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Study of Melting and Solidification of the Phase Change Materials

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Abstract
This study experimentally investigate the melting and solidification characteristics of selected phase change materials (PCMs). PCMs were polyethylene glycols (PEGs) and Palmitic acid. By using an aluminum box, the PCMs was heating then cooling for melting and solidification respectively. The box divided into three sections. One of them was the heating source (hot water at 100°C), the middle section filled with tested PCM and the remaining section was a cooling source (cold water at 25°C). Twelve thermocouples used for each processes (charging and discharging). The study conclude that the heat storage of Palmitic acid was higher than these of polyethylene glycols due to the higher latent heat storage of Palmitic acid.

***Keywords:** Heat storage, melting, phase change materials, solidification*

INTRODUCTION
Phase change materials (PCMs) absorb heat as a sensible heat and also absorb charging and discharging heat as a latent heat through transition of phase. H Ambarita et al., [1], investigated experimentally the processes of melting and solidification for PCMs. Parrafin wax and Steric acid were used as PCMs. The aim of this study was study and explore PCMs characteristics for melting and solidification conditions. Box of glass used for experiments and divided to three sections (hot, PCMs and cold). Hot and cold water contained constants. Nine thermocouples used to record the temperature valued and these thermocouples were distributed uniformly into the middle section of PCMs. The results show that the Paraffin wax was better than Steric acid as a thermal storage. Sadegh Motahar and Rahmatollah Khodabandeh [2], studied experimentally the heat pipe using effects on charging and discharging of PCM material for a vertical cylinder. The temperature of experiments was constant using a reservoir of constant temperature at below the point of melting for both heating and cooling. The tests were done with heat and without it. The results show that the using of heat pipe will enhanced the heat transfer performance. The surface temperature of heat pipe was measured. Heat pipe can be considered as isothermal surface. Using several reservoir temperature show an increasing of 15°C in the temperature of reservoir for the experiment of melting with decreasing into the time of melting by 53% also the temperature decreasing of 10°C reduces the time of solidification by 49%. S. Arena et al, [3], studied experimentally and numerically the storage of thermal heat for phase change materials in applications of medium scale solar power (CSP) applications. Boxes and devices of heat transfer were used to contain PCM, and the simulation of charging and discharging were done. The numerical model of 2-D axisymmetric developed COMSOL Multiphysics to simulate the thermal energy storage with conduction and natural heat transfer. The profile distribution of temperature inside PCM was determined using these models. These models indicate the response of heat

