Research on Development and Encapsulation of Phase Change Energy Storage Materials

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Abstract. Phase change energy storage technology has the advantages of high heat storage density and constant temperature, and has great commercialization potential. The development of phase change materials is very important for the application of phase change energy storage technology. In order to solve the problems of poor heat transfer performance and easy leakage of phase change materials, extensive research has been carried out around the heat transfer and heat storage enhancement and encapsulation of phase change materials. The characteristics of thermal energy storage technology were compared, and the classification and properties of latent heat energy storage phase change materials were summarized. The research progress of heat transfer and heat storage enhancement is discussed from the aspects of increasing heat transfer area, increasing thermal conductivity, melting potential heat and specific heat capacity. The encapsulation of phase change materials is discussed, and the future development direction of phase change energy storage is prospected.

Keywords: heat transfer, phase change energy storage, thermal conductivity, phase change material, encapsulation

1. Introduction

Energy saving, consumption reduction and emission reduction have become the development goals of the energy field at this stage. The total installed capacity of new energy power generation, represented by wind power and photovoltaic power, has grown rapidly. However, the impact of the volatility of new energy power generation on the power grid has also led to a large area of wind and light abandonment. Based on this, energy storage technology coupled with new energy power generation has received extensive attention in recent years. Energy storage refers to the process of storing energy in some form through media or equipment and releasing it in a specific form when needed. Energy storage can be divided into sensible heat storage, phase change storage and thermochemical storage [1].

The market development potential of thermal energy storage is huge. In 2020, the installed capacity of the global thermal energy storage system is about 234GW·h. According to the International Renewable Energy Agency, global thermal energy storage scale will triple by 2030 [2]. In order to further improve the efficiency of energy storage system, different research institutions have carried out a lot of research work on the development of various energy storage materials and related technologies, especially in the development and encapsulation of phase change energy storage materials have made important progress[3-5].

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2. Energy storage technology

Energy storage refers to the technology of storing energy in a specific medium and converting it into electricity or other forms of energy when needed. Comparison of the characteristics of sensible heat energy storage, phase change energy storage and thermochemical energy storage materials is shown in Table 1.

Table 1. Characteristics of the materials for energy storage

	Sensible heat energy storage	Phase change energy storage	Thermochemical energy storage
Energy storage materials	Gravel, soil, water	Paraffin wax, fatty acids, polyols, esters, alkanes, ice, crystalline hydration salts, metal alloys, molten salts, etc.	Metal hydrides, oxides, hydroxides, peroxides, carbonates, sulfates, etc.
Volume heat storage density /(kW·h)·m^{-3})	50	100	500
Mass heat storage density/(kW·h)·m^{-3})	0.02-0.03	0.05-0.10	0.50-1.00
Energy storage scale /MW	0.001-10.000	0.001-1.000	0.01-1.00
Energy storage cycle	Days	Weeks	Long term (months)
Cost /(Yuan(kW·h)$^{-1}$)	0.8-79.0	79.0-390.0	63.0-780.0
Transmission distance	Short distance	Short distance	Theoretically infinite
Technology maturity	Industrial application	Pilot test	Laboratory research
Technical difficulty	Easy	Medium	Complex

3. Phase change materials

Phase change materials refer to latent heat storage materials that undergo physical phase change at a certain temperature to achieve energy storage and release. Phase change temperature, latent heat, specific heat capacity and thermal conductivity are important properties of phase change materials. *P*hase change temperature determines the application scenario of phase change energy storage. Typical phase change material properties are shown in Table 2.

Table 2. Properties of typical phase change materials

Phase change materials	Thermal conductivity/(W·(m·K)$^{-1}$)	Phase transition temperature/°C	Latent heat/(J·g^{-1})	Literature
RT10 paraffin	0.200	9.0	134.90	[1]
A16 paraffin	0.180	15.0-17.0	213.00	[2]
$CaCl_2·6H_2O$	---	30.0	187.49	[2]

$Na_2SO_4 \cdot 10H_2O$	0.700	32.4	241.00	[2]
$Ba(OH)_2 \cdot 8H_2O$	1.255	78.0	266.00	[3]
65% capric acid + 35% lauric acid	0.143	18.0	140.80	[4]
36% stearic acid +64% palmitic acid	0.288	40.0-65.0	---	[5]
$NaNO_3$	0.580	306.0	182.00	[6]
Na_2NO_3	2.000	854.0	275.70	[6]

4. Heat transfer and heat storage enhancement technology

Most phase change materials have the problems of low thermal conductivity and poor heat transfer performance. Based on this, scholars have enhanced heat transfer and storage in a variety of ways.

4.1 Increase the heat transfer area

Increasing the heat transfer area between the phase change material and the heat transfer fluid is one of the main methods to enhance the heat transfer of the phase change energy storage material. With the increase of heat transfer area, heat flow will increase, thus improving heat transfer rate. It is a common method to add metal fins with good thermal conductivity. The shapes of fins include rectangle, Y shape, snowflake shape, wheel shape, triangle, tree shape and so on. Cagatay [7] studied the natural convection heat transfer of molten salt phase change materials in rectangular fins and fractal fins rectangular containers. They found that natural convection heat transfer effect of the two finned structures was significantly enhanced. The simulation results show that natural convection heat transfer effect can be improved by up to 20%. Fan [8] compared the melting process of phase change materials in light tubes, flat finned tubes and Y-type longitudinal finned tubes. The results showed that Y-type finned tubes significantly increased heat transfer area, so enhanced heat transfer effect was the best. Wu [9] showed that tree-shaped fins could significantly shorten the solidification time.

4.2 Improve thermal conductivity

In order to reduce the time and temperature difference of heat energy storage and release in phase change energy storage system and improve the efficiency of phase change energy storage system, it is an effective way to improve thermal conductivity of phase change materials. The main method to improve thermal conductivity is to add high thermal conductivity and small size materials to form composite phase change materials [10]. See Table 3 for the effect of the addition of high thermal conductivity materials on the thermal conductivity of phase change materials.

Table 3. Effect of high thermal conductivity materials on thermal conductivity of phase change materials

Phase change materials	Thermal conductivity/$(W \cdot (m \cdot K)^{-1})$	high thermal conductivity materials	Thermal conductivity of composite phase change materials /$(W \cdot (m \cdot K)^{-1})$	Literature
Paraffin wax	0.250	Aluminum foam	2.480	[11]

Paraffin wax	0.250	Nano Fe_3O_4	0.400	[12]
Palmitic acid	---	Nano TiO_2	0.350	[13]
Stearic acid	0.260	Expanded graphite	0.750-3.560	[14]
$Ca(NO_3)_2$-$NaNO_3$	0.681	Expanded graphite	5.660	[15]
$LiNO_3$-KCl	0.930	Expanded graphite	5.590	[16]
$LiNO_3$-NaCl	0.800	Expanded graphite	4.710	[16]
NaCl-$CaCl_2$-$MgCl_2$	1.174	Expanded graphite	2.084	[17]

4.3 Increase latent heat of melting

Latent heat of melting is an important performance parameter of phase change materials, which determines the capacity of latent heat storage. In general, latent heat of phase change materials is reduced when a higher proportion of metal-based materials is added. Jiang [18] reported that latent heat of paraffin wax and stearic acid decreased from 141J/g and 140J/g to 72.9J/g and 66.7J/g, respectively, after adding aluminum foam. Warzoha [19] found that after mixing multi-walled carbon nanotubes, Al or TiO_2 with a volume fraction of 20% in paraffin to make a nanocomposite phase change material, latent heat of melting was reduced by about 15% to 17% compared with pure paraffin; however, When graphene nanoparticles with a volume fraction of 20% are incorporated, latent heat of melting could be increased by about 11%.

