

INVESTIGATION ON THE APPLICATION OF PHASE CHANGE COMPOSITE WITH CNTS IN WATER HEATER

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ABSTRACT

In this work, the phase change composite materials were prepared by adding CNTs in a certain proportion into the melting paraffin waxes with intensive sonication. Structure and thermal properties of the composite phase change material was characterized using FTIR Spectrometer, X-ray diffractometer and differential scanning calorimetry. The composites were added into the water heater. The results showed that the thermal conductivity of the composite materials increased slightly with the increase of temperature. The thermal conductivity of the composites increased obviously when the temperature reached melting point, after this temperature the thermal conductivity of the composites began to decline. On the whole, the addition of CNTs can increase the enthalpy of phase transformation and the enthalpy of phase change, and there is no obvious change in the melting point of the composite. The addition of composite into water heater is conducive to keep temperature and energy conservation of the equipment.

KEY WORDS: Paraffin Wax, CNT, Composite, Water Heater

1. INTRODUCTION

The water heater is a product which used as a necessary electronic product in most of the families. Due to the big volume of the water tank, the response time of the heat system is long and the big volume limits the using place[1]. Heat storage material is added in the water storage tank of the water heater, and the hot water can be directly heated by the heat storage material, which greatly shortens the time of the water outlet[2]. At the same time, the use of phase change materials instead of storing the efficient storage tank, storage tank volume can be reduced, but also the use of peak power, peak, valley power stops when the exothermic heat storage, give full play to the advantages of technology and phase change heat pump heating technology respectively, has good operation performance and economic benefit[3-5].

Phase change materials (PCMs) have been a main topic in research for the last tens years[6-8]. Some natural substances, such as and paraffin waxes, fatty acids and other compounds, have the required high latent heat of fusion in the temperature range from 0 to 150 °C and these materials could be used for solar applications, though have certain shortcomings[9-11]. The common shortcoming of many potential phase change heat storage materials is their low heat conductivity[12, 13]. To overcome this problem, a wide range of investigations were carried out to enhance the thermal conductivity of the organic phase change materials (PCMs)[11, 14, 15]. The often used method is to disperse solid particles with high thermal conductivity, such as expanded graphite, copper and other metal particles and so on, to form composite PCMs[5, 16, 17].

2. EXPERIMENTAL

Paraffin wax (PW, industrial grade) were obtained from Sinopharm Chemical Reagent Co., Ltd. and were used without further purification. Pristine multi-walled CNTs (P-CNTs) were supplied by Chendu Organic Chemicals Co., Ltd., Chinese Academy of Sciences. The purity of the CNTs was 95%. The average diameter, average length, and specific surface area of the CNTs were 30 nm, 50 μm, and 60 m² /g, respectively. To enhance the dispersibility of CNTs in organic materials, it is necessary to physically or chemically attach

functional groups to their surfaces without significantly changing their desirable properties. In this work, we used ball milling method to treat the pristine CNTs. The details of the treatment of the ball milling method were reported in our previous papers[18, 19]. The composites used in this paper were prepared by adding the treated CNTs into melting PW with ultrasonic agitation in the mixing container at a constant temperature of 70 °C.

Short-hot-wire method was used to measure the thermal conductivities (k) of pure PW and the composites. In our measurements, the PCM sample was melted and poured into a stainless steel cylinder container kept at a temperature higher than the melting point of the sample. A waterproof lid with pre-positioned hot wire and thermocouple was used to seal the container after sample encapsulation. The container was then put into a temperature-controlled thermostat bath with temperature variation less than 0.1 °C. Instead of monitoring the temperature of the bath, we monitored the temperature on the spot with the pre-positioned thermocouple inside the sample. When the temperature of the sample reached a steady value, it waited further 20 min to make sure that the initial state is at equilibrium. A platinum wire with a diameter of 70 μm was used for the hot wire, and it served as both a heating unit and as an electrical resistance thermometer. The platinum wire immersed in media was kept at equilibrium with the surroundings. When a regulation voltage was supplied to initiate the measurement, the electrical resistance of the wire changed proportionally with the rise in temperature. The thermal conductivity was calculated from the slope of the rise in the wire's temperature against the logarithmic time interval. At every tested temperature, the thermal conductivity were measured three times and taken the average values as the final results. 20 min interval was needed between every measurement. After the above-mentioned careful check on the measurement condition and procedure, it could obtain the thermal conductivities around the melting point.

