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PERFORMANCE OF PARAFFIN AS PCM SOLAR THERMAL ENERGY STORAGE

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ABSTRACT
The continuous increase in the level of greenhouse gas emissions and the rise in fuel prices are the main driving forces behind the efforts for more effectively utilize various sources of renewable energy. In many parts of the world direct solar radiation is considered to be one of the most prospective sources of energy. In this study, the thermal performance of a phase change thermal storage device is discussed. The storage unit is a solar wax melting system being developed for latent heat storage studies. Paraffin was used as PCM in thermal energy storage with a melting temperature of 42-50 ^{0}C.This study is based on experimental results of the PCM employed to analyze the thermal behavior of the storage unit during the charge and discharge periods of the paraffin. The time wise temperatures of the PCM and solar intensity were recorded during the processes of charging. The heat transfer characteristics were studied.

Keywords: Thermal energy storage (TES), Latent heat storage (LHS), Phase change material (PCM), expanded graphite (EG).

1. INTRODUCTION

Energy storage, especially thermal energy storage (TES), plays an important role in conserving available energy and improving its utilization because the discrepancy between energy supply or availability and demand can be overcome by implementation of a proper energy storage system. Among the various thermal energy storage methods, the latent thermal energy storage employing a phase change material (PCM) has been widely noticed as an effective way due to its advantages of high energy storage density and its isothermal operating characteristics (i.e. charging/ discharging heat at a nearly constant temperature) during the solidification melting processes, which is desirable for efficient operation of thermal systems. In a latent heat storage system, energy is stored during melting and recovered during solidification of a PCM.

The use of the latent heat of a PCM as a thermal energy storage medium has gained considerable attention recently by finding however practical difficulties usually arise in applying the latent heat method due to its low thermal conductivity, density change, and stability of properties under extended cycling and sometimes phase segregation and sub cooling of the PCMs. Over the last decade, a number of studies have been performed to examine the overall thermal behavior and performance of various latent heat thermal energy storage systems. These studies focused on the melting/freezing problem of the PCM and on the convective heat transfer problem of the HTF used to store (melt) and/or retrieve energy (solidification) from the unit (Mithat et al., 2007). PCMs have been widely used in latent heat thermal storage systems for heat pumps, solar engineering, and spacecraft thermal control applications. The uses of PCMs for heating and cooling applications for buildings have been investigated within the past decade (Atul et al., 2009). The increase of the heat transfer rate obtained by using vertical fins could be very useful for applications of PCM modules inside water tanks.

These PCM modules are used to store in a reduced volume. Using modules with vertical fins could solve the problem of slow heat transfer rate from the PCM to the water and increase the availability of the energy. The storage system would be more flexible to match the energy demand (Albert et al., 2008). Suffocation was also found as a suitable method to increase LHTES capacity of paraffin (Cemil, 2006). The shape-stabilized PCMs can keep the same shape in a solid state even when their temperature is above the melting point of the paraffin. They exhibit same phase transition characteristics as paraffin and up to 80% of the latent heat of paraffin. Thermal conductivity of the shape-stabilized PCMs is increased significantly by the introduction of expanded graphite (EG) (Min et al., 2001).

