

THERMAL PERFORMANCE ANALYSIS OF NANO ENHANCED PARAFFIN WAX AND MYRISTIC ACID

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ABSTRACT

In the present study, Paraffin wax and Myristic acid were chosen as phase change materials for the analysis. Further, nanoparticles of copper and micro particles of aluminium and Graphite were used for the analysis of enhancement in thermal performance of phase change materials. Charging and storing period analysis have also been conducted to compare the performance of different composites. From the charging period analysis, it has been found that Graphite composites are performing better than copper and aluminium composites. From the both charging and storing period analysis, among composites of Paraffin wax, both 1% copper and 1% graphite composites are giving more satisfactory results than all other composites of paraffin wax and among composites of Myristic acid, it can be concluded that graphite composites are giving more satisfactory results than all other composite, in which 3% graphite is the optimum composition.

KEYWORDS: Phase change materials, energy storage, nano composite

1.0 INTRODUCTION

The standard of living in a society is measured by the amount energy consumed. The development of an efficient non-conventional energy harvesting system is an important approach to reduce the climatic changes and dependence on conventional fuels. Since the availability of some the main renewable energy sources is not continuous and the demand and the supply of the energy normally does not occur simultaneously, there is need of efficient thermal energy storage system. Phase change materials (PCMs) are the better option to store these excess energy when their availability is more can be made use when demand arises.

Abhat (1993) compared the performance of sensible heat and latent heat thermal energy storage, concluded that PCM can achieve a significant reduction in storage volume. Bjurstrom, Carlsson (1985) and Adebiyi, Russell (1987) studied on charging of PCM and concluded that when the melting temperature of PCM is equal to the geometric mean of the ambient temperature and temperature of HTF, maximum exergy would be recovered from HTF. Velraj et al. (1999) performed an experiment on heat transfer

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enhancement in LHTES using bubble agitation in this they poured small amount of water in a tube which was evacuated so that the saturation temperature of water is equal to the phase change temperature of PCM, this help in heat transfer enhancement by creating steam bubbles. Hoshi et al. (2005) classified the storage materials based on their melting points, such as low temperature materials ($MP < 220^{\circ}\text{C}$), medium temperature materials (MP up to 420°C) and high temperature materials ($MP > 420^{\circ}\text{C}$). Zalba et al. (2003) compared the properties of organic and inorganic PCMs and found that high latent heat as the positive aspect and least corrosion resistance, highly thermal/chemical instability are negative aspects of inorganic PCMs. Lecuona et al. (2013) performed experiments on portable solar cooker of the standard concentrating parabolic type by incorporating technical grade paraffin and erythritol as PCMs. Al-Kayie et al. (2014) presented effects of various inclination (10,20 and 30) on solar water heater integrated with a PCM nanocomposite (without TES, with paraffin wax PCM and with copper Nano composite of paraffin wax) and results indicated that there was a considerable enhancement in performance of the system with paraffin wax, while in the case of nanocomposite no significant enhancement was observed. Mahfuz et al. (2014) analysed the performance of paraffin wax based PCM thermal energy storage shell and tube water heating system by the exergy, energy and cost analyses. The charging of the paraffin wax PCM, paraffin wax was done during the day time. The energy, exergy efficiencies of the thermal storage system and total life cycle cost were developed for different flow rate of the heat transfer fluid. Chaichan and Kazem (2015) investigated the use of phase change material for extracting solar energy from the concentrated solar heater for water distillation. The solar energy stored in the paraffin wax PCM during the day time is used for the distillation purpose which increased the distillation efficiency of the system and there by the productivity increased by about 180%. Zhao et al. (2013) investigated the high temperature energy storage using encapsulated phase change materials for storing solar energy and conducted transient two-dimensional heat transfer analysis. NaNO_3 encapsulated with stainless steel in a cylindrical shaped capsule is used as phase change material. Elmozughi et al. (2014) did the analysis of encapsulated phase change materials by considering 20% void and buoyancy driven convection in a stainless steel capsule. The effect of thermal and volume expansions of the potential PCM sodium nitrate during charging and discharging were evaluated. Memona et al. (2015) prepared macro-encapsulated paraffin light weight aggregate for the development of normal weight aggregate concrete by the introduction of paraffin into porous light weight aggregate through vacuum impregnation. Sancheza et al. (2015) did studies on a thermal storage system for solar power plant consists of a thermocline tank with PCM capsules together with filler materials. It was based on the principle of multi-layered solid-PCM thermocline. The encapsulation was done by developing an external coating over a PCM pellet. Cai et al. (2011) studied the effect of Nano SiO_2 addition on the morphology, thermal energy storage, thermal stability and combustion properties of electro spun lauric acid/ polyethylene terephthalate (PET) ultrafine composite fibres as form stable phase change materials. The results showed that the LA/PET SiO_2 composite fibres with nano- SiO_2 had desired morphologies with reduced average fibre diameters as compared to the LA/PET fibres without nano- SiO_2 due to the increased conductivity of the spin dopes and the strong hydrogen bonding among the components in the fibres and the incorporation of nano- SiO_2 increased the thermal degradation temperature. Li (2013) analysed the effect of addition of Nano graphite on the thermal conductivity of paraffin based PCM. The dispersed Nano graphite enhanced the heat transfer and the

charging performance in terms of efficiency of PCM. Yang et al. (2014) explored the effect of Nano Si_3N_4 on the thermal behaviour of Si_3N_4 / paraffin composites. The melting processes were monitored by 3D optical microscopy. Transient Hot-Bridge method (THB-Instrument, Linseis, Inc.) was approached to measure the thermal conductivities. With the Nano- Si_3N_4 addition the thermal conductivity of the PCM was enhanced by 35% and the thermal diffusivity of the PCM by 47%. Jiang et al. (2015) did the synthesis, characterisation and analysis of the morphology, phase change behaviour, thermal energy storage and thermoregulation performance, thermal stability, as well as heat-transfer properties of paraffin micro capsules modified with Nano Al_2O_3 . Nourani et al. (2016) investigated the phase change temperature, heating rate, latent heat and effective thermal conductivity of paraffin – nano – Al_2O_3 stabilized by Sodium stearoyl lactylate as a stable phase change material with a high thermal conductivity for application in solar energy storage systems where sodium stearoyl lactylate was used as a surfactant. . The results showed that the effective thermal conductivity of the PCMs thus prepared increased by increasing nano- Al_2O_3 mass fraction, showing a nonlinear relationship with mass fraction in both the solid and liquid states. Sharma et al. studied the thermal behaviour of composite of palmitic acid and TiO_2 nano particles for thermal energy storage system and the thermal energy storage behaviour, morphology, chemical compatibility and other thermal properties of these composites were investigated. In the present work we have chosen Paraffin wax and Myristic acid as PCM. Since the melting temperature of both the materials are above 50, these are suitable for applications like solar water heating, solar stills, solar dryers, solar air heaters etc. But the low thermal conductivity (0.2W/mK) hampers its application, though both have very high latent heat of fusion. The addition of nano particle can overcome the shortcomings of the selected PCM, like low thermal conductivity and supercooling.

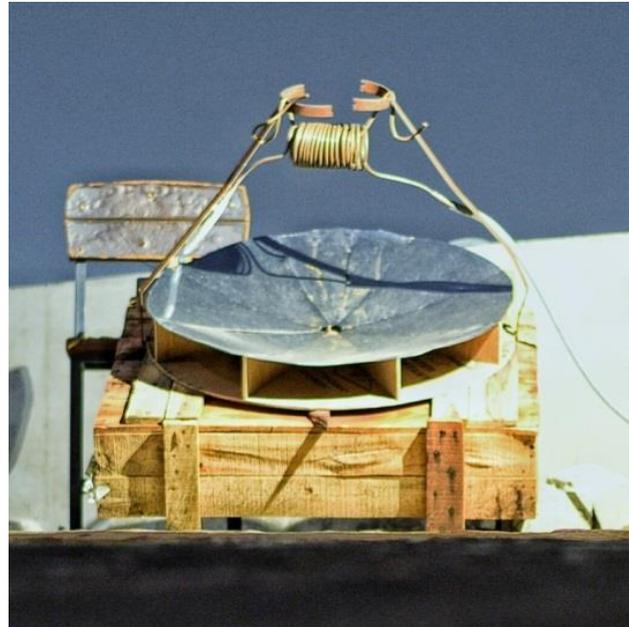
In the present work, designing and fabrication of an economical system which uses low melting point PCMs for storing energy and analysing the effect of addition of different nano sized metallic particles in the charging and discharging period of PCM.