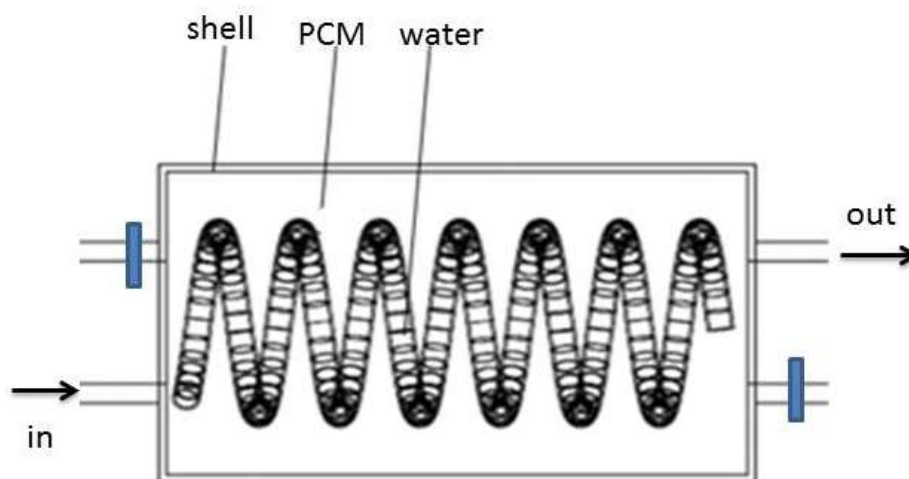


Fig. 1 The sketch map of the water heater

Melting temperature (T_m) and latent heat capacity (L_s) of pure PA and composites were measured using a differential scanning calorimetric (DSC) instrument (Diamond DSC, Perkin Elmer, USA). The DSC measurements were performed at a heating rate of 5 °C /min and in a temperature range 15-70°C.

The water heater in this paper was designed and manufactured by ourselves. The sketch map of the water heater is showed in Fig.1.

3. RESULTS AND DISCUSSION

3.1 The morphology of the composites

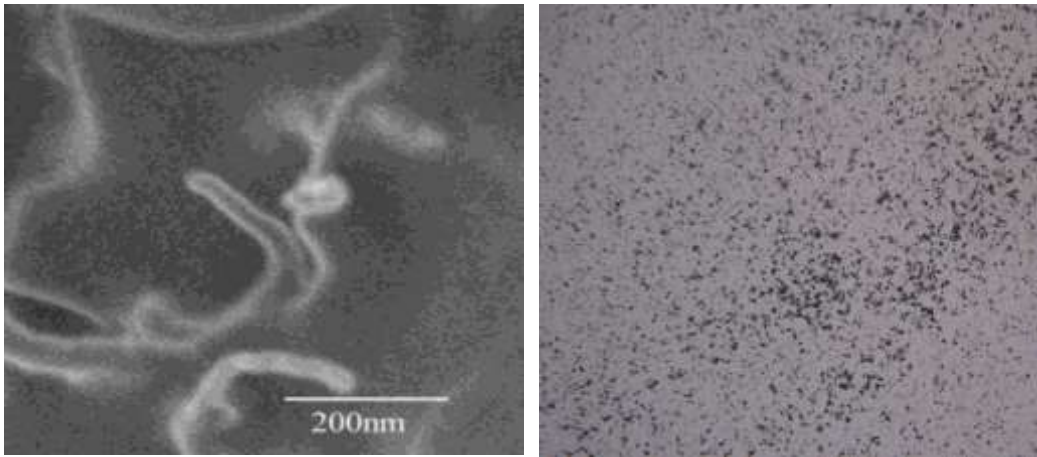


Fig.2 SEM images (left) and Typical longitudinal section photograph (right) of the CNTs composite
 Fig.2 shows the SEM images and the typical longitudinal section photograph ($\times 80$) of the composite with 5.0 wt% CNTs. As shown in the figure, the composite is homogeneous in the longitudinal section photograph of the composite. In the SEM images, the CNTs were separated individually in the basic matrix.

3.2 Thermal conductivity of composites

Thermal conductivity is one of the most important properties of PCMs. The relationship between the thermal conductivities and temperatures is also important for PCMs for applications. Fig. 3 depicts the dependence of the thermal conductivity with temperature. It is shown that thermal conductivities of composite PCM with 5.0 wt% CNTs is higher than that of pure PW. The PCM in this work is in solid state when temperature is lower than 60 °C, while it is in the liquid state when the temperature is higher than 65 °C. The thermal conductivity of PCM in liquid state is lower than that in solid state. In fact, convection in the liquid could enhance the thermal transportation in PCM when it turns into liquid state. This might be caused by the interaction of the matrix with the additive in solid state[20].

