Review of Effective Parameters of Macro-encapsulated Paraffin on Performance of Thermal Energy Storage System

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ABSTRACT

Thermal energy storage (TES) can be achieved by increasing the internal energy of a material as sensible heat, latent heat, and thermo-chemical heat, or combination of these. The usage of macro-encapsulated paraffin to store the heat in the form of latent heat is increased, because large quantity of thermal energy is stored in smaller volumes. Macro-encapsulation can be achieved by many techniques such as tubes, pouches, spheres, panels, plates or other receptacles. On one hand, Paraffin is characterized by a high energy storage density, but on the other hand it suffers from the low thermal conductivity, which limits the power that can be extracted from the TES. This review summarizes the effective parameters of macro-encapsulated paraffin on performance of TES system. It has been appeared that the efficiency and heat capacity of Solar Water Heater (SWH) increased with use of paraffin. The efficiency of Latent Heat Storage (LHS) unit can be enhanced by addition of an appropriate ceramic particles, Al powder and inserting a metal foam in both Phase Change Material (PCM) and Heat Transfer Fluid (HTF) sides. The smaller the capsules the higher the charging and discharging rate. The smaller the thickness of capsules the more heat carrying capacity of SWH system. In the packed bed LHS system, the charging and dis-charging process time can be reduced with increasing the inlet temperature and the mass flow rate of HTF. The performance of LHS unit depends on the collector location, collector tilt, wind velocity, and the solar time. The paraffin in copper tubes is the best effect on efficiency. The heat storage capacity of the combined sensible and latent heat storage system is raised approximately 60% in relation to the conventional Solar Heat Storage (SHS) system.

Keywords: Thermal energy storage, sensible heat, latent heat, Macro-encapsulation of Paraffin.

1. Introduction

Solar thermal energy is widely applied to support home activity such as for cooking, distillation of sea water, and heating of water. Utilization solar power to heat water can be achieved by collecting solar energy and use it to heat water. In addition to reducing of dependence on fossil fuels and thus the carbon footprint, the electrical energy cost could be reduced by utilization of solar water heaters. There are various forms of energy available. According to the law of conservation of energy, energy can neither be created nor be destroyed it can only be converted from one form of energy to another useful form of energy. Different forms of energies require specific techniques for their proper storage purpose. These techniques are judged on the factors such as cost (economy), time for which energy can be stored, amount of energy that can be stored through a particular method etc. [1]. Phase change materials (PCM's), such as Paraffin, attract attention as thermal energy storage materials because their energy densities are much higher than those using sensible heat. The idea to use PCM's for the purpose of storing thermal energy is to make use of the latent heat of a phase change, usually between the solid and the liquid state. There are three possibilities to integration of phase change materials into thermal energy system [2], as shown in figure 1.1:

a) PCM Micro– encapsulation.

b) PCM Macro– encapsulation.

c) PCM in tank, immersed heat exchanger (bulk storage).

