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An overview of PCM usage to enhance solar water heating system

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Abstract: Solar water heating system is the efficient application of solar energy in the industrial and residential purposes. The thermal energy storage is required to store the excess energy comes in the summer season, and it can be used when sunshine is not available. Thermal energy storage system incorporating phase change materials (PCM) are used to store the excess energy as latent heat. Because latent heat storage is one of the effective method of storing thermal energy. The use of phase change materials in solar domestic hot water system would improve the performance of the system due to it's high energy storage density and isothermal operation. Phase change materials also improve the thermal stratification of energy storage tanks. Many articles reveal that the performance of stratified tanks is better than the performance of fully mixed tanks. It is important to identify the parameters needed to characterize the stratification of solar domestic hot water tanks to improve its performance. This paper reviews some of the important PCMs, the use of PCMs and the parameters to characterize the stratification and to improve the performance in solar water heating systems.
Keywords: PCM, Solar water heating, Latent heat, Stratification, Energy storage.

1. Introduction.

The solar energy option has been opted as one of the outstanding alternative energy sources for fulfilling future energy needs. Solar water heating is one of the assets of the direct use of solar energy, and it is an alternative thermal application from an economic standpoint. There is a variety of developments in recent years to improve the functionality of solar household hot water systems [1]. Depends on the heat transfer mechanisms inside the storage systems, solar household hot water system can be divided into two parts. (i.e.,) Single phase natural (or) forced circulation systems and two phases thermosyphon energy storage systems. The hot water is used for domestic purposes or for meeting the needs of the industries and commercial establishments. Domestic, commercial and industrial buildings often have a hot water requirement at around 60^oC and bathing, boundary and cleaning operations in the household sector need it at about 50^oC [2]. PCM's with melting range 50^oC-60^oC can be used in the solar water heating system to meet hot water demands in buildings. Since the thermal conditions of PCM's are small, several methods exist to enhance the transfer of heat. Latent heat storages with higher energy densities are more alternative for small storage. The primary motive of the present paper is to discuss the utilization of phase change materials in Solar water heating system and improvements made in the Thermo syphon water heaters using PCM.

2. Phase change materials.

Every phase change thermal energy storage system requires a suitable PCM for solar energy storage application. Avoiding the problems of super cooling, phase separation and stability over a long period of use are important criteria for successful application of the PCM [3]. PCMs store the energy when a material changes from solid to liquid state and release the energy from the liquid state to solid state. The temperature of PCM increases as they absorb solar energy like conventional storage materials. PCMs absorb large amounts of heat without getting hotter unlike conventional storage materials during phase change process. PCM solidifies and releasing its stored heat when the atmospheric temperature around the PCM falls down. There are significant numbers of organic and inorganic phase change materials that meet the required thermodynamic and kinetic criteria. However, many cannot be used due to the problems of chemical stability, toxicity, corrosion, volume change, availability at reasonable cost, etc.

2.1 Types of PCM's.

The categories of PCM's are Salt hydrates, Paraffins, Nonparaffin organic and Inorganic compounds and eutectics.

2.1.1 Salt hydrates.

Salt hydrates are opted because of their high latent heat storage density. Salt hydrates such as sodium sulphate decahydrate and calcium chloride hexahydrate have suitable phase change temperatures for space heating applications.

2.1.2 Paraffins.

These materials are used as PCMs due to their availability in large temperature range and high heat of fusion. Only technical grade paraffins could be used as PCMs in latent heat storage applications. Paraffins have suitable nucleating properties and congruent melting.

2.1.3 Non – Paraffin organic solids.

Non–paraffin natural solids are the highest category of candidate materials for latent heat storage. High heat of fusion and Inflammability, varying levels of toxicity, Low thermal conductivity, Instability at high temperatures and Low flash points are some characteristics of these organic materials. Full ranges of PCMs have been investigated, including paraffin wax, salt hydrates, and nonparaffin organic compounds [4].

2.1.4 Inorganic compounds and eutectics.

Apart from many natural salt hydrates, there are many inorganic compounds, which undergo solid, liquid phase transformation with high latent heat of fusion at high temperatures. Also Apart from pure compounds, eutectics of organic compounds can be used to obtain the required melting point. It is possible to get a fixed melting or freezing point eutectic mixture of organic salts. The main uses for PCMs are when space availability is less in thermal storage units in direct gain or sun space passive solar systems. Now-a-days phase change materials are used in solar domestic hot water heating or passive solar space heating systems.

