACT

The performance of simultaneous charging and discharging process of a thermal energy storage system is experimentally investigated in this study. The microencapsulated phase change material (MEPCM) is used as the energy storage medium. The different combinations of the inlet cooling/heating water flow rates are adopted when the PCM in the ESU is initially in solid phase and melted, respectively. During the experiment, the system shows a high heat transfer rate between the cooling water and the heating water due to the thermal enhancement by the carbon fiber. The final states of the ESU are different under the same working condition with different initial states. The results of this experiment shows a great potential of the system in the practical application scenarios where the request of heat exchange and energy storage needs to be both satisfied.

Keywords: energy storage, simultaneous charging and discharging, MEPCM, heat transfer

NONMENCLATURE

α	mass fraction of MEPCM particles in ESU
β	mass fraction of PCM core in a particle
γ	mass fraction of carbon fiber in ESU
c_p	specific heat capacity (J kg^{-1}K^{-1})
h	latent heat capacity (J kg^{-1})
λ	thermal conductivity (W m^{-1} K^{-1})
P	power (W)
$\dot{m}$	mass flow rate (kg h^{-1})
T	temperature (°C)
ΔT	temperature difference (°C)
t	time (s)
E	calculated energy stored or release (J)
Subscript	
i	initial

1. INTRODUCTION

The increasingly serious energy issue and the environment problems make the development of the renewable and the sustainable energy resources more and more important. However, the new energy resources, such as the solar energy and the wind energy, are usually periodic and intermittent. Therefore, the thermal energy storage (TES) has been a key technology to balance the mismatch between the energy supplement and the demand [1]. The latent heat storage with the phase change material (PCM) as the storage medium can release/store a large amount of energy within a narrow temperature range, it is promising in energy storage application. But most of the organic PCMs have the inherent drawback of low thermal conductivity [2]. This drawback results in a slow heat transfer between the PCMs and the heat source/energy acceptor so the application of PCMs is limited.

The studies on the PCM usually focus on the method to enhance the heat transfer of PCM and the single melting/solidification process and the temperature variation of the PCM rather than the performance of the energy storage/release. Murray and Groulx [10] investigated a 2-tube cylindrical latent energy storage system with bulk PCM as the storage medium. The performance of the system as a heat exchanger is studied. But the results showed a poor heat exchange between the cooling fluid and the heating fluid due to the low thermal conductivity of the PCM.

In the previous work of the authors [11], a thermal enhanced MEPCM composite has been verified to have a high rate in heat transfer. Hence, it has a great potential in the TES system. In the current study, a TES system with this composite as the energy storage material is investigated during the simultaneous charging and

Selection and peer-review under responsibility of the scientific committee of the 11th Int. Conf. on Applied Energy (ICAE2019).

discharging process. The performance of the system as a heat exchanger is examined under various working conditions.

2. ENERGY STORAGE UNITS AND EXPERIMENTAL SYSTEM

2.1 Energy storage unit and the property

The energy storage unit (ESU) in this experiment is made of MEPCM composite. The fabrication method of this composite has been detailed introduced in the previous work [11]. As illustrated in Fig.1, it composes of MEPCM particles, carbon fiber and epoxy resin. As the main content of the energy storage, the MEPCM particles have the PCM cores of high-carbon paraffin and the shells of urea resin to protect the cores from leakage. The carbon fiber is selected as the heat transfer enhancer and the epoxy resin serves as the adhesive. The properties of the components are listed in Table 1.

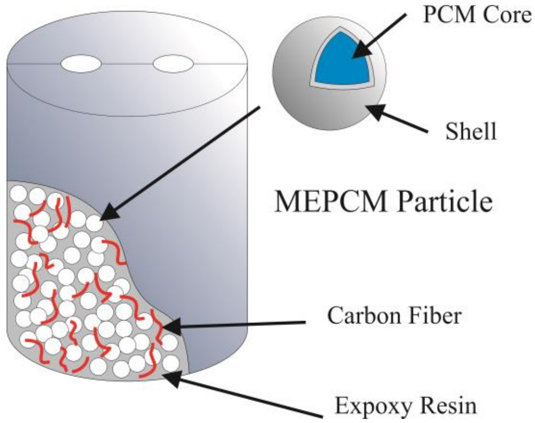


Fig. 1. Schematic diagram of MEPCM composite

Table 1. Properties of the additives

	c_p [J kg^{-1} K^{-1}]	h [kJ kg^{-1}]	λ [W m^{-1} K^{-1}]	Dimension	Note
high-carbon paraffin	2411	200 (50 ~ 60 °C)	0.214	D: 10 ~ 20 µm (MEPCM particle)	Core of MEPCM
urea resin	1674	/	0.227		Shell of MEPCM
carbon fiber	851	/	550	L: 6mm, D: 10 µm	Thermal enhancer
epoxy resin	1499	/	0.257	/	Adhesive

L-length, D-Diameter

The composite has 3 key parameters to describe the components. The mass fraction of MEPCM particles in the ESU is denoted as α. The value of α is 65% in this experiment. The mass fraction of PCM core in a single particle is denoted as β. Its value is 70%. And the mass fraction of carbon fiber is denoted as γ. The value of γ is 20%. So the specific heat capacity (c) and the specific latent heat capacity (h) of the ESU used in this experiment is calculated to be 1818 J kg^{-1} K^{-1} and 91000 J kg^{-1}, respectively.

