Erythritol based Nano-PCM for Solar Thermal Energy Storage

R Manickam[1], P.Kalidoss[2], Dr.S.Suresh[3], Dr.S.Venkatachalapathy[4]

[1]*Dept. of Mechanical Engineering & Saranathan College of Engineering, TN, India*
[2]*Research Scholar, Dept. of Mechanical Engineering & NIT Trichy, TN, India*
[3]*Associate Professor, Dept. of Mechanical Engineering & NIT Trichy, TN, India*
[4]*Associate Professor, Dept. of Mechanical Engineering & NIT Trichy, TN, India*

---***---

Abstract - *Phase Change Material (PCM) plays an important role as a thermal energy storage device by utilizing its high storage density and latent heat property. The thermo-physical policies of Erythritol, (a sugar alcohol), was investigated as a potential material for developing increasingly meaty solar thermal energy storage systems than those currently available. This latent heat storage medium could be utilized for commercial and industrial applications using solar thermal energy storage in the temperature range of 100–150°C. The objective of this investigation was to determine via experimentation, if TiO2 and CNT nanoparticles sparse in pure Erythritol for mixtures of 1, and 3% (by weight) improved the thermal performance of Erythritol for solar thermal energy systems. Nanoparticles only physically interacted with Erythritol, and not chemically, plane without 25 thermal cycles. Without cycling, Nano-Erythritol studied here suffered a lower subtract in heat of fusion than pure Erythritol, which makes Nano-Erythritol increasingly suitable for solar thermal storage applications at 100–150°C.*

Key Words: Phase change material (PCM), Nanoparticles, Thermal cycling, Heat of fusion, Melting temperature, solar thermal energy storage.

1. INTRODUCTION

Recently, a lot of materials are unchangingly selected as PCM for thermal storage system including Water and Barium hydroxide, but these thermal storage systems are limited in heat storage density, safety and phase transpiration temperature. Organic PCMs such as sugar alcohols can potentially underpass the gap between peak heat demand and supply by storing energy in the form of latent heat due to their availability and suitable melting and freezing temperature ranges. AL2O3 nanoparticles used paraffin to disperse sodium stearoyl lactylate as a surfactant and found composite relaxing temperature of 2.5, 5.0, 7.5, and 10.0 wt percentage nano AL2O3 is 1.20, 1.50, 1.35, 1.65 C higher then unadulterated paraffin and 4.13 kJ/kg, 5.41 kJ/kg , 14.86 kJ/kg and 22 kJ/kg. (M.Nourani.[1]). Reported a make good in the heat limit of nano titania value erythritol by 40% in strong stage and 14% in liquid (or gas) stage when an value semester of 0.2 vol% of nano-titania was put to use.(L.Zhichao[2]). The objective of this investigation was to determine via experimentation, if Al2O3 and CuO nanoparticles sparse in pure MI for mixtures of 1, 2 and 3% (by weight) improved the thermal performance of MI for solar thermal energy systems. Without thermal cycling MI-A is increasingly suited for thermal energy storage than MI-C. (D.K. Singh [3]). The thermal conductivity of the PCMs was found to increase by 407.8 percent with a mass of 10 percent unalleviated one of the short stat threads. The loss of enthalpies, however, is 11.3% for variegated parts or materials made of 10% short stat threads. With their low space between parts and good thermal conductivity of CNT offer ramified unused quality as mixed substances. (Zhang Q [4]). A review of the integration of PCM into solar collectors and water storage tanks was presented. They discussed the techniques used to modernize the characteristics of PCM heat transfer, such as the use of highly conductive additives and fins. (Abokersh MH [5]).Studied eicosane / graphene Nano platelets (GNPs) and found that the midpoint latent heat of join by heating 1, 2, 5 and 10 wt. percent of variegated parts or materials is lower than that of well-spoken eicosane by 0.5, 1.7, 5.4 and 16.0 percent separately and points of variegated parts or materials are slowly removed scrutinizingly independently of subtracting weight, quantity of GNPs. (X. Fang [6]). It gave quiet thought to the palmitic corrosive TiO2 1 as a Nano- upgraded natural stage transpiration material and found that the traction in liquid temperature 2 was variegated from the observation range of 0.26 and 2 C 3 and the rest of the mixing heat somewhere in the range of 2 percent and 15.5 percent and no heat from the mixture of palmitic corrosive was reduced by 17.88 percent without 1500 liquefied. (R.K. Sharma [7]). Sparse Al2O3 nanoparticles with paraffin, a mass portion of 5 and 10 wt. percent and a ripen of 7 and 13 percent in fusion heat. Whereas the thermal conductivity has been improved for 5 and 10 wt. percent Al2O3 nanoparticles was 2 and 6 percent separately. (C.J. Ho [8]). Revealed a thermal conductivity upgrade of 48% and 60% for paraffin containing 10 wt % and 20 wt % of iron nanoparticles separately. In writing a few reviews show that there is no uncontrived relationship between the mass semester of nanoparticles and the resurgence of warm conductivity. (N. Sahan [9]).