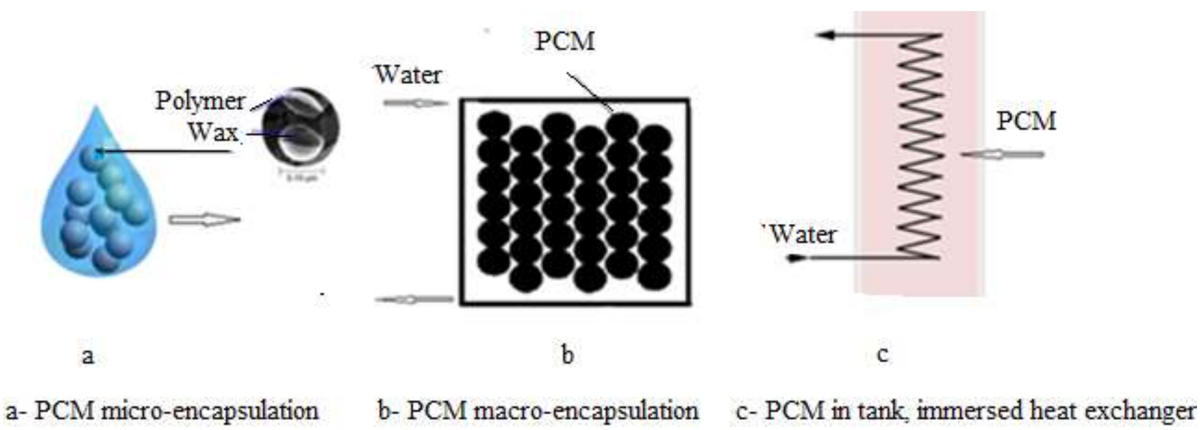

Figure 1.1: Integration of phase change materials into (TES), [2]

1.1 Solar Energy

Solar energy indicates to conversion of the sun's rays into useful forms of energy, such as: electrical, chemical, mechanical or thermal energy. Solar thermal energy (STE) refers to conversion of sun's rays into heat. Thermal energy storage refers to the technology that allows the transfer and storage of heat energy. Thermal energy storage is achieved by increasing the internal energy of a material as sensible heat, latent heat, and thermo-chemical heat, or combination of these, as shown in figure 1.2. Sensible heat storage which is based on storing thermal energy by heating or cooling a liquid or solid storage medium. Latent heat storage which refers to a heat storage system that uses the energy absorbed or released during a change in phase (e.g. a solid melting to liquid) , without changing temperature (isothermal). Thermo-chemical storage in which chemical reactions are used to store and release thermal energy [3, 4].

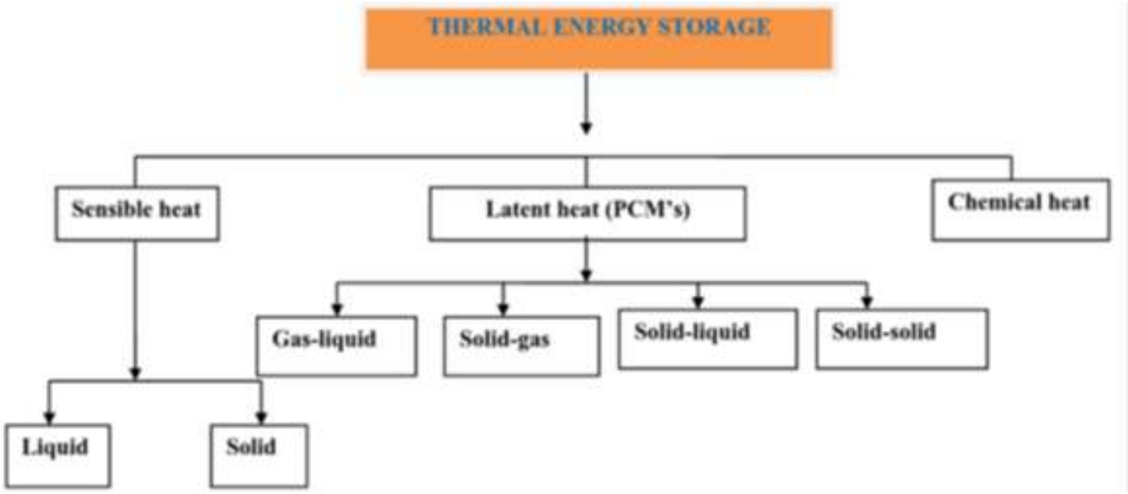

Figure 1.2: Classification of heat storage media [1]

1.2 Paraffins

There are a large number of organic and inorganic chemical materials, which can be abbreviated as PCM from the point of view melting temperature and latent heat of fusion (figure 1.2). A large number of PCM's are available in any required temperature range from −5 up to 190 °C [5, 6].