4.4 Improve specific heat capacity

In order to further increase energy storage capacity of phase change material, sensible heat of material during heat storage process can also be increased, that is, the specific heat capacity of material can be increased. Shin [20] showed that the specific heat capacity of material was increased by 14.5% by adding 1% SiO_2 nanoparticles with a diameter of 20nm-30nm to the alkali metal chloride salt eutectic nanofluid.

5. Encapsulation technology

In order to solve the leakage problem of phase change materials, it is necessary to encapsulate phase change materials in certain matrix materials. According to the size of encapsulated phase change material, encapsulated phase change material is divided into macroscopic (> 1mm), microscopic (1-1000μm) and nano-encapsulation (0-1000nm). According to encapsulation method, it can also be divided into capsule encapsulation and porous skeleton encapsulation [21].

5.1 Macro encapsulation

Macro encapsulation is a common encapsulation method in phase change energy storage applications. Encapsulation containers can be spherical, tubular, cylindrical, or rectangular in shape. The most commonly used encapsulation material is usually plastic. When high thermal conductivity is required, metal encapsulation is required. It should be noted that the selection of encapsulation materials also needs to consider its compatibility with phase change materials.

A variety of macro- encapsulation materials have been reported at this stage, among which tin-plated food cans and plastic bottles are the cheapest macro- encapsulation containers. Sari [22] prepared paraffin/high density polyethylene (HDPE) composite material as solid-liquid phase variable energy storage material. Cai [23] used twin-screw extruder technology to prepare HDPE, paraffin, organic montmorillonite and expansion flame retardants into stable phase change materials. Chen et al. [24] directly synthesized a series of new morphologically stable paraffin-based/polyurethane composites with high latent heat and wide phase transition temperature range (20~65 °C) by bulk polymerization method.

5.2 Microscopic encapsulation

Microencapsulated phase change materials, whose size is less than 1000μm, are also called microencapsulated phase change materials, which have higher heat transfer rate than macroscopic encapsulated phase change materials, but it is also more difficult to make. Microcapsule phase change materials have very high specific surface area and can withstand volume changes during phase change. High heat transfer rate enables rapid melting and solidification. In terms of thermal and chemical stability, microencapsulated phase change materials are more reliable than macroscopic encapsulation. However, microencapsulated phase change materials may lead to increased undercooling, allowing phase change material to remain liquid even below freezing point. Therefore, nucleating agents need to be added to prevent undercooling [25].

5.3 Nano encapsulation

When material size is reduced to less than 1000nm after encapsulation, nanocapsulated phase change materials are obtained [26]. Compared with macroscopic and microscopic encapsulation, nanocapsules are more structurally stable and have great potential in thermal energy storage applications [27]. Sari [28] synthesized micro/nano-capsule phase change materials of polystyrene/tetracycline-octadecane eutectic mixture by emulsion polymerization.

5.4 Porous skeleton encapsulation

Porous skeleton encapsulation refers to the use of porous media with large specific surface area as the skeleton carrier material, and the capillary force and surface adsorption effect are used to imprison the liquid phase change material in the pores. Commonly used porous media include expanded graphite, porous SiO_2, aerogel, ceramics, metal foam, diatomite, expanded perlite and so on [29].

4. Conclusion

This paper focuses on the research progress of heat transfer enhancement and encapsulation of phase change materials in phase change energy storage systems. Scholars have carried out a series of studies on heat transfer enhancement of phase change materials in terms of increasing heat transfer area, increasing thermal conductivity, increasing latent heat of melting and increasing specific heat capacity, thus improving heat transfer performance of phase change materials. In addition, the effects of various encapsulation techniques to solve the problem of material leakage during phase change process are introduced. It is pointed out that the use of materials with high thermal conductivity can simultaneously realize heat transfer enhancement and encapsulation of phase change materials, which is an important development direction in the future. In the future, the stability and thermal conductivity of phase change materials need to be further optimized to realize the commercial application of new phase change materials.

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