transfer between the PCM and a wall. The numerical results were compared with experimental results. Rohit Kothari et al., [4] produced a model of heat transfer. This model was conduction heat transfer and 1-D. the model studied the melting and solidification of PCM. This PCM was putting inside an annulus. The studied cases were sub- processes for both melting and solidification of PCM. Then with time, the analyzing of each sub-process were done. These sub-processes were completely solidification, partially melting and completely melting for sub-process melting and reverse process for solidification. For each sub-process, the temperature distribution solution was done. This solution done using a state of a quasi-steady. The model show a good agreement with the experimental results. The results show the increasing of PCM thickness increased the duration of melting. Abdullah. N. Olimat et al., [5] conducted experimentally the thermal properties of Plus ICE H190 PCM using the apparatus of (DSC and TG). The temperatures of both melting and solidification at several rates of heating were measured. PCM stability and decomposition were investigated. The tests show that this PCM can be used for the devices of thermal storage with high consistency. The results show the possibility the using of PCM as the media of absorb and release the heat at the range of 170°C and 200°C. Cheng Wang and Ye Zhu [6] introduced the numerical and experimental works in recent decades focused on the enhancement of PCM properties also the performance of improvement in the units of heat storage applications beside optimization of these units. They conclude that there were a lot of contribution can be made between PCM and the units of heat storage. K Kavitha and S Arumugam [7] discussed the thermal performance for the thermal storage device of phase change. They developed the unit of solar storage for wax melting. The PCM wax was a paraffin used as storage of thermal energy with the temperature of melting of 42−50°C. The experimental work was done to analyze the thermal performance of PCM during melting and solidification. The time and intensity of solar energy were recorded and the characteristics of heat transfer were studied. Md. Abdul Aziz et al. [8] investigated experimentally the melting and solidification characteristics of PCM. Here, PCM used in application of solar cold storage to provide the required latent heat when the power failure or at the situations of no shines of sun. They analyzed the temperature distributions and heat transfer rates of PCM for both melting and solidification. The container used made from steel of (100cm × 76cm × 5.5cm) dimensions, contain the PCM. The enhancement of heat transfer for melting and solidification was observed when insert 10 fins of aluminum in container. Than Tun Naing et al. [9] explained an approach of heat storage system developing. The approach used the waste heat from 42°C to 50°C taken from factories. The behavior of melting and solidification for PCM which due to hot oil was observed. A perforated plate inserts in the region of PCM which putted into the storage heat container. The using of perforated plate will decreased the PCM solidified height. Metal fiber used to repeat the processes of melting and solidification. The results show that the using of metal fiber was more effective than perforated plate. M. J. Hosseini et al. [10] investigated experimentally and numerically the effects of Stefan number and height of fins on the heat exchanger performance. Heat exchanger was shell and tube, contains a PCM. They studied the times and progresses of both melting and solidification, the distribution of temperature along three directions (longitudinal, angular and radial) at different shell sections (fin and mid). The results show the importance of two parameters on the performance of heat exchanger. These parameters were the Stefan number and time of melting. The increasing in Stefan number and decreasing in the time of melting cause decreasing in heat transfer rate. Pasam

Bhagyalakshmi et al. [11] presented the spherical balls to collect the PCM and the water used as a heat transfer media. PCM were Paraffin wax and Palmitic acid. Three ways used to carried the process of solidification, these were cold water, natural without water and hot water. Reduction in stability observed for the case of natural without water and hot water but for cold water, the sudden drop in the temperature was observed for the base material.

Experimental Work

The aluminum container has the dimensions of (90cm length x 35cm width x 30cm height). This container is divided into three parts and the middle part has the dimensions of (30cm length x 30cm width x 35cm height). Aluminum sheet metal was selected as a material of the container for its high thermal conductivity, the parameter was important for time of both melting and solidification of phase change material. The container parts obtained by two dividers from aluminum too. Each wall of container and the dividers has the thickness of 1mm. The middle part contain the phase change material (polyethylene glycols or Palmitic acid). The mass of each PCMs was 1 kg. The first part filled with hot water with 100°C and used as a heat source for PCM melting. To ensure 100°C in this part, an electrical heater with thermostat used. On the other side of the container, the water of (25−26°C) filled this part and the water continuous flowed into this part to confirm water temperature by connected this part with the hydrant. The heat transferred from the heat source to phase change material (charging process), then heat transfer from the phase change material to cold sink (discharging process). Twelve type K thermocouples used to measure the temperatures in phase change material. For each 5 minutes the temperatures recorded. The thermocouples distributed into phase change material with three levels to ensure a good observation of temperature distribution for each phase change material. Fig. 1 shows thermocouples locations in the middle part of box which contain the PCMs and Table 1 shows the coordinates of thermocouples positions into the phase change material. Fig. 2 shows the aluminum box used in experiments.

