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Effect of Charging and Discharging Process of PCM with Paraffin and Al_2O_3 Additive Subjected to Three Point Temperature Locations

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ABSTRACT

This analysis focused on investigating thermal storage behaviour on phase change material along with Al_2O_3 as an additive. The experimental investigation was performed by three set temperature points, i.e. 40 °C, 50 °C and 60 °C with the mass circulation rate through the tank of 5 kg/min, 3 kg/min and 2 kg/min. The forced circulation method was used to circulate the liquid, water was used as a working medium and Al_2O_3 as nano particle. Paraffin acts a phase change material to conduct the experimental procedure. The combination of paraffin with Al_2O_3 improves the latent heat storage of the material. The performance, with respect to charging and discharging of the material, was investigated and it was observed that the temperature location point of 50 °C shows the best results in terms of charging and discharging phenomena, compared to other two temperature location points. During the process of charging, the maximum rate of heat transfer can be achieved by Al_2O_3 nanofluids. Paraffin along with Al_2O_3 are characterized by the best thermal storage behaviour during the latent heat storage at charging process and dissipation of heat during discharge process. The rapid cooling comparison for three set location points has been studied and best solidification was achieved at the point of 60 °C; this is due to the rapid cooling at higher elevation temperatures. The energy that was stored in thermal form is to be transferred with the aid of heat exchanger, a special type heat exchanger employed in this analysis to transfer the heat. From this analysis it is concluded that paraffin with Al_2O_3 are characterized by the best performance in terms of the charging and discharging phenomenon.

Keywords: PCM material behavior, paraffin wax, charging and discharging, solar heater, three point locations, Al_2O_3 methods of charging and discharging.

