Effects of Dopamine-Modified and Organic Intercalation on the Thermophysical Properties of Octadecane/Expanded Vermiculite Composite Phase Change Materials

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Cite This: ACS Omega 2022, 7, 13538–13545

ABSTRACT: For phase change materials (PCMs) confined in porous structure, the interface interaction between the PCM and the porous skeleton is the key factor to determine the thermal storage performance of PCM. In this study, the modified expanded vermiculite (EVM) was prepared by dopamine modification and DTA+ intercalation method and a series of EVM-based composite phase change materials with form shape (fs-CPCMs) were prepared by physical impregnation using n-octadecane as PCMs. The heat storage performance of the composite phase change materials were improved obviously, and the encapsulation ratio is increased to 84.7% and 83.1%. The nonisothermal crystallization process of prepared composite phase change material were further studied. The effects of dopamine modification and organic intercalation on the encapsulation performance of EVM-based fs-CPCMs were analyzed. The results of XRD, FT-IR, thermal cycle, and TGA tests showed that EVM-based composite phase change materials had good chemical compatibility, thermal reliability, and thermal stability. This study provides a theoretical basis for the preparation of EVM-based fs-CPCMs with high thermal stability and good heat storage performance.

INTRODUCTION

Latent heat storage is an important way of thermal energy storage, which is based on the excellent heat storage and release performance of phase change materials (PCMs).¹,² PCMs are mainly divided into inorganic PCMs, organic PCMs and eutectic PCMs.³ Compared with the inorganic and eutectic PCMs,¹ organic PCMs are attracting more and more attention because of the advantages of low supercooling, good stability, and high heat storage density.⁴ Among a large number of organic PCMs, n-octadecane, as a solid—liquid low-temperature organic PCM, has been widely studied and applied in the different fields because of good stability, high energy storage density, suitable phase change temperature range, and no supercooling phenomenon.⁵,⁶

However, the leakage of solid—liquid PCMs is a key problem that seriously limits its practical application.⁷ In order to solve this problem, porous substrate encapsulation, microencapsulation, polymer molding, and inorganic nanocomposite were adopted.⁷,⁸ Among them, the encapsulation of phase change materials into porous material carrier to form composite phase change materials with stable shape (ss-CPCMs) is a simple and effective means.⁹

Natural clay porous minerals are commonly used as porous packaging substrates because of their good chemical stability, unique lamellar pore structure, high specific surface area and low cost, which mainly includes diatomite, expanded vermiculite, and expanded perlite. Among them, expanded vermiculite (EVM), as a typical porous clay mineral, could effectively adsorb phase change materials because of its abundant pore structure, high specific surface area, good thermal and chemical stability, and other significant energy storage characteristics. Moreover, it is low cost, easy to obtain, and environmentally friendly, so EVM has become a research hotspot.¹⁰,¹¹ Guan et al.¹² prepare paraffin/expanded vermiculite with the 53.2 wt % encapsulation ratio and a latent heat of 103 J/g. Deng et al.¹³ studied the polyethylene glycol/expanded vermiculite composite phase change material with the maximum encapsulation capacity of PEG in EVM was 66.1 wt %. Wen et al.¹⁴ synthesized a lauric acid/expanded vermiculite composite phase change material with a 70 wt % encapsulation ratio and a latent heat of 126.8 J/g. Obviously, when EVM was directly used to package organic PCMs, the
encapsulation ratio was unsatisfactory, thus limiting the thermal storage performance (<130 J/g).

The phase transformation process of PCM encapsulated in a porous structure is incomplete because of the surface interaction of the porous material matrix or pore size limitation. At present, the limiting factors of the encapsulated matrix on the phase transformation behavior of organic phase change materials are not clear, and there are few studies on the improvement of these limiting factors. Because this phenomenon is caused by the influence of the packaging matrix, it is important to study whether the modification of packaging matrix can restrain or eliminate this negative effect. The surface properties of porous minerals are one of the main factors influencing the phase change material phase change behavior, through proper surface function design, can achieve the controllable phase transition behavior of phase change materials, thus improving heat and heat storage properties of phase change materials. The study on the limitation factors offers an insight into the improvements in the heat storage and release behaviors of PCMs as well as the increase in its application values. In addition, it is of theoretical significance in the preparation of composite PCMs with high heat storage capacity.