2.0 METHODOLOGY

2.1 Experimental setup

The experimental apparatus consists of insulated hot water bath, hot water pump, parabolic solar concentrator with copper water circulation coil, copper helical coil heat exchanger, PCM cylinder, data acquisition system (Agilent 34972A LXI), T type thermocouples and insulation tanks for storage. The main components of the experimental setup are shown in its pictorial view in Figure 1(a&b). Water was stored in hot water tank which is having multi-layer insulation such as black spray paint, cardboard, thermocol covered with Aluminium foil and black sheet. Water was pumped into the coil attached with solar concentrator using the hot water pump (model star RS25/6 WILO company Germany, capacity 800 -3400 litre per hour, head of 2-6 m) connected to the tank. Parabolic solar concentrator fabricated from Aluminium sheet and multi loop 3/8 in copper coil was placed just below the focus (focal length of 50 cm) so that the entire area of the coil was covered by the concentrated solar radiation. The hot water was made to flow through the helical copper coil heat exchanger constructed from copper (1/4" diameter) tube having outer diameter 8cm and length

10cm, it was placed in a borosilicate 1 L container containing PCM (Paraffin wax and Myristic acid composites) is shown in Figure 2(a), this container along with heat exchanger was kept in insulation box insulated similar as that of hot water tank finally the water flow back to hot water tank from the heat exchanger. Three insulation boxes were constructed for the storage of the charged



(a)



(b)

Figure 1. Parabolic collector (a) and the photograph of the experimental set-up (b)

Table1. Properties of Paraffin Wax and Myristic acid

Material	Melting point(°C)	Latent heat of fusion(kJ/kgK)	Thermal conductivity(w/mK)	Density(kg/m ³)
Paraffin Wax	58-60	189	0.21 (s)	795 (l, 70°C) 920 (s,20°C)
Myristic acid	52-54	204	0.17 (s)	861 (l, 55°C) 990 (s,24°C)

PCMs is shown in Figure 2(b). Two T type thermocouples were fixed, one at the inside of the coil and other at the periphery of the container. PCMs used are the Paraffin wax and Myristic acid. Micro particles used are the copper, graphite and aluminium, with compositions 1%, 3%, and 5%. The properties of PCMs and Nano particles used in the present study are given in Table 1 and Table 2

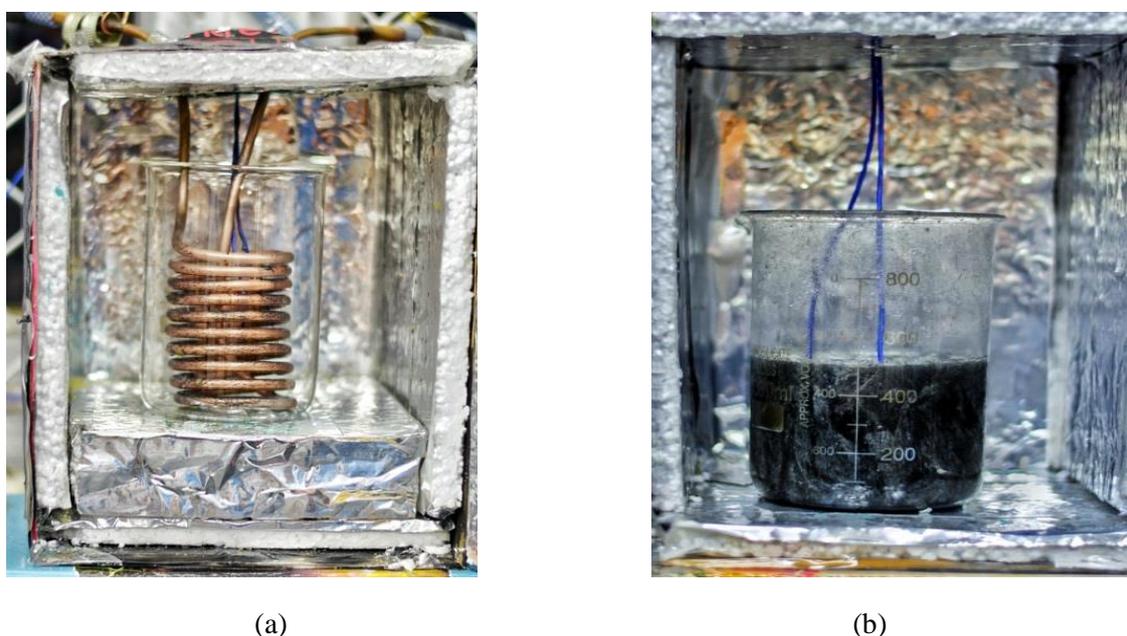


Figure 2. Insulated charging box with copper coil heat exchanger and PCM container (a) and Insulated storage box with sample for storing (b).

Table 2. Properties of added materials to Paraffin Wax and Myristic acid

Material	Size	Thermal conductivity(w/mK)	Purity (%)
Copper	30-50nm	350-380	99.5
Graphite	400-1200nm	150-180	99.8
Aluminium	40µm	200-240	98

2.2 Experimentation Procedure

500g of required PCM was kept in hot water bath to ensure the complete melting, this molten PCM was taken out of the hot water and kept on the magnetic stirrer followed by ultra sonicator for around 3-4 hours. The required quantities of micro particles are added to the molten PCMs, later it was removed from the sonicator and kept in cold water bath to solidify. After ensuring the complete solidification of the composites, it is removed from the container and grinded into powder with the help of dry grinder then the grinded powder is kept in the charging container. Twenty composites samples of Paraffin wax and Myristic acid are shown in Figure 3(a)-3(t). Fill the powdered sample in the container kept in the storage box and Ensure that the thermocouple positions are maintained. Connect the data acquisition system to the laptop, with the Keysight connection expert software make the interface between data acquisition system and laptop. Then launch the Keysight benchvue software to select the thermocouple whose values are to be recorded. In order to have similar operating condition water from hot water tank is pumped to the coil kept at the focus of solar concentrator and this water is bypassed to tank without allowing it to pass through test coil. The procedure will continue till the required operating condition is reached. Once the required temperature is attained the water from solar coil is made to pass through the test coil till the PCM is completely melted. After the complete melting the PCM container is removed from the charging box and kept in storage box and the PCM temperature is recorded for eight hours.



(a) Pure Paraffin wax



(b) 1% Copper



(c) 3% Copper



(d) 5% Copper



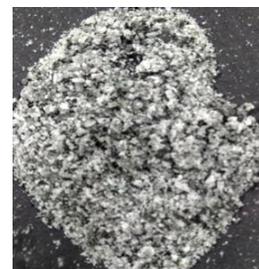
(e) 1% Al



(f) 3% Al



(g) 5% Al



(h) 1% graphite

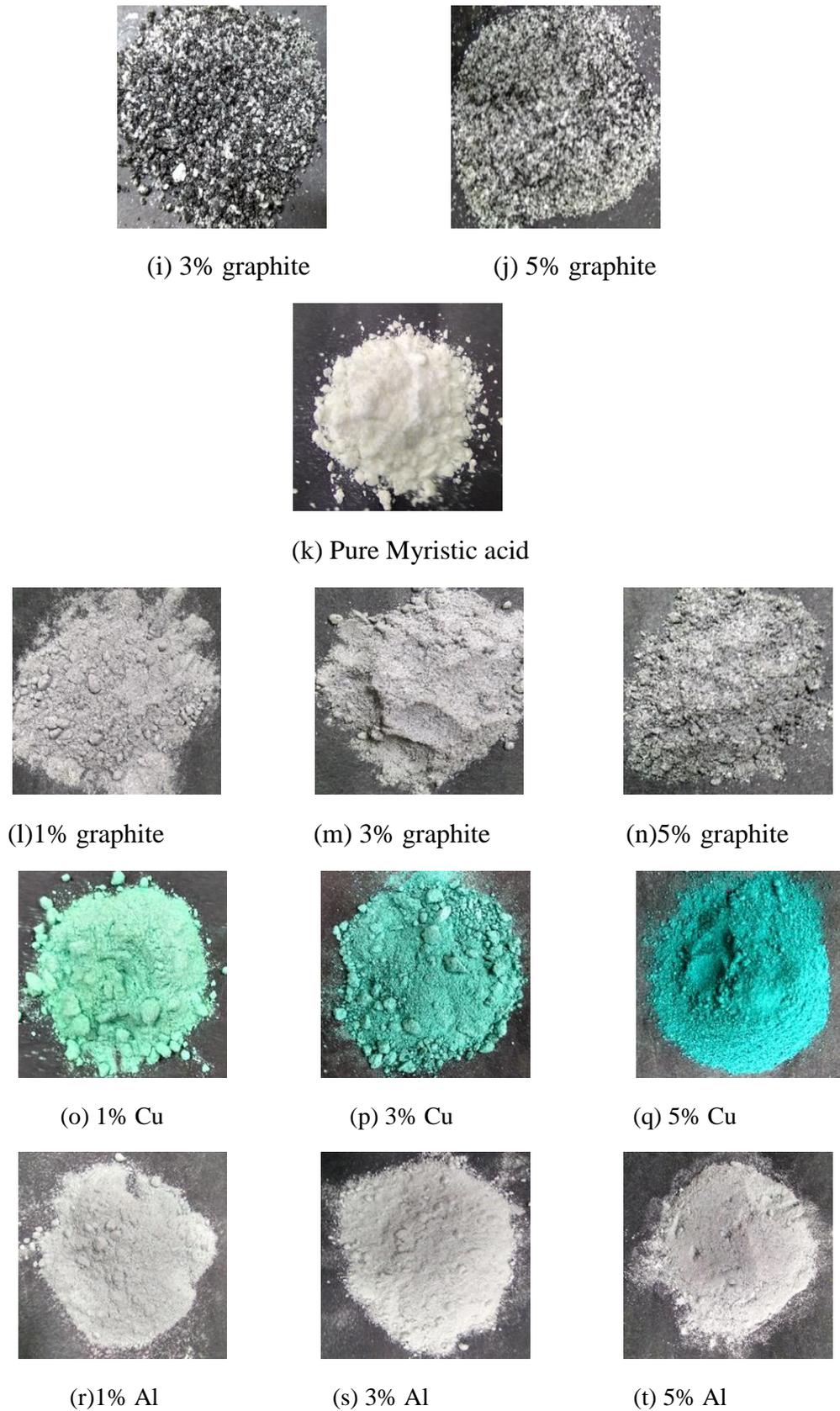


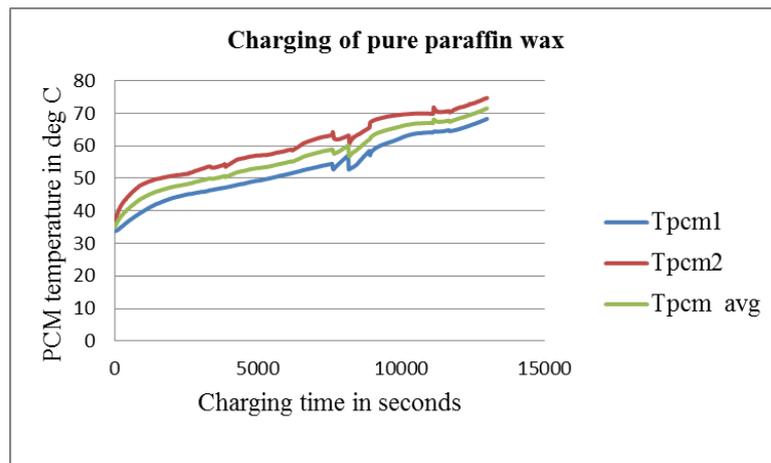
Figure 3. Samples of Paraffin wax and its composites (a) to (j), and Myristic acid and its composites (k) to (t).