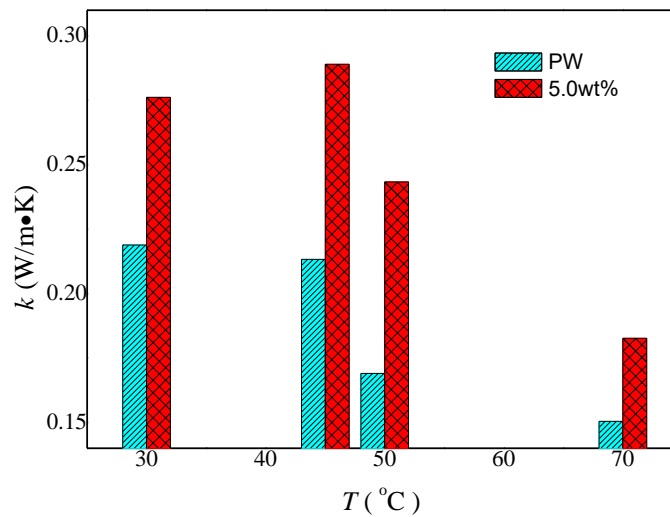


Fig. 3 Thermal conductivity of PCM with temperature

3.2 Melting temperature and latent heat capacity

DSC analysis was conducted to investigate the influence of the addition on the thermal properties including melting temperature and the latent heat storage capacity of the composites. Table 1 presents the solid-solid phase change temperature (T_{s-s}), melting temperature (T_m) of composite. There is no evidently changing with the adding of CNT loadings for either T_{s-s} or T_m . T_{s-s} of the composite is about 35 °C, which is close to that of pure PW. T_m of the composite is 62.3 °C, which is very close to T_m of pure PW. Namely, the CNT nanoparticles addition had no influence on the phase change temperature of the composites. Table 1 also shows latent heat capacity of solid-solid phase change (L_{s-s}) and latent heat capacity of solid-liquid phase change (L_s) of PCM. The composite PCM is slightly lower than that of pure PW.

Table 1 The phase change temperatures and the latent heat capacity of the PCM.

Case	T_{s-s} (°C)	T_m (°C)	L_{s-s} (J/g)	L_s (J/g)
PW	35.5	62.5	35.5	151.3
5.0wt%	34.8	62.3	35.9	150.1

3.3 Water heater with PCM

In order to test the water heater with PCM, we added the PCM into the water heater and observe the temperature and the volume of outlet water. In the observation, the PCM in the water heater was heated. It stops heating when the temperature is 75 °C. Then the outlet valve is opened and adjusts the valve to control the temperature of outlet water at about 40 °C. The current speed of the water is set as 3L/min. The cold water which is inlet the water heater is about 25 °C. The temperature of PCM and the existing water is written every 5 min. Fig. 4 depicts the temperature of exiting water and the PCM. As shown in the figure, the temperature of outlet water is higher than 40 °C at the beginning of the test. The temperature of the PCM decrease with time, while that of outlet water is almost constant, in another words, it changed slightly. The totally volume of the water with temperature no lower than 40 °C is about 2.5 times of the water heater volume itself.

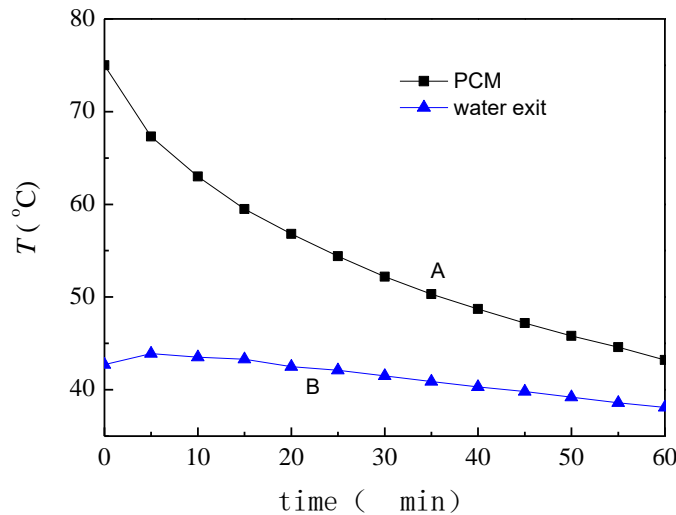


Fig. 4 The temperature of PCM and water of the water heater

4. CONCLUSIONS

Paraffin wax (PA) dispersible multi-walled carbon nanotubes (CNT) were obtained by ball milling treatment through ball milling the pristine CNTs. The CNT addition leads to substantial enhancement in the thermal conductivity of the composite phase change material. The phase change temperatures of composite with CNT mass fraction of 0.05 is close to those of pure PW. The latent heat capacities of the composite both for solid-solid phase change and solid-liquid phase change are close to those of pure PW. The thermal conductivity of the composite is higher than that of pure PW at the

same temperature. The addition of PCM into water heater could enhance the use efficiency of the water heater and it can peak shaving the energy.