The detailed dimensions of the ESU are presented in Fig.2. The total mass of the ESU is 2.57 kg. To facilitate the installation, the ESU is divided into 4 half cylinders. In the experiment, the tubes for the heat transfer fluid (water) are placed in the 2 holes with the diameter of 10 mm. Plane S and plane E are selected to arrange the temperature measurement points. To avoid the end effect, the locations of plane S and plane E are 50 mm from the water inlet side and the water outlet side, respectively. The points in the figure are the distribution of the measurement points. For the points in the lower part of the ESU, they are used to make sure the temperature is symmetric during the experiment. A series of holes with the diameter of 1.5 mm are drilled from the 2 ends of the ESU to the planes to place the sheathed thermocouples. The thermocouples have the same diameter with the holes to ensure a tight contact. And the thermal conductive silicone is used to reduce the contact thermal resistance between them. At the points of L5, M5 and R5, the normal thermocouples are fixed to detect the lateral surface temperature.

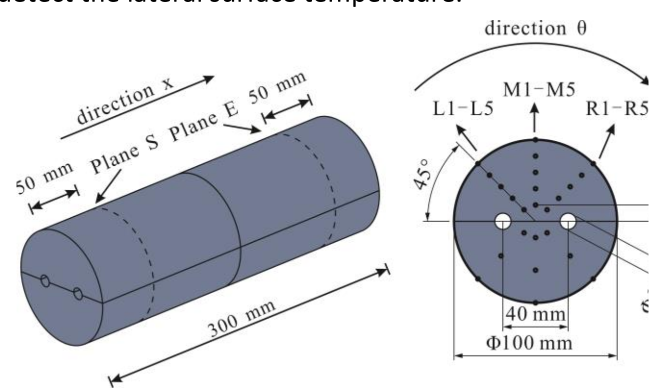


Fig. 2. Dimension of ESU and distribution of the points for temperature measurement

2.2 Experimental system

As shown in Fig. 3, the experimental system consist of the ESU with the thermal insulation and the acrylic shell, the heating/cooling circulation system and the data acquisition system.

The tubes for the water has a wall thickness of 1 mm. The outer diameter of them is the same with the holes. To reduce the contact thermal resistance, the thermal conductive silicone is also applied to fill the tiny air gaps between the tubes and the ESU. To reduce the heat loss, a 20 mm-thick thermal insulation material is used to enfold the ESU. The thermal conductivity of the material is 0.035 W $m^{-1}K^{-1}$. The temperature difference between the 2 sides of the thermal insulation is taken to assess the heat loss during the experiment. The ESU and the thermal insulation are supported by the acrylic shell.

The cooled water provided by the cooling circulation system can reach as low as 10 °C. And the power of the heating circulation is 4.5 kW to heat the water and 1.5 kW to maintain the water temperature in the tank. In the experiment, the cooling water and the heating water can be circulated to pass through the ESU at the same time. The flow rate is adjusted by the valves and monitored by the turbine flowmeters.

The temperature variations of the ESU and the inlet/outlet water are detected by the T-type thermocouples and recorded by a data acquisition apparatus (Model: Agilent 34972A, the U.S.) with a time interval of 60 s.

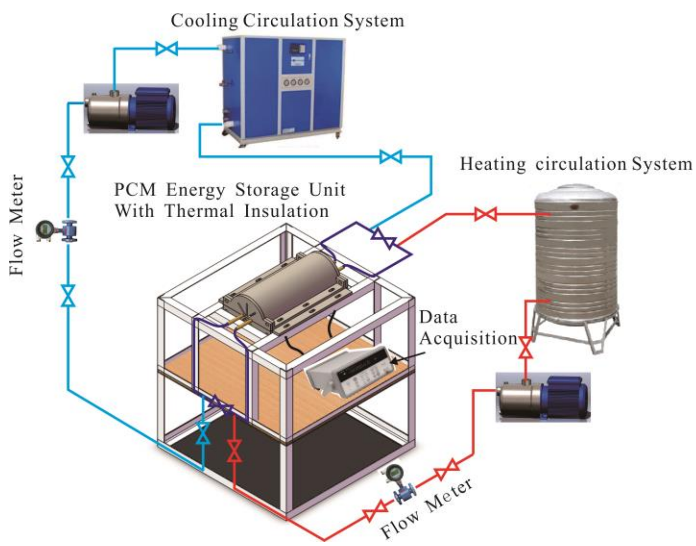


Fig. 3. Schematic diagram of the experimental system

3. THEORY

The power of the cooling/heating water is calculated with Eq.(1).