A PCM with an easily adjustable melting point would be a necessity as the melting point is the most important criterion for selecting a PCM for passive solar applications (Farid et al., 2004). It was found that almost 95% of the stored energy was in the form of latent heat while the remaining 5% was as sensible heat (Hamdan and Elwrrl, 1996).The melting time depends on the rate of natural convection which in turn depends on the Rayleigh number. The higher the value of the Rayleigh number, the higher the rate of natural convection, the lesser the time of melting (Soma and Topas, 1993). The use of paraffin wax as a phase change material in small aluminum containers packed in conventional water storage tanks represents an approach for simple and inexpensive thermal energy storage. Such storage can be reliably used with conventional and existing solar water heating systems. The suitability of the melting temperature of paraffin wax enables the storage of excess energy available in daytime hours as latent heat, and then the release of this stored heat to maintain the water temperature in an acceptable range for most domestic applications (Ahmet Sari et al., 2001). In recent years fatty acid esters are used as phase change materials (Ahmet Sari et al., 2010). It is found that phase change process of the binary mixture takes place over a temperature range and the temperature range depends on both the heating rate and the mixture composition (Kousksou et al., 2010). Soft computing techniques can be used to model of a solar collector with PCM (Yasin et al., 2010). Different metals are also used with PCMs to improve the thermal storage performance (Zhao et al., 2010) and (Zivkovic and Fujill, 2001).Graphite was also used to increase thermal diffusivity of the Paraffin (Sumin and Lawrence., 2009, Yajuan et al., 2010, Mehling et al., 2000, Yanxiang et al., 2009, Min et al., 2001).The progress in latent heat storage energy systems depends on the development of efficient heat exchangers for energy transfer between a PCM and a working fluid during charging and discharging (Banaszek et al., 1999).

Latent heat storage of the PCM can also be increased by using multiple PCMs (Zhen and Arun, 1997).The efficiency of PCM is dependent on the encapsulated quantity and energy storage capacity per unit mass during its melting and solidifying. The enthalpy of melting and solidifying of paraffin could be extended by Sulfonation (Chemil, 2006). Rectangular container requires half of the melting as for the cylindrical container of the same volume (i.e. equal mass of the PCM filling the container) and the same heat transfer area between heat transfer fluid and the container' s wall (Zivkovic and Fujill, 2001). Lower values of initial temperature did not make significant contribution on the solidified mass fraction of PCM. It as well infers that for solidification, initially there is a higher heat flux release for lower coolant fluid temperatures (Eman et al., 2007).

PCM $CaCl_2$_6H2O has excellent solidifying and melting characteristics for solar discharging properties are significant (Veerapan et al., 2009). Esters are also considered as promising PCMs for thermal energy storage (Ahmet Sari et al., 2010). Stearic acid is a good PCM for energy storage for domestic solar water heating. It has a suitable melting point of 60–61^{0}C, 90% purity commercial grade stearic acid, and a high latent heat of 186.5kJ/ kg. It was observed that the melting and solidification times were not affected by the flow rate of the heat transfer fluid in the tested laminar range. Similar results are reported by Sari et al. (Ahmet Sari et al., 2001). The Palmatic acid was confined in maximum percentage of 80 wt% without leakage of melted PCM from porous structure of the EG and therefore, the composite was described as form-stable PCM (Ahmet Sari and Ali, 2009). Adding expanded graphite into paraffin to form paraffin graphite composite also proves to be a feasible method for heat transfer enhancement (Zhao and Zhou, 2011).

2. MATERIALS AND METHODS

A Solar Wax melting chamber of area 0.2601 m^2 was constructed to study the melting /solidification characteristics of Paraffin wax. Commercial grade paraffin wax was used in the experiment. Copper – Constantan monojunction thermocouples were used to measure the temperature. Solar radiation was measured using Pyranometer .Polyurethane foam was used for thermal insulation purposes. Two transparent glass plates are used to cover the system. Paraffin was taken in five different masses and tested for latent thermal energy storage.

3. EXPERIMENTAL

Experiments have been conducted to determine the charging and discharging behaviors of the PCM. A solar cooker of area 0.2601 cm^2 was constructed to study the melting and solidification characteristics of Paraffin wax.

Paraffin's are taken in five different masses of 1Kg, 2Kg, 3Kg, 4Kg, 4 1/2Kg and 5Kg and tested for the maximum solar thermal energy storage. Melting starts in the lower region of the storage container close to the inner wall and, then, molten PCM ascends to the top part of the storage container as a result of natural convection currents.