3.0 RESULTS AND DISCUSSIONS

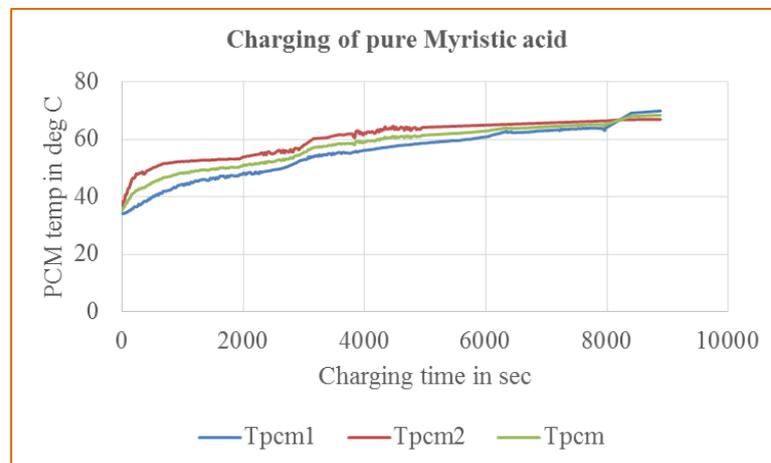
3.1 Charging Period analysis

3.1.1 Pure Paraffin wax and pure Myristic acid

During experimentation it is found that pure paraffin wax took 3h 5min and pure Myristic acid took 2h 40min for complete charging. The variation of PCM temperatures with time during charging of pure Paraffin wax and pure Myristic acid is shown in Figure 4(a)-4(b).



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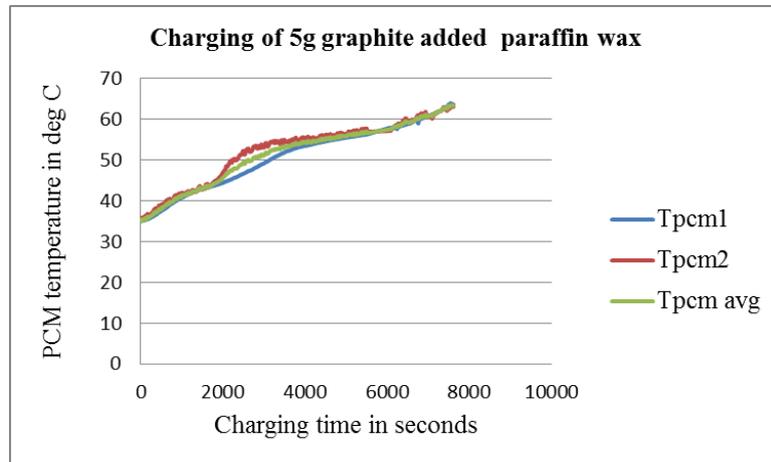


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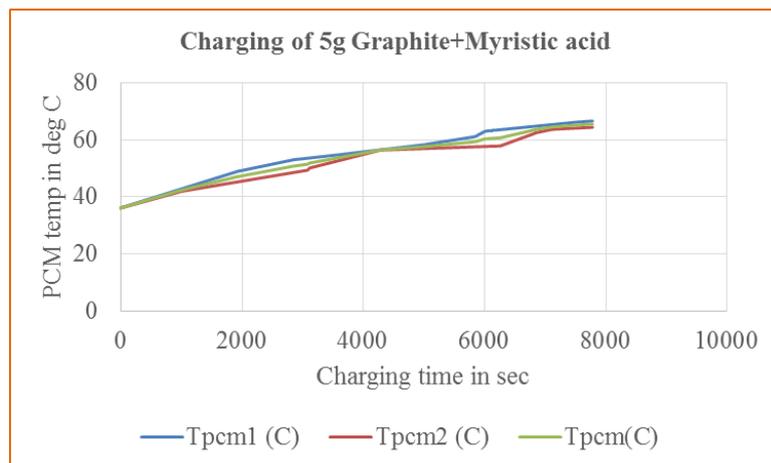
Figure 4 (a). Charging time vs PCM temp of Pure Paraffin Wax (b).Charging time vs PCM temp of Pure Myristic acid

3.1.2 With Graphite micro particles

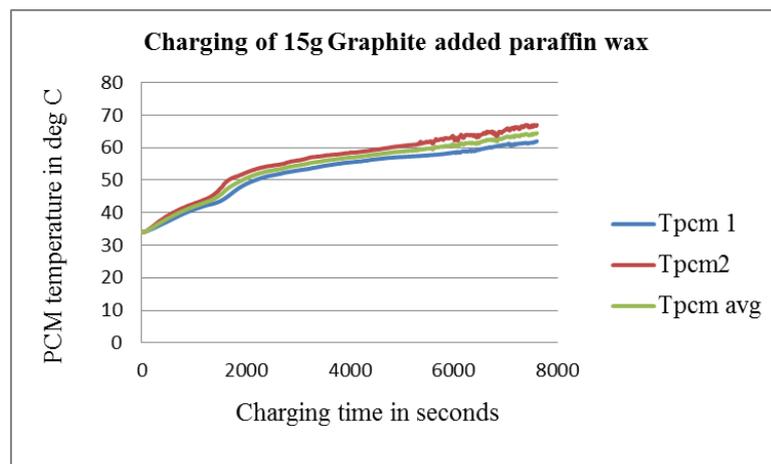
The variation of PCM temperatures with time during charging of different compositions of graphite micro composites of Paraffin Wax and Myristic acid is shown in Figure 5(a)-5(f).



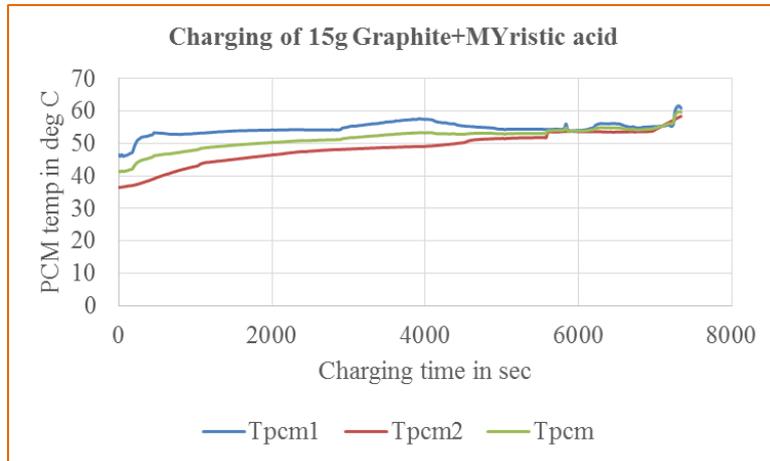
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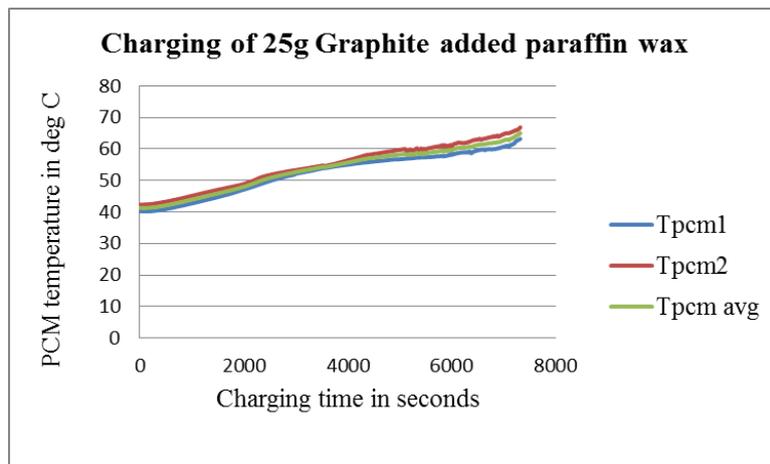
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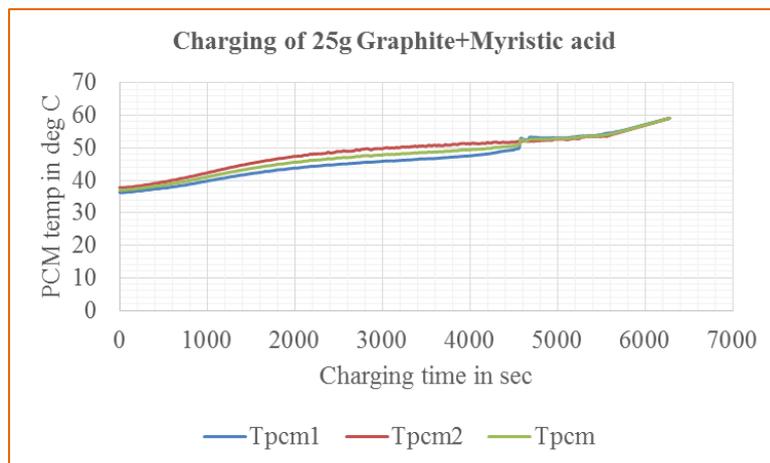
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(d)