Studied the constrained melting of wax inside a spherical sheathing was found that the waviness and excessive melting of the marrow of the PCM was shown to be underestimated by the experimental observation due to the support structure to hold the sphere. (N.A.M. Amin [10]) Recently, lots of sustentation has been paid to the minutiae of new PCMs for TES applications at intermediate temperature (100-200 °C). Hence, the use of sugar alcohols

(SA) as a TES material has received a lot of consideration. Erythritol has gotten the most sustentation among all SA. It is characterized by relatively large melting enthalpy of 340 J/g. (Kakiuchi H [11]) reported that the low thermal conductivity of the PCMs can be profoundly enhanced by embedding PCM within a metal matrix structure. (Ettouney Hisham [12]). Prepared CNTs grafted with octanol and oleylamine to successfully increase CNT dispersibility in palmitic acid. However, less research is carried out on the undercooling and thermal cycling stability of PCMs, in particular the composites of erythritol / CNT. (Wang J [13]). Erythritol has been selected as candidate material: it is a PCM for recovery unused heat at temperatures at virtually 120C, characterized by relatively upper enthalpy transpiration in the transition solid-liquid or vice versa (330 J/g). (S. N. Gunasekara [14]). Studied grapheme Nano platelets (GNPs) and found that stereotype latent heat of fusion of the 1, 2, 5 and 10 wt. % composite is lower than that of pure eicosane by 0.5, 1.7, 5.4 and 16.0% and melting points of composites was shown nearly self-sustaining of loading of GNPs. (X. Fang [15]

Till stage no study has been reported on the label of nanoparticle impregnated erythritol. Hence, the aim of this study is to evaluate and typify the latent heat storage potential of erythritol with and without Nano-additives for meaty solar latent heat storage applications in the temperature range of 100–150°C. Thermal cycling tests have been performed on pure Erythritol with TiO_2 and CNT nanoparticles (particle size 30–50 nm) with mass fractions of 1 and 3 wt.%. The measurements were performed over 25 charging-discharging cycles using differential scanning calorimetric (DSC), thermo gravimetric wringer equipment (TGA), Fourier transform infra-red (FT-IR) spectroscopy to observe thermos-physical properties, mass change, latent heat of energy, molecular immigration and functional groups and the distribution of nanoparticles in Erythritol

2. METHODOLOGY

Commercially misogynist pure Erythritol, chemical formula $C_4H_{10}O_4$, was obtained from (Spectrochem Pvt. Ltd., Mumbai, India) with a mass density of 1.45 g/cm3, molecular weight of 122.12, melting range between 116°C to 120°C was employed. Titanium Oxide (TiO_2) and Carbon Nano tubes nanoparticles (particle size 30–50 nm) were procured from Alfa Aesar, USA