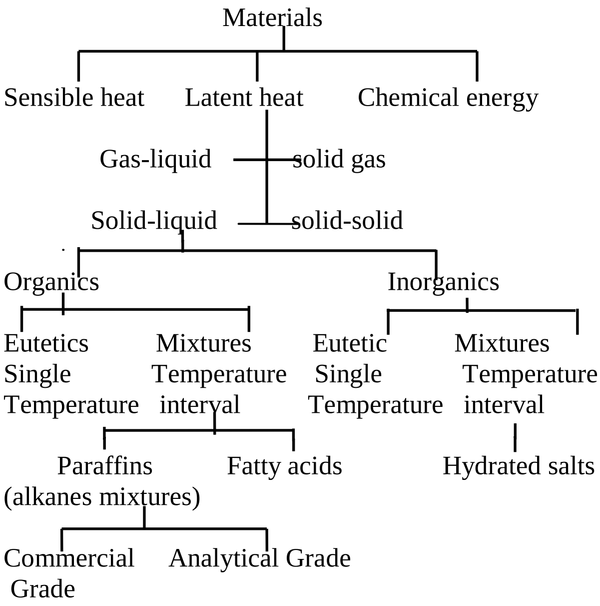

Figure 1 Classification of energy storage materials (Belen et al., 2003)

Figure 2 Wax melting Chamber

Figure 3 Paraffin wax

The melt region extends radially upward (i.e. boundary layer develops along the inner wall).

Figure 4 Paraffin wax

Figure 5 Melted paraffin

During melting two regions coexist during the charging process, which are: the melted PCM region in the liquid phase and the non-melted PCM region in the solid phase. In the solid region, the conduction inside the solid matrix of the PCM is responsible for the heat transfer process inside and this region receives heat from the melted part by convection.

When the solid matrix of the PCM melts, convection mechanism of the heat transfer drives the recirculation in the melted PCM, which is due to the buoyancy forces induced by the density gradients as a result of temperature differences. The recirculation inside enhances mixing and heat transfer within the molten PCM, which can be explained by the fact that the points near the upper part reach to the melting temperatures in shorter times than the lower points do.

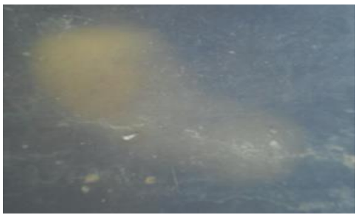

Figure 6 Non-melted paraffin

Note that the density of the molten PCM is lower than that in the PCM in the solid phase. At larger operating times, the region of the molten PCM extends to cover larger regions of the PCM container. It was absorbed that paraffin wax with mass of 4Kg have maximum fig 10 solar radiation, and its efficiency was calculated as 8.56%.Air temperature of the inside the system was also studied, it reaches a maximum temperature of 87^0 C inside the system.