(e)



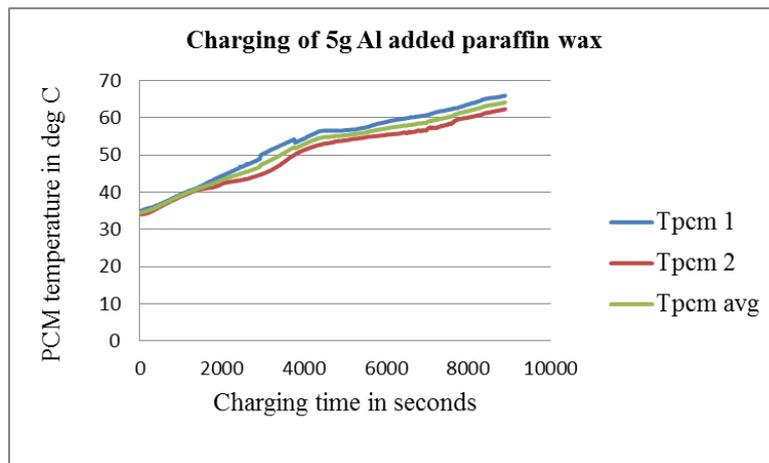
(f)

Figure 5 (a) Charging time vs PCM temp of 5g Graphite added in Paraffin Wax (b) in Myristic acid(c), of 15g Graphite added in Paraffin Wax (d) of 15g Graphite added in Myristic acid(e) Charging time vs PCM temp of 25g Graphite added in Paraffin Wax (f) Charging time vs PCM temp of 25g Graphite added in Myristic acid

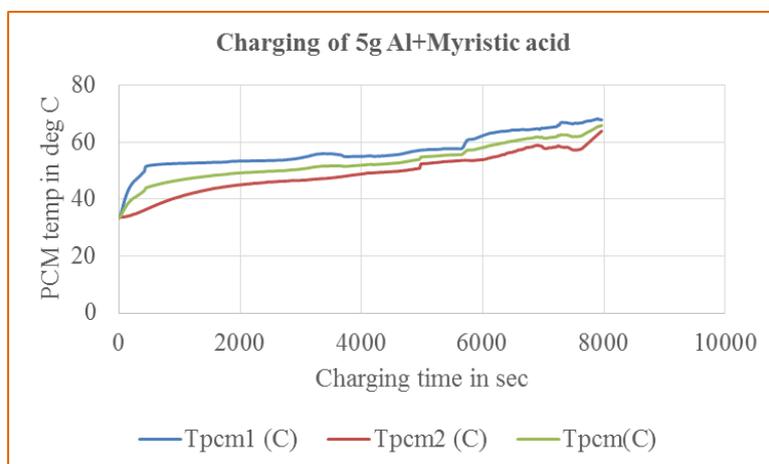
On addition of 1% Graphite micro particles to pure paraffin wax, the charging time duration is reduced to 2 h 15 min, with 3% Graphite micro particles it took 2h 7 min and with 5% Graphite micro particles found to be completely melted in 2h 2 min. In the case of Myristic acid, 1% Graphite composite took 2h 12 mins for complete melting and 3% Graphite composite charging time is found to be 1h 56 min and for 5% Graphite composite of Myristic acid it was 1h 44 min. Since the density of Graphite micro particles is low, it dispersed uniformly during the stirring and it is found that deposition rate of Graphite micro particles is less and moreover high thermal conducting graphite particles made the composite conductive.

3.1.3 With Aluminium micro particles

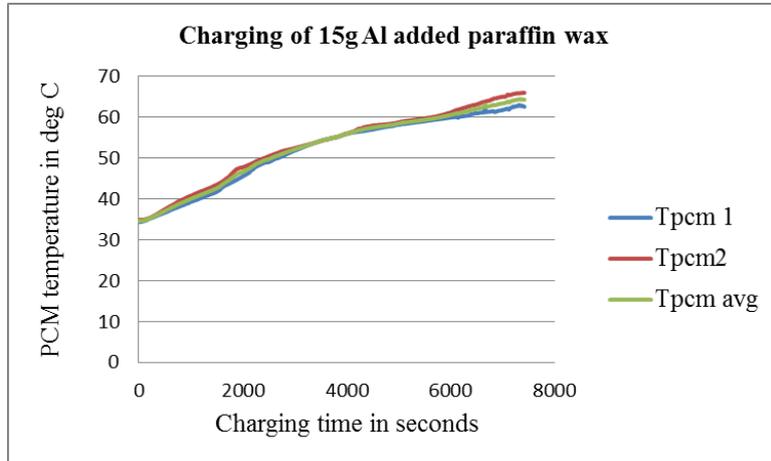
The variation of PCM temperatures with time during charging of different compositions of Aluminium micro composites of Paraffin Wax and Myristic acid is shown in Figure 6(a)-6(f)



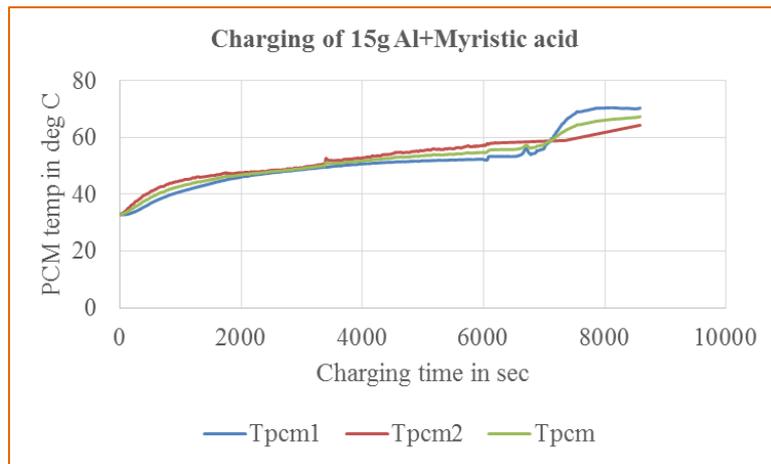
(a)



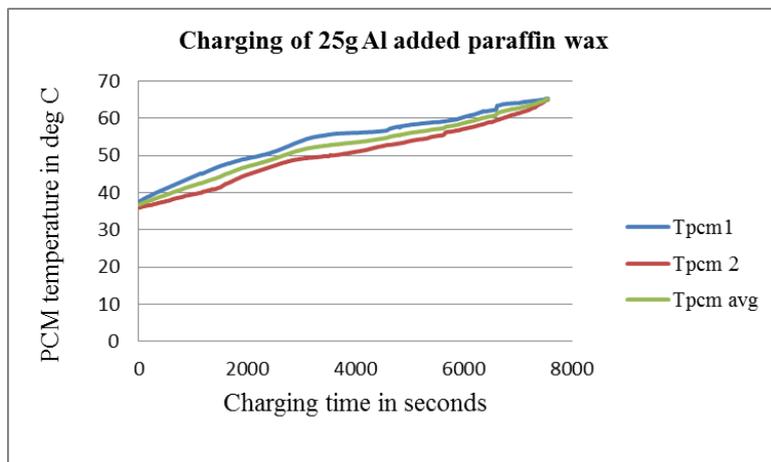
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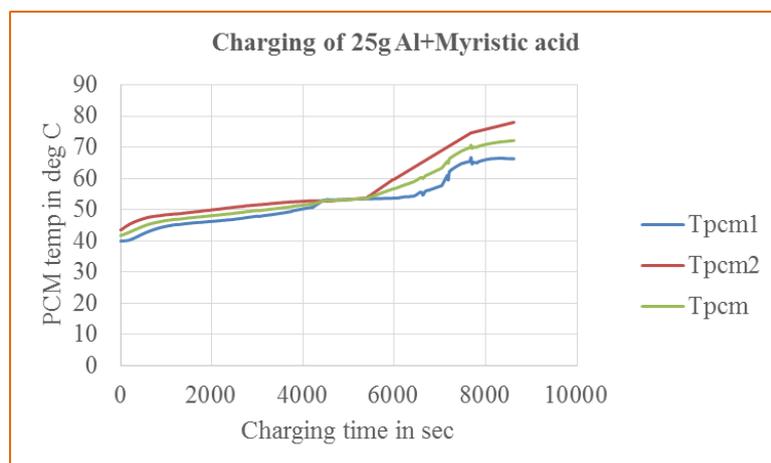
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(d)



(e)