INTRODUCTION

Though there is a depletion of Natural Energy resources, people are looking into solar energy resources for generating the power using the renewable energy and clean developing mechanisms involved in it. Several researchers conducted different investigations on solar photovoltaic and solar thermal storage behaviour using different applications. There are major drawbacks due to the high temperature distribution and fluctuations during the thermal storage behaviour of the system. Hence, phase change materials can overcome these difficulties. In phase change materials, defined as the materials that can store latent heat and sensible heat, there is a lesser storage in sensible heat, as compared to latent heat, due to the certain limitations of the thermal behaviour of the material. Storage of the latent heat is 5 to 14 times greater compared to some methods of storage behaviour, leading to improvement in the thermal efficiency of the materials [Rai et al., 2012]. Yang et al. [2021], investigated the thermodynamic properties of the phase change material behaviour and proved that the addition of other nanoparticles to the phase change materials can improve the cooling capacity of phase change material, as well as the thermal conductivity properties of the material. Zhou et al. [2012], and Bruch et al. [2017], investigated the thermal storage charging and discharging process of phase materials using rock and sand in the presence of oil, subjected to such parameters as mass of the materials and temperature limits of the material. From them studies, it was experimentally found out that thermocline behaviour of the material is considered as an important phenomenon to enhance the fluid property movement and thermal storage behaviour of the system. The temperature distribution factor predominantly causes abrupt change in thermal expansion and contraction of the material,; hence, it is required to optimize the quantity of the pcm by various cooling methods to evaluate the heat rejection rate [Khanna et al., 2018]. Chen et al. [2018], developed a passive ventilation system with some mathematical numerical calculations for measuring the temperature change in the portion of wall subjected to the phase change material. From their study, it was found out that the storage capacity of the wall attained maximum capacity of 48% and the capacity rate of heat release can achieve 50% with respect to the indoor temperature limits. Sajawal et al. [2019], developed a new model based on double pass solar heater, which is made up of phase change material, and experimentally proved that the system consists of rectangular finned sections with the composition of 44% hydrocarbon, gives superior results compared to other studies. Manoj Kumar et al. [2020], an in-depth investigation and detailed study about the thermal storage of phase change materials enhanced with carbon hybrid nano composite materials. They used evacuated solar heater for the purpose of natural convection mode to be made and they have used first law and second law of thermodynamics to investigate the mass flow properties for SiO_2 and CiO_2 particles,. The results revealed that there is an improvement in 1% of mass flaw rate while compared to other conventional methods of storage. Kumar et al. [2021], proved that phase change material is an promising trend to fulfil the latent heat storage behaviour and can applicable to use in different applications such as solar heater, solar cooker, PCM concrete and shutter etc. They proved paraffin is the best material because it can withstand very high temperatures and high latent heat. Zhang et al. [2017], investigated the latent thermal storage behaviour with paraffin as an phase change material and performed five kinds of simulations for the charging and discharging process as well as measured the mass flow rate of the room and experimentally proved that paraffin is the best material to store latent heat of the system. Suraparaju et al. [2021], investigated the detailed study analysis on PCM bed to evaluate the thermal storage performance and behaviour, solar based basin enhanced with straggled fins using different approaches. Their detailed analysis and comparative study showed that the productivity of solar stills, using paraffin as a medium with different depths measured at 2,3 and 4 cm, yields the best results in terms of increase in efficiency, reaching 2% as compared to conventional systems. Belessiotis et al. [2018], conducted SEM analysis on paraffin materials to find any crack propagation due to repetitive fatigue loads and specifically they have conducted thermo gravimetric analysis of the material to find out the performance of paraffin percentage determination. This study is different, being an experimental study in the field of solar energy sector which compromised the results compared to other conventional studies. The results also proved that paraffin possesses the highest latent heat up to 156 j/g with maximum mass percentage of 80%, achieved through optimal performance ratio. Ren Yang et al. [2019], adopted a different approach, using epoxy materials sealed with graphite and paraffin to estimate the thermal storage behaviour of the system and from their results it was concluded that there is an increase in energy storage due to the relative density motions occurred as a result of forced convection movement layer of the liquid paraffin, which substantially withstands the maximum time 3 hours, respectively, and the mass of paraffin may reached up to 95% in paraffin materials. Qu, Y. Wang et al. [2019], investigated some leakage problems occurred in the phase change materials due to the inherent to very poor thermal conductivity of the material and they conducted investigation on two different materials, such as hybrid carbon nanoadditive and graphite wallet nanotubes. Efficiency coefficient method, was been applied to measure the thermal behaviour of the phase change materials with respect to paraffin as a material media. Their experimental studies show that n-octadecane exhibited optimal performance to overcome the thermal leakage problems. Wang et al. [2016], investigated the application of nanofluids with the combinations of synthetic oil and Al_2O_3 particle as a working medium and from the experimental results it was found that better absorber results were achieved as compared to other conventional methods of latent heat storage,. In addition, they proved that nanofluids yielded the best storage results and discharge results in the field of phase change materials and thermal behaviour storage of system. Krishnakumar et al. [2018], conducted, detailed study about Al_2O_3 combined with ethylene glycol to measure its thermal behaviour during charging and discharging phenomena of phase change materials subjected to different conductive ratios, and from them detailed study it is understood that this combination of fluids has better potential,; hence, it can be used to achieve best performance in terms of rapid cooling and uniform solidification at elevated temperatures. Jiang et al. [2019], developed a model to measure the performance of the Al_2O_3 particle movement behaviour and they developed a fuzzy logic program to measure its thermal conductivity and temperature distribution of the Al_2O_3 particle and proved that Al_2O_3 and deionized water possess better absorption and dissipations compared to other conventional methods.

METHODOLOGY

Figure 1 shows the methodology involved during this experimental process. In this process, the pulsulating pump with rated power of 4 watts and rated current of 6A, operating pressure of 200 kPa was utilised for this experimental setup [Long et al., 2008 and Chong et al., 2021]. Heat exchanger is an important medium in this analysis which transfers the latent heat rate from the phase change materials with average effectiveness value of 0.7 which improves the overall thermal behaviour of the system [Tay et al., 2012]. Data logger is used to measure the mass flow rate values and the inlet and outlet temperatures of working fluids under different operating conditions. Data logger is like a computerized system that receives all the input data and stores it in a separate drive from which the information can be retrieved at any time for further investigation to be carried out. The data such as temperature distribution, latent heat storage, sensible heat storage, cooling water and the circulation of Al_2O_3 with paraffin was monitored regularly through data acquisition system enhanced with monitoring, recording the data every minute during the experimental analysis [Hosseinizadeh et al., 2011]. The properties of paraffin were shown in Table 1, and the properties of Al_2O_3 were shown in Table 2.

