

The Effect on Heating Rate for Phase Change Materials Containing MWCNTs

Tun-Ping Teng and Chao-Chieh Yu

Abstract—This study experimentally investigates the influences of the additive concentrations of the MWCNTs and heating/cooling rate for the nanocomposite-enhanced phase change materials (NEPCMs). The variations of temperature and phase change heat of NEPCMs by DSC experiments are to evaluate the feasibility for heat storage. Experimental results demonstrate that adding MWCNTs reduced the melting onset temperature and increased the solidification onset temperature for paraffin. This phenomenon makes the phase change heat of NEPCMs applicable to a wider temperature range, and the highest decreased ratio of phase change heat with 3.0 wt.% of MWCNTs was only 2.0 % to compare with paraffin at 2.0 °C/min. of cooling rate in this study.

Index Terms—MWCNTs, NEPCMs, paraffin, phase change heat

I. INTRODUCTION

The technologies of collection and storage of heat by solar energy meet the trend of the carbon reduction nowadays. The utilization of solar energy is restricted by the alternation of day and night and weather conditions. Thus, the development of highly efficient thermal storage materials and devices is a critical issue. The phase change materials (PCMs) have the advantage of high density of thermal storage, so the PCMs are most concerned materials for thermal storage usage [1]-[2].

Most PCMs have the disadvantage of low thermal conductivity, which makes it difficult to overcome the problem of rapid load changes in the charging and discharging process [2]. Many studies have proposed various modified techniques to enhance the thermal conductivity of PCMs, such as inserting fins, adding metallic or nonmetallic particles, incorporating porous matrix materials or expanded graphite, inserting fibrous materials, and incorporating macro, micro, and nano capsules [3]-[9]. Adding particles or fibers with high thermal conductivity to PCMs is a convenient and cost-effective approach to enhance their thermal conductivity. However, these additives also create the problem of sedimentation because of additives size, dispersion technique, and surface property of materials which gradually result in lower thermal performance in the long-term period. The development of nanotechnology has led to nanoscale additives, which can more effectively solve the problems of sedimentation and increasing viscosity. The carbon

nanotubes (CNTs) and carbon nanofiber (CNFs) with high thermal conductivity were the most widely added material that the phase change material formed nanocomposite-enhanced phase change materials (NEPCMs) in all nano-additives [10]-[14].

This study employed the direct-synthesis method to produce NEPCMs by adding the MWCNTs to paraffin. Experiments employing differential scanning calorimeter (DSC) were to assess the onset temperature, peak temperature, and phase change heat of melting/ solidification for NEPCMs and paraffin at the different temperature, heating and cooling rate to discuss the feasibility of NEPCMs in thermal storage system.

II. EXPERIMENTAL

A. Sample Preparation

Fig. 1 shows field-emission scanning electron microscope (FE-SEM, S4800, Hitachi) photographs of MWCNTs ($d=20\text{-}30\text{ nm}$, Cheap Tubes Inc.). The NEPCMs produced by the direct-synthesis method were used to disperse the MWCNTs into three weight fractions (1.0, 2.0, 3.0 wt.%) in the paraffin, forming the experimental samples in this study. The paraffin was first melted to the liquid state by a hot plate to add the appropriate amount of MWCNTs in the liquid paraffin. The liquid paraffin was then alternately dispersed at 120 °C by an electromagnetic stirrer/hot plate (PC420D, Corning) and a high-speed homogenizer (T25 digital, IKA) at 6000rpm to evenly disperse the MWCNTs for 40 minutes in the liquid paraffin. Finally, the liquid NEPCMs were then dispersed at 90 °C for one hour using an ultrasonic vibrator (D400H, TOHAMA) to complete the modification procedures of PCMs.

B. Experimental Process

A DSC is often used to determine the phase change temperature and phase change heat of PCMs [7, 9, 13, 15]. A DSC (Q20, TA) with a mechanical cooling system (RCS40, TA) was used to assess different samples of charging and discharging experiments to determine the melting and solidification temperature. The range of experimental temperature was 25~90°C at the different heating and cooling rates of 2.0, 4.0, and 6.0 °C/min. The calorimetric precision and temperature accuracy of the DSC were $\pm 0.1\%$ and $\pm 0.1^\circ\text{C}$, respectively. This experiment controlled the sample's weight at $5.0 \pm 1.0\text{ mg}$ in the aluminum sample pan (Tzero Pan, No.: T100915) using a precision electronic balance (XS-125A, Precisa) at a precision of 0.1 mg. The thermograms of the DSC charging and discharge

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experiments were analyzed by a computer software (Universal Analysis 2000, TA) at a temperature range from 30 to 70°C to calculate the phase change heat for all samples. Comparing the experimental results of DSC for the NEPCMs and paraffin at the same experimental parameters reveals the effects of additives for the melting and solidification temperature and phase change heat of paraffin.