$$P_{input/output} = \dot{m} c_{p,\mathrm{water}} \Delta T \tag{1}$$

where $\dot{m}$ is the mass flow rate of the cooling/heating water, $c_{p,\mathrm{water}}$ is the thermal capacity of the water and ΔT is the temperature difference between the inlet and the outlet.

The net energy stored in or released from the ESU is the difference between the energy input and the energy output with the formula as below:

$$E_{net} = \sum \left| \left(P_{input} - P_{input} \right) \Delta t \right| \tag{2}$$

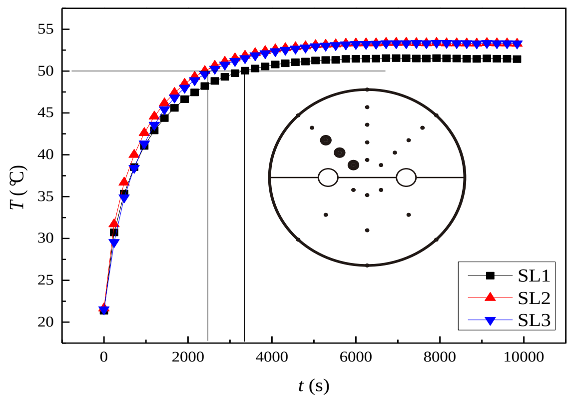
4. RESULTS AND DISCUSSION

4.1 Simultaneous charging/discharging with the PCM initially in solid phase

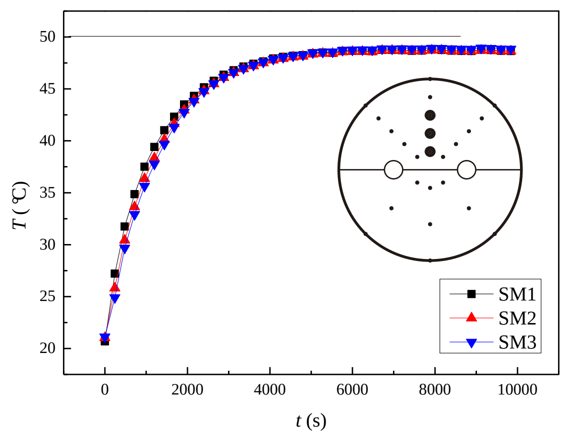
Experiments are performed to study the heat transfer of the system as a heat exchanger, which means the ESU is charged and discharged simultaneously. During the experiment, the heating water and the cooling water will individually flow through one tube at the same time. The PCM in the ESU is in solid phase with the initial temperature of 20 °C. The inlet temperature is 70 °C and 20 °C for the heating water and the cooling water, respectively. The flow rate is 100 kg/h for both the heating water and the cooling water.

Fig. 4 shows the temperature variation of plane S during the experiment. Since the carbon fiber enhances the heat transfer performance of the ESU, the temperature of the ESU increases rapidly even at the cooling water side. As the temperature increases, the rate of the temperature increase slows down. In Fig. 4(a), the temperatures of the points at the heating side exceed the melting point when they are stable. For SL2 and SL3, it needs about 2400 s to reach the melting point of PCM. While for SL1, the time needed is about 3300 s, since SL1 is more close to the cooling side. The stable temperature of SL1 is also lower than SL2 and SL3. In Fig. 4(b), the temperatures of SM1, SM2 and SM3 are all lower than the melting point when the temperatures are stable. Moreover, the temperatures of the 3 points are almost same in the steady state. This indicates that the heat transfer direction is vertical to the center line of the ESU. All the energy from the heating side is transferred to the cooling water. At the cooling side as shown in Fig.4(c), the temperature of SR1 is higher than SR2 and SR3, since it is closer to the heating side. Although the cooling water is 20 °C, the stable temperatures of the 3 points are still around 45 °C, which indicates a large local temperature gradient.

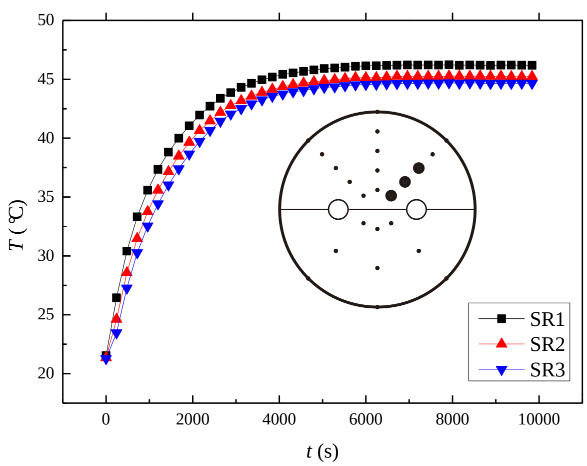
The variation of the cooling power and the heating power is shown in Fig.5. The net energy is the accumulation of the difference between the energy input and the energy output, which is calculated with Eq. (3). Due to the huge temperature difference between the heating water and the ESU in the beginning, most of the energy input is stored in the ESU. After a sharp increase, the rate of the energy accumulation decelerates distinctly after 2500 s because of the slowdown of the heating power and the increase of the cooling power. This indicates that the energy transferred between the cooling water and the heating water has been dominant instead of the energy storage. The heating power and the cooling power stabilize gradually around 57 W, which means the system reaches the steady state. The net energy is still increasing slowly due to the heat loss.



(a) Temperatures of SL1, SL2 and SL3 (heating side)



(b) Temperatures of SM1, SM2 and SM3



(c) Temperatures of SR1, SR2 and SR3 (cooling side)

Fig.4. Temperature variation during simultaneous charging and discharging (T_i=20°C)

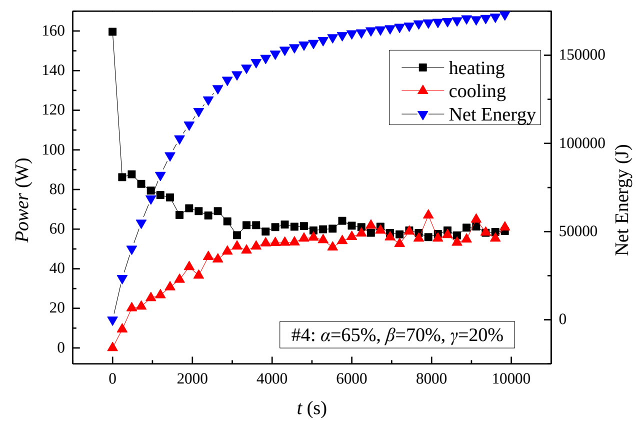


Fig. 5. Power of fluid and net energy input (T_i=20°C)

4.2 *Simultaneous charging/discharging with the PCM initially melted*

To study the influence of the initial temperature of the ESU, the experiment is conducted with the PCM initially melted. The ESU is initially heated and kept at 70 °C to make sure the PCM fully melted. The other working conditions are kept same with part 4.1.

Fig. 6 shows the variation of the cooling power, the heating power and the net energy released from the ESU. At the beginning, the energy is mainly released from the ESU to the cooling water. As the experiment proceeds, the ESU is gradually cooled down until the power of the heating water gets equal to the cooling power. The energy stored in the ESU is no longer released. Then the energy input is entirely conveyed to the cooling side. The power stabilizes at about 51 W. Since the thermal conductivity of the PCM will be changed during the phase transition process, the system may get different final states with different initial states.

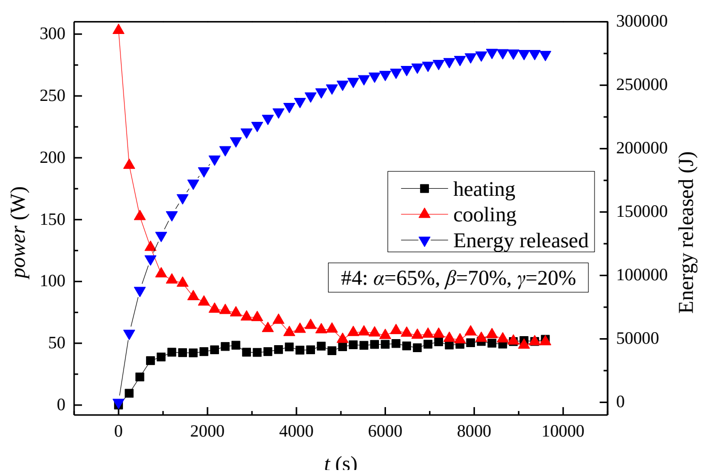


Fig. 6. Power of fluid and net energy released (T_0=70°C)

5. CONCLUSION

In this experiment, the simultaneous charging and discharging performance of a latent heat energy storage system is investigated with different initial states. The initial state of the ESU affects the final temperature field under the same working conditions. After the system functions in steady state, it shows a relatively high heat transfer rate between the cooling water and the heating water. The system has a great potential to be used as heat exchanger with energy storage.

ACKNOWLEDGEMENT

This work was supported by the National Key Research and Development Program of China (No. 2018YFF0216003).

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