EXPERIMENTAL SET UP

Figure 2 shows the actual experimental set up. A rectangular acrylic tank having the capacity of 220×140×140 mm was used to conduct the analysis. The diameter of inner tubes was 10 mm and the material used for inner tube is copper. Copper possesses better mechanical strength and its composition proved high endurance limit and

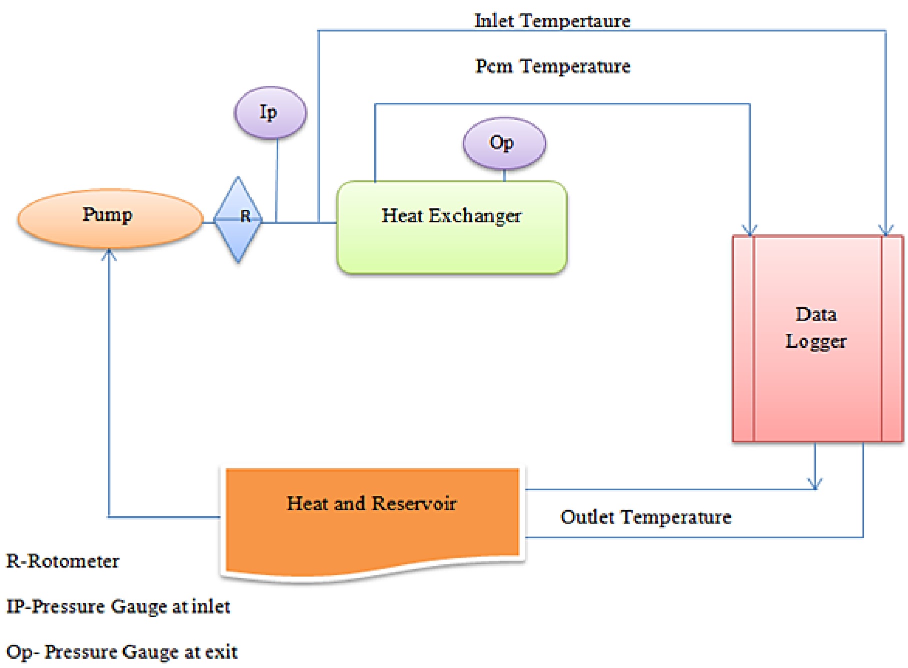

Figure 1. Methodology

Table 1. Paraffin physical properties

No	Properties	Units of measurement	Values
1	Density	kg/m³	900
2	Fusion heat rate	J.g-1	200–220
3	Capacity of specific heat	J. (g.K)$^{-1}$	2.5–3
4	Point of melting temperature	°C	57–61

Table 2. Al_2O_3 properties

No	Properties	Units of measurement	Values
1	Atomic weight	g/mol	101.96
2	Particle size	mm	14
3	Thermal conductivity	W/m. K	36
4	Point of melting temperature	°C	2045
5	Hardness	BHN	1700–2000
6	Morphology	-	Spherical
7	Density	gr/ml	3.26
8	Molecular formula	-	Al_2O_3

minimum erosion. PCM materials with Al_2O_3 additives were filled between the tank and tube. From the top of the tank, the PCM materials were filled and three thermocouple sensors PB1, PB2 and PB3 were used in this experimental analysis for finding the charging TC and discharging TD temperatures, respectively. In addition to that, four thermocouple sensors were fitted at the tank, two temperature measurement sensors vertically TBV and two temperature measurement sensors horizontally TBH to measure the mixture of PCM with Al_2O_3 additives temperatures during uniform flow rate and turbulent flow rate. The tank was subjected to better insulation for minimising the losses.