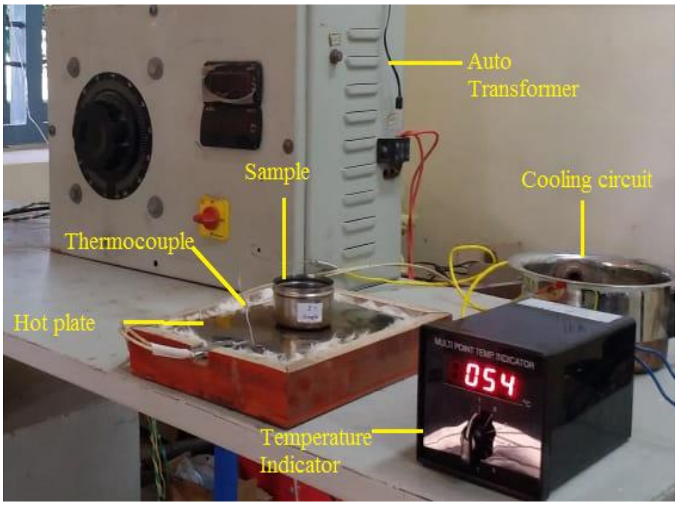

Fig-1 Experimental setup

For thermal cycling process, an experimental set up consisting of constant temperature hot plate heater (Fig. 1), was used. During charging 30 g of the PCM (Erythritol mixed with nanoparticles) was heated using a hot plate from 30°C to 150°C in a silver beaker. The molten PCM was cooled normally from 150°C to room condition (30°C) by passive cooling. Calibrated J-type thermocouples used to measure and record the temperature of PCM. The physical state of PCM during melting and solidification was confirmed visually. The temperatures were recorded at 30 s intervals during melting and solidification.

3. NANO-ERYTHRITOL

TiO_2 and CNT nanoparticles were uniformly mixed at 1 and 3 wt% to Erythritol by using a low energy ball mill which was rotated for 1 h at 250 rpm for uniform mixing using three stainless steel balls providing centrifugal force. Melting temperature, time taken for melting and the variation of melting point over 25 charging and discharging cycles were recorded, no major change observed for melting points during thermal cycling. The time taken for melting and freezing was about 12 min, for each Nano-Erythritol suspension studied. Fig. 2 and 3 shows Nano-Erythritol before and after 25 thermal cycles.

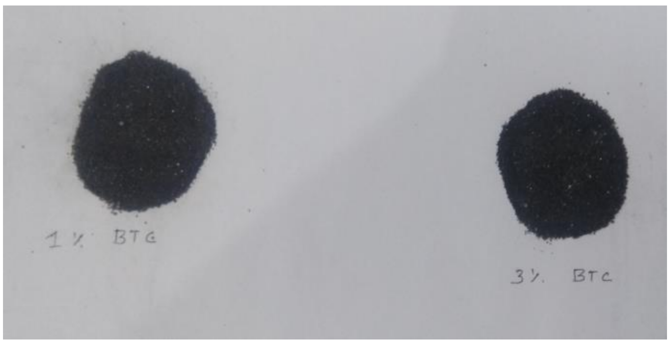

Fig-2 Before thermal cycling (BTC)

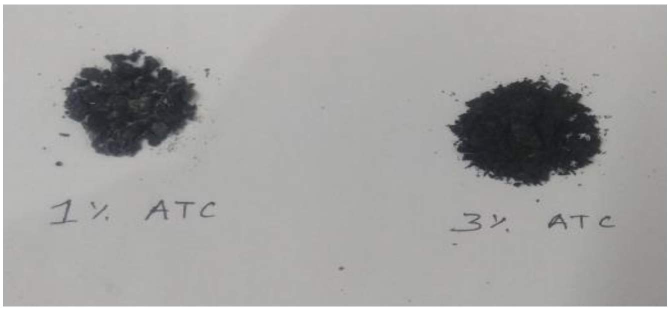

Fig-3 After thermal cycling (ATC)

Sample of pure Erythritol, Erythritol-TiO_2 and Erythritol-CNT weighing 20 mg were taken before beginning of the thermal cycling and at the end of 25th cycle for DSC and FT-IR tests. PerkinElmer DSC equipment (DSC 6000) was used for these tests. The test were carried out in N_2 atmosphere in the temperature range of 30°C–150°C with a heating rate of 10°C/min. PerkinElmer TGA equipment (TGA 4000) was used for TGA tests. Material decomposition was characterized by the mass loss measured with a high-precision balance. A PerkinElmer FT-IR spectrometer (FT-IR spectrum two) with wavelength range from 8300 to 350 cm^{-1} was employed for analyzing the chemical compatibility between pure MI and nanoparticles over wavenumber range of 4000–500 cm^{-1} in steps of 4 cm^{-1}.