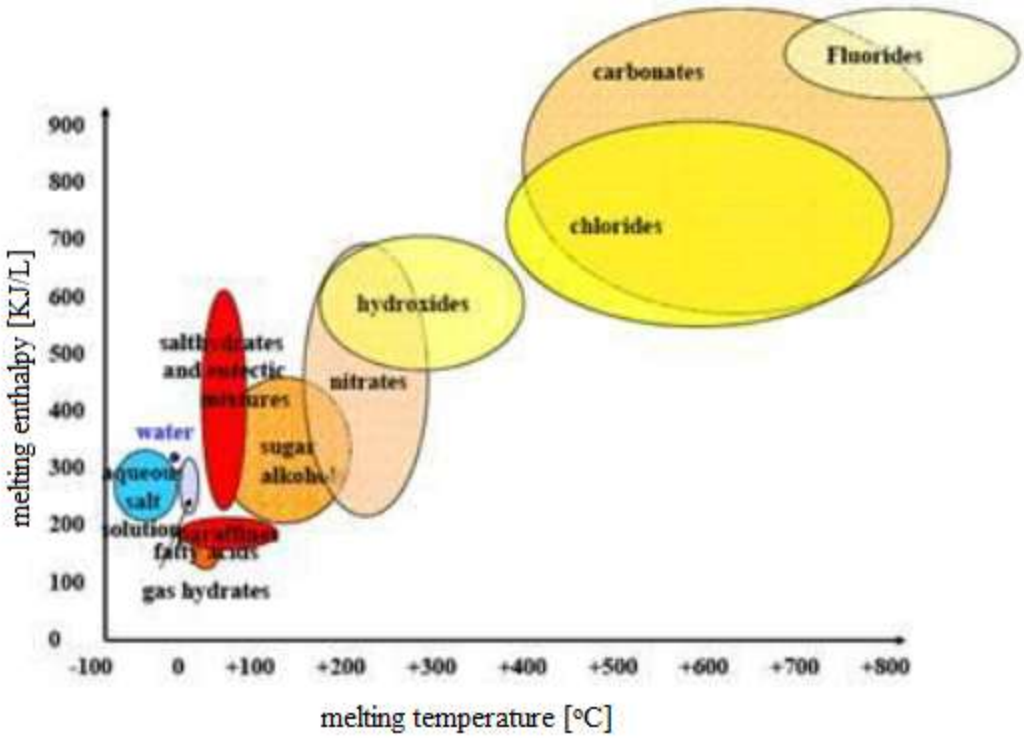

Figure 1.3: Melting enthalpy of various PCM groups
in relation to their melting temperature [7]

Paraffins are an organic materials, which include congruent melting means melt and freeze repeatedly without phase segregation and consequent degradation of their latent heat of fusion, self-nucleation means they crystallize with little or no supercooling [8]. These materials are characterized by several advantages such as: chemical and thermal stability, suffer little or no supercooling, non-corrosives, non-toxic, high heat of fusion and low vapour pressure, but on the other hand Paraffins have some disadvantages which are: low thermal conductivity, high changes in volumes on phase change, inflammability, lower phase change enthalpy [9, 10].

The normal Paraffins of type CnH_{2n+2} are a family of saturated hydrocarbons with very similar properties. Paraffins between C_5 and C_{15} are liquids, and the rest are waxy solids. Paraffins wax is the most-used commercial organic heat storage PCM. It consists of mainly straight chain hydrocarbons that have melting temperatures ranging from 23 to 67 ^{o}C [11]. Paraffin wax typically contains primarily linear alkanes in the C_{20} to C_{40} range. It is microcrystalline, hard, brittle, and has a low affinity for oil. It melts in the range of 46 - 68 ^{o}C [12]. For improvement of charging and discharging processes of the storage, two parameters have to be optimized, which are: the inner surface between the heat transfer medium and the PCM and the thermal conductivity of the PCM during melting and solidification processes [13]