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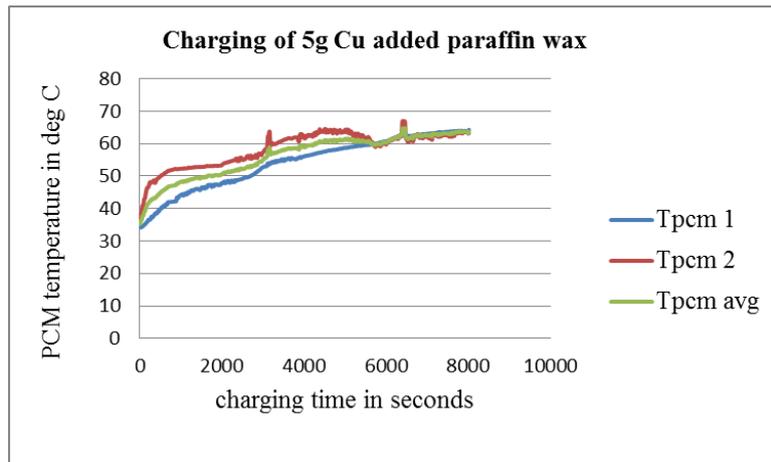
Figure 6 Charging time vs PCM temp of 5g Al added in Paraffin Wax (a) Charging time vs PCM temp of 5g Al added in Myristic acid (b) Charging time vs PCM temp of 15g Al added in Paraffin Wax (c) Charging time vs PCM temp of 15g Al added in Myristic acid (d) Charging time vs PCM temp of 25g Al added in Paraffin Wax (e) Charging time vs PCM temp of 25g Al added in Myristic acid(f)

Considering Aluminium micro particles, on addition of 1% Al micro particles to the pure Paraffin wax, the charging duration is reduced to 2h 30 min which is not as significant as when compared to that of 3% Al micro particles which melted in 2h 5 min and the charging duration of 5% Al micro particles added paraffin wax is 2h 7min. Beyond 3% there is no much reduction in charging duration due to the significant deposition of Al micro particles. From the analysis of 1%3%5% of Al composites of Myristic acid it is found that , by addition of 1% Al micro particles the composite melted in 2h 13min but 3% and 5% Al composites were melted in 2h 22min and 2h 31 min respectively. It is found that beyond 1% of Al micro particles sedimentation rates are more because the extra added particles might have disturbed already dispersed particles and made them to settle down.

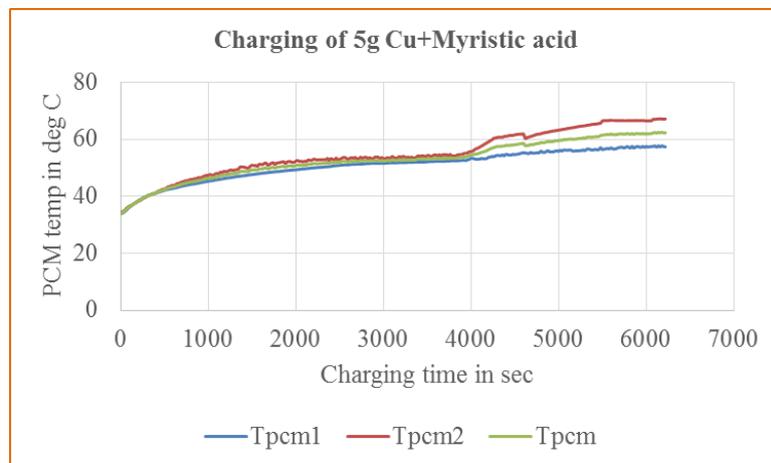
3.1.4 With Copper Nano particles

From the analysis Copper composites of paraffin wax it is found that 1% copper nanoparticles added to the pure paraffin wax resulted in decrease in the charging duration i.e. to 2h 25 min but when 3% copper Nano particles were added, there was a

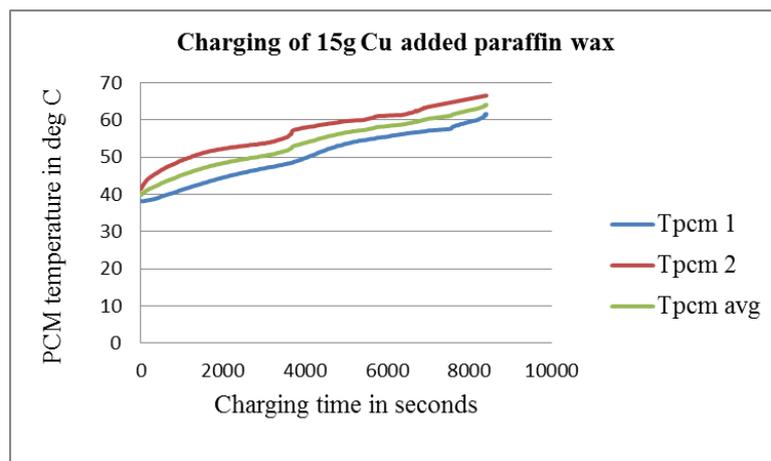
considerable enhancement in charging duration to 2 h 6 min and with 5% copper nanocomposite there was no significant reduction in the charging duration i.e. it took 2h for complete charging. When the composition is increased from 1% to 3% there is considerable reduction in charging time due to increase in the conductivity of the composite whereas when it is increased to 5% due to deposition and increase in the viscosity of the composite there was no much reduction in charging duration. The variation of PCM temperatures with time during charging of different compositions of Copper Nano composites of Paraffin Wax and Myristic acid is shown in Figure 7(a)-7(f)



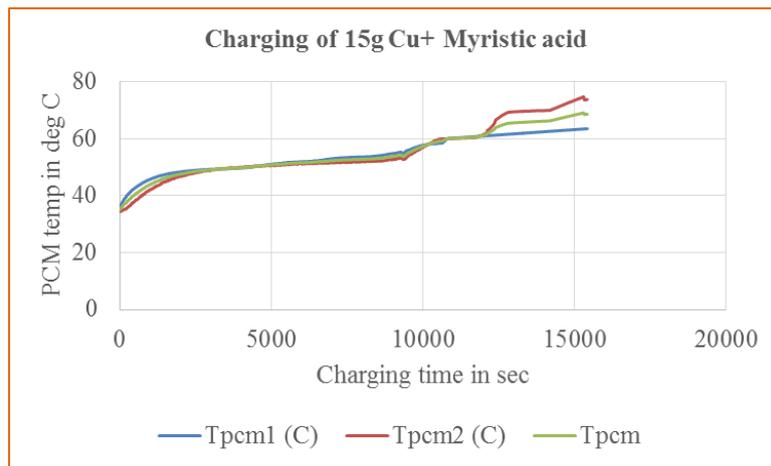
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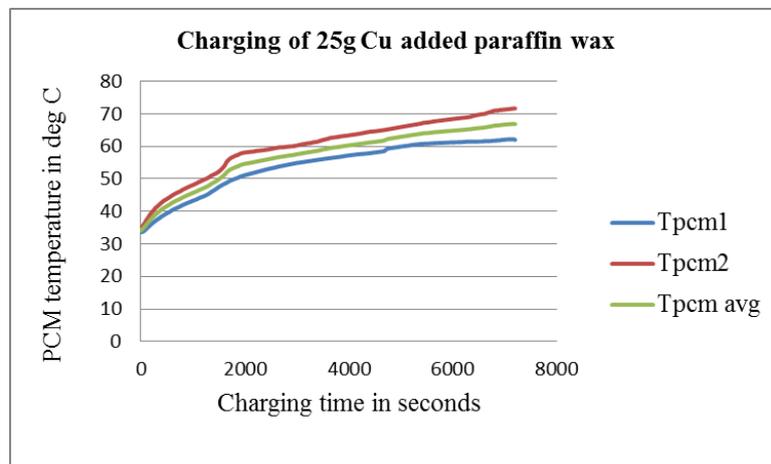
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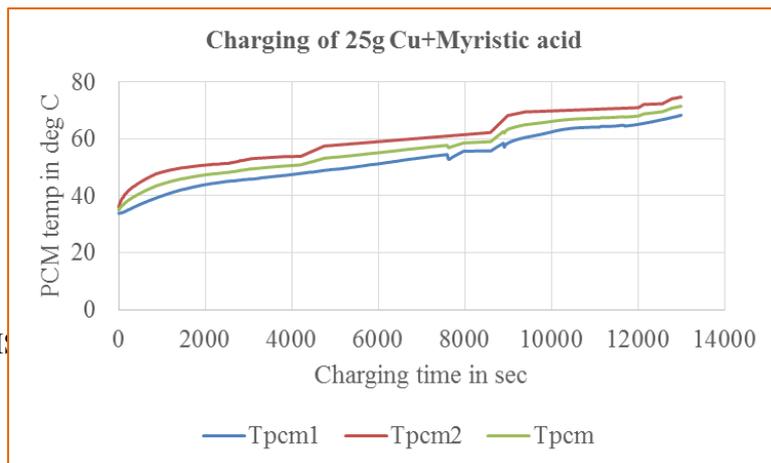
(c)



(d)



(e)



(f)

Figure 7. Charging time vs PCM temp of 5g Cu added in Paraffin Wax (a) Charging time vs PCM temp of 5g Cu added in Myristic acid (b) Charging time vs PCM temp of 15g Cu added in Paraffin Wax (c) Charging time vs PCM temp of 15g Cu added in Myristic acid (d) Charging time vs PCM temp of 5g Cu added in Paraffin Wax (e) Charging time vs PCM temp of 5g Cu added in Myristic acid (f)

The results of study of 1%, 3%, 5% copper composite of Myristic acid showed that 1% composite melted in 2h 4min but in the case of both 3% and 5% of copper composite there was a significant increase in viscosity of the composite due to which there was no proper phase change was found even after 3h 30min of observation. The paste form of 15g and 25g Cu composite is shown in Figure 8(a) and 8(b).