EXPERIMENTAL PROCEDURE

Before the experimental process, the composite material was poured into the tank and the mass was measured,. The measured mass was found to be 33 kg and the process of charging took place to cool the room with respect to temperatures of the room. The values are given by variation of temperature and the water at the inlet was 1)1.5 L/min and 40 °C 2) 1.5 L/min and 50 °C 3)1.5 L/min and 60 °C, respectively. A series of melting and solidification experiments were conducted to study the effect of mass flow rate of HTF on the thermal behaviour of the PCM. At the beginning of the experiment, paraffin wax was solid in the rectangular prism.

RESULTS AND DISCUSSION

Method of the charging process

The charging process is applied at three different temperatures of 40°C, 50°C and 60°C,

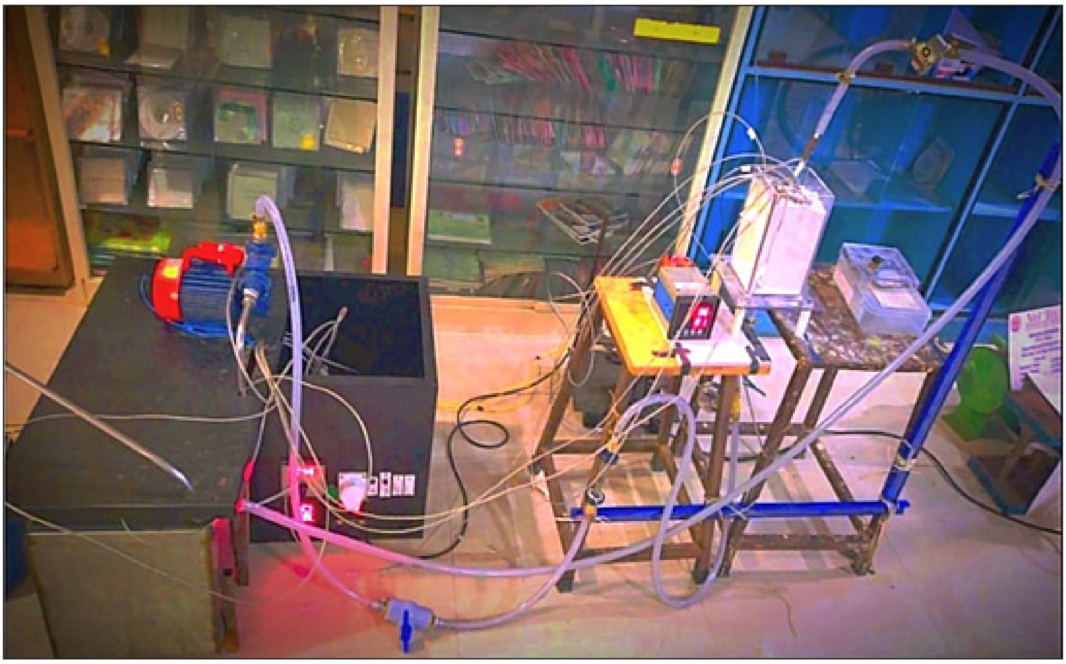

Figure 2. Actual experimental set up

with corresponding mass flow rates of 5 kg/min, 3 kg/min and 2 kg/min circulated in the PCM tank with the aid of forced convection through motor, carried out for entire process. During the starting process, the temperature behaviour of paraffin falls below the room temperature. The energy will be stored in the form of sensible heat. This is due to low storage capacity, as the energy required by the charging process will be increased due to the melting temperature of paraffin. Figure 3 shows the typical charging process during the temperature set up process of 40 °C, as the temperature of the material increases, resulting in increase in charging time. This is due to the high latent heat of paraffin resulting in good thermal storage behaviour and good potential characteristics to store the energy. Figure 4 shows the typical charging process during the temperature set up process of 40 °C, as the temperature of the material increases resulting in increase in charging time. This is due to the high latent heat of paraffin resulting in good thermal storage behaviour and good potential characteristics to store the energy. Figure 5 shows the typical charging process during the temperature set up process of 60 °C, as the temperature of the material increases resulting in increased charging time. This is due to the high latent heat of paraffin resulting in good thermal storage behaviour and good potential characteristics to store the energy.