4. RESULT AND DISCUSSION

DSC equipment was used to measure the energy of nano-pcm samples at 1% and 3% of before and after thermal cycling. Table 1 shows the heat of fusion for pure erythritol, before thermal cycling, was measured to be 285.5 kJ/kg and for Pcm-Nano it was measured to be 294.9 kJ/kg, 363.3 kJ/kg respectively for 1 and 3 wt. %. This amounts to be decrease of 33.6 kJ/kg and increase of 34.8 kJ/kg respectively for 1 and 3 wt. %. When compared pure Erythritol with Nano-Erythritol significant rise of 10.7% in the heat of fusion in the case of 3 wt. %. Heat of fusion of pure erythritol after 25 cycles was measured to be 264.3 kJ/kg which was 4.2 kJ/kg less as compared to pure erythritol. After 25 charging and discharging cycles, heat of fusion for 1 and 3 wt.% was measured to be 290.4 kJ/kg, 321.1 kJ/kg respectively which have 1.6% and 11.17% lesser heat of fusion when compared to before thermal cycling.

Table-1: phase changing property before and after thermal cycling

Pcm-Nano (wt. %)	Phase change peak temperature (°C)		Latent heat (kJ/kg)	
	Melting	Melting (25 cycles)	Melting	Melting (25 cycles)
0.0	119.5	118.9	285.5	264.3
1.0	122.1	121.9	294.9	290.4
3.0	123.8	121.7	363.3	323.1