(a)



(b)

Figure 8. 25g Cu added Myristic acid after 3h 30 minutes (a) 25g Cu Myristic acid paste (b).

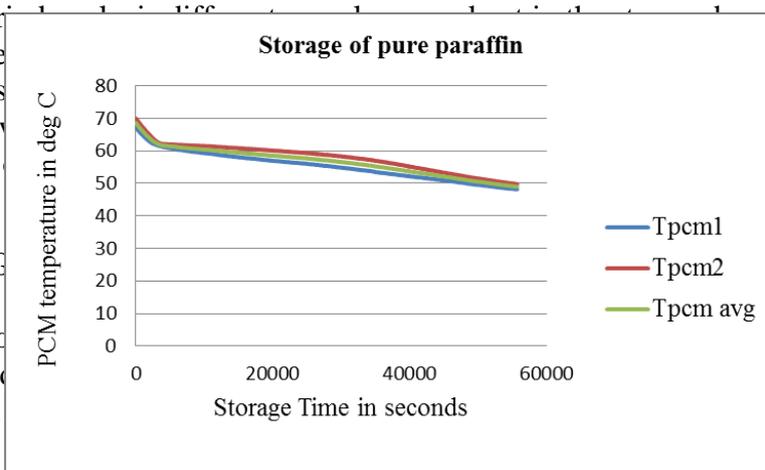
3.2 Storing Period analysis

3.2.1 Pure Paraffin wax and pure Myristic acid

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3.2.2 With G

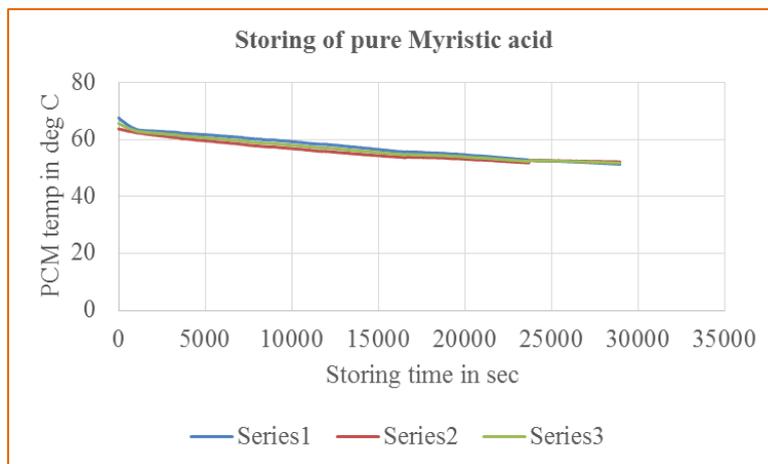
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 Graphite added...
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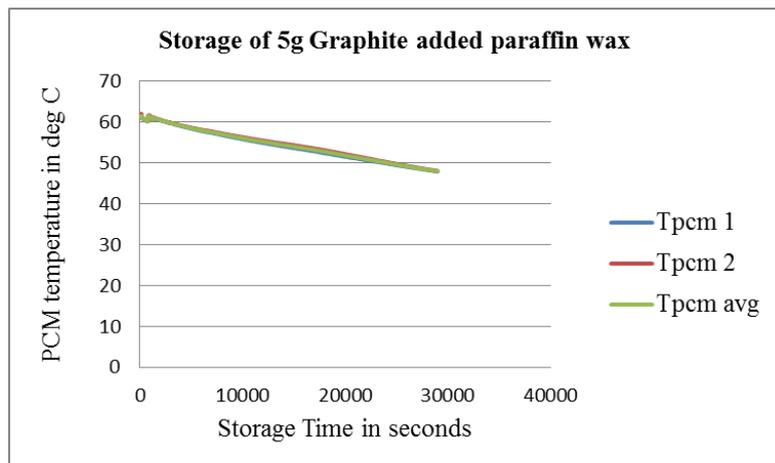
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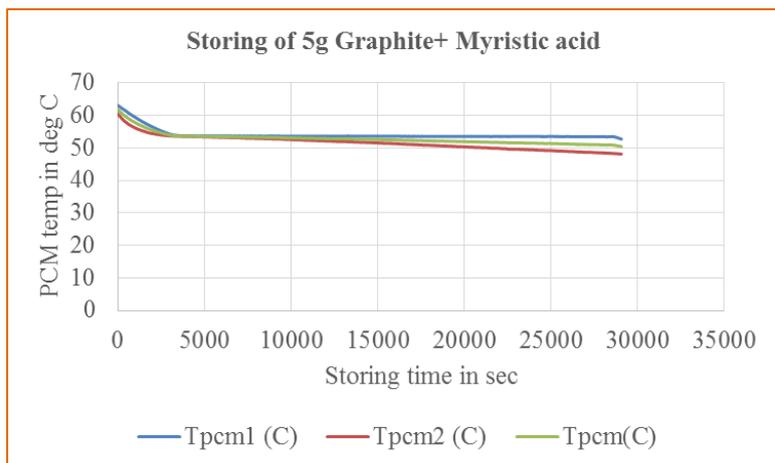
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Figure 9 Storing time vs PCM temp pure Paraffin Wax (a) Storing time vs PCM temp of pure Myristic acid (b)

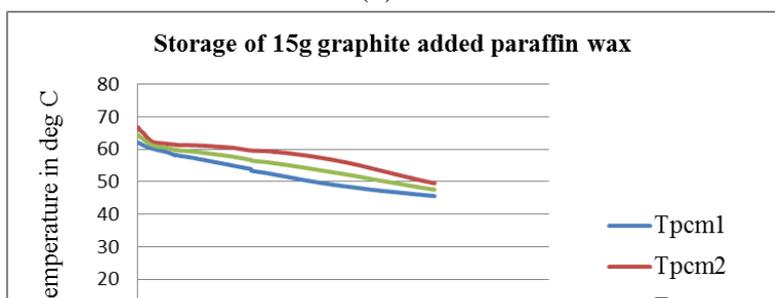
In the case of 1% and 3% Graphite added composite, temperature drop was around 11°C in eight hours and 5% Graphite added Myristic acid composite showed a temperature drop of 13°C. The reduced performance of Graphite composite of Myristic acid is due to the increased thermal conductivity of the composites. The variation of PCM temperatures with time during charging of different compositions of graphite micro composites of Paraffin Wax and Myristic acid is shown in Figure 10(a)-10(f).

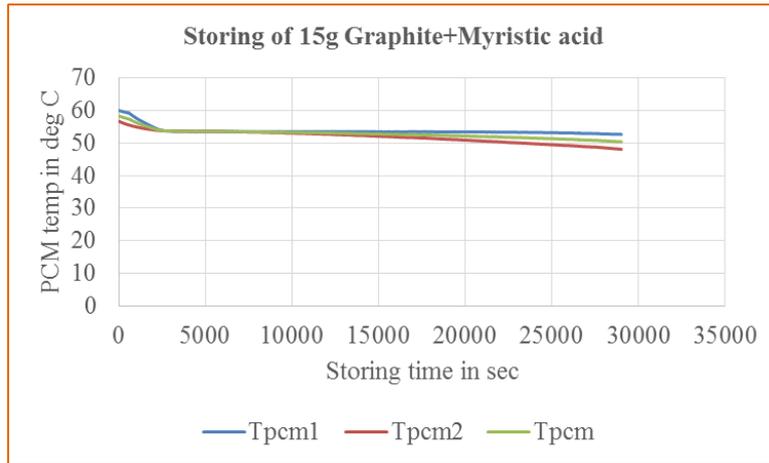


(a)



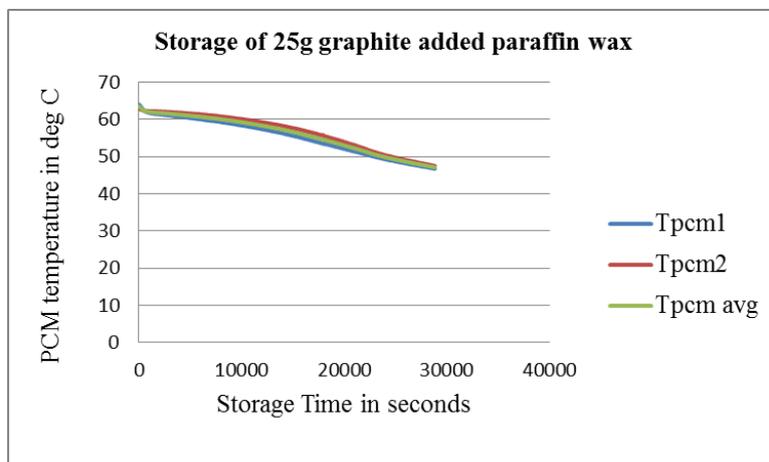
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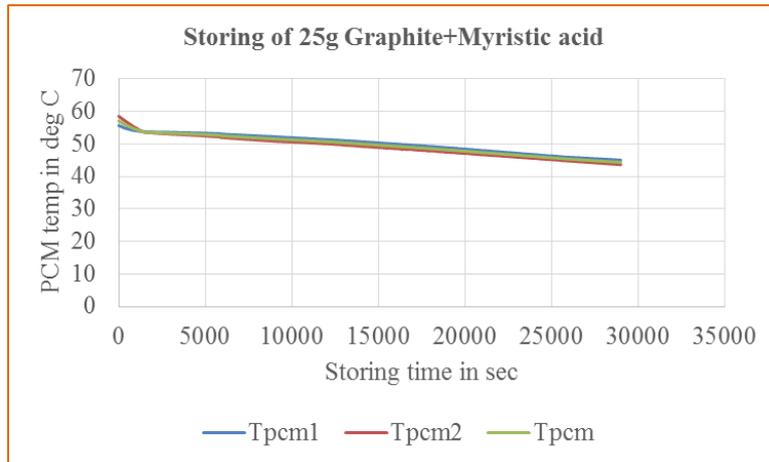