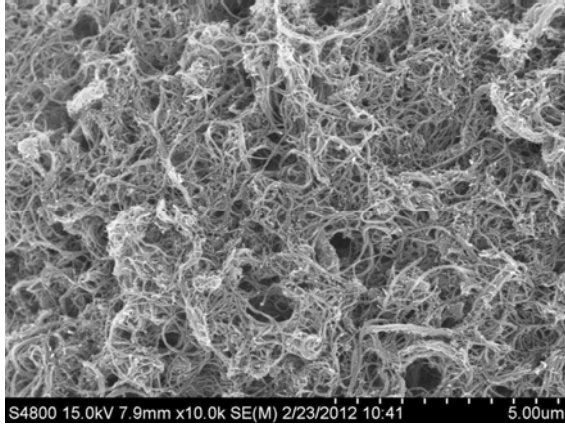


Fig. 1. FE-SEM image of MWCNTs.

C. Data Analysis

To easily compare the experimental data after adding the MWCNTs to paraffin (D_{MWCNTs}), all data obtained from the paraffin were to form baseline values (D_{pw}). The differences before and after adding the MWCNTs to paraffin were presented as a percentage ($R_d\%$), calculated as follows:

$$R_d\% = \left[(D_{MWCNTs} / D_{pw}) - 1 \right] \times 100\% \quad (1)$$

III. RESULTS AND DISCUSSIONS

Figs. 2-4 respectively demonstrate the DSC thermograms for NEPCMs containing MWCNTs at different concentrations and heating/cooling rates. The test data of paraffin are illustrated in these figures. Those figures show that the MWCNTs can slightly decrease the melting onset temperature (T_{mo}) and increase the solidification onset temperature (T_{so}) of paraffin. The MWCNTs can also enhance the melting peak (T_{mp}) temperature and slightly decrease the solidification peak temperature (T_{sp}) of paraffin. Adding MWCNTs caused a greater range in the phase change temperature than the paraffin. In addition, the heat changes are more evenly in the phase change range and the phase change temperatures are in a wider range. This phenomenon is mainly from the high thermal conductivity of MWCNTs. Furthermore, the excellent combination between MWCNTs and paraffin as well as the dispersion performance of MWCNTs in paraffin lead to the relatively uniform of heat changes in the phase change. However, the combination and dispersion performance are mainly attributed to the surface properties of the MWCNTs and paraffin. Adding MWCNTs with high thermal conductivity to paraffin promotes the early occurrence of phase change onset temperature through rapid heat transfer.

Using calculated results by Eq. (1) to compare the difference of experimental results for NEPCMs and paraffin

at different concentrations of MWCNTs and heating/cooling rates (Figs. 2-4). The calculated results are shown in Table 1. The data in Table I show that the MWCNTs can slightly decrease the T_{mo} and phase change heat (H_m and H_s), and increase the T_{so} and the T_{mp} of paraffin. This phenomenon makes the phase change heat of NEPCMs applicable to a wider temperature range. As MWCNTs only provide enhanced heat transfer performance of NEPCMs and will not participate in the process of phase change, phase change heat decreases with the increase of concentration of MWCNTs. The experimental results show that the maximum phase change heat rate of decline is 2.0% for NEPCMs with 3.0 wt.% of MWCNTs at 2.0 °C/min. of cooling rate.

TABLE I: EXPERIMENTAL DATA AND CALCULATED RESULTS FOR DSC EXPERIMENT.