Charging of PCM is defined as the active storage system subjected to forced convective transfer and it transfers that stored heat with the help of heat exchanger and solar associated components. The amount of heat generated during the process depends on specific heat of the system [Pielichowska et al., 2014]. The Figure 3 above represents the charging behaviour of the system at 40 °C, for each and every 10 minutes increase in interval it was found out that temperature of the material increased due to the melting phenomenon of the paraffin [Diani et al., 2019]. An increase in thermal conductivity of the material was found. At the first ten minutes, the temperature behaviour of the material was lower and found to be 30 °C, where as there is an increase in time interval with average time range of 10 mins,. It was found that an increase in temperatures and the maximum temperature of 50 °C could be achieved with respect to 1 hour time.

Figure 4 represents the thermal charging behaviour of the system at 50 °C., For each and every 10 minutes increase in interval, it was found that the temperature of the material increased due to the melting phenomenon of the paraffin and increase in thermal conductivity of the material. At the first ten minutes, the temperature behaviour of the material was lower and found to be 39 °C, where as there was an increase in time interval with average time range of 10 mins,. It was seen that there was an increase in temperatures and the maximum temperature of 52 °C could be achieved with respect to 1 hour time. Figure 4 represents the thermal charging behaviour of the system at 60 °C. For each and every 10 minutes increase in interval it was found that the temperature of the material increased due to the melting phenomenon of the paraffin and increase in thermal conductivity of the material. At the first ten minutes, the temperature behaviour of the material was lower and found to be 40 °C, where as there was an increase in time interval with average time range of 10 mins,. It was seen there is an increase in temperatures and the maximum temperature of 53 °C could be achieved with respect to 1 hour time.