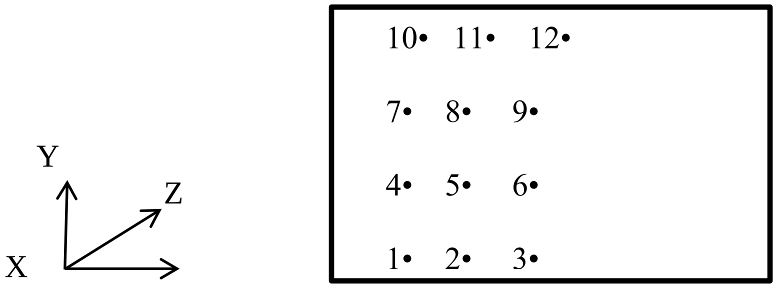


Figure 1: *Thermocouples distributions into the phase change material.*

Table 1: *Coordinates of thermocouples positions.*

Thermocouple No.	X Coordinate(cm)	Y Coordinate(cm)	Z Coordinate(cm)
1	7.5	7.5	7.5
2	15	7.5	7.5
3	22.5	7.5	7.5
4	7.5	15	15
5	15	15	15
6	22.5	15	15
7	7.5	22.5	22.5
8	15	22.5	22.5
9	22.5	22.5	22.5
10	7.5	30	30
11	15	30	30
12	22.5	30	30

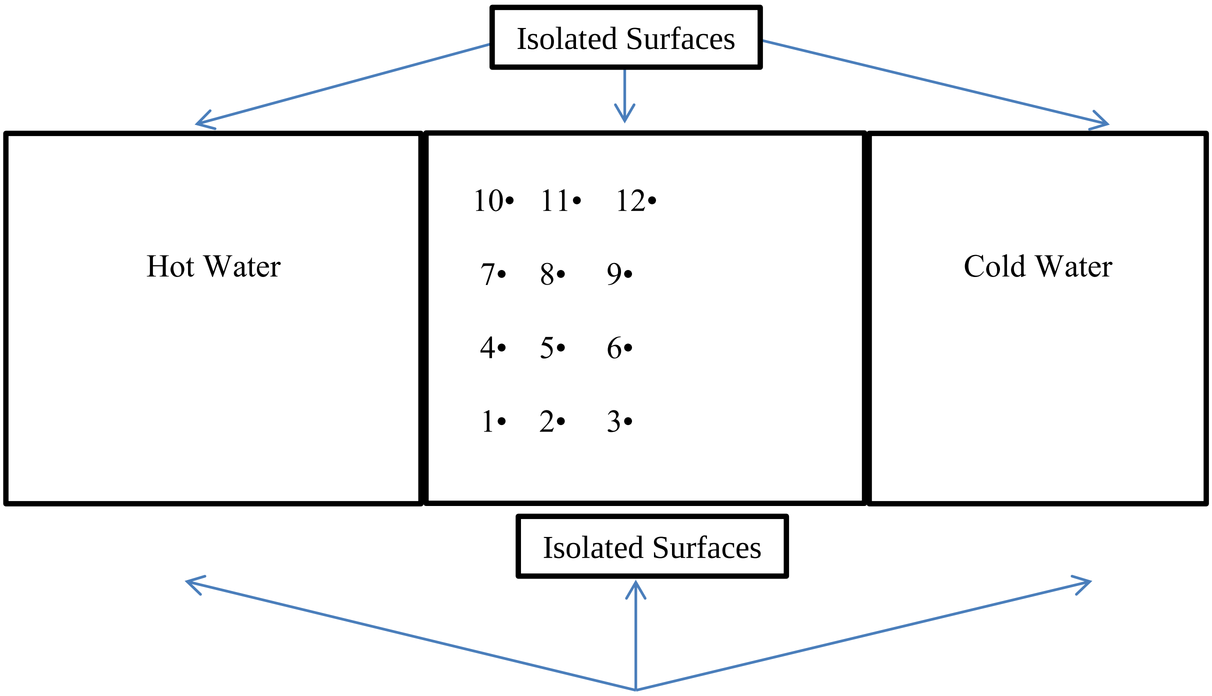


Figure 2: *Aluminum box used in experiments.*

The thermo physical properties of PCMs were tabulated in the Table 2.