The modified EVM was prepared by dopamine modification and the DTA + intercalation method, and then, a series of EVM-based composite phase change materials with different fractions (fs-CPCMs) were prepared by physical impregnation using n-octadecane as PCMs. The heat storage performance of the composite PCMs were improved obviously, and the encapsulation ratio is increased to 84.7% and 83.1%. The nonisothermal crystallization process of prepared composite phase change materials were further studied. The effects of dopamine modification and organic intercalation on the encapsulation performance of EVM-based fs-CPCMs were analyzed. The results of XRD, FT-IR, thermal cycle, and TGA tests showed that EVM-based composite phase change materials had good chemical compatibility, thermal reliability, and thermal stability. This study provides a theoretical basis for the preparation of EVM-based fs-CPCMs with high thermal stability and good heat storage performance.

2. EXPERIMENTAL SECTION

2.1. Materials. Octadecane was obtained from China National Medicines Co., Ltd. EVM was purchased from Lingshou County, Shijiazhuang City, Hebei Province, China. Dopamine hydrochloride was purchased from Sigma-Aldrich. Dodecyltrimethylammonium bromide (DTAB, 99%) was obtained from China National Medicines Co., Ltd. EVM was purchased from Lingshou County, Shijiazhuang City, Hebei Province, China. Dodecyltrimethylammonium bromide (DTAB, 99%) was obtained from China National Medicines Co., Ltd.

2.2. Preparation of D-EVM, D-O-EVM, and EVM-Based fs-CPCMs. The EVM modification process is shown in Figure 1a. First, the pretreated EVM and 200 mL of dopamine hydrochloride solution (4.0 g/L) were put into a 500 mL filter bottle with a vacuum of 0.05 MPa and soaked at 25 °C for 3.5 h. Then the samples were separated and dried in an oven at 80 °C for 2 h to obtain D-EVM. D-EVM was mixed with DTAB solution (20 g/L) and then placed in a water bath, heated, and stirred at 65 °C for 2 h. The samples were continuously washed with deionized water until there was no bromine left. After the procedure was repeated three times, dopamine modified organic intercalated expanded vermiculite (D-O-EVM) was obtained.

In the second step (Figure 1b), EVM-based fs-CPCMs was prepared by a simple physical impregnation method with n-octadecane as the PCM. The sufficient octadecane, EVM, and modified EVM was mixed and heated at 80 °C for 2 h. Then, the impregnated EVM-based fs-CPCMs was transferred to filter paper heated to 80 °C, and the filter paper was constantly changed to remove the leaky octadecane until there was no trace of liquid leakage. Finally, the EVM-based fs-CPCMs were obtained.

2.3. Characterization. The structure and morphology of EVM and modified EVM were investigated by SEM (JSM-IT300), FT-IR (Nicolet IS10, 4000–400 cm⁻¹) and XRD (Rigaku DMAX 2400, 10.0°/min) tests were used to study the chemical stability of the composite phase change material. The pore structure and distribution obtained from the mercury intrusion porosimetry (AutoPore IV 9500 Version 2.03.01) and BET. Differential scanning calorimeter (DSC, NETZSCH214, 0–80 °C) was used to test the thermal properties of octadecane and EVM-based fs-CPCMs at a thermal treatment rate of 5, 6, 7, 8 °C/min in a N₂ atmosphere. Thermo gravimetric analysis (TGA, NETZSCH STA449F5, heating rate: 20 °C/min, N₂) was used to test the weight loss.