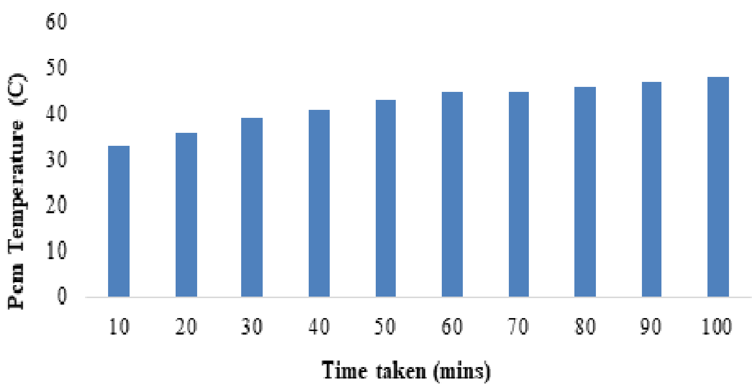

Figure 3. Charging at constant temperature of 40°C

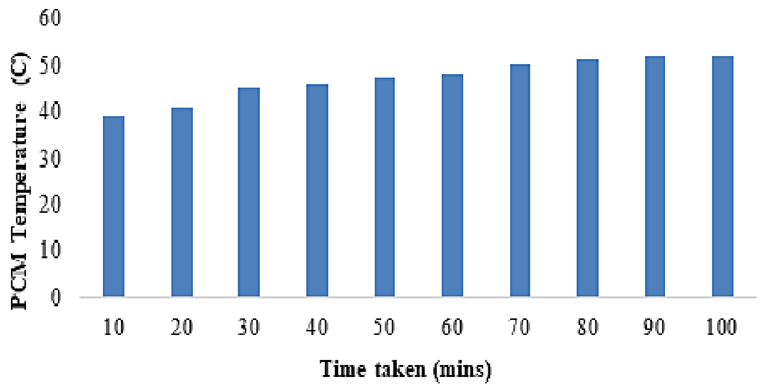

Figure 4. Charging at constant temperature of 50 °C

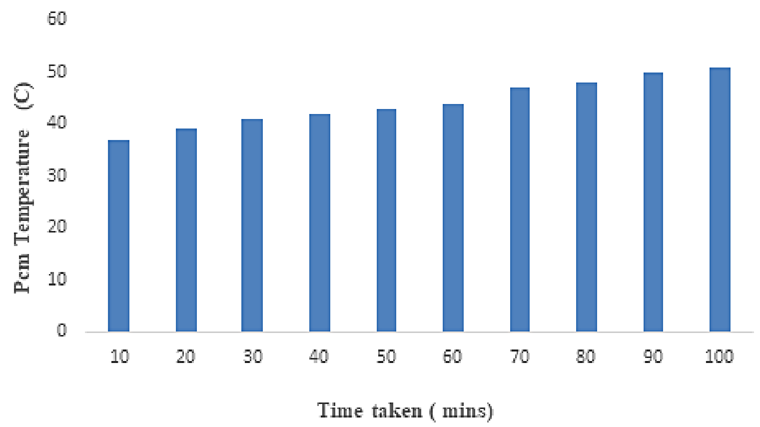

Figure 5. Charging at constant temperature of 60 °C

Method of discharging process

Discharging in phase change materials is defined as the releasing of heat in order to solidify or cool the material to measure its thermodynamic and thermal heat release rate of the material with respect to time [Belessiotis et al., 2018]. Figures 6–8 represent the discharging phenomena of the material with respect to time, the time interval was split into 10 minutes of cycles of operation, which indicates the release of heat every 10 minutes. Due to the presence of uniform cavity phenomenon subjected to different temperature release may result in uniform solidification [Ren et al., 2019]. From the Figures 6, 7 and 8 it is understood that there is an uniform abrupt change in temperatures of PCM subjected to the discharging phenomenon.

Discharging in the phase change material is the indication of solidification or heat release rate subject to cooling with respect to ambient

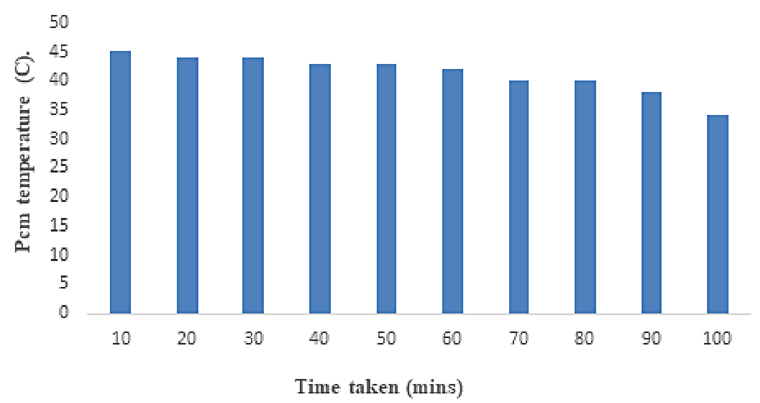

Figure 6. Discharging at constant temperature of 40 °C

temperatures. It is a slow stage process that can predict the release of heat and used to measure the solidification rate with respect to time in certain intervals,. Figure 6 represents the discharging phenomenon of the phase material. It was observed that the solidification rate rapidly decreased for every 10 minute interval. In the first ten minutes, the temperature of the material was found to be 45 °C and it reaches to 40 °C at 1 hour. It was observed that the ambient temperature was reached at 1.4 hours due to rapid cooling and release of slow latent heat. This is due to the better thermal conductivity of paraffin material and its good release of heat [Pielichowska et al., 2014].

Figure 7 represents the discharging phenomenon of the phase material. It was observed that solidification rate rapidly decreased for every 10 minute interval. In the first ten minutes, the temperature of the material was found to be 47 °C and it reached 45 °C at 1 hour. Also, it was observed that it was not possible to achieve the ambient temperature with the time interval of 1.4 hours, however, the corresponding temperature at 1.4 hours reached 36 °C. Figure 8 represents the discharging phenomenon of the phase material. In the first ten minutes the temperature of the material was found to be 50 °C and it reached 41 °C at 1 hour; also it was observed that it was not possible to achieve the ambient temperature with the time interval of 1.4 hours, however, the corresponding temperature at 1.4 hours was noted to be 32 °C. This is due to less turbulent motion resulting in slow rapid cooling and lesser stirring rate, as well as less lack of turbulent layer behaviour [Zhang et al., 2020].