Table 2: *Thermophysical properties of PCMs.*

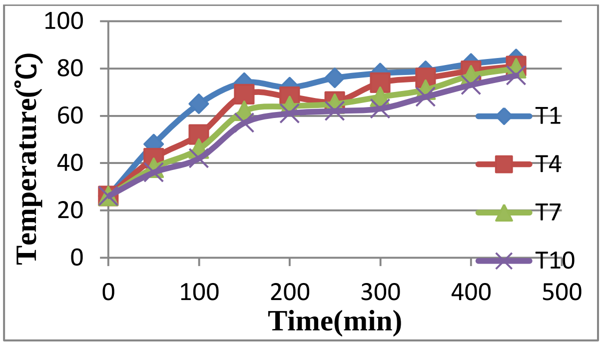
PCM	Melting Temperature (°C)	Density (Kg/m^3)	Thermal Conductivity (W/m.K)	Latent Heat Storage (KJ/Kg)
Polyethylene glycol [12]	37.1	1200	0.2	154.91
Palmitic acid [13]	61–63	942	0.162 @ 68.4 °C	204–212

Oil heated to 100°C, and the heat was transferred to PCMs (polyethylene glycols or Palmitic acid), therefore the melting process began until all of this PCM was melted. This period call the melting process time, then the solidification process began until all of the PCM was solidify. This period is called as the solidification process time. The temperatures recorded for each processes for each period is 5 minutes for each temperature reading.

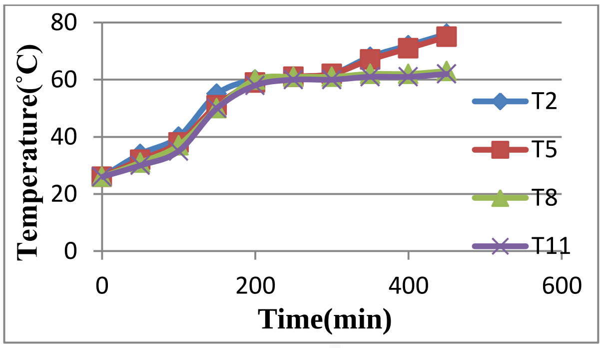
RESULTS AND DISCUSSION

For the same total time melting process for each polyethylene glycols and Palmitic acid, the comparison done between them, the charging process starts from the upper level of PMC towards to the bellow due to gravitational force, while the discharging process stats start from the bottom level of PCM upward to the up due to the buoyancy force. These behaviors occurred for both polyethylene glycols and Palmitic acid. The total time required for melting was approximately 8 hours for polyethylene glycols and approximately 10 hours for Palmitic acid. The amount of mass for each PCM remains in container without melting due to low heat transfer between the hot source and PCM. The results show that the charging rate of Palmitic acid was less than the charging rate for polyethylene glycols. Fig. 3 and 4 show respectively the temperature values with time for Palmitic acid and polyethylene glycols during melting process at 100°C of hot source constant temperature. The temperatures near to hot source were higher than those in the middle and left sides with respect to the hot source side. The results show that the charging temperature of Palmitic acid was greater than those of polyethylene glycols and the heat transfer rate to polyethylene glycols was higher those for Palmitic acid.

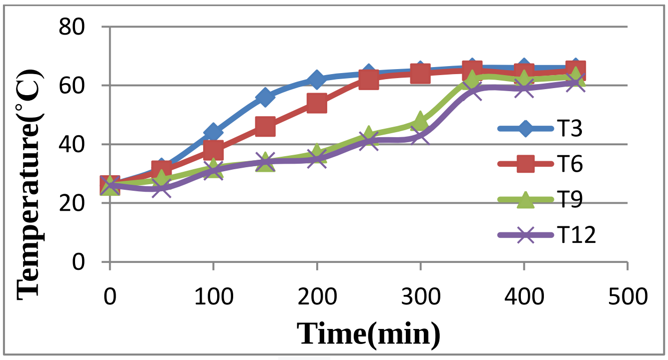
Fig. 5 and 6 show respectively the temperature values with time for Palmitic acid and polyethylene glycols during solidification process at 25°C of cold sink constant temperature. The temperature values of PCMs decrease with increasing in time until to solidification temperature. The difference between Fig. 5 and 6 is the temperature value of solidification process starting. The time required for polyethylene glycols solidification was longer that for Palmitic acid. The results show that the Palmitic acid was better from polyethylene glycols in stored heat due to higher latent heat storage for Palmitic acid.