3. RESULTS AND DISCUSSION

3.1. Pore Distribution and Encapsulation Mass Fractions of EVM and Modified EVMs. The pore size distribution of EVM, D-EVM, and D-O-EVM was investigated by SEM, and the EVM-based fs-CPCMs was prepared by physical impregnation method with n-octadecane as the PCM. The sufficient octadecane, EVM, and modified EVM was mixed and heated at 80 °C for 2 h. Then, the impregnated EVM-based fs-CPCMs was transferred to filter paper heated to 80 °C, and the filter paper was constantly changed to remove the leaky octadecane until there was no trace of liquid leakage. Finally, the EVM-based fs-CPCMs were obtained.

Figure 2. Pore distribution and porosity of EVM, D-EVM, and D-O-EVM.
distribution and main pore parameters of EVM, D-EVM, and D-O-EVM are shown in Figure 2. The average pore diameter, pore volume, and porosity of EVM were 1.12 μm, 4.29 mL/g, and 89.8%, respectively. Compared with EVM, the average pore diameters of D-EVM and D-O-EVM were increased, which might be interpreted as follows: The amination modification results in a weak hydrogen bond between dopamine terminal and EVM (O−H···N and N−H···O), which leads to the reduction of van der Waals forces between the layers of EVM, thus increasing the average pore diameter (1.24 μm) and porosity (82.56%) of D-EVM. The interlayer force between DTA⁺ and EVM produced by organic intercalation further increased the pore size (1.48 μm), but the space occupation of DTA⁺ slightly reduced the pore volume (3.41 mL/g) and porosity (79.5%) of D-O-EVM.

The encapsulation rate (φ) that determines the heat storage capacity is defined as eqs 1:

$$φ = \frac{(M_{f-CPCMs} - M_{Matrix})}{M_{f-CPCMs}}$$

where $M_{f-CPCMs}$ and $M_{Matrix}$ respectively, represent the weight of EVM-based fs-CPCMs and the corresponding weight of EVM and modified EVMs. The experimental encapsulation rates (φ) were determined for Od/EVM, Od/D-EVM, and Od/D-O-EVM.

It was found that the dopamine modification and organic intercalation were beneficial for the increase in encapsulation capacity, which might be attributed to the amination modification restricting the spillover of octadecane molecules from the surfaces of EVMs, and the organic intercalation might increase the amount of interlayer charge and the affinity with organic PCMs, thus enhancing the package effect of octadecane (Table 1).

### 3.2. Microstructure and Morphology Analysis

The surface morphology of EVMs before and after modification and EVM-based composite phase change materials is shown in Figure 3. Obviously, EVM exhibited anisotropy nonuniform layer pore structure, which provided numerous micron-scale pores space for octadecane. After encapsulation, the pore structure and surface of EVM were largely occupied by octadecane. EVM modified by dopamine and DTA⁺ showed similar morphology to EVM, indicating that modification did not significantly change the morphology of EVM, which is an important prerequisite for maintaining high encapsulation ability. EDX mapping results of N element (Figure 3d) reflected the uniform distribution of dopamine on EVM surface, which is conducive to the binding of dopamine, EVM, and octadecane functional groups, thus facilitating the phase change behavior and heat storage properties of octadecane by

|                | total intrusion volume | average pore diameter | porosity | φ   |
|----------------|-----------------------|-----------------------|----------|-----|
| EVM            | 4.29                  | 1.12                  | 89.8     | 70.5% |
| D-EVM          | 4.06                  | 1.24                  | 92.1     | 84.7% |
| D-O-EVM        | 3.41                  | 1.48                  | 79.5     | 83.1% |

![Figure 3](https://doi.org/10.1021/acsomega.1c06815)
constructing appropriate combinatorial interactions. In addition, the good affinity between DTA+ and octadecane in the layers also had a positive effect on octadecane encapsulation in the pores.

