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Thermal Stability and Light Transmission Capability of Nano TiO₂ Enhanced Phase Change Material as Thermal Energy Storage

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Abstract. InPhase Change Material (PCM) already pick up some interests among recent researchers and engineers due to its unique characteristic of storage and releasing high quantity of heat energy during phase transition process. However, there's some disadvantages for this material such as low absorption of irradiance and super cooling phenomena occurred. To overcome this problem high conductive nanoparticles are dispersed in to the PCM resulting a new composite called nano-enhanced PCM (NEPCM). In this present paper, the impact of adding Titanium (IV) oxide nanoparticles (TiO₂) on pure paraffin wax also was investigated. Output reveal that NEPCM have greater thermal stability than pure PCM. When increasing the %wt, the thermal stability also increases, as shown clearly when using Sodium Dodecylbenzene Sulfonate (SDBS) as surfactant.

Keywords:Phase Change Materials (PCMs), nano composite, Thermal stability, Light Transmission

1. Introduction

Latent heat storage (LHS), Sensible heat storage (SHS) and Thermal chemical storage (TCS) are the basic types of thermal energy system [1,2], which has its own advantages and disadvantages. It was found that the LHS has higher thermal energy storage density compare to SHS[2,3].

Phase change material (PCM) is the most suitable candidate which have large latent heat capabilities. With this characteristic of this material, waste heat from the system being operated can be harvest and can save a high grades of energy sources like in photovoltaic modules. PCM also suitable with this application due to its heat storage capabilities per smaller volume change. This can be proven when it



can absorb and restore 15x more thermal energy compare than any other common sensible heat storage materials like water and rock[4] in the same volume while its remain at constant temperature.

In general, PCM consist of 3 types which is organic, inorganic and eutectic PCM. Eutectic group typically combination of various mixing containing organic and inorganic group [5] which exhibits congruent melting and freezing without segregation[6]. Meanwhile, the inorganic PCM mostly made up from salt hydrate or metallic, causing a high heat of fusion, high thermal conductivity and sharp melting point. Unfortunately, inorganic PCM experienced subcooling process between their particles, incongruent melting and corrosiveness[7]. Thus, organic PCMs are the one preferred form for thermal energy storage applications that will benefit at industrial waste energy storage and solar harvester sectors [8,9].

Common organic PCM that can be found scattering around the world are paraffin wax (PW) and fatty acid, offering decent capabilities in high latent heat of fusion, low vapor pressure during melting process, and thermal stability[10]. Unfortunately, there's a limit in their characteristic capabilities due to its thermal stability, low absorption of sunlight radiation, decreasing the heat transfer rate during melting or solidifying processes. About 0.18-0.24 W/m.K is the value for common thermal conductivity of paraffin wax[11]. This will reduce the effectiveness for the energy (heat) being absorb as much as possible in the PCM to be used for another purpose. Another factor that will increase the PCM's effectiveness are high light radiation absorption and thermal stability.

Carbon nanotubes, graphite, graphene, metal and metal oxide are some examples of nanoparticles that can be dispersed in PCM[12], but some modification need to be made in order to disperse it very well in PCM. By mixing this two materials (PCM-nanoparticles), all thermal-physical properties such as thermal stability, thermal conductivity, supercooling, phase change temperature and its duration will be altered[13,14]. For past decade, with advance nanotechnology recently, many nanoparticles can be mass produced, increasing the new improvement in engineering and industrial processes profession[15].

Babapoor et al reported that from his experimental study, addition of different nanoparticles into the base PCM improve in its thermal-physical properties exponentially[16]. Mixing a high conductive material with the PCM may be an ultimate answer to enhancing the thermal conduction properties of it. He et al. described that water-based TiO₂ give better results and enhancement than the model prediction. Murched et al also concluded that various nanofluids such as Al₂O₃/water, Al₂O₃/ethylene glycol, TiO₂/water and TiO₂/ethylene glycol showing increasing thermal stability than respective base fluids.

