Investigation on Thermal Properties of AL₂O₃ Based Phase Change Material Composite for Solar Thermal System Application

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Abstract. Sustainable Development Goal and Paris Agreement are guidelines provided by the global community for a better future. One of the ways is through the utilization of solar energy. But solar energy is plagued by unpredictable energy delivery, which can be solved through latent heat energy storage system. In this study, a phase change material (A70) composite with 0.1% wt AL₂O₃ is prepared using probe sonication. The composite is characterized through Differential Scanning Calorimetry (DSC), Thermogravimetric Analyzer (TGA) and UV-VIS-NIR spectrometer. The DSC showed a 5.02% decrease in the value of latent heat while the composite was thermally stable for the temperature range 30°C to 200°C where majority of domestic solar application lies. The composite and pure A70 may be useful for thermal system application where indirect heat absorption like heat exchangers, heat sinks, photovoltaic thermal and concentrated photovoltaic thermal system.

1. Introduction
Solar energy is a readily available resource for successful implementation of Sustainable Development Goal 7 for reliable and affordable energy source and a method for reduction of carbon emission as agreed upon in Paris Agreement(2015)[1]. But solar energy is plagued by its unpredictability of delivering energy. To counter this unpredictability, a thermal energy storage is of utmost importance. Thermal energy storage can be classified into three namely: a) Sensible b) Latent and c) chemical energy storage[2]. The latent heat is a convenient form of thermal storage due to its capability to store energy at a temperature without considerable change in volume[3].
In thermal systems, there are several areas a phase change material may be utilized like heat exchangers, heat sink, solar water heater, photovoltaic thermal system, concentrated photovoltaic system, building cooling and heating load, greenhouse etc[2]. In concentrated photovoltaic thermal system, PCM spheres were used for improving the overall efficiency of the system by 15% compared to water cooling by Su et al. [4]. Nano-enhanced RT55 prepared with Al$_2$O$_3$ was implemented on a photovoltaic thermal system with an improvement of 13.2% in efficiency compared to without nano-enhanced PCM by S.A.Nada et al. [5]. Al-Waeli et al. [6] communicated a maximum temperature of 60.5 °C and an efficiency of 85.7 % for nano-enhanced paraffin wax with silicon carbide in a numerical study of photovoltaic thermal system. Nano-CuO with paraffin wax prepared through sonication was tested under 10 suns by M. Chen et al.[7]. The nano enhanced PCM reported 2.3times the maximum temperature compared to pure PCM. The nano enhanced PCM showing greater absorption of light.

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 A70 phase change material and its composite with Al$_2$O$_3$ is investigated for thermal system application. The latent heat storage capacity is determined through Differential Scanning Calorimetry (DSC), the thermal stability is analysed through Thermogravimetric Analyser (TGA), and the light transmission through UV-VIS-NIR spectrometer. The three parameters measured will provide a pathway into determining the suitability of Al$_2$O$_3$ for direct absorbing solar thermal application.

2. Methods and Materials

2.1. Materials
PLUSICE A70 with melting point 70 °C and latent heat of 170 J/g was used as the PCM. It was purchased from the company Phase Change Material Products Ltd. Alumina particles were purchased from Sigma-Aldrich.

2.2. Methods
Paraffin based A70 PLUCISE with melting temperature 70 °C was used for the preparation of micro-enhanced PCM. The material additive used was Al$_2$O$_3$. The required weight of PCM was measured using Analytical Macrobalance (Model: TX323L, UNIBLOC) and the required weight percentage of material additive was measured using Analytical Microbalance (Model: EX224, OHAUS). The PCM was melted using a water bath at temperature 80 °C. The mixture was sonicated for 30 mins using Probe Sonicator (Model: FS-1200N). For example, A70 PCM with 0.1%Al$_2$O$_3$, 5 g of A70 was measured using Macrobalance and 5 mg of Al$_2$O$_3$ was measured using Microbalance. A70 was placed in a water bath of 80 °C. Once the PCM melted, five drops of Triton were added followed by the addition of 5 mg of Al$_2$O$_3$. This resultant mixture was probe sonicated for 30 mins. The probe sonication was done with water bath at 80 °C to keep the PCM in liquid form.