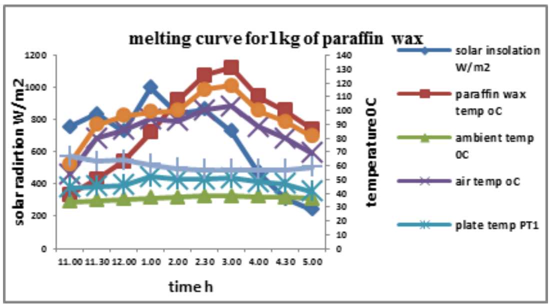

Figure 7 Melting curve for 1kg of paraffin wax

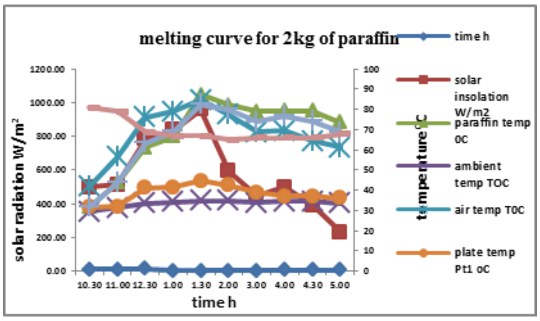

Figure 8 Melting curve for 2kg of paraffin wax

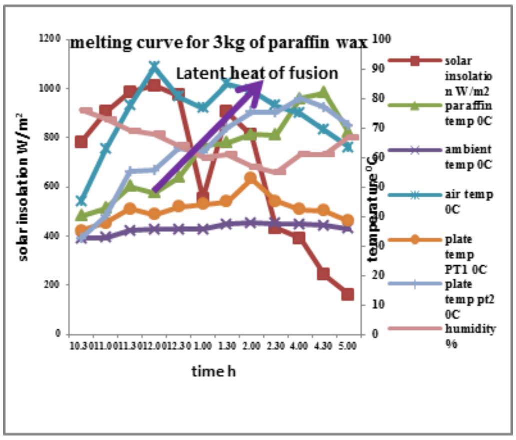

Figure 9 Melting curve for 3kg of paraffin wax

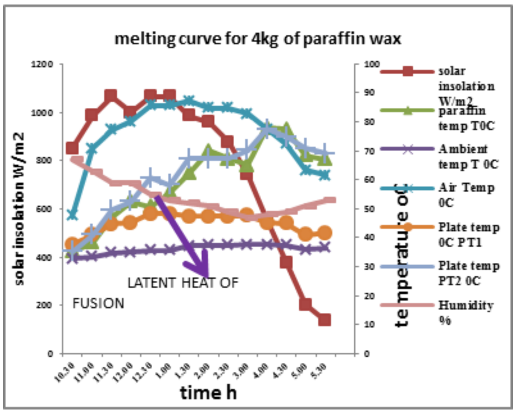

Figure 10 Melting curve for 4kg of paraffin wax

4. RESULTS AND DISCUSSION

A paraffin wax (PCM) stores thermal energy, when it melts and releases the stored thermal energy when it solidifies. Below the melting point the energy stored in the PCM is sensible heat, but when it reaches the melting point the material begins to melt and energy is stored as latent heat, this is termed as latent heat.

The PCM temperature will begins to fall as it loses its thermal energy and when the PCM temperature reaches below the melting point, the PCM will begin to solidify thus releasing its stored latent energy this was termed as the discharge period. These charging and discharging characteristics of the PCM was shown in the Figure.(7-12). The latent heat of fusion was not absorbed in the melting characteristics of wax mass taken as 1kg and 2kg Figure. (7, 8). From the Figure. (9-12) it was noted that the PCM temperature increases faster at the beginning, which is initially in the solid phase and then a sudden drop in the temperature of the PCM was witnessed as it reaches a temperature of around 50^0 C, which is close to its reported melting point. This sudden drop in temperature of the PCM was witnessed, when the wax mass was taken as 3kg, 4kg, 4.5kg, 5kg.

This sudden drop in temperature of the PCM was witnessed, during the melting of wax, when it was taken in the wax melting chamber in the proportion of 3kg, 4kg, 4.5kg, and 5kg.In the figure 9 it was observed that during the melting of the paraffin wax its temperature increases gradually but there was a sudden decrease in temperature to 48.1^0C from 50.1^0C.After that the temperature of the paraffin starts to increases sharply. This sudden decrease in temperature was due to the phase change characteristics of the PCM from solid to liquid state at this stage and therefore it was absorbing large amount of heat without increasing its temperature following this the temperature of the PCM starts to increase.

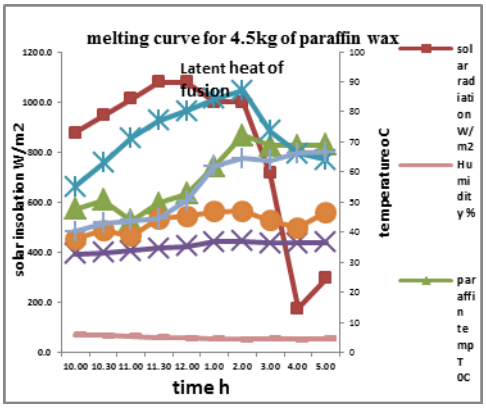

Figure 11 Melting curve for 4.5kg of paraffin wax

This was also absorbed in the Figure.10, 11, 12 where the temperature decreases from 52.6^0C to 50.7^0C and from 50.6^0C to 43.80C and from 45^0C to 40^0C respectively due to the latent heat of fusion. Figure.13 represents the efficiency curve for the various masses of paraffin wax.