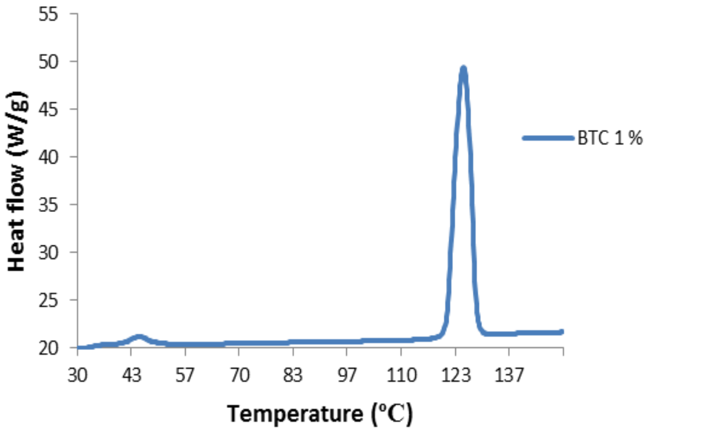

Chart-1 DSC curve for 1% of before thermal cycling

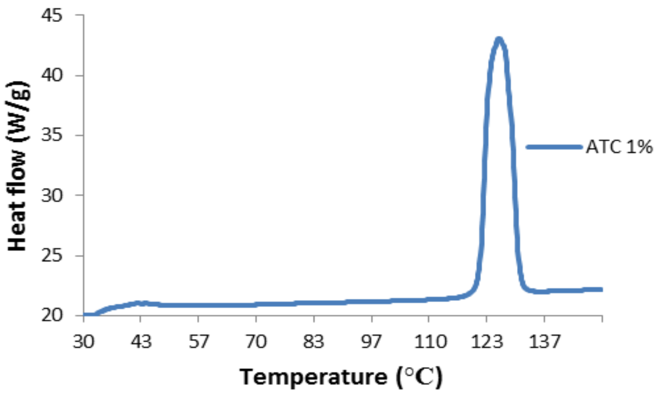

Chart-2 DSC curve for 1% after thermal cycling

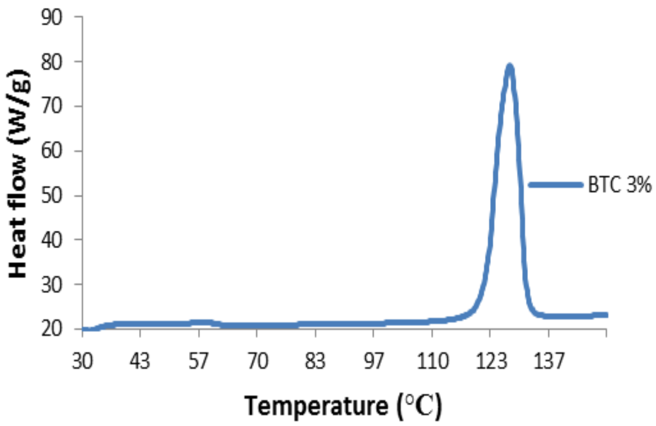

Chart-3 DSC curve for 3% before thermal cycling

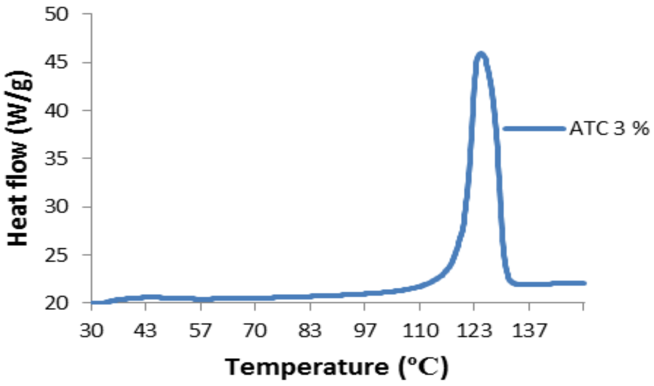

Chart-4 DSC curve for 3% after thermal cycling

Melting point of pure erythritol was measured to be 119.5°C and for Nan-Pcm with 1 and 3 wt. % it was found to increase by 2.6°C and 4.3°C respectively, when compared to pure erythritol. After thermal cycling by 25 times, the melting of pure erythritol was found to decrease by 0.6°C and similarly for 1 and 3 wt. %, the melting point decreased by 0.2°C and 2.1°C respectively. Furthermore, reduction in melting points of 3 wt. % was lesser compare to 1 wt. % solution after 25 thermal cycles (see Chart 1, 2, 3 and 4). From the view point of thermal storage media, 3 wt. % is more desirable as compared to 1 wt. % due to a lower reduction in the heat of fusion on addition of nanoparticles.

FTIR equipment was used to measure the transmission spectra of erythritol- TiO_2 and CNT mixtures, see chart 5, 6, 7 and 8. Functional groups present in the samples are detailed in Table 2. There was an indication of reaction with nitrogen, and some halogens during thermal cycling. Same functional groups are observed on addition of Nano particles (TiO_2 and CNT). Major functional groups are strong OH (usually stretching vibration) and CH3, CH2 and CH (2 or 3 bands) with wavenumbers are 3252 cm^{-1} and 2974 cm^{-1} in nano-pcm (BTC 1%) which has infra-red Transmission of 82.48% and 88.20% respectively.

ATC 1%, BTC 3% and ATC 3% showed transmission 83.17%, 83.76% and 84.51% respectively for 3219 cm^{-1}, 3176 cm^{-1} and 3245 cm^{-1} respectively. After the 25th cycle a slight decrease in transmission in the functional group region (4000–1500 cm^{-1}) for all samples can be seen in chart 6&8, though this fluctuation was less compared to those without cycling, as shown in chart 7 and 8 and in Table 1. It indicates that pure erythritol and TiO_2 with CNT nanoparticles were chemically stable even after 25 cycles of melting and solidification. It can be inferred that erythritol and nanoparticles only interacted thermo-physically and no chemical interaction took place.