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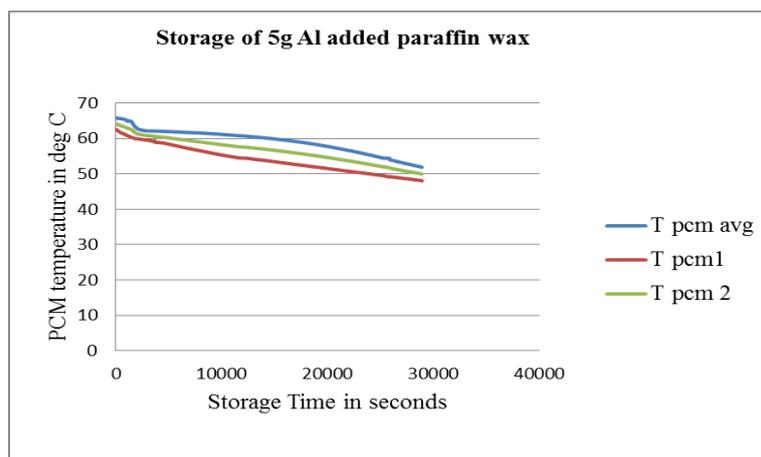


(f)

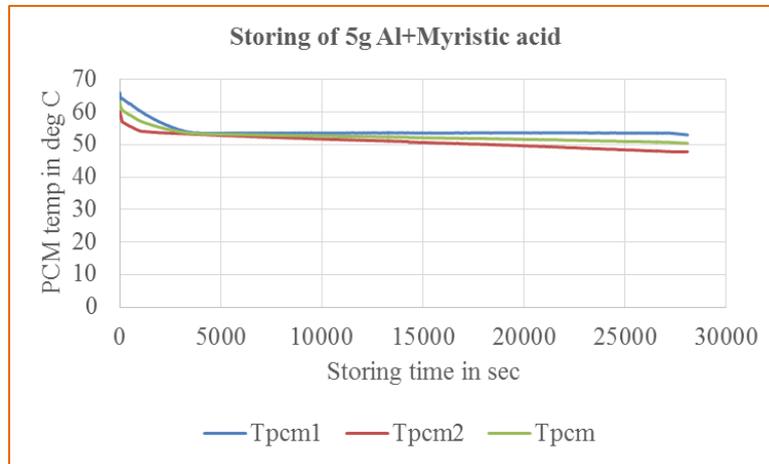
Figure 10 Storing time vs PCM temp of 5g Graphite added in Paraffin Wax (a) Storing time vs PCM temp of 5g Graphite added in Myristic acid (b) Storing time vs PCM temp of 15g Graphite added in Paraffin Wax (c) Storing time vs PCM temp of 15g Graphite added in Myristic acid (d) Storing time vs PCM temp of 25g Graphite added in Paraffin Wax (e) Storing time vs PCM temp of 25g Graphite added in Myristic acid (f).

3.2.3 With Aluminium micro particles

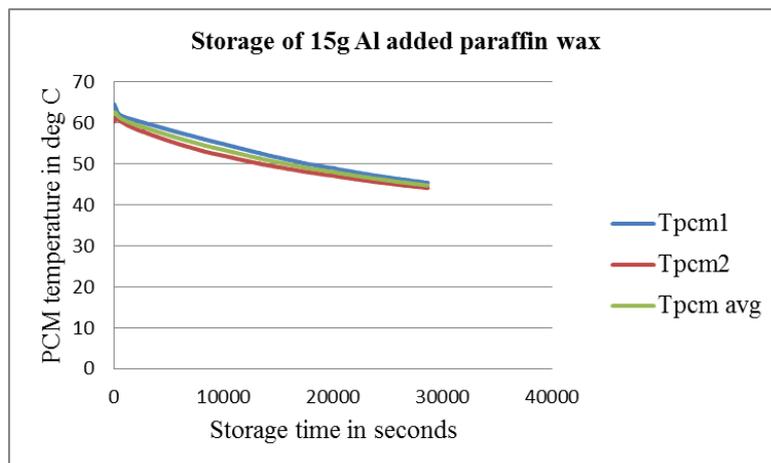
Storage period analysis of Aluminium added paraffin wax composites showed that 1% composite was having a drop of 15.159°C while 3% composite showed 17.543°C and the temperature drop of 20.38°C was for 5% composite. The storage period analysis of Al composite of Myristic acid revealed that for 1% Al composite 13°C temperature drop was observed and 17.131 °C for 3% composite whereas in case of 5% composite 19.341°C temperature drop was observed. The variation of PCM temperatures with time during charging of different compositions of Aluminium micro composites of Paraffin Wax and Myristic acid is shown in Figure 11(a)-11(f)



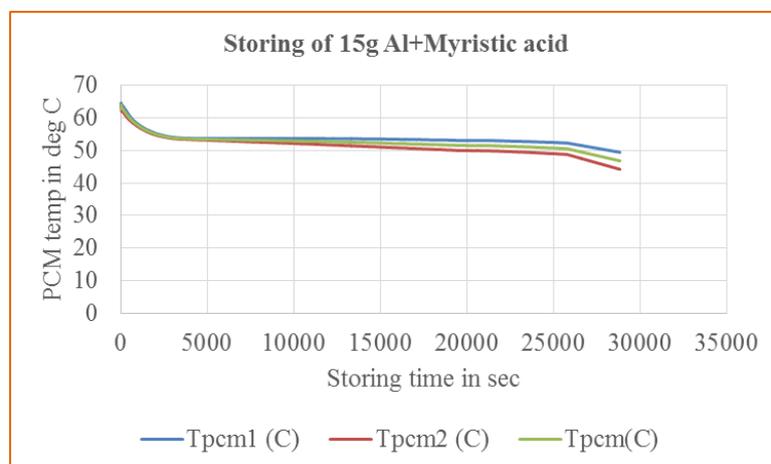
(a)



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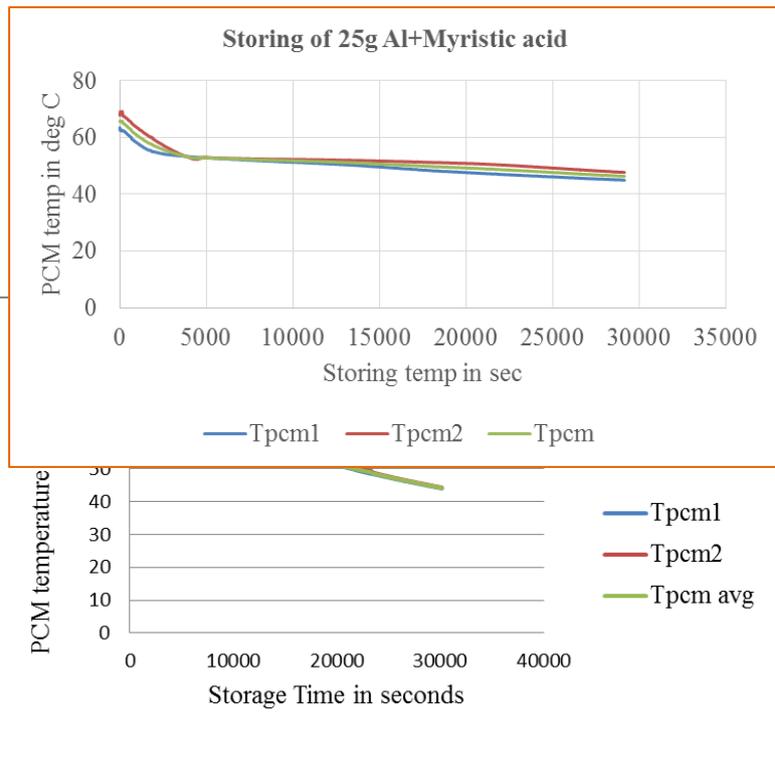
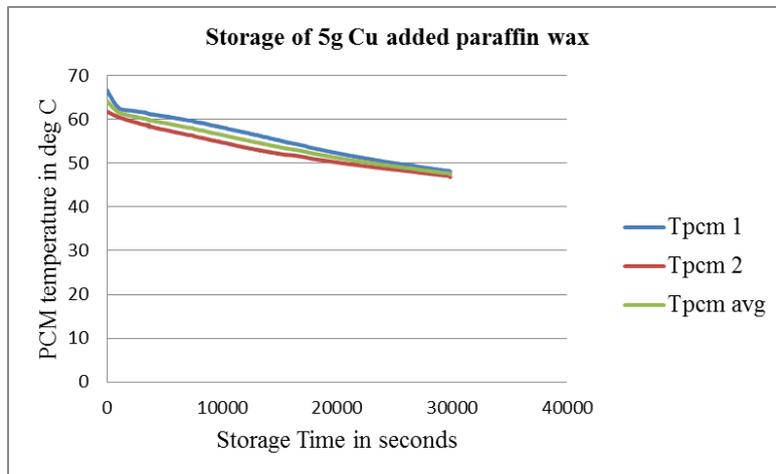