1.2.1 Macro-encapsulation of Paraffin

Macro-encapsulation means filling the PCM in a macroscopic containment that fit amounts from several ml up to several liters. These are often containers and bags made of metal or plastic [14]. The advantage of the macro-encapsulation is that the possibility to apply with both liquid and air as heat transfer fluids and easier to ship and handle [15]. The macro-encapsulation is characterized by the possibility to serve directly as heat exchangers, to be incorporated in building products, possibility of using different PCM’s in one tank and availability of a wide range of temperatures [16]. On other hand, it requirements for a high heat transfer rate, which means that the modules should be as small as possible and / or improvement of the thermal conductivity. Macro-encapsulation may be achieved by a myriad techniques: ball capsules, spherical capsules, cylindrical capsules, stripe capsules, bag capsules, profiles with fins, flat and tube containers, and plates [15, 17]. Thermal conductivity and thermal storage efficiency of macro-encapsulated paraffin wax can be enhanced by addition of an appropriate ceramic particles and an aluminum powder. By means of inserting a metal foam in both PCM and HTF sides can be improved the equivalent thermal conductivity. The smaller capsules in which paraffin is filled, the higher charging and discharging rate. The smaller the thickness of capsules, the more heat transfer between paraffin and HTF and the more heat carrying capacity of the SWH system [2].

2. Investigative Review of Latent Heat Storage Unit using Macro-encapsulated Paraffin

K. Kavitha and S. Arumugam used Paraffin as PCM in thermal energy storage with a melting temperature of 42-50 ^{o}C. Their 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. 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. A solar cooker of area 0.2601 cm^2 was constructed to this experimental study. The obtained results give a good estimation of the PCM 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. [18].

The thermal behavior of a commercial paraffin with a melting temperature of 58 ^{o}C is analyzed as a (PCM) candidate for domestic hot water applications. The characterization of 108 Kg of PCM was analyzed in a shell-and-tube heat exchanger under different HTF mass flow rates in terms of temperature, power released / absorbed and energy rates during charging and discharging processes. It was observed that the discharge showed slower response than the charge because of the presence of natural convection during the melting process and the creation of a solid layer around the tube bundle when the solidification process is started. The duration of the charging and discharging process was also effected by the different HTF mass flow rates. At the beginning of power released / absorbed processes, the higher the mass flow rate, the higher the power. However, as the processes continued, this temperature gradient decreased and the influence of the mas flow did not become as relevant [19].

The feasibility of storing solar energy using PCM (Paraffin) was studied by M. Kulkarni and D. Deshmukh. This energy was utilized to heat water for domestic purposes during nighttime. The system consists of two simultaneously functioning heat-absorbing units. One of them is a solar water heater and the other a heat storage unit consisting of Paraffin. The water heater functions normally and supplies hot water during the day. The storage unit stores the heat in PCM during the day supplies hot water during the night. The stainless steel water tank has a capacity of about 30 liters, with an internal diameter of 28 cm and a height of 48 cm, it houses the 9 kg PCM inside the square tank having length 40 cm & width 28cm and allows for heat transfer between the surface and the water. Experiment results show with using PCM cooling rate during the night decrease & efficiency and heat storage capacity increases. Results showed that the efficiency of solar water heater and also heat storage capacity increased with use of PCM. Hence with using PCM material efficiency & heat capacity of solar water heater increases at reduced initial heating rate because PCM take heat to get heated. As PCM based solar water heater store maximum solar energy, it reduces the size of tank and hence can reduce cost of Solar Water Heater. The use of PCM in solar water heater helps to reduce cooling rate of water, thus it enhances the maximum utilization of solar energy and hence improves efficiency of system [20].

A storage unit utilizes small cylinders, made of aluminum and filled with paraffin wax as the heat storage medium, was designed by S. kumar and T. Balusamy. The Solar Domestic Hot Water (SDHW) storage tank used in the experiments had a 75 Litres water capacity. Experiments were performed in both charging and discharging processes. The storage tank is completely insulated to prevent loss of heat. They found that, by using paraffin, efficiency of solar water heater is increased from 36.52% to 47.02% compared with the sensible heat storage method. Also the heat energy stored is increased from 11682kJ to 15042kJ. Hence with using PCM material efficiency and heat capacity of solar water heater increases at reduced initial heating rate because PCM takes heat to get heated. As PCM based solar water heater store maximum solar energy, it reduces the size of tank and hence can reduce cost of Solar Water Heater (SWH) [21].