CONCLUSIONS

The experimental analysis of the tank was carried out in this study and the temperatures at three point level measurements were taken with respect to inlet condition with flow rate of 1.5 L/min was investigated with respect to 40 °C, 50 °C and 60 °C with mass flow rate of 5 kg/min, 3 kg/min and 2 kg/min. It was experimentally

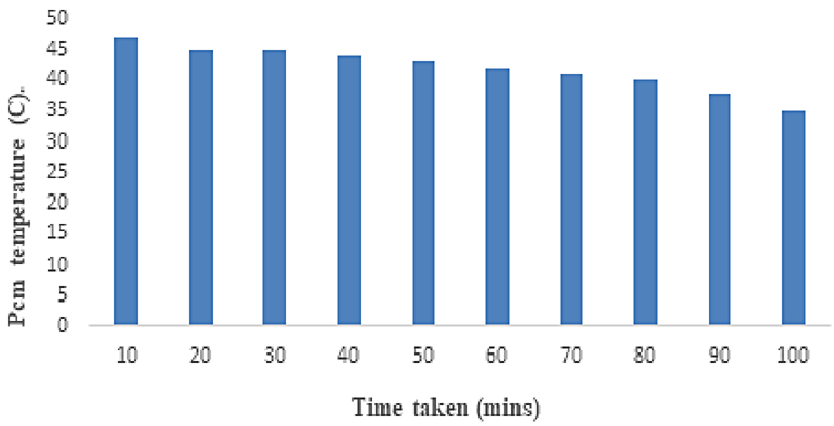

Figure 7. Discharging at constant temperature of 50°C

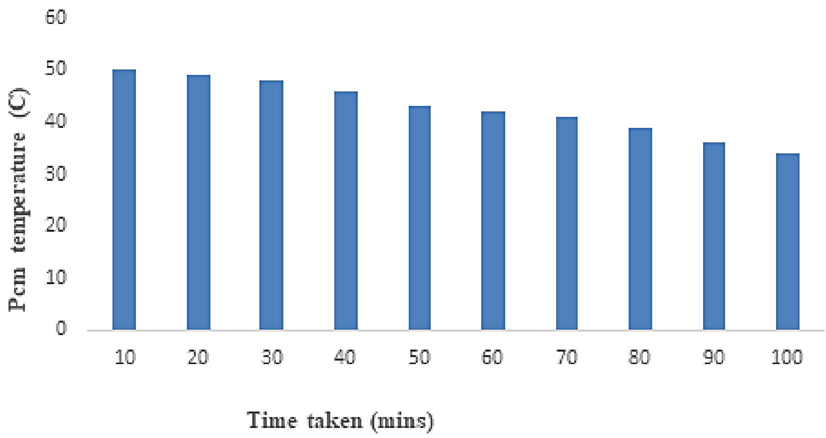

Figure 8. Discharging at constant temperature of 60°C

found that the use of PCM with Al_2O_3 constitutes a superior method of the charging and discharging phenomena at the continuous time intervals of 10 mins and the time required for charging in high temperature region was increased up to 30% at minimum temperature point while the discharge during the solidification process reached nearly 22%, compared with another charging and discharging method. Hence, Al_2O_3 along with paraffin constitute a better technique, comparing with other phase change materials, and Al_2O_3 can be used an nanoadditive for charging and discharging to achieve the best results at minimum temperature limits.

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Future proposed work

The future research work will involve a SEM analysis of the Al_2O_3 particles with Titanium TiO_2 particles mixed in different proportions to find the propagation of the discharge behaviour at higher temperatures. The SEM analysis of nano particles has to be performed at Indian institute of Madras and needs involve the help of Centre for conducting research studies at College of Engineering,Anna university, Guindy.

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