Figure 11 Storing time vs PCM temp of 25g Al added in Paraffin wax (d) (e) Storing time vs PCM temp of 25g Al added in Myristic acid

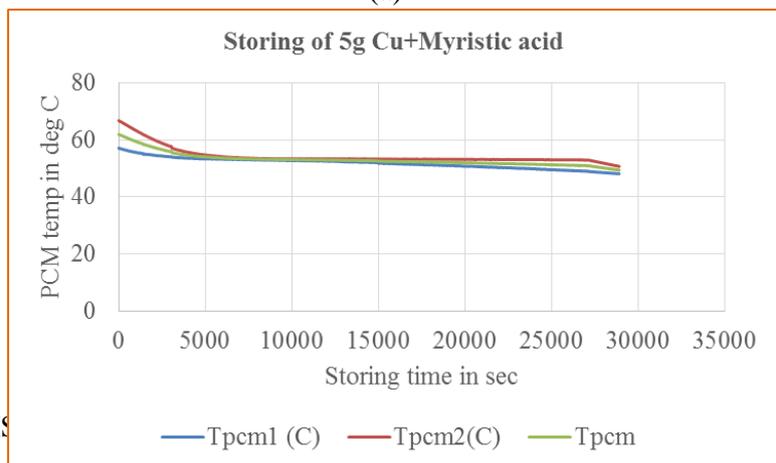
Storing time vs PCM temp of 15g Al added in Myristic acid

3.2.4 With Copper Nano particles

In copper nanocomposites, the temperature drop of 16.024°C was found in 1% copper added paraffin wax and it was around 18.097°C for 3% composite whereas in 5% composite temperature drop was found to be less than that of 3% composite i.e. 16.349°C The storage period analysis of copper composite of Myristic acid, it was found that a temperature drop of 13°C for 1% composite and for 3% composite it was around 17°C and for 5% composite the 30°C temperature drop were observed. This large increase in the drop might be due to improper phase change from solid to liquid. The variation of PCM temperatures with time during charging of different compositions of Copper Nano composites of Paraffin Wax and Myristic acid is shown in Figure 12(a)-12(f)

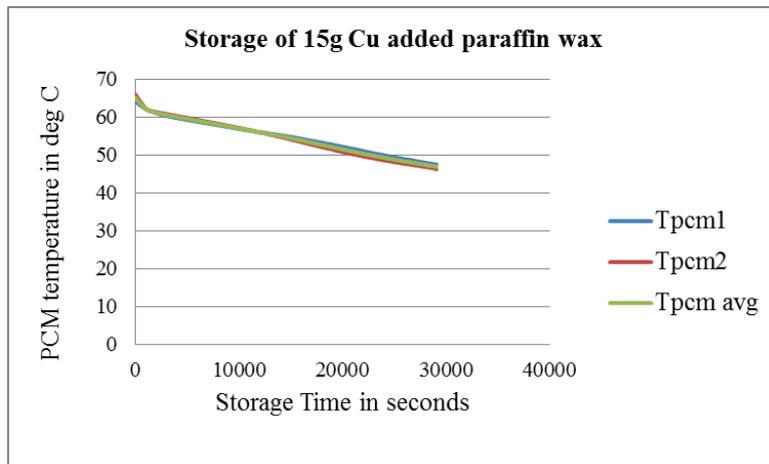


(a)

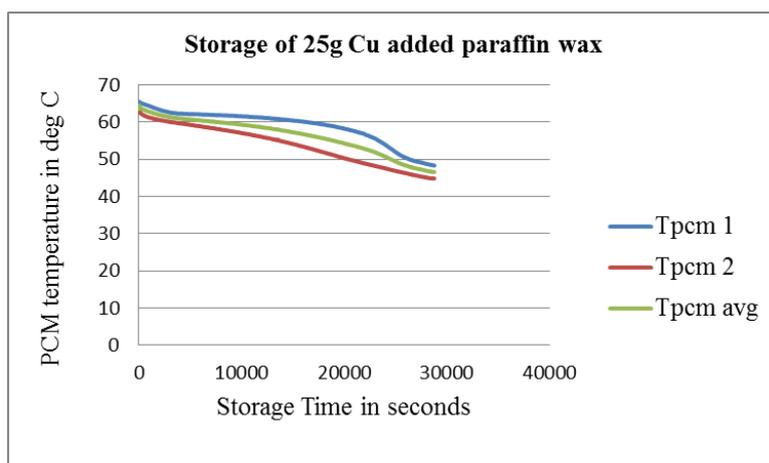
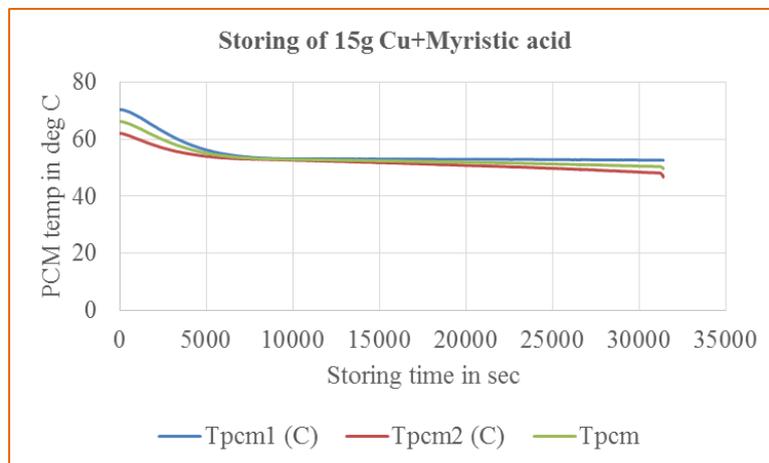


IS

(b)



(c)



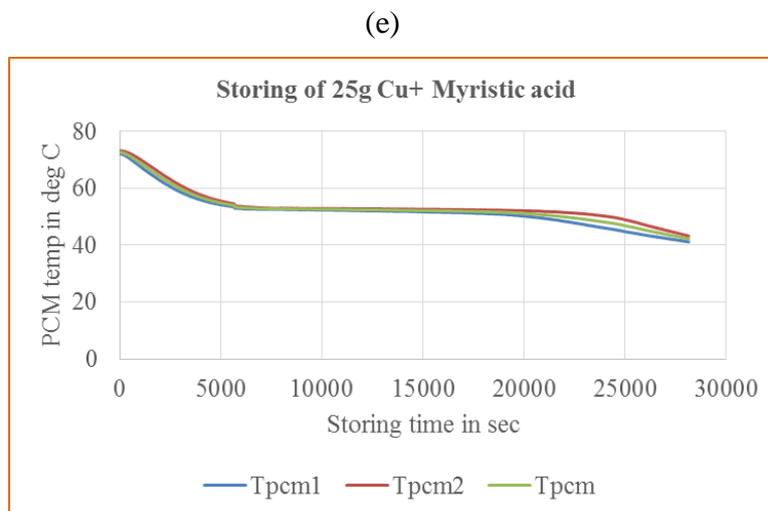


Figure 12 (a) Storing time vs PCM temp of 5g Cu added in Paraffin Wax (b) Storing time vs PCM temp of 5g Cu added in Myristic acid (c) Storing time vs PCM temp of 15g Cu added in Paraffin Wax (d) Storing time vs PCM temp of 15g Cu added in Myristic acid (e) Storing time vs PCM temp of 25g Cu added in Paraffin Wax (f) Storing time vs PCM temp of 25g Cu added in Myristic acid

4.0 CONCLUSIONS

The performance analysis of pure Paraffin wax and pure Myristic acid was done and compared with that of the various compositions of nanocomposites of Paraffin wax and Myristic acid. The conclusions of present work are summarized as follows

- From the charging period analysis of graphite composites, there was no significant enhancement in the performance by adding beyond 1% graphite to the Paraffin wax. Whereas in the case of Myristic acid there was a clear enhancement in thermal performance from 1% to 5% of Graphite composites.
- Charging period analysis of aluminium composites, revealed that 3% Aluminium added paraffin wax is better performer than 1% and 5% composites and whereas in Aluminium composite of Myristic acid 1% composite was found have shorter charging duration than remaining.
- From the experimental analysis, 5% copper paraffin wax composite showed marginal better charging performance than 1% and 3%. In the case of copper composites of Myristic acid, there is no significant enhancement in performance by adding beyond 1% of copper to pure Myristic acid.

- From the storage period analysis of graphite composite 1% graphite composite is marginally better performer than other two composites of paraffin wax. Among Myristic acid composites, 1% and 3% composites have almost similar enhancement in performance and that was better than 5%.
- Storage period analysis of aluminium composites of both Paraffin wax and Myristic acid revealed that 1% aluminium added composite was best in storing energy than 3% and 5% composite. Among 3% and 5% composite, 3% composite is marginally better performer.
- Among the copper composite of Paraffin wax and Myristic acid, 1% copper composite showed better performance with significantly less temperature drop compared to that of 3% and 5%.
- From the both charging and storing period analysis, among composites of Paraffin wax, both 1% copper and 1% graphite composites are giving more satisfactory results than all other composites of paraffin wax and among composites of Myristic acid, it can be concluded that graphite composites are giving more satisfactory results than all other composite, in which 3% graphite is the optimum composition.

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