(3a)

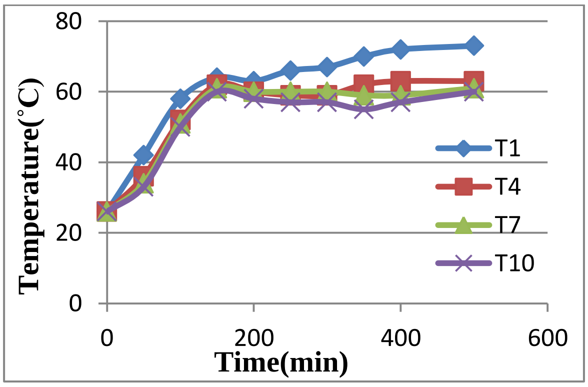


(3b)

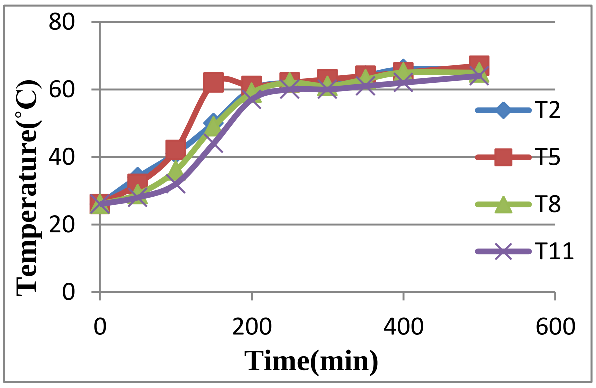


(3c)

Figure 3: *Temperature values of Palmitic acid melting.*



(4a)



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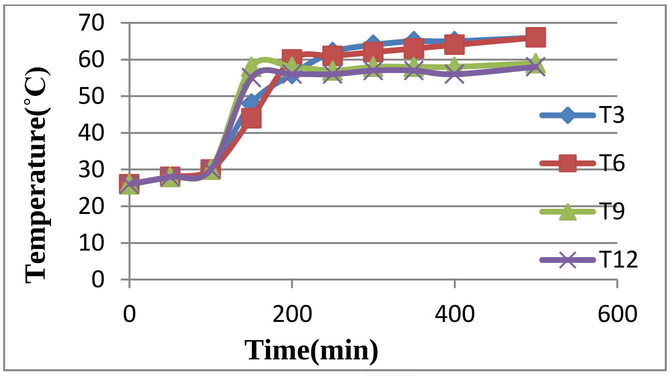
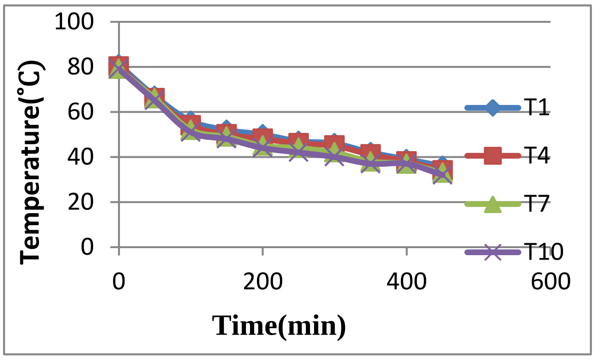
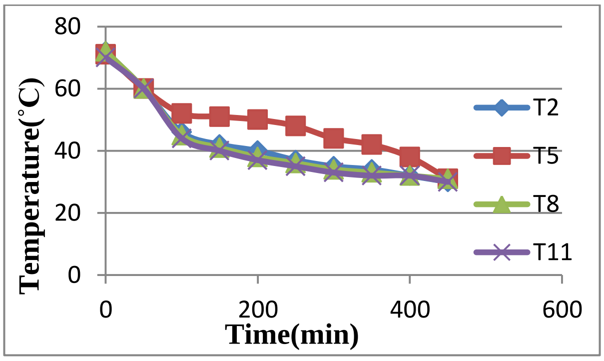