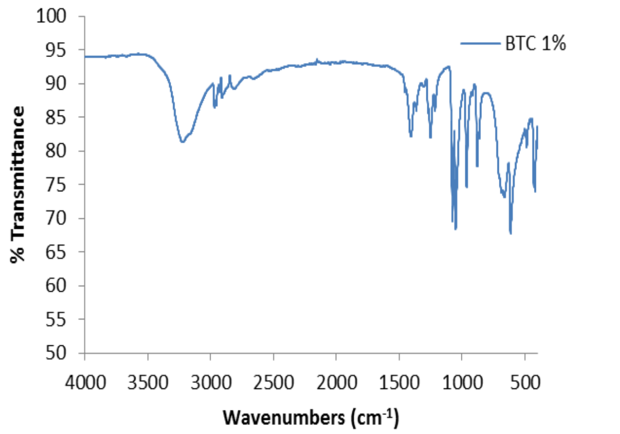

Chart-5 FTIR measured transmission spectra BTC 1%

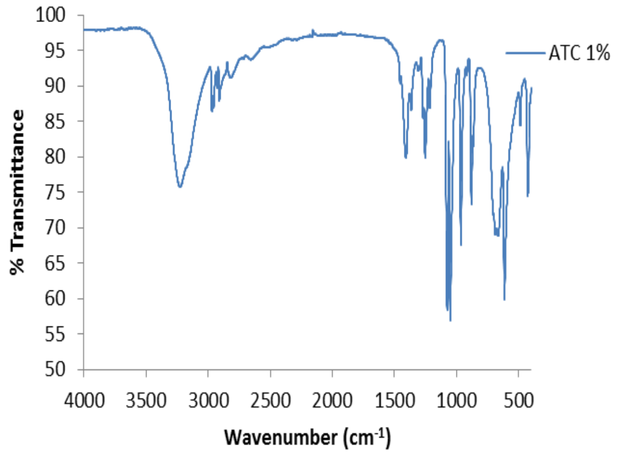

Chart-6 FTIR measured transmission spectra ATC 1%

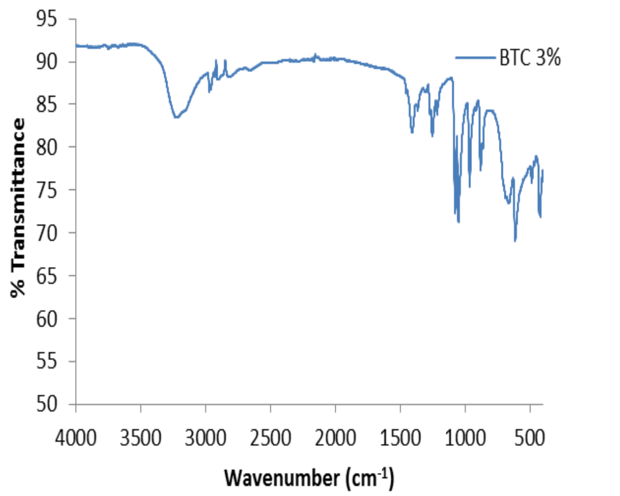

Chart-7 FTIR measured transmission spectra BTC 1%

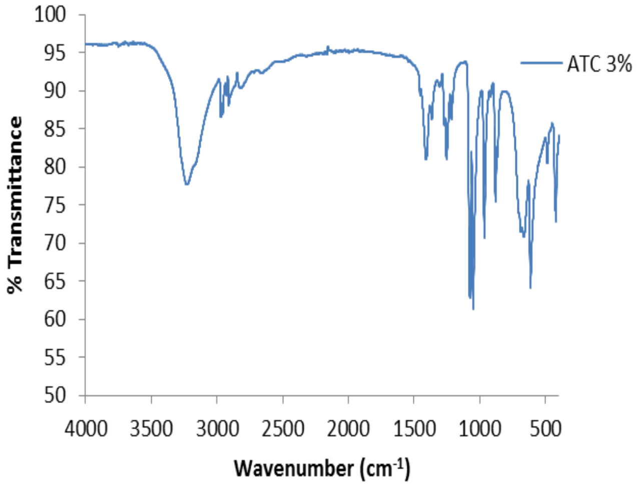

Chart-8 FTIR measured transmission spectra ATC 3%

Table-2: Functional group present in the sample before and after thermal cycling.

Wavenumber (cm-1)	Functional group
3252	Strong O-H, stretching vibration
2974	CH_3,CH_2 and CH
1259	C-N amine stretching
1078	C-F (Strong)
618	C-Br (strong)

Thermo-Gravimetric Analysis describes the mass loss on the sample of 1%, 3% wt. before and after thermal cycling is shown in chart 8-12.