From the Figure.13 it was absorbed that PCM with 4kg of mass reaches the maximum efficiency of 8.56%. So the designed solar melting chamber is capable for melting 4kg of paraffin.

5. CONCLUSIONS

An experimental investigation has been conducted in order to study the melting and solidification characteristics of paraffin as a phase change material. The obtained results give a good estimation of the phase change material melting and solidification processes. For the designed wax melting chamber the maximum efficiency of 8.56% was achieved for the load of mass 4kg paraffin wax. It can be concluded that presented work could provide guidelines for thermal performance and design optimization of the latent thermal energy storage unit.

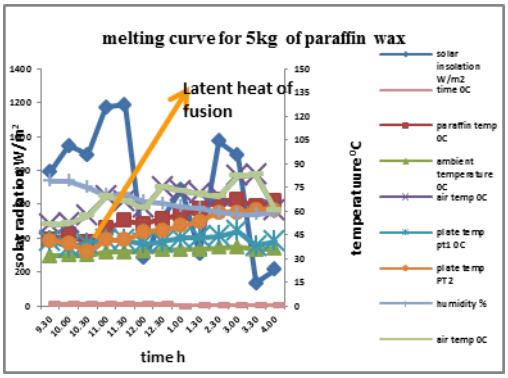

Figure 12 Melting curve for 5kg of paraffin wax

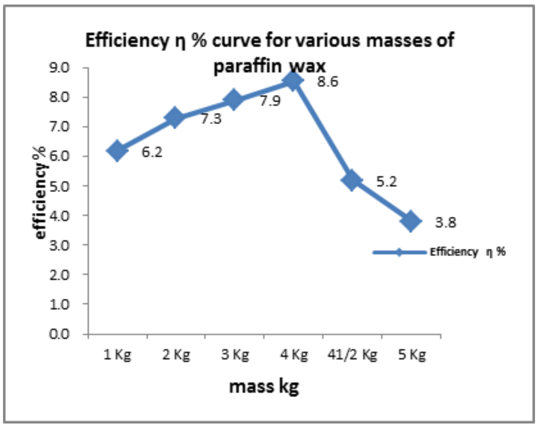

Figure 13 Efficiency curve for various masses of paraffin wax

REFERENCES

Ahmet Sari, A., et al. 2001. Thermal Energy Storage System using steric acid as a phase change material, Solar Energy 71(6): 365–376.

Ahmet Sari and Ali Karaipekli. 2009. Preparation Thermal properties and thermal reliability of Palmitic acid/expanded graphite composite as Form-stable PCM for thermal energy storage, Materials & Solar Cells 93: 571–576.

Ahmet Sari, Alper B., et al. 2010. Synthesis, Thermal energy storage properties and thermal Reliability of some fatty acid esters with glycerol As Naval solid-liquid phase change materials, solar Energy materials and solar cell 94:1711-1715.

Al- Hinti, A., Al - Ghandoor, A., Maaly, I., Abu Naqeera, Z. and Al- Khateeb Al - Sheikh, O. 2010. Experimental Investigation on the use of water-phase change Material storage in conventional solar water heating Systems, Energy Conversion and Management 51: 1735–1740.

Albert C., Cristian S., Marc M., Joan R., Luisa C., F. and Daniel G. 2008. Natural convection heat transfer coefficients in Phase change material