3. Investigation on phase change materials.

Form stable fatty acids/ poly methyl methacrylate blends will increase the feasibility of using PCM in latent heat thermal storage applications like space heating [5]. Thermal cycle tests of a phase change storage unit has been attended and studied the effect of 1000 thermal cycles [6]. The thermal reliability of salt Hydrated PCMs having melting temperature between 15^{o}C and 32^{o}C has been reported for repeated thermal cycles by calculating latent heat of fusion and melting temperature. Thermal cycling test of commercial grade stearic acid, acetamide and paraffin wax for 300 and 1500 thermal cycles has been performed respectively[8,9]. The thermal cycling test of a mixture $CaCl_2.6H_2O$ with some nitrate hydrated Ca $(No_3).4H_2O$ and Mg $(NO_3).6H_2O$ or anhydrous nitrates NH_4No_3 and KNo_3 has been carried out [10]. The decreasing heat storage capacity of $CH_3COONa.3H_2O$ during thermal cycling has been investigeatd and performed calorimetric measurements [11]. The heats of fusion for palmitic and lauric acid after 120 thermal cycles has been determined [12]. The thermo physical properties of some saturated fatty acids using the DSC technique has been investigated after 450 thermal cycles [13]. The solid-liquid phase transition in lauric, palmitic, steraric acid and their binary systems has been studied [14]. The thermal reliability of stearic acid, palmitic acid, mystric acid and lauric acids latent heat storage materials has been studied for a number of thermal cycles [15,16]. Sugar alcohol such as erythritol, mannito and galactitol were able to use as heat storage material [17]. Paraffin is readily available from many manufactures and is usually less expensive than some salt hydrates. Many works have been carried out in order to study the thermal characteristics of paraffin during solidification and melting processes [18-23].

Paraffin is known to be an attractive, chemically stable and nontoxic material without a regular degradation, and it has high latent heat storage capacities over a narrow temperature range. The reliability of some selected inorganic and organic phase change materials has been investigated [24]. Paraffin wax and erythritol has shown reasonable good thermal reliability in view of changes in latent heat of fusion and melting temperature. Erythritol has very high storage density; therefore, it can be a promising PCM for higher temperature thermal energy storage purposes.

4. Solar water heating system with PCM.

In recent years using phase change materials in solar water, heating system is increasing research attention because it leads improvement in performance over ordinary solar water heating system. A theoretical model has been developed to predict the transient behavior of the shell and tube storage unit with the PCM filling the shell side and the heat transfer fluid circulating inside the finned tubes [25]. The performance phase change material energy storage has been studied for solar water heating system, over the entire heating season [26]. The heat transfer enhancement in a phase change material (paraffin) was analyzed with and without fins during the melting and solidification of paraffin [27]. The utilization of granular phase change composites of small particle diameter [1-3mm] was investigated in latent heat thermal energy storage systems [28]. The system efficiency of solar collector with PCM was evaluated. Use of vertical fins could be very useful for applications of PCM modules inside water tanks to increase the heat transfer rate. These PCM modules are used to store the energy in a reduced volume. The storage system would be more flexible to match the energy demand [30]. The heat transfer coefficient by natural convection has been calculated for cylindrical modules containing PCM (sodium acetate trihydrate) with external vertical fins, were situated in the middle upper part of a cylindrical water tank as shown in Fig 2. Use of external fins in PCM modules heat transfer rate to the surrounding water. The temperature difference required to achieve a required heat transfer coefficient by natural convection was also reduced.

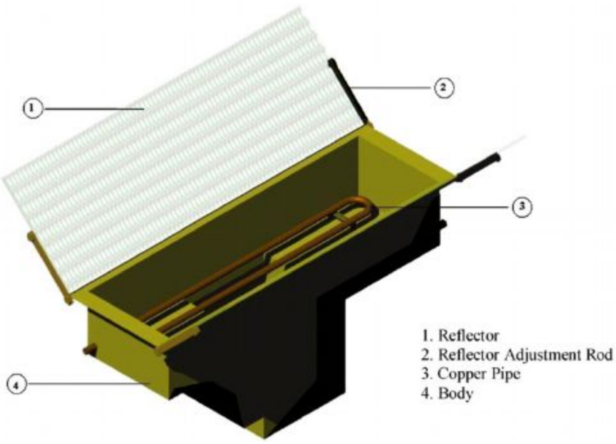

Fig. 1, Experimental setup

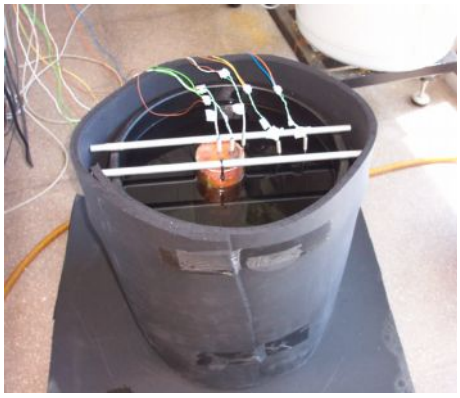

Fig. 2, Instrumentation of the experiments

The effect of using PCM modules in a stratified solar domestic hot water system has been studied. Three kilograms with 80:20 weight percent ratio mixtures of paraffin and different fatty acid, steric acid, palmitic acid, myristic acid have been used as phase change material [31]. Graphite was added to the PCM to increase heat transfer in PCM modules. In the cooling experiments, the average tank water temperature dropped below the PCM melting temperature in 6-12 hours. The maximum drop was for the paraffin wax and stearic acid mixture, and the minimum was for the paraffin wax and myristic acid mixture. During the reheating experiments, it was observed that 3Kg of PCM could increase the temp of 14-36 of water at the upper part of the tank by 3-4^{o}C. This fact took place in10-15min. It was concluded the paraffin and steric acid mixture gave the best results to improve the performance of solar domestic hot water system. The modelization of a new technology where PