# RESEARCH ON ENERGY STORAGE CHARACTERISTICS OF COMPOSITE PHASE CHANGE MATERIAL IN A HEATING TRANSFER SYSTEM

by

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*Aiming at the problems of lack of energy in undeveloped areas with low low-density residents and few heating users, and large heat loss, we propose a heating energy vehicle connected with mobile energy storage to assist the operation of district heating. Using paraffin-expanded graphite as the phase change material for energy storage, this paper studies the effect of expanded graphite on energy storage characteristics and finds that 10% expanded graphite can shorten the heat storage time and heat release time by 50% and 36.4%, respectively. Two economic operation modes are recommended for auxiliary district heating and synergetic coupling.*

Key words: *phase change, energy storage, mobile energy device, heating transfer*

## Introduction

With the improvement of China's comprehensive strength, the energy consumption required to supply residential heating and domestic hot water has been increasing rapidly, accounting for about 71% of the total energy consumption of residential buildings, which has led to an increasing appeal to efficient use of energy. Now the central heating system can meet the requirement of high heating load in regional users due to its high stability and continuity. However, for the energy-deficient and low-density residential areas in some undeveloped suburbs in China, the huge cost of laying pipelines over long distances has to be faced seriously. Although the use of small boilers for heating could effectively solve this problem, the fossil fuel emissions from boiler combustion will greatly exacerbate environmental problems. Alternatively, the solar heating system might be a potential solution to the problem, but it requires a higher investment cost than that of the central heating system, furthermore, it has intermittent and unstable characteristics, which cannot meet the continuous heating demand of the end heating users. In view of the rapid development of urban economic construction and the gradual improvement of residents' living standards, the reasonable allocation of heat sources, pipe networks, and comprehensive and effective use of energy is of great significance for improving the cleanliness of regional heating and reducing air pollutant emissions. With the progress of energy-efficient utilization research, a large amount of waste heat generated in the industry could be used as secondary energy waste heat. An economically feasible solution

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is to use mobile energy vehicles, which has certain advantages in solving the above problems in fewer pipelines and simpler energy storage from waste heat, and it can also solve the space and time mismatch between waste heat group and heat user group. In order to achieve the purpose of waste heat recovery, energy-saving, and emission reduction, it is one of the key technologies to realize the efficient connection of industrial energy-saving and building energy-saving, and it can replace the traditional fossil energy in undeveloped areas [1-3].

For a mobile energy vehicle, the phase change heat storage material is the main factor affecting its efficiency and effectiveness. As far as heat storage methods are considered, its heat storage density of latent heat storage is higher than that of sensible heat storage, furthermore, its heat storage and heat release are extremely stable and approximately isothermal, and the operation process is simple. Therefore, most scholars have conducted in-depth research on optimizing phase change heat storage devices and soliciting suitable phase change heat storage materials [4]. For example, Kurnia *et al.* [5] found that in the melting process and solidification process, the flower-shaped tube has the best heat transfer effect. Kamkari *et al.* [6] studied the influence of the installation angle of the rectangular heat accumulator on the heat transfer efficiency, and the results showed that the heat transfer efficiency is higher when placed horizontally. Chen *et al.* [7] proposed a cylindrical phase-change thermal storage vessel and conducted a heat transfer analysis on this structure. Karaipekli *et al.* [8] used the expanded perlite as the substrate and the decanoic acid-myristic acid eutectic as the phase change medium and obtained a shape stabilized phase change material with an absorption rate of up to 55 wt.%. Wang *et al.* [9] chose $Ba(OH)_2 \cdot 8H_2O$ as the heat storage material, and studied the influence of the initial and final temperature of the phase change material and the proportion of latent heat on the system exergy efficiency, and they found that a higher temperature difference between the beginning and the end of the change material increased leads to a higher heat storage capacity of the phase change material and a lower exergy efficiency. Xu *et al.* [10] added expanded graphite to paraffin, palmitic acid, and stearic acid to test the performance of composite phase change materials. The results showed that composite materials could shorten heat storage and heat release time. Wang *et al.* [11] used stearic acid and stearyl alcohol as main energy storage agents, nanozinc oxide and micron Cu as high thermal conductivity fillers, and expanded graphite as a porous matrix to prepare phase change heat storage materials, and they suggested a mixing mass ratio of 63.85:36.15:1.00:1.00:8.00 for practical applications.

At present, much work is focused on the optimization of the mobile thermal energy storage system or solicitation of low temperature phase change materials to obtain superior performance. However, there was little research on the actual heating demand of the lack of energy in the undeveloped areas with low-density residents. To this end, this paper is to study the influence of different proportions of expanded graphite in phase change material on heat storage and heat release performance.

## Auxiliary heating energy system

Mobile energy storage connected to heating energy vehicles is to assist district heating so that the indirect heat supply and demand contradiction during the peak heat consumption period can be effectively alle*via*ted, and the continuous and efficient supply of the entire heating system from the waste heat group to the user group can be guaranteed.

When the system is heated, the industrial waste heat from thermal power plants, cement plants, and coking plants is extracted and stored in the heat storage device in the energy vehicle through phase change materials. When heat is released, the mobile energy vehicle is to exchange heat with the end-users [12].

The heat circulation system is shown in fig. 1, where the heat source (excess heat or waste heat) is absorbed, and the absorbed heat can be released to the mobile energy vehicle, which can be transported the heat to the end-users.

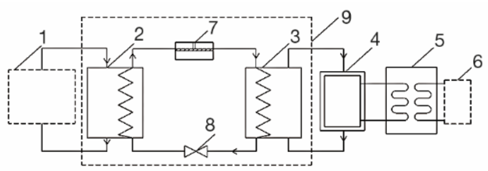


**Figure 1**. **Heat circulation system;** *1 – waste heat source, 2 – evaporator, 3 – condenser, 4 – mobile energy vehicle, 5 – plate heat exchanger, 6 – user, 7 – compressor, 8 – throttle valve, 9 – heat pump system*

Aiming at the energy shortage in undeveloped areas with low low-density residents and few heating users, we combine the heating demand of the heating users at the end of the system with the peak shaving operation and propose a heating energy vehicle to assist in district heating operation, which includes two emergency heating operations. The system could effectively configure district heating sources and pipe networks, rationally use and save energy, and maximize comprehensive energy utilization to meet the heating load demand of regional users. The combined heating system with auxiliary district heating and synergy is shown in fig. 2.

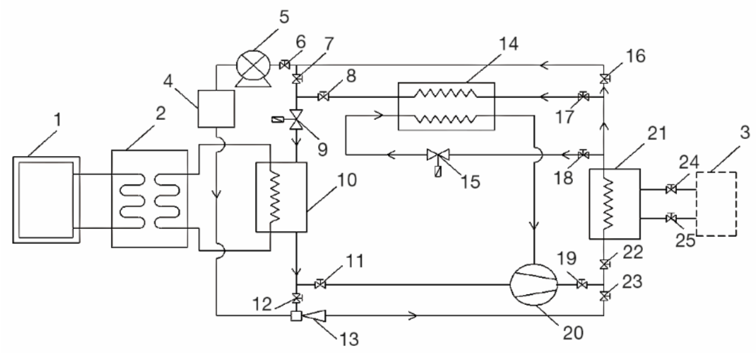


**Figure 2. Combined heating system with auxiliary district heating and synergy;** *1 – mobile energy vehicle, 2 – plate heat exchanger, 3 – user, 4 – generator, 5 – circulating pump, 6-8 – valve, 9 – throttle valve, 10 – evaporator, 11 and 12 – valve, 13 – ejector, 14 – economizer, 15 – throttle valve, 16-19 – valve, 20 – compressor, 21 – condenser, 22-25 – valve*

### *Emergency heating operation mode I*

When a large-scale heat supply is failed, or the main heating network can not be operated normally, the emergency heating operation mode I is used, the phase change heat released by the heat storage material in the mobile energy vehicle is absorbed and exchanged by the plate heat exchanger with the refrigerant in the evaporator. The refrigerant is compressed by the compressor into a high temperature and high pressure working medium, which is then entered into the condenser to release heat and exchange heat with the hot water supply pipe to realize heat supply.

The condensed refrigerant is divided into two paths: One path flows into the economizer to release heat, which is absorbed by the refrigerant in another path, and then flows through the throttle valve and the evaporator to complete the cycle. The other path enters the throttle valve for throttling and pressure reduction, and then flows into the economizer to absorb the heat released by the first path, and then mix with the first path in the compressor to complete the air supplement process. It can increase the circulation flow of the refrigerant and reduce the exhaust temperature of the system, which can ensure the stable operation of the heat pump unit in a low temperature environment where the outdoor temperature is not lower than –15 °C. The installed economizer allows the high-pressure liquid refrigerant from the condenser to obtain a greater degree of re-cooling, which greatly improves the operating efficiency of the system [13].

### *Emergency heating operation mode II*

When the system is operated at the peak period of heat consumption, and it is necessary to increase the heat supply of the heating network in a short period, this triggers the emergency heating operation mode II, the phase change heat released by the heat storage material in the mobile energy vehicle is absorbed and exchanged through the plate heat exchanger with the refrigerant in the evaporator. The refrigerant flowing out of the evaporator is boosted in the diffuser chamber of the ejector and becomes a high temperature and high-pressure refrigerant, which then flows into the condenser. The water pipe leading to the user can exchange heat with the condenser to provide heat to the user group. The high temperature and high-pressure refrigerant flowing out of the condenser improve the operating efficiency of the system [14].

## Heat storage characteristics of composite heat storage materials

In order to optimize the charging and discharging performance of the heat accumulator, we adjust the heat exchange tube bundle to both sides and the bottom so that the so-called heat storage dead zones can be avoided. The layout structure and size parameters are shown in fig. 3. The heat exchange tube has a diameter of 19 mm. About 15% of the space at the top of the heat storage device is reserved to prevent the thermal expansion of the phase change heat storage material.

In order to obtain accurate numerical simulation results during modeling, the following assumptions are made:

– The phase change material is isotropic and uniform.
– The shell of the heat storage device is regarded as an adiabatic wall without energy loss.
– Only the solid-liquid phase of the phase change heat storage material (paraffin-expanded graphite) is considered.

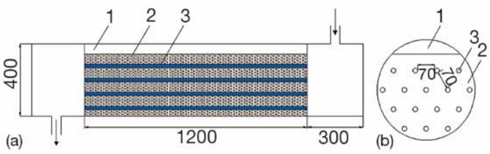


**Figure 3. Physical model diagram; (a) front view and (b) side view;** *1 – shell; 2 – heat storage material; 3 – heat exchange fluid*

In our experiment, phase change materials with different proportions of expanded graphite were used as the carrier [15], and the initial temperature of the heat storage material was 17 °C, the temperature of the inner wall of the heat exchange tube was 80 °C.

The temperature change curve of the pure paraffin and the composite phase change material in the heat storage device during the heat storage process was shown in fig. 4. The inlet temperature of the heat exchange fluid in the heat storage process was 80 °C. The temperature change curve of the pure paraffin and the composite phase change material in the heat storage device is shown in fig. 5. During the heat release, the inlet temperature of the cold fluid was 10 °C.

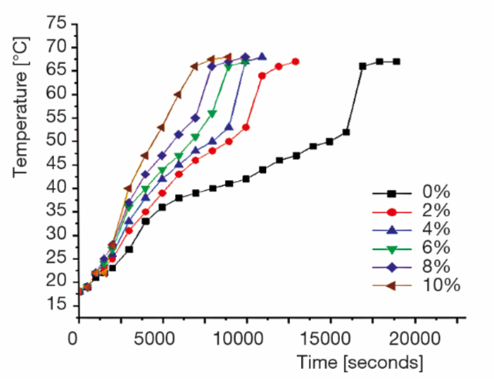


**Figure 4. The heat storage temperature of composite phase change material changed with time**

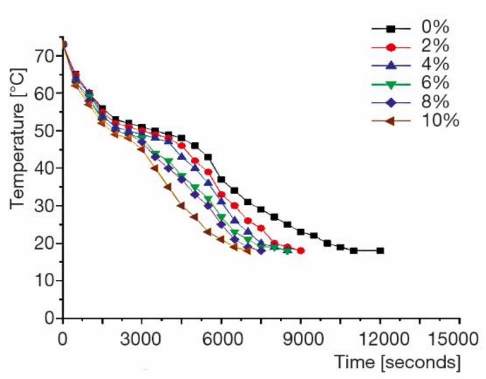


**Figure 5. The curve of heat release temperature of composite phase change material with time**

The phase change materials are widely used in battery cooling systems, thermal energy storage systems, and textile engineering. In heat storage, it could be seen from fig. 4 that before the phase change, the heat transfer was mainly conducted by heat conduction, and the temperature rose quickly. The temperature rise of pure paraffin was slow, and the temperature rise of composite materials was faster, and it was related to the content of expanded graphite added in the composite. As the mass percentage of expanded graphite increased, the heat storage period of composite phase change materials was shortened. When the content of expanded graphite was 2%, the heat storage time was shortened by 27.8% compared with pure paraffin. The heat storage time of 4%, 6%, 8%, and 10% expanded graphite were shortened by 38.8%, 44.4%, 47.2%, and 50%, respectively, than that of pure paraffin. The results showed that the thermal conductivity of the composite was gradually increased with the increase of the expanded graphite content. When the expanded graphite content was 10%, the thermal conductivity of the composite phase change material reached the maximum.

It could be seen from fig. 5 that in the early stage of heat release of the heat storage material, the temperature's drop curve of the heat storage material basically coincided, indicating that the added expanded graphite had little effect on convective heat transfer; in the middle of the exotherm, the temperature reduced slowly, the more the expanded graphite content, the faster the temperature drop, and the shorter the heat transfer time. When the content of expanded graphite was 10%, the temperature drop gradient was faster than other proportions of expanded graphite, the heat release time was the shortest, and it was 36.4% shorter than pure paraffin. In the late stage of heat release, when the temperature of the heat storage material reached a certain value, the heat exchange with cold water was stopped, and the heat release process ended.

## Conclusion

Aiming at the energy shortage in undeveloped areas with low-density residents, in this paper, we combine the heating demand of the heating users at the end of the system with the peak shaving operation mode analysis of the multi-energy complementary heating system, and proposes a mobile energy storage connected heating energy vehicle to assist district heating operation. The heat storage and heat release process of the composite phase change material was analyzed through simulation, and 10% expanded graphite can complete the heat storage and heat release process in the shortest cycle. Compared with pure paraffin, the heat storage and heat release times were shortened by 50% and 36.4%, respectively. It can effectively improve the energy storage efficiency of connected heating energy vehicles.

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