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EXPERIMENTAL STUDY ON SOLAR ENERGY STORAGE IN PHASE CHANGE MATERIALS USING CYLINDRICAL SHELL TYPE HEAT EXCHANGER

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ABSTRACT

In the present work an attempt is made to store solar energy in Paraffin and Palmitic acid and the eutectic mixture of the two and compared with each other. Cylindrical type tube heat exchanger is used for the storage purpose and water is used as a heat transfer fluid (HTF). The storage time for charging and discharging processes of the three materials are measured. The conditions of discharging process are discharging by hot water in the storage tank, discharging by cold water and by keeping the storage tank empty. The results showed that the eutectic mixture has better storage capacity, and time to retain the high temperatures compared with the base materials. It is suggested that this phase change material (PCM) is suitable for storing the hot water for a longer period of time during adverse climatic conditions.

Keywords: cylindrical heat exchanger, eutectic mixture, heat transfer fluid, solar energy, phase change material.

INTRODUCTION

Solar energy storage has become an essential crisis in the current time due to the depletion of fossil fuels and environmental issues related to that [1], and also the need of energy has been increased more than its production. Solar energy storage can be accomplished either by sensible heat storage or by latent heat storage system. Comparing the two types the latent heat storage system requires less volume of material to store the same amount of energy [2-4]. The selection of a suitable material for application and the selection of heat exchanger is very important [5]. In the recent years many researchers are concentrating in this area to capture the energy to better extent.

Mahfuz *et al* [6] have studied the energy, exergy and cost analyses of thermal energy storage system using paraffin wax as PCM for solar water heating application in shell and Tube type heat exchanger. Water used as heat transfer fluid and with the varying flow rates of the HTF they experienced varying energy and exergy efficiencies. They concluded that the total life cycle cost will be decreased with the increase of flow rate. Valeria Palomba *et al* [7] have chosen commercial paraffin blend with a melting temperature of 82 ^{o}C which can be suitable for solar cooling applications. Characterization tests have conducted in lab for charging and discharging processes. They reported that the storage density increased by 50%, discharge efficiency ranges from 45% to 60% and an average discharging power between 0.7 and 1.2kW.

Xiangyu Li *et al* [8] have prepared composite PCM of paraffin wax and expanded perlite with two grades of particle size to apply directly into the cement mixture. To prevent leakage, hydrophobic silane method and compared with nanosilica deposition method and the results showed that these composites were superior under certain conditions. Ahmet Sari *et al* [9] have developed a form-stable composite PCM with paraffin and Expanded Graphite (EG) and got the promising results with 10%EG with paraffin. They concluded that the thermal conductivity is increased, melting time with increasing EG is decreased and the latent heat storage capacity is almost same as the base material. Hamidreza Ghasemi Bahraseman *et al* [10] have designed and prepared a composite of expanded graphite matrix combined with phase change material from 0-90 Vol%. Tests have conducted at a controlled solar radiation and temperature data were noted by thermocouples and infrared camera. The results shown that 80%EG-20% PCM has 7 times faster rate of charging compared with other percentages with 30% reduction in storage capacity.

Min Li *et al* [11] have prepared Capric-palmitic binary fatty acid and is absorbed into attapulgite by vacuum method to prepare capric-palmitic/attapulgite composite PCM. Various property tests have conducted to know the thermal properties. The results shown that the structure of the composite is open-ended tubular capillary which is having an optimum absorption ratio of 35% of the binary fatty acid. Found from properties that there is no chemical reaction between the binary fatty acid and attapulgite. Nan Zhang *et al* [12] have prepared first an eutectic mixture of lauric-palmitic-stearic acids and later this mixture is incorporated in expanded perlite by vacuum impregnation method. Property tests have been conducted to know the absorption of this eutectic mixture in the pores. After 1000 cycles also there was no significant changes found in thermal properties. After all the property tests they have concluded that 55 wt% of eutectic mixture in the composite is suited for building energy conservation. Atul Sharma *et al* [13] have chosen lauric acid, myristic acid, stearic acid and palmitic acid binary mixtures with varying weight percentages and DSC test is done. The results showed that latent heat of these PCMs have increased for the binary mixtures at different proportions and recommended that these mixtures are suitable for buildings, solar water heating and drying and foot warmers applications. Xiaojiao Yang *et al* [14] have prepared a ternary eutectic mixture of myristic acid, palmitic acid and stearic acid first and added expanded graphite to prepare a composite PCM. Property tests have been conducted to know the latent heat capacity, charging and discharging temperatures and thermal stability. The results indicated that the composite PCM has good phase change temperature, high latent heat capacity and thermal conductivity, good thermal reliability and stability.