M. Tailor and others designed a storage unit consisting of small cylinders made of aluminum and filled with commercially paraffin wax as the heat storage medium. After performing the experiments as results they got that, between time period of 10:00am to 12:00pm no major difference in both solar water heater. Paraffin Wax get melt at 37 to 400 ^{o}C and when the radiation of sun get low, wax gives its latent heat to water so we got better performance in compare to normal S.W.H. model. In addition after 4pm in normal SWH outlet temperature get decrease, but at that time due to PCM (Paraffin) they got higher efficiency. By readings, when they considered overall efficiency at that case they got 12% to 16% more efficiency in compare to normal SWH and when they considered efficiency between 2:00pm to 6:00pm they got 17% to 22% higher in compare to normal SWH [22].

S. Kumar, P. Mahesh and others investigated and analyzed the thermal energy storage incorporating with and without Phase Change Materials (PCM) for use in solar water heaters .This energy is utilized to heat water for domestic purposes. The system consists of two simultaneously functioning heat-absorbing units. One of them is a solar flat plate collector and the other a heat storage unit consisting of 770 gm of PCM (paraffin). The melting point of Paraffin is 56 ^{o}C. The storage unit utilizes cylindrical tubes made of copper and curved cylindrical tubes made of steel filled with paraffin wax as the heat storage medium. The present experiment focuses to maintain 60 liters of water at a temperature of around 70 ^{o}C during the day time with a flow rate of 5 ml/sec through a flat plate collector. Copper is used for the collector plate and the runner tube and the storage tank is of stainless steel material. The solar water heater with PCM is experimentally analyzed and the various parameters were studied. They found that the thermos-syphon effect can further improved by increasing the head of the system. Results showed that the performance depends on the collector location, collector tilt, wind velocity, and the solar time. The performance of paraffin wax in different geometries is studied. They found that the PCM with in the copper tube is more effective than the steel tube and the performance of the collector should be increased in a clear sunny day [23].
The performance of sensible heat storage (SHS) and combined storage units incorporated with solar flat plate collector was analyzed by S. Safivudeen and others. They used filled paraffin in spherical capsules as PCM and water as HTF in the TES unit. The experiments are carried out to study the performance of the TES unit for mass flow rates of HTF. Discharging experiments were conducted for discharging and batch wise discharging methods for both SHS system and combined storage system. A Thermal storage system is developed for the hot water to use at 45 ^{o}C for bathing applications using combined storage system. The results indicated that the heat storage capacity of the combined sensible and latent heat storage system is raised approximately 60% in relation to the conventional SHS system. It was also found that the mass flow rate plays crucial role in heat extraction from the collector and combined systems reduce the size of the storage tank [24].

3. Conclusions

After review of various literature on SLH storage unit using macro-encapsulated paraffin, various parameters of macro-encapsulated paraffin technique and difficulties encountered in successful performance of thermal energy storage system, the following conclusions were made:
The efficiency and heat capacity of SWH increased with use of paraffin. The efficiency of LHS unit can be enhanced by addition of an appropriate ceramic particles, Al powder and inserting a metal foam in both PCM and HTF sides. The smaller the capsules the higher the charging and discharging rate. The smaller the thickness of capsules the more heat carrying capacity of the SWH system.
In the packed bed LHS system, the charging and dis-charging process time can be reduced with increasing the inlet temperature and the mass flow rate of HTF. The performance of LHS unit depends on the collector location, collector tilt, wind velocity, and the solar time. The paraffin in copper tubes is the best effect on efficiency.
The heat storage capacity of the combined sensible and latent heat storage system is raised approximately 60% in relation to the conventional SHS system.

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