3.3. Chemical Stability Analysis. Good chemical compatibility between PCM and packaging substrate is a necessary condition to maintain high heat storage. XRD and FT-IR spectra of octadecane, EVMs before and after modification, and EVM-based composite phase change materials are shown in Figure 4, which demonstrate the chemical stability of their composite phase change materials.

Obviously, the characteristic diffraction peaks of octadecane (2θ = 4°, 8°, 12°, 23°) and EVM (2θ = 9°, 27°, 28°) could be observed in the XRD spectrum of fs-CPCMs, indicating that the octadecane confined in the EVM-based encapsulation carrier was still in the crystalline state, which ensures the good heat storage capacity of the fs-CPCMs. Both dopamine modification and organic intercalation increased the d value but did not damage the typical pore structure of EVM. No new reaction was observed, indicating that only physical changes occur for the octadecane and EVM-based encapsulation carrier.

In the infrared spectrum of EVM, the peak values at 457, 997, and 3428 cm⁻¹ were Si–O–Mg bending vibration, Si–O–Si and Si–O–Al stretching vibration, and O–H stretching vibration, respectively. After dopamine modification, the characteristic absorption peaks of D-EVM roughly coincide with EVM. The peaks at 2920 and 2851 cm⁻¹ of the spectra D-O-EVM were ascribed to the stretching vibration of the C–H bond in DTA+, demonstrating that organic intercalation had been successfully performed in D-O-EVM. The characteristic absorption peaks of octadecane were 841, 1107, 1241, 1280, 1342, 1466, 2888, and 3425 cm⁻¹, which are attributed to the oscillation-group of the interim-CH₂, cutting stretching vibration of –CH, bending vibration of –CH₂, C–H stretching vibration, and O–H stretching vibration, respectively. After octadecane was encapsulated into EVM-based encapsulation carrier, the spectra of composite phase change materials was from the absorption peaks of octadecane and EVMs, and no new functional group was discovered, indicating that physical action rather than chemical interaction occurred between octadecane and EVMs, which further illustrated that the prepared fs-CPCMs showed desirable chemical compatibility.

3.4. Analysis of the Thermal Energy Storage. The DSC curves of octadecane and fs-CPCMs are shown in Figure 5. To ensure accuracy, each sample was tested three times and averaged. The relevant parameters are summarized in Table 2.

As shown in Figure 5, the DSC curves of octadecane’s three measurements almost coincide, with obvious endothermic and exothermic peaks, indicating that octadecane, as a PCM, has good heat storage characteristic. Octadecane, as a PCM, has good heat storage characteristic. After octadecane was encapsulated into EVM-based encapsulation carrier, the spectra of composite phase change materials was from the absorption peaks of octadecane and EVMs, and no new functional group was discovered, indicating that physical action rather than chemical interaction occurred between octadecane and EVMs, which further illustrated that the prepared fs-CPCMs showed desirable chemical compatibility.

Table 2. Phase Change Parameters of Octadecane and EVM-Based fs-CPCMs

| samples         | melting process | solidification process |
|-----------------|-----------------|------------------------|
|                 | T_M (°C) | H_M (J/g) | H̅_M (J/g) | T_S (°C) | H_S (J/g) | H̅_S (J/g) |
| octadecane      | 32.9     | 229.2   | 227.2     | 19.3     | 236.8     | 237.9      |
| Od/EVM          | 33.9     | 230.3   | 17.9      | 242.0    |           |            |
| Od/D-EVM        | 34.7     | 222.1   | 17.2      | 235.0    |           |            |
| Od/D-O-EVM      | 35.2     | 174.4   | 16.8      | 185.7    |           |            |
| Od/D-O-EVM      | 35.4     | 175.1   | 18.0      | 183.7    |           |            |
| Od/D-O-EVM      | 35.6     | 192.4   | 16.3      | 201.0    | 200.5     |            |
| Od/D-O-EVM      | 36.0     | 193.0   | 16.6      | 202.6    |           |            |
| Od/D-O-EVM      | 34.5     | 192.4   | 17.1      | 197.8    |           |            |

In the infrared spectrum of EVM, the peak values at 457, 997, and 3428 cm⁻¹ were Si–O–Mg bending vibration, Si–O–Si and Si–O–Al stretching vibration, and O–H stretching vibration, respectively. After dopamine modification, the characteristic absorption peaks of D-EVM roughly coincide with EVM. The peaks at 2920 and 2851 cm⁻¹ of the spectra D-O-EVM were ascribed to the stretching vibration of the C–H bond in DTA+, demonstrating that organic intercalation had been successfully performed in D-O-EVM. The peak spectra of the octadecane were 841, 1107, 1241, 1280, 1342, 1466, 2888, and 3425 cm⁻¹, which are attributed to the oscillation-group of the interim-CH₂, cutting stretching vibration of –CH, bending vibration of –CH₂, C–H stretching vibration, and O–H stretching vibration, respectively. After octadecane was encapsulated into EVM-based encapsulation carrier, the spectra of composite phase change materials was from the absorption peaks of octadecane and EVMs, and no new functional group was discovered, indicating that physical action rather than chemical interaction occurred between octadecane and EVMs, which further illustrated that the prepared fs-CPCMs showed desirable chemical compatibility.
phase change behavior. The dopamine’s two ends were respectively connected to EVM and octadecane through formed weaker hydrogen bonds (O−H···N and N−H···O), which avoided direct connection between octadecane and EVM (O−H···O), thus reducing the confinement effect of EVM matrix, which was beneficial to increase encapsulation capacities, promote phase change behavior, and improve heat storage characteristics of fs-CPCMs, which was consistent with the DSC results. The D-O-EVM promotes the crystallization degree of octadecane during the solidification process and significantly alleviates the inhibition of the phase transformation of octadecane by the original EVM matrix, which could be attributed to the organic intercalation provides abundant nucleation sites for octadecane, which reduces the nucleation activation energy and accelerates the resolidification process of octadecane.

3.5. Kinetics of Nonisothermal Crystallization Analysis. For visualization of crystallization exothermic behavior under nonisothermal conditions, the crystallization processes of octadecane and EVM-based fs-CPCMs at cooling rates of 5, 6, 7, 8 °C/min are displayed in Figure 6. It could be observed that with the increase of cooling rate, the exothermic peaks of octadecane and EVM-based fs-CPCMs move to the lower temperature direction, and the exothermic peaks become wider, which occurs because the overall crystallization rate was accelerated although the lower temperature had sort of impact on the motion of octadecane. Moreover, $T_p$ values of octadecane were significantly different from those of EVM-based fs-CPCMs at different cooling rates, indicating that EVMs and modified EVMs had an influence on the crystallization process of octadecane.

The relationship between the relative crystallinity ($X_T$) and time ($t$) or temperature ($T$) could better illustrate the nonisothermal crystallization behavior of octadecane in the EVMs and modified EVMs pores, and their values could be derived from the eqs 2 and 3.

$$X_T = \frac{\int_{T_a}^{T_b} \left( \frac{dT}{dT} \right) dT}{\int_{T_a}^{T_b} \left( \frac{dT}{dT} \right) dT} \times 100\%$$

$$t = \frac{T_B - T}{\phi}$$

where $X_T$ represents relative crystallinity of PCMs, the $dH_C/\ dT$ is the heat flow of crystallization, $T_B$ and $\phi$ are the temperature at which crystallization begins and cooling rate in the cooling process. $T$ and $t$ represent any temperature and the cooling time in the crystallization process, the half crystallization time ($t_{1/2}$) of octadecane and EVM-based fs-CPCMs could be obtained from Figure 7 and Figure 8, respectively, and the data are summarized in Table 3.