Hadi Fauzi *et al* [15] have added surfactants like sodium myristate, sodium palmitate and sodium stearate to eutectic fatty acids (myristic and Palmitic acids) at 0, 5, 10 and 15%.The results proved that 5% of sodim stearate in eutectic mixture has the highest latent heat of fusion of 191.85J/g and 5% sodium myristate in eutectic mixture has the least under cooling of 0.34 ^{o}C and the highest thermal conductivity of 0.242 W/m K. Maria C. Browne *et al* [16] have done corrosive tests of various metals with five different PCMs. Three fatty acids, one salt hydrate and Micronal are used as PCMs and Copper, brass, aluminium, stainless steel, mild steel and Perspex are used to test the corrosion rate when immersed in PCMs. The results shown that stainless steel is suitable for PCMs. After 722 days the results were calculated and aluminium, copper and brass have slight affinity towards corrosion after few cycles. .Kabeel *et al* [17] have experimentally investigated the performance of a finned plate solar air heater (FPSAH) by using paraffin wax as a PCM. The mass flow rates and the mass of the PCM have changed to know the instantaneous and daily efficiencies. The results showed that the efficiencies are increasing with an expense of the decrease in outlet temperatures. With the increase in the paraffin mass the temperature reach 8.6^{o}C after 4 hours of the sunset. And the daily efficiency is increased by 10.8-13.6%. Mahyar Silakhori *et al* [18] have prepared palmitic acid and polypyrrole form stable composite and done various tests to find its properties. The obtained results shown that 79.9wt% of Palmitic acid in the composite has highest latent heat of 166.3J/g. The composite shown better thermal and chemical stability during thermal cycling tests and can be considered as this composite is suitable for low temperature solar energy storage.

Meng *et al* [19] have prepared a composite phase change material by embedding copper foam into pure paraffin. A tube-in-tank thermal storage unit is built to test this composite PCM for charging and discharging processes at different inlet temperatures and inlet flow velocities of heat transfer fluid. A 3D mathematical model based on enthalpy-porosity is established to investigate the detailed heat transfer characteristics of the Latent thermal energy storage unit and concluded that this composite PCM has obtained good results. Fengxia Gao *et al* [20] have synthesized a new type bifunctional microcapsules to encapsulate a n-eicosane paraffin and cuprous oxide composite. Fourier-transform infrared spectroscopy and X-ray spectroscopy tests have conducted to check the chemical structures. The thermal analysis showed the optimum conditions. They have concluded that the bifunctional feature is best suited for both industrial and domestic applications. Kailiang Huang, Guohui Feng, Jianshun Zhang [21], A new PCM floor including plaits and macro-paked PCM layer and was investigated that the heat storage and releasing process with experimental and simulation method. Mathematical model was established for heat transfer analysis. Thermal characteristics of PCM floor was tested under stable operation condition. The results showed that the PCM base floor is able release more energy than an ordinary concrete floor and concluded that storage by capric acid is much more suitable and useful than sensible heat storage by concrete within the floor.

Akgun. M *et al* [22] in their study analyzed thermal energy storage performance of Paraffin in a novel tube-and-shell system. Three kinds of paraffin with different melting temperatures are used as PCMs. Water is used as the heat transfer fluid (HTF). The thermo-physical properties of the paraffin used are determined through the differential scanning calorimeter (DSC) analysis. The effects of the Reynolds number and the Stefan number on the melting and solidification behaviors are determined. Bhagyalakshmi *et al* [23] have done characterization study on paraffin wax (PW) and palmitic acids (PA). Prepared eutectic mixtures of these two materials with various weight percentages. The differential scanning calorimetric test results shown that 40 wt% of PW and 60 wt% of PA eutectic mixture has good latent heat capacity than the other combinations. This was the earlier work done by us and this eutectic mixture has chosen for solar energy storage applications using spherical type and cylindrical type storage units. Spherical type storage unit has been discussed in another paper. In this paper mainly concentrated on cylindrical type storage unit with 40-60 wt% PW-PA. The obtained results were compared with the base materials.

Table-1. Properties of the phase change materials.