From the studies it is evident, the presence of material additives to pure PCM has shown an improvement in its thermal characteristics. In this study, pure A25H phase change material and its composite with TiO₂ is investigated for thermal system application. The Thermal stability is determined through ThermogravimetricAnalyser (TGA), light transmission through UV-VIS-NIR spectrometer, and observe chemical properties through Fourier Transform Infrared Spectroscopy (FTIR). These parameters measure will provide a pathway into determining the suitability of TiO₂ for thermal stability and light absorption enhancing of paraffin wax.

2. Methods and Materials

2.1. Materials

Based fluid PCM that are being experimented in this paper was PLUSICE A25H, being purchased from the company Phase Change Material Products Ltd. It has melting point 25°C and latent heat of 226 J/g. Titanium (IV) oxide (TiO₂) particles which is <25nm and Sodium Dodecylbenzene Sulfonate (SDBS) surfactant were purchased from Sigma-Aldrich Chemistry.

2.2. Methods

To measured the weight of PCM, Analytical Macrobalance (Model: TX323L, UNIBLOC) was being used and for %wt of TiO₂ and SDBS, Analytical Microbalance (Model: EX224, OHAUS) was being used. Probe Sonicator (Model: FS-1200N) was the equipment to sonicated the mixture.

In case of preparation A25H 0,1%wt of TiO₂ with surfactant, 12 g of PCM and 12mg of each TiO₂ and SDBS being measured using weight balance mention above. A25H was immersed in water bath temperature of 40°C. Then SDBS will be added once the PCM completely melted, sonicated for a while before adding the TiO₂ nanoparticles. This mixture then being sonicated for 30 mins. The probe

was operated at 40°C to ensure that the PCM is in liquid form. This procedure was repeated for 0.5%, 1.0% and 5.0% weight percentage and without surfactant.

2.3. Characterization Technique

Perkin Elmer TGA 4000 was used for the thermal stability analysis in this mixture. Nitrogen gas (N₂) being supplied during the heating process with rate of 10°C/min. The sample was placed in a ceramic hard crucible for it to withstand when the TGA start to heat up from 30°C to 500°C, monitoring any weight change

Fourier transformation infrared (FTIR) spectra were measured in a range from 4000 cm⁻¹ to 400 cm⁻¹ via a Bomem 8 spectrometer. In order to perform this analysis. 1mg composite in a liquid form were placed at the top of diamond FTIR to be analysed.

For light Transmission capability, Lambda 750 UV-VIS-NIR spectrometer are being used. This machine emitted light ray from 200-800 nm of wavelength to be analysed by how much light get pass through the composites.

3. Results and Discussion

3.1. Thermal Stability

The rate of degradation over temperature is represented in Figure 1 without surfactant and Figure 2 with surfactant. The thermal degradation for pure A25H PCM occurs between 120 0C and 2500C. Table 1 shows that a change occurs to the thermal stability properties due to the addition of the TiO₂ nanoparticle to the A25H PCM. The maximum degradation rate of pure A25H PCM is -25.70%/wt/min at 213.57°C.

The results show that after adding TiO₂ nanoparticles at any concentration, a very little change happened to the thermal stability of A25H. However, the results also indicated that the degradation rate and temperature without surfactant are much higher compare to adding surfactant at any concentration. The highest degradation temperature is 236.66°C for 1.0% wt without surfactant, producing -24.58 %wt/min degradation rate showing that it is the optimize %wt we can add in A25H PCM. This shows that a sufficient increase of degradation temperature point but maintaining the near rate of degradation same with pure A25H. Same conclusion can be made with adding the surfactant where in 5.0% wt, the degradation rate was -22.72 %wt/min at 230.35°C. A small decrease of maximum degradation rate for the price of higher degradation temperature.