2.3. Characterization Technique
The latent heat and the melting of the pure A70 and its composites were determined using Linseis Differential Scanning Calorimeter Analyzer (Model: DSC-1000/C). The measurement was carried out under N$_2$ atmosphere from temperature 30 °C to 100 °C at a heating rate of 10 °C/min. The thermal stability investigation was carried out using Perkin Elmer TGA 4000 under an N$_2$ atmosphere at a heating rate of 10 °C/min. The sample was placed in an alumina crucible and the weight change was monitored from 30 °C to 600 °C.

3. Results and Discussion

3.1. Latent Heat
The pure A70 PCM and its composite with 0.1% Al$_2$O$_3$ is determined using DSC. The area under the peak represented the latent heat of the pure PCM and composite. The temperature at the peak of the
DSC curve represents the melting temperature of the pure PCM and its composite. This is represented in Fig.1. The latent heat value for pure A70 PCM was determined to be around 172.17 J/g and melting point of pure A70 PCM is 70.3 \(^{\circ}\)C. The peak area for composite with 0.1% Al\(_2\)O\(_3\) is 163.53 J/g and its melting point temperature is 70.8 \(^{\circ}\)C. A decrease in latent heat of 5.02\% with respect to pure PCM is noted in composite. As the particle added do not change phase during the same phase transition temperature of the pure PCM[8], the reduction in latent heat may be attribute to this reason. A slight shift in melting temperature is also noted, from 70.3\(^{\circ}\)C to 70.8\(^{\circ}\)C for pure PCM to composite respectively.

3.2. Thermogravimetric Analysis (TGA)

The thermogravimetric analysis (TGA) of the composite and the pure PCM is represented in Fig.2. The rate of degradation over temperature is represented in Fig 3. The thermal degradation temperature of pure A70 PCM and its composite is evaluated at 3 \% weight loss. It is noted that for pure PCM and composite the thermal degradation temperature are 273 \(^{\circ}\)C and 273.16 \(^{\circ}\)C respectively. The thermal degradation also occurs between 250 \(^{\circ}\)C and 400 \(^{\circ}\)C for pure PCM and composite respectively which is a characteristics of paraffin wax[9].

![DSC curve](image)

**Figure 1.** DSC curve of Pure A70 PCM (A) and 0.1\% composite with Al\(_2\)O\(_3\) (AAL0.1) with their respective melting point temperature.

This shows that very little change occurs to the thermal stability properties due to the addition of the Al\(_2\)O\(_3\) particle to the A70 PCM. Maximum rate of degradation of pure A70 PCM is at -10.73 \%/wt/min at a temperature of 385.33 while that of 0.1\% Al\(_2\)O\(_3\) is around -11.48 \%/wt/min at 389.67 \(^{\circ}\)C. A slight increase in the maximum rate of degradation as well as temperature is noticed.
3.3. Light Transmission
The light transmission of pure A70 PCM and 0.1%wt of Al₂O₃ composite with A70 is determined through UV-VIS spectrometer and is represented in Fig.4. We can define the range 200-300nm as ultraviolet, 300-700nm as visible range and 700-800nm as near infrared. The transmission of pure A70 is lower compared to the composite except for the ultraviolet region. A considerable increase in transmission percentage can be seen in the composite in the visible and near infrared region. Due to the lower transmission of pure A70 compared to its composite with Al₂O₃, A70 is a better alternative in terms of direct solar radiation absorbing material. A low transmission percentage is a material better equipped for solar thermal application.
Figure 4. Light transmission of A70 (A) and its composite with 0.1% wt Al₂O₃ (AAI 0.1) in the ultraviolet, visible and near infrared region.

4. Conclusion

Phase change material A70 composite with Al₂O₃ is successfully prepared using probe sonication method. The prepared composite showed a decrement of 5.02% in the latent heat value using DSC. The TGA curve showed that thermal degradation of pure A70 and the composite occurred between the temperature 250 °C to 450 °C. Hence, very little change in the thermal degradation temperature due to the preparation technique. But there was an increase in the maximum degradation rate of the composite from -10.73%wt/min of pure A70 to -11.48%wt/min of the composite. The composite may not be suitable for direct solar absorption application as the composite had higher light transmission percentage compared to pure A70. This increase in transmission percentage, decreases the light absorbed by the composite and hence the energy. To understand the suitability of the composite in other thermal system application further properties of the composite need to be performed. In the case of heat exchangers, heat sinks and building application, the thermal conductivity plays an important role. 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 A70 with Al₂O₃ on other thermal system application like heat exchanger, heat sinks, and concentrated photovoltaic thermal systems.

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