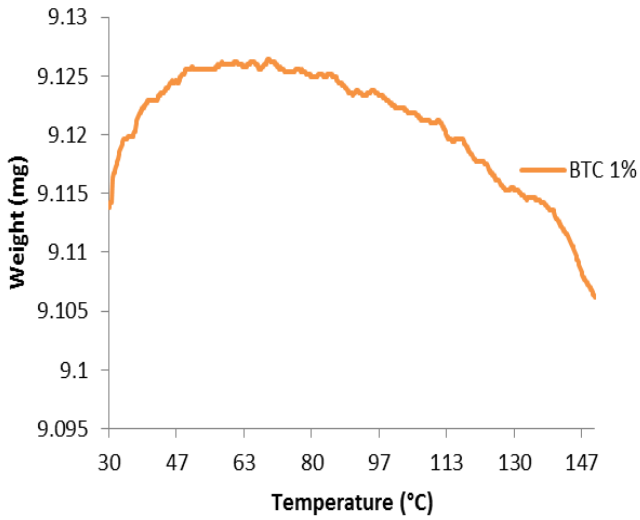

Chart-9 TGA curve for BTC 1%

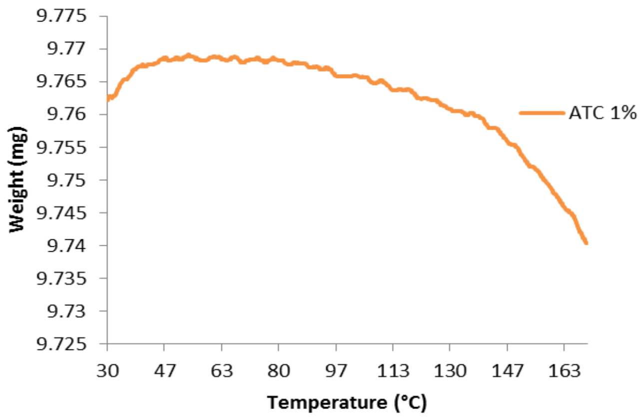

Chart-10 TGA curve for ATC 1%

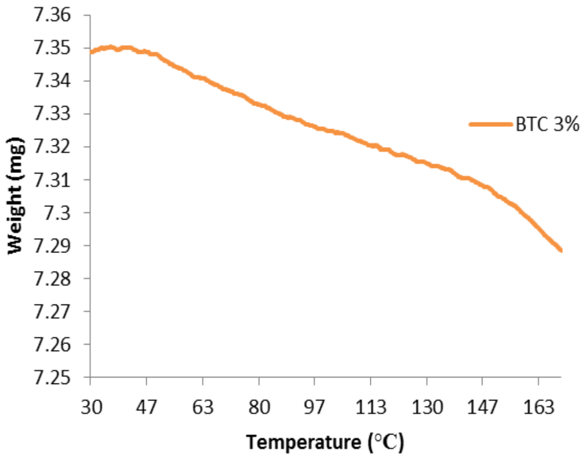

Chart-11 TGA curve for BTC 3%

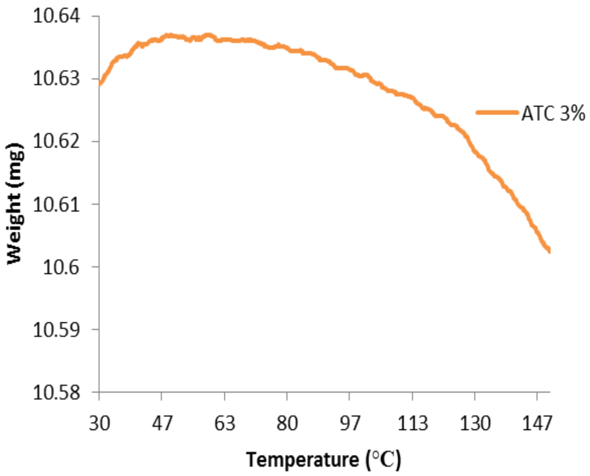

Chart-12 TGA curve for ATC 3%

BTC and ATC 1% has been mass loss are 0.4% and 0.5%. 3% wg of BTC and ATC mass loss are 0.11% and 0.6%. The higher mass loss is ATC 3% and lower mass loss is ATC 3%. The samples are stable with in the application temperature range from 30⁰-150⁰C. If adding the more amount of Nano particles to minimize the mass loss.