3.2. Light Transmission Capability

The light transmission of pure A25H PCM and all %wt of TiO₂ composites was determined through UV-VIS spectrometer and is represented in Figure 3. We can define the range 200-300nm as ultraviolet, 300-700nm as visible range and 700-800nm as near infrared. Infrared radiation (IR) makes up 50%, 42% for visible light and ultraviolet radiation makes up just over 8% of the total solar radiation. The percentage transmission (%T) of pure A25H is lower compared to all the composite in the ultraviolet. But a considerable decrease in transmission percentage can be seen in the composite in the visible and near infrared region. This will directly inverse the absorbance factor which will increase the potential to absorb more light radiation. It shows that all NEPCM are better alternative in terms of direct solar radiation absorbing material, but 1.0%wt and 5.0% wt with surfactant give us the ideal solar application due to its lowest transmittance and highest absorbance than the other composites. A low transmission percentage and high absorbance is a material better equipped for solar thermal application.

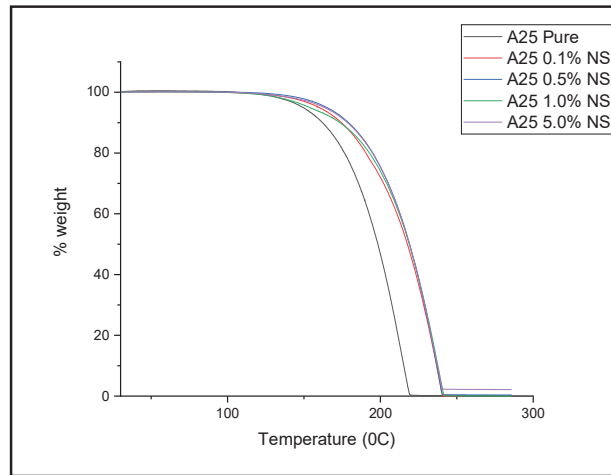


Figure 1. TGA analysis of A25H with different %wt TiO2 without surfactant

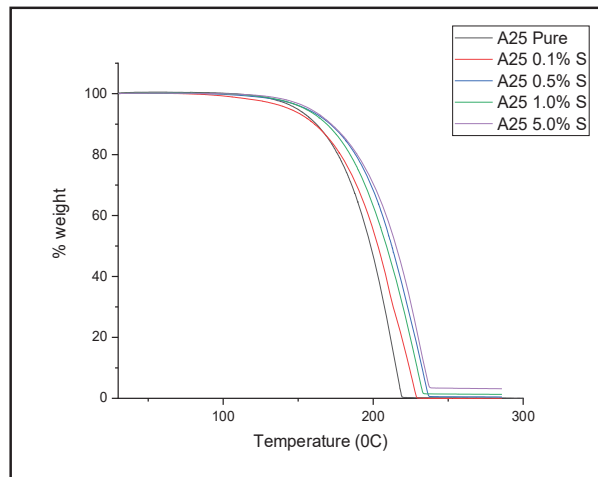


Figure 2. TGA analysis of A25H with different %wt TiO2 with surfactant

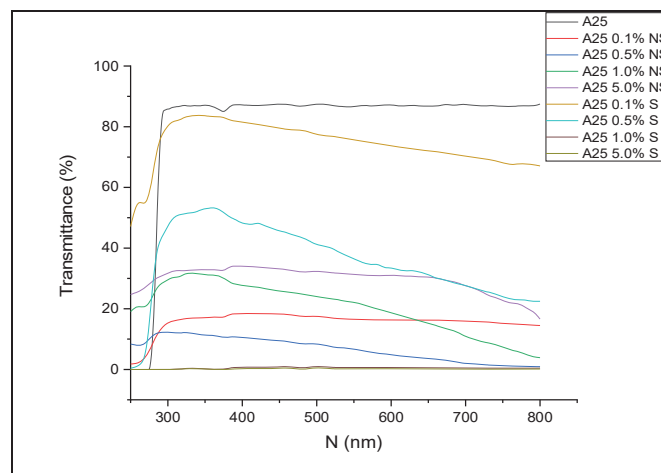


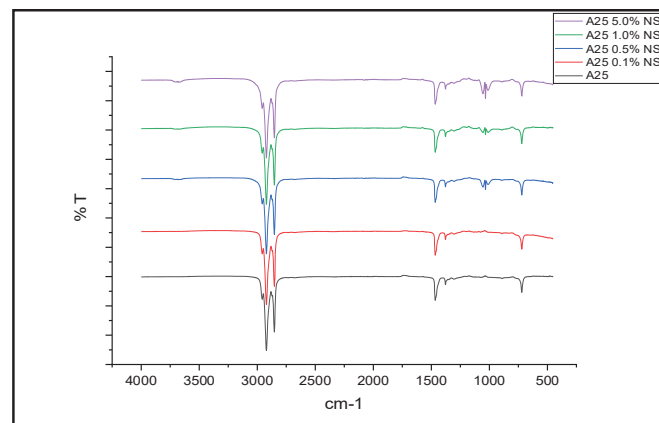
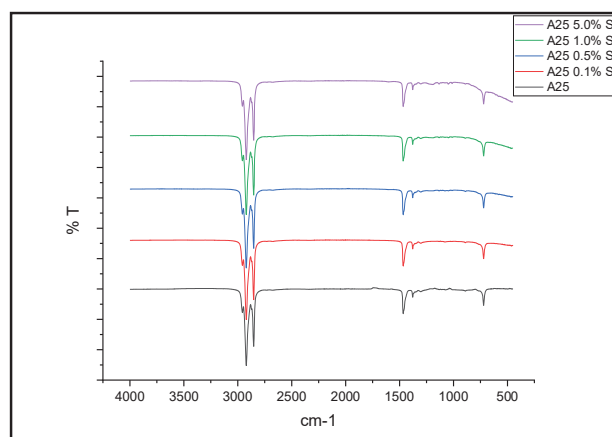
Figure 3. UV-VIS transmittance analysis of NEPCM

Table 1. Degradation rate and temperature of different %wt

%wt	Without surfactant		With surfactant	
	Degradation temperature (°C)	degradation rate (%wt/min)	Degradation temperature (°C)	degradation rate (%wt/min)
0	213.57	-25.70	213.57	-25.70
0.1	236.07	-24.51	211.94	-18.59
0.5	235.65	-25.72	226.64	-19.81