As could be seen from Figure 7, the nucleation and crystal growth of octadecane prompted the relative crystallinity to increase rapidly as the temperature decreased. When the cooling rate is 6 °C/min, the octadecane crystallization peak ($T_p$) appeared at 14.9 °C. The $T_p$ moved to a lower temperature, and its intensity increased as the cooling rate increased, which indicated that the crystallization time of octadecane decreased with increase of the cooling rate. This phenomenon was same to the EVM-based fs-CPCMs. Moreover, it could be observed from $t_{1/2}$ that the crystallization

Figure 6. Nonisothermal crystallization DSC thermograms of (a) octadecane, (b) Od/EVM, (c) Od/D-EVM, and (d) Od/D-O-EVM at cooling rates of 5, 6, 7, and 8 °C/min.
Figure 7. Relation diagram of relative crystallinity of the (a) octadecane, (b) Od/EVM, (c) Od/D-EVM, and (d) Od/D-O-EVM with crystallization temperature.

Figure 8. Relation diagram of relative crystallinity of the (a) octadecane, (b) Od/EVM, (c) Od/D-EVM, and (d) Od/D-O-EVM with crystallization time.
time of EVM-based fs-CPCMs were all slower than the octadecane at the same cooling rate, which might be because the micro nanopores of the packaging matrix had a certain inhibitory effect on the crystallization behavior of octadecane.

In order to further investigate the effect of dopamine modification and DTA+ intercalation on octadecane nucleation during nonisothermal solidification process, the activation energy (ΔEₐ) was calculated by the Kissinger’s equation defined by eq 4, and the crystal growth capacity of the octadecane and EVM-based fs-CPCMs could be calculated by the joint equation of Avrami equation and Ozawa (eq 5).

where A represents the gas constant and R represents frequent factor, n is Avrami index and m represents Owaza index, and K(T) represents cooling crystallization function.

The values of ΔEₐ could be expressed by the slope of the curves (Figure 9) and are listed in Table 3. The nucleation activation energy of octadecane is −8.08 kJ/mol. The nucleation activation energy of EVM-based fs-CPCMs is smaller than that of octadecane, which indicated that the nucleation barrier in EVMs and modified EVMs is lower. We think the reason for the improved performance of octadecane crystallization is that modification treatment could enhance the van der Waals forces on the surface of the mineral matrix and promote the ability of the surface of mineral pores to induce the nucleation process, indicating that the modified EVM was more conducive to reducing the crystallization nucleation barrier of octadecane, contributing to the nucleation of octadecane, thereby improving the crystallization behavior of fs-CPCMs to some extent.

3.7. Thermal Stability Analysis. As shown in Figure 10, the TGA figure of EVM-based fs-CPCMs illustrates the thermal stability. The decomposition rate of octadecane was the highest at 226.6 °C, and the maximum thermal mass loss was 99.4%, indicating the decomposition process was basically complete.

Table 3. Crystallization Process and Kinetic Parameters of Octadecane and EVM-Based fs-CPCMs under Nonisothermal Conditions