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REFERENCES

- [1] M. Faegh, M.B. Shafii, Experimental investigation of a solar still equipped with an external heat storage system using phase change materials and heat pipes, *Desalination*, 409 (2017) 128-135.
- [2] D. Gao, Z. Chen, D. Zhang, L. Chen, Lattice Boltzmann modeling of melting of phase change materials in porous media with conducting fins, *Applied Thermal Engineering*, 118 (2017) 315-327.
- [3] F. Agyenim, N. Hewitt, P. Eames, M. Smyth, A review of materials, heat transfer and phase change problem formulation for latent heat thermal energy storage systems (LHTESS), *Renew Sust Energ Rev*, 14 (2010) 615-628.
- [4] A. Arnault, F. Mathieu-Potvin, L. Gosselin, Internal surfaces including phase change materials for passive optimal shift of solar heat gain, *International Journal of Thermal Sciences*, 49 (2010) 2148-2156.
- [5] T.P. Teng, C.M. Cheng, C.P. Cheng, Performance assessment of heat storage by phase change materials containing MWCNTs and graphite, *Appl Therm Eng*, 50 (2013) 637-644.
- [6] No need for air conditioning with phase change materials in the walls, *Mater World*, 9 (2001) A7-A7.
- [7] A.M. Abyzov, S.V. Kidalov, F.M. Shakhov, Thermal Conductivity of the Diamond-Paraffin Wax Composite, *Phys Solid State+*, 53 (2011) 48-52.
- [8] M. Alfe, V. Gargiulo, L. Lisi, R. Di Capua, Synthesis and characterization of conductive copper-based metal-organic framework/graphene-like composites, *Mater Chem Phys*, 147 (2014) 744-750.
- [9] Y. Tian, C.Y. Zhao, A numerical investigation of heat transfer in phase change materials (PCMs) embedded in porous metals, *Energy*, 36 (2011) 5539-5546.
- [10] W.H. Zhao, S. Neti, A. Oztekin, Heat transfer analysis of encapsulated phase change materials, *Appl Therm Eng*, 50 (2013) 143-151.
- [11] Y. Wang, S.M. Chiao, T.F. Hung, S.Y. Yang, Improvement in toughness and heat resistance of poly(lactic acid)/polycarbonate blend through twin-screw blending: Influence of compatibilizer type, *J Appl Polym Sci*, 125 (2012) E402-E412.
- [12] M. Kyotani, K. Hiratani, T. Okada, S. Matsushita, K. Akagi, Carbon Materials Preparation of 2D Carbon Materials by Chemical Carbonization of Cellulosic Materials to Avoid Thermal Decomposition (*Global Challenges 7/2017*), *Global Challenges Volume 1, Issue 7, Global Challenges*, 1 (2017) n/a.
- [13] B. Mortazavi, H. Yang, F. Mohebbi, G. Cuniberti, T. Rabczuk, Graphene or h-BN paraffin composite structures for the thermal management of Li-ion batteries: A multiscale investigation, *Applied Energy*, 202 (2017) 323-334.
- [14] C.Y. Zhao, W. Lu, Y. Tian, Heat transfer enhancement for thermal energy storage using metal foams embedded within phase change materials (PCMs), *Sol Energy*, 84 (2010) 1402-1412.
- [15] A. de Gracia, L.F. Cabeza, Numerical simulation of a PCM packed bed system: A review, *Renewable & Sustainable Energy Reviews*, 69 (2017) 1055-1063.
- [16] M.R. Reddigari, N. Nallusamy, A.P. Bappala, H.R. Konireddy, Thermal Energy Storage System Using Phase Change Materials - Constant Heat Source, *Therm Sci*, 16 (2012) 1097-1104.
- [17] A.K. Misra, Fluoride Salts as Phase-Change Materials for Thermal-Energy Storage in the Temperature-Range 1000-1400-K - Thermal-Analysis and Heat of Fusion Measurements, *J Electrochem Soc*, 135 (1988) 850-854.
- [18] J.F. Wang, H.Q. Xie, Z. Xin, Y. Li, Increasing the thermal conductivity of palmitic acid by the addition of carbon nanotubes, *Carbon*, 48 (2010) 3979-3986.
- [19] J.F. Wang, H.Q. Xie, Z. Xin, Thermal properties of paraffin based composites containing multi-walled carbon nanotubes, *Thermochim Acta*, 488 (2009) 39-42.
- [20] L. Jin, R. Zhang, X. Du, Computational homogenization for thermal conduction in heterogeneous concrete after mechanical stress, *Construction and Building Materials*, 141 (2017) 222-234.