1.0	236.66	-24.58	227.97	-21.47
5.0	234.78	-24.19	230.35	-22.72

3.3. Fourier transformation infrared (FTIR)

Figure 4 & Figure 5 plots a FTIR spectrum of NEPCM with various concentration with or without surfactant. The 600 cm⁻¹ band represented the stretching band of TiO₂. The transmitted 1000cm⁻¹ band can be described as the anatase form of TiO₂. 1628 cm⁻¹ band and the broad 3400 cm⁻¹ band links to the characteristic of the O-H stretching in the sample as there's a water in the sample present.

**Figure 4.** FTIR analysis of NEPCM without surfactant**Figure 5.** FTIR analysis of NEPCM with surfactant

4. Conclusions

The liquid form PW A25H was melted so that TiO₂ nanoparticles can be added to make PW/TiO₂ composites using probe sonication method. The TGA results showed that pure A25H PCM and all of

composites undergoes degradation process between 120°C to 250°C, providing very little change in term of degradation rate for non-surfactant sample but huge increase in term of maximum degradation temperature by at least 10-11% from 213.57°C for pure A25H to 236.66°C for 1%wt. This composite may be suitable for direct solar absorption application as the composite had higher light absorbance compared to pure A25H. To understand the suitability of the composite in other thermal system application further properties of the composite need to be performed. Thermal conductivity plays an important character when it applied in heat exchanger and heat sinks. In the future studies, further weight composition needs to be prepared, thermal conductivity of the material, and thermal reliability needs to be investigated. These investigations may shed more knowledge on the suitability of A25H with TiO₂ on other thermal system application like heat exchanger, heat sinks, and concentrated photovoltaic thermal systems.

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