| samples | Φ (°C/min) | T_B (°C) | T_P (°C) | T_E (°C) | t_1/2 (min) | ΔE_a (kJ/mol) |
|---------|------------|----------|----------|----------|-------------|---------------|
| octadecane | 5 | 9.8 | 14.9 | 24.2 | 1.68 | -8.08 |
| 6 | 8.2 | 14.2 | 24.3 | 1.77 |
| 7 | 6.6 | 13.0 | 24.2 | 1.86 |
| 8 | 5.1 | 12.0 | 23.6 | 1.93 |
| 5 | 12.5 | 16.6 | 24.6 | 1.98 |
| 6 | 11.6 | 15.6 | 24.5 | 2.12 |
| 7 | 10.2 | 14.5 | 24.3 | 2.31 |
| 8 | 9.0 | 13.5 | 24.1 | 2.48 |
| Od/EVM | 5 | 12.2 | 17.1 | 24.1 | 1.84 |
| 6 | 10.6 | 16.3 | 23.2 | 1.93 |
| 7 | 9.1 | 15.4 | 23.1 | 1.97 |
| 8 | 7.7 | 14.2 | 23.9 | 2.04 |
| Od/D-EVM | 5 | 10.1 | 14.9 | 23.6 | 1.75 |
| 6 | 8.5 | 13.8 | 23.2 | 1.86 |
| 7 | 6.9 | 12.6 | 23.0 | 1.94 |
| 8 | 5.4 | 11.6 | 23.2 | 1.99 |
| Od/D-O-EVM | 5 | 12.2 | 17.1 | 24.1 | 1.84 |
| 6 | 10.6 | 16.3 | 23.2 | 1.93 |
| 7 | 9.1 | 15.4 | 23.1 | 1.97 |
| 8 | 7.7 | 14.2 | 23.9 | 2.04 |
| Od/D-O-EVM | 5 | 10.1 | 14.9 | 23.6 | 1.75 |
| 6 | 8.5 | 13.8 | 23.2 | 1.86 |
| 7 | 6.9 | 12.6 | 23.0 | 1.94 |
| 8 | 5.4 | 11.6 | 23.2 | 1.99 |

“T_B and T_E are, respectively, the temperature at which the solidification process begins and ends, while T_P is the peak temperature; t_1/2 is the half crystallization time; E_a is the nucleation activation energy during nonisothermal solidification process.

Figure 9. Nucleation activation energies of octadecane and EVM-based fs-CPCMs.

Figure 10. TGA curves of octadecane, Od/EVM, Od/D-EVM, and Od/D-O-EVM.

Figure 11. DSC curve of Od/D-EVM before and after 100 cycles.
completed. By contrast, the maximum decomposition rates of Od/EVM respectively occurred 261.1 °C, which were slightly different from that of pure paraffin, indicating that the encapsulation of matrix had little effect on the thermal stability of paraffin. The final mass losses of Od/D-EVM and Od/D-O-EVM were, respectively, 79.6% and 84.8%, which were consistent with the package effects of two fs-CPCMs. It could be found that the mass of EVM-based fs-CPCMs might hardly be lost in the application temperature range below 100 °C. Therefore, the prepared EVM-based fs-CPCMs had high heat storage capacity and good thermal stability.

3.8. Thermal Reliability Analysis. The premise of wide application of the composite phase change materials is good thermal cycling reliability. Od/D-EVM has the best heat storage and better phase change properties. It is necessary to further study thermal reliability after cyclic testing of Od/D-EVM to judge whether it is an ideal composite phase change material. Figure 11 displayed the DSC curves of Od/D-EVM before and after 100 cycles. It showed that Od/D-EVM has complete endothermic and exothermic peaks before and after the 100-cycle test. The latent heat before and after the cycles was 192.6 and 183.4 J/g, respectively. The latent heat loss rate is only 4.8%, indicating that Od/D-EVM fs-CPCM has good thermal cycling reliability.

4. CONCLUSIONS

In this study, the modified expanded vermiculite (EVM) was prepared by dopamine modification and DTA intercalation method, and a series of EVM-based fs-CPCMs were prepared by physical impregnation using n-octadecane as PCMs. The heat storage performance of the composite phase change materials were improved obviously, and the encapsulation ratio is increased to 84. 7% and 83.1%. The nonisothermal crystallization process of the prepared composite phase change material was further studied. The effects of dopamine modification and organic intercalation on the encapsulation performance of EVM-based fs-CPCMs were analyzed. The results of XRD, FT-IR, thermal cycle, and TGA tests showed that EVM-based composite phase change materials had good chemical compatibility, thermal reliability, and thermal stability. This study provides a theoretical basis for the preparation of EVM-based fs-CPCMs with high thermal stability and good heat storage performance.

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Complete contact information is available at: https://pubs.acs.org/10.1021/acsomega.1c06815

Notes
The authors declare no competing financial interest.