Process	Items	Heating rate (°C/min)		
		2	4	6
Melting Process (charging)	T_{mp} (°C)			
	Paraffin (test data)	60.46	60.72	61.06
	$R_d\%$			
	MWCNT1.0 wt. %	0.53	0.64	0.59
	MWCNT 2.0 wt. %	0.58	0.69	0.72
	MWCNT 3.0 wt. %	0.45	0.61	0.69
	T_{mo} (°C)			
	Paraffin (test data)	53.95	54.02	54.09
	$R_d\%$			
	MWCNT1.0 wt. %	-0.54	-0.65	-0.68
	MWCNT 2.0 wt. %	-0.45	-0.52	-0.55
	MWCNT 3.0 wt. %	-0.46	-0.50	-0.54
Solidification Process (discharging)	H_m (J/g)			
	Paraffin (test data)	188.4	190.8	191.7
	$R_d\%$			
	MWCNT1.0 wt. %	-0.96	-0.58	-0.68
	MWCNT 2.0 wt. %	-1.54	-0.89	-1.15
	MWCNT 3.0 wt. %	-1.59	-1.57	-1.77
	T_{sp} (°C)			
	Paraffin (test data)	60.32	58.64	57.94
	$R_d\%$			
	MWCNT1.0 wt. %	-1.87	-0.44	0.29
	MWCNT 2.0 wt. %	0.45	-0.29	0.40
	MWCNT 3.0 wt. %	-2.65	-1.02	-0.29
Solidification Process (discharging)	T_{so} (°C)			
	Paraffin (test data)	60.74	60.62	60.52
	$R_d\%$			
	MWCNT1.0 wt. %	1.56	1.63	1.60
	MWCNT 2.0 wt. %	1.56	1.68	1.72
	MWCNT 3.0 wt. %	1.50	1.58	1.55
	H_s (J/g)			
	Paraffin (test data)	190.3	186.0	185.0
	$R_d\%$			
	MWCNT1.0 wt. %	-0.79	-0.70	-0.81
	MWCNT 2.0 wt. %	-2.00	-1.02	-0.86
	MWCNT 3.0 wt. %	-2.00	-1.45	-1.57

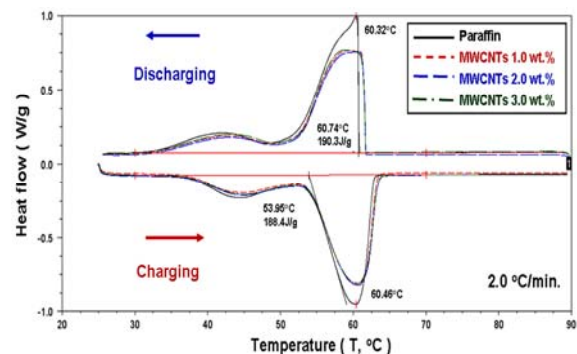


Fig. 2. DSC thermograms for NEPCMs at 2.0 °C/min. of heating/cooling rate.

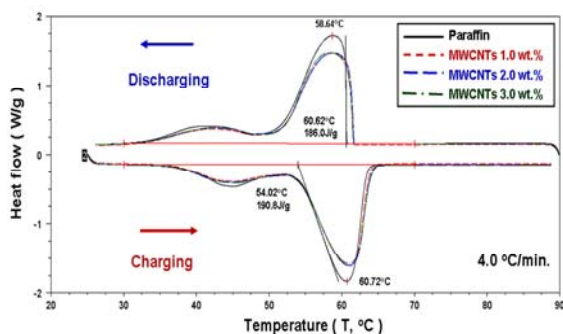


Fig. 3. DSC thermograms for NEPCMs at 4.0 °C/min. of heating/cooling rate.

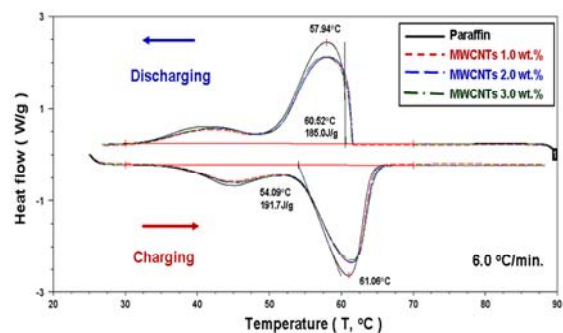


Fig. 4. DSC thermograms for NEPCMs at 6.0 °C/min. of heating/cooling rate.

IV. CONCLUSIONS

This study employs a direct-synthesis method to prepare NEPCMs by adding different concentrations of MWCNTs to paraffin. This study investigates the influences of the concentrations of the MWCNTs on their temperature and phase change heat variations at the charging and discharging process by DSC experiments. Experimental results demonstrate that adding MWCNTs can reduce the melting onset temperature and increased the solidification onset temperature for paraffin. This makes the phase change heat applicable to a wider temperature range, and the highest decreased ratio of phase change heat with 3.0 wt.% of MWCNTs is only 2.0% compared with paraffin at 2.0 °C/min. of cooling rate in this study. Therefore, adding MWCNTs to improve the applicable temperature range and uniform phase change heat transfer of paraffin has great potential in the future.

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