(PCM) modules with External Vertical fins, Applied Thermal Engineering 28:1676– 1686.
Atul, S., Tyagi, V. V., Chen, C. R. and Buddhi D., 2009. Review on thermal energy storage with Phase change materials and applications, Renewable and Sustainable Energy Reviews 13: 318–345.
Banaszek, J., Domananski, R., Rebow, M., et al. 1999. Experimental study of solid-liquid phase change in A spiral thermal energy storage unit, Applied Thermal Engineering 19:1253-1277.
Belen Z., Jose Marın Luisa Cabeza, F. and Harald M. 2003. Review on thermal energy storage With phase change: materials, heat transfer analysis and applications, Applied Thermal Engineering 23: 251–283.
Cemil A. 2006. Enthalpy of melting and Solidification of sulfonated paraffins as phase Change materials for thermal energy storage, Thermochimica Acta 451: 126–130.
Eman -Bellah, Mettawee, Ghazy Assassa. 2007. Thermal conductivity enhancement in a latent heat torage system, Solar Energy 81: 839–84.
Hamdan, M. A. and Elwrrl F. A. 1996. Thermal Energy Storage using phase change material, solar Energy 56: 183-189.
Kousksou, T., Jamil, A., et al. 2010. Paraffin Wax Mixture as phase change materials, solar energy Materials & Solar cells 94: 2158-2165.
Mehling, Hiebler, S. and Ziegler, F. 2000. Latent heat Storage using a PCM-graphite composite material, TERRASTOCK stuttgurt Germany A: 070.
Min X., Bo F. and Kecheng G. 2001. Thermal Performance of high conductive shape-stabilized Thermal storage material, Solar Energy Material & Solar Cells 293-296.
Min X., Luyi S., Chengya H., Yonghua Z. and Kecheng G. 2001. High Thermal Conductivity Shape-Stabilized Phase Change Materials, Polymer Structure & Modification Lab, Mat. Res. Soc. Symp.
Min X., Luyi S., Chengya H., Yonghua Z. and Kecheng G. 2001. High Thermal Conductivity Shape-Stabilized Phase Change Materials, Polymer Structure & Modification Lab, Mat. Res. Soc. Symp. Proc. 661: Materials Research Society.
Mithat, A., Orhan, A. and Kamil, K.. 2007. Experimental study on Characteristic of paraffin as PCM, Energy Conversion and Management 48: 669–678.
Mohammed Farid, Amar Khudhair, Siddique Ali Razack and Said Al-Hallaj, 2004. A review on phase Change energy storage materials and applications, Energy Conversion and Management 45: 1597– 1615.
Soma Das and Tapas Kumar Dutta, 1993. Mathematical Modeling and Experimental Studies on Sola Energy Storage in a Phase Change Material Solar Energy Printed in the U.S.A. 51(5): 305-312.
Sumin, K. and Lawrence T. D. 2009. High latent heat Storage and high thermal conductive phase change Materials using exfoliated graphite nonoplatelets, Solar Energy Materials NA Solar Cells 93:136-142.
Veerappan, M., Kalaiselvam, S., Iniyan, S. and Ranko G. 2009. Phase change characteristic study of Spherical PCMs in solar energy storage, Solar Energy 83: 1245–1252.
Yajuan, Z., Quanqui, G., Jingli, S., et al. 2010. Heat transfer enhancement of paraffin wax using Graphite foam for thermal energy storage, Solar Energy Materials & Solar Cells 94:1011-1014.
Yanxiang L., Min W., Ruigang L. and Yong H. 2009. Cellulose-based solid–solid phase change materials synthesized in ionic liquid, Solar Energy Materials & Solar Cells 93: 1321–1328.
Yasin, V., Ahmet Koca., et al. 2010. Forecasting of thermal energy storage performance of phase Change Material in a solar collector using soft computing techniques, Expert system with Applications 37: 2724-2732.
Zhen, X. G. and Arun, M. 1997. Thermodynamic Optimization of Energy Storage Using Multiple Phase Change Materials, Applied Thermal Engineering 17(11): 1067-1083.
Zhao, C.Y., Lu, W. and Tian, Y. 2010. Heat transfer Enhancement for thermal energy storage using Metal Foams embedded within phase change Materials (PCMs), Solar Energy 8 4: 1402-1412.
Zhou, D. and Zhao, C . Y. 2011. Experimental Investigations on heat transfer in phase change Materials (PCMs) embedded in porous materials, Applied Thermal Engineering 31: 970-977.
Zivkovic, B. and Fujill, I. 2001. An Analysis of isothermal Phase change material within rectangular and cylindrical containers, Solar Energy 70(1): 51-56.