Material	Melting temp (^{o}C)	Solidification temp (^{o}C)	LHS capacity during charging(J/g)	LHS capacity during discharging(J/g)
Paraffin wax	58.8-67.2	61.7-52.8	138	135.2
Palmitic acid	62.2-67.9	55.1-61.0	193.7	193.7
Eutectic mixture	52.6-59.8	40.9-47.1	214.7	194.6

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Experimental set up and procedure

Figure-1. Solar collector with PCM storage unit.

Figure-2. Cylindrical storage unit.

Figure-1 shows the solar water heater connected to a thermal energy storage unit. The setup consists of a solar collector, insulated water tank and a cylindrical drum for energy storage. There are 16 cylinders each of 75mm diameter and 120mm of height are attached to a central cylinder of 100mm diameter and 400mm height. The central cylinder has a provision to fill the PCM and all cylinders are internally connected to receive the material. Water from the overhead tank passes through the solar collector during sunny hours and sent to the solar tank. The heated water from the solar tank will later sent to the thermal storage tank to melt the material.

This process occurs when the sunlight is available. The hot water supply cut once the tank filled allowed the material to melt. The melting process carried out till the PCMs reaches their end point temperatures. The solidification process carried out in three ways- solidification by i) Hot water , ii) cold water and iii) without water in the tank. For all the three cases the melting process remains same. The HTF inlet temperature is maintained 75 ^{o}C.

Table-2. Specifications of storage unit.

Components	**Material**	**Dimensions** (mm)	**Volume in m^3**
Storage Cylinder	Stainless Steel	400 X 500	0.06283
Central tube	Stainless Steel	100 X400	0.003297
Side tubes	Stainless Steel	75 X 120	0.01176
Insulation	Foam	50	----

Solidification processes

Hot water solidification process

The intention of this type of storage is to find the maximum time the material and heat transfer fluids maintains at their temperatures. In this method the temperatures are recorded for continuously for 3 days and averaged the values. The temperatures have maintained at higher values for more than 6 hours and after that also the rate of cooling was very slow. During this solidification process the outside temperatures were at 28^{o}C with mild breeze in the atmospheric air and the top cover of the storage unit is not insulated.

Cold water solidification process

In this case once the material reached its highest melting temperature the heat transfer fluid (Hot water) is removed from the storage tank and filled with cold water with an inlet temperature of 35 ^{o}C-39 ^{o}C to solidify the material. The changes in the temperatures of the material and the cold water have measured for three days and averaged the values. The atmospheric conditions remain same like other cases.

Natural Solidification process

In this case once the material attained its melting temperature the hot water is drained from the storage tank and kept the drum empty. This is done to ensure the solidification time for the material when there is no fluid to transfer the heat. In this case both the material and the empty drum were at constant temperatures for a longer period of time and changes were very slow. Like the above cases the surrounding air temperatures were less than 30 ^{o}C and mild breeze throughout the solidification process. All the three cases top of the storage unit is not insulated.

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RESULTS AND DISCUSSIONS

Experiments for cylindrical type storage unit have conducted during the month of April in Chennai city. The temperatures were sufficiently high to obtain 60-65 °C of hot water from solar flat plate collector. To rise the temperatures of water to 75 °C, auxiliary heater has used whenever required. The melting process used to start in the evening at around 4 PM and it takes 3 hours to get melted the material. The process is repeated daily to get the required temperatures. The melting process remains same for all the cases. The solidification process follows the melting process. The surrounding temperatures are at an average of 28-30 °C after 8 pm. Time vs temperature graphs were plotted.

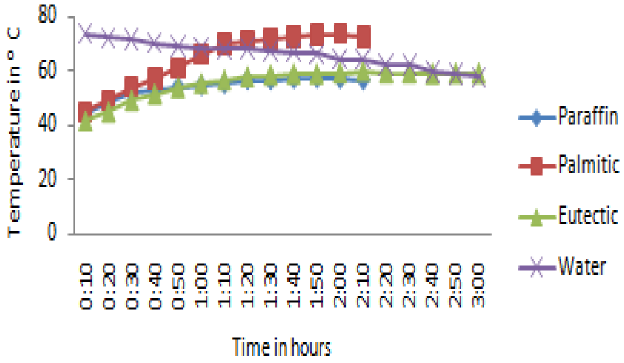

Figure-3. Melting curve for phase change materials.