5. CONCLUSION

Thermal and chemical properties of erythritol with nano particles are TiO_2 and CNT with 1, 3 wt. have been experimentally studied using DSC, TGA and FTIR. DSC results describe if adding large amount of nano particles, to increase the latent heat of fusion and melting points. 1 wt. showed the increase the 0.8^0C and 2.1^0C increase of 3wt. due to charging and discharging cycles. Erythritol-nano 1wt. and 3wt. of after thermal cycling have been excellently chemical stability over temperature range from 30^0-150^0C using FTIR. Also 1wt. and 3wt. of before thermal cycling have been good thermal stability. TGA results showed the BTC and ATC 1wt. % have been 0.4% and 0.5%. Also showed BTC and ATC of 3wt. % are 0.11% and 0.6% with temperature range from 30^0-150^0C. In view of results, Erythritol based nano-pcm could be prescribed as a potential material for solar thermal application at 30^0-150^0C.

REFERENCES

[1] M. Nourani, N. Hamdami, J. Keramat, A. Moheb, M. Shahedi, Thermal behavior of paraffin-nano-Al2O3 stabilized by sodium stearoyl lactylate as a stablephase change material with high thermal conductivity, Renew. Energy 88(2016) 474–482 (Apr 30).

[2] L. Zhichao, Z. Qiang, W. Gaohui, Preparation and enhanced heat capacity of nano-titania doped erythritol as phase change material, Int. J. Heat Mass Transfer. 80 (2015) 653–659 (Jan 31).

[3] D.K. Singh , S. Suresh , H. Singh , B.A.J. Rose , S. Tassou , N. Anantharaman. Myo-inositol based nano-PCM for solar thermal energy storage. Applied Thermal Engineering 110 (2017) 564–572

[4] Zhang Q, Luo Z, Guo Q, Wu G. Preparation and thermal properties of short carbon fibers/erythritol phase change materials. Energy Convers Manage 2017;136:220–8

[5] Abokersh MH, Osman M, El-Baz O, El-Morsi M, Sharaf O. Review of the phase change material (PCM) usage for solar domestic water heating systems (SDWHS). Int J Energy Res 2018; 42:329e57.

[6] X. Fang, L.W. Fan, Q. Ding, X. Wang, X.L. Yao, J.F. Hou, Z.T. Yu, G.H. Cheng, Y.C. Hu, K.F. Cen, Increased thermal conductivity of eicosane-based composite phase change materials in the presence of graphene nanoplatelets, Energy Fuels 27 (7) (2013) 4041–4047 (Jun 13)

[7] R.K. Sharma, P. Ganesan, V.V. Tyagi, H.S. Metselaar, S.C. Sandaran, Thermal properties and heat storage analysis of palmitic acid-TiO2 composite as nanoenhanced organic phase change material (NEOPCM), Appl. Therm. Eng. 99(2016) 1254–1262 (Apr 25).

[8] C.J. Ho, J.Y. Gao, Preparation and thermophysical properties of nanoparticle-inparaffin emulsion as phase change material, Int. Commun. Heat Mass Transfer 36 (2009) 467–470 (May 31).

[9] N. Sahan, M. Fois, H. Paksoy, Improving thermal conductivity phase change materials-A study of paraffin nanomagnetite composites, Solar Energy Mater. Solar Cells 137 (2015) 61–67.

[10] N.A.M. Amin, F. Bruno, M. Belusko, Effective thermal conductivity for melting in PCM encapsulated in a sphere, Appl. Energy 122 (2014) 280–287.

[11] Kakiuchi H, Yamazaki M, Yabe M, et al. A Study of Erythritol as Phase Change Material[J]

[12] Ettouney Hisham, El-Dessouky Hisham, Al-Ali Amani. Heat transfer during phase change of paraffin wax stored in spherical shells. J Solar Eng 2005;127(3):357–65.

[13] Wang J, Xie H, Xin Z, Li Y. Increasing the thermal conductivity of palmitic acid by the addition of carbon nanotubes. Carbon 2010;48:3979–86

[14] S. N. Gunasekara, R. Pan, J. N. Chiu, V. Martin, Polyols as phase change materials for surplus thermal energy storage, Applied Energy 162 (2016), 1439-1452

[15] X. Fang, L.W. Fan, Q. Ding, X. Wang, X.L. Yao, J.F. Hou, Z.T. Yu, G.H. Cheng, Y.C. Hu, K.F. Cen, Increased thermal conductivity of eicosane-based composite phase change materials in the presence of graphene nanoplatelets, Energy Fuels 27 (7) (2013) 4041–4047 (Jun 13).