(4c)

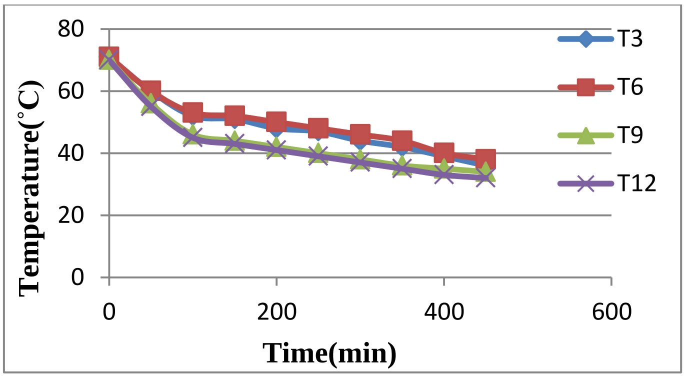
Figure 4: *Temperature values of polyethylene glycols melting.*



(5a)

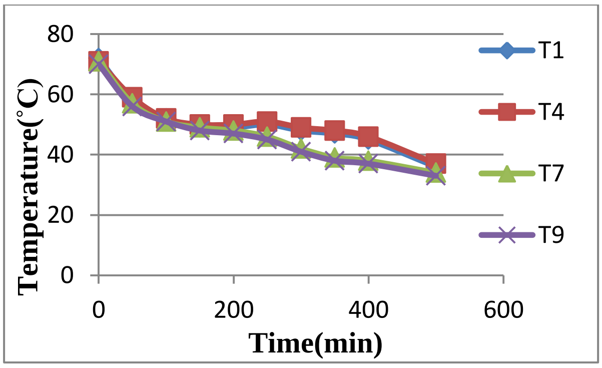


(5b)

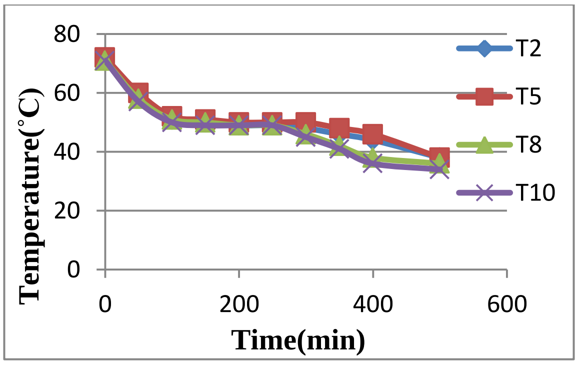


(5c)

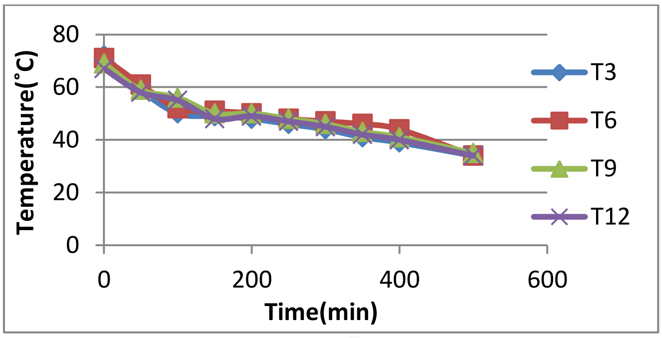
Figure 5: *Temperature values of Palmitic acid solidification.*



(6a)



(6b)



(6c)

Figure 6: *Temperature values of polyethylene glycols solidification.*

CONCLUSIONS

PCMs can be used as a heat storage unit. The charging processes of PCMs start from the upper level toward the bottom and vice versa, the discharging processes of PCMs start from the bottom upward to the upper level. Palmitic acid was better from polyethylene glycols in stored heat due to higher latent heat storage for Palmitic acid. Therefore, Palmitic acid is appropriate for thermal storage applications.

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