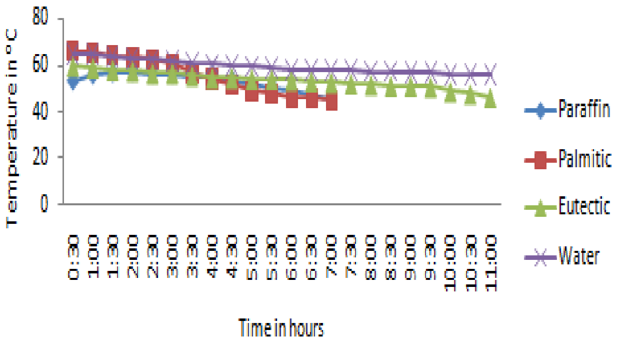

Figure-4. Hot water solidification curve.

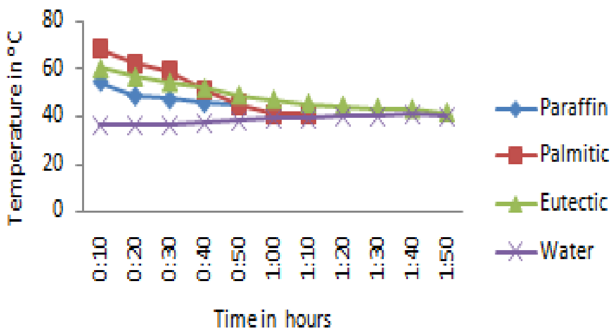

Figure-5. Cold water solidification curve.

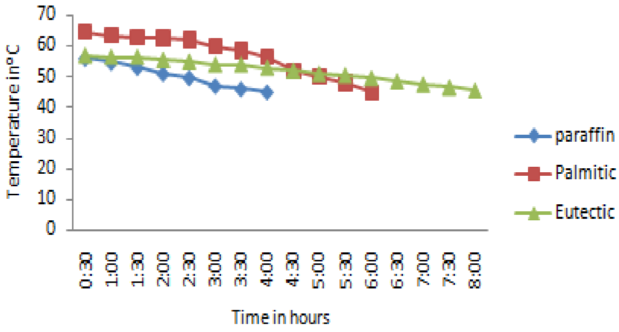

Figure-6. Natural solidification curve.

- The melting and solidification curves of paraffin in all the three cases are linear without any abnormal changes. Due to the wide range of temperature (nearly 9°Cfor both charging and discharging) for its storage capacity of 135J/g of energy makes the paraffin wax to gain and lose its temperatures gradually.
- In case of Palmitic acid the inlet temperature of water for melting is maintained above 80 °C because of its melting temperature range is above 60 °C. It has sharp charging and discharging curves with in a small range of 5.7 °C (62.2-67.9 °C). Due to this small discharging temperature range it lost its temperature during cold water solidification period within an hour. The curves in all cases are not as gradual as in case of Paraffin wax.
- The melting range of eutectic mixture is 7.6 °C (52.2-59.8 °C) to store 214J/g. This wide range makes the melting curve uniform. The solidification range is also sufficiently high which shows the slow rate of cooling of the material. The curves are almost linear and possess near the properties of paraffin wax. During cold water solidification also it took nearly 2 hours time to give up the temperatures to the HTF.

CONCLUSIONS

The experimental tests have been conducted to Paraffin wax, Palmitic acid and Eutectic mixture of these two PCMs for their storage capacity and the results were compared for the three materials in the melting and solidification processes.

- The melting temperature range of paraffin wax is 58.8-67.2 °C and that of the palmitic acid is 62.2-67.9 °C have reached in 120 minutes. The eutectic mixture has reached its end point of melting temperature (52.2-59.8 °C) gradually in 3 hours time. The rate of change of temperatures is gradual in case of all the materials. The three materials possess good holding temperatures when hot water retained in the tank during the solidification process. Among the three materials the eutectic mixture has taken nearly 11 hours to come down to 45 °C temperature. The base materials also took nearly 7 hours and it is a very slow change in the eutectic material temperatures compared to the base materials.

- During solidification of cold water present in the tank, there is a sudden fall of temperature in case of palmitic acid. The base materials lost their temperatures within an hour. The eutectic PCM has gradually lost its temperature and the overall change in the cold water temperature was not appreciable.
- During natural solidification process, Paraffin wax has solidified within 4 hours and process was gradual. Palmitic acid has taken more than 6 hours to come down to that stage and the solidification was slow in the early hours and has increased after 4 hours. The eutectic mixture has a slow change in its natural solidification process and curve is almost linear and took nearly 8 hours to come down to its solidification temperature.
- It is concluded that the eutectic PCM is able to store energy for a longer period of time than the base materials. These PCMs are suggested in solar water heating applications to store the solar hot water at higher temperatures twice that of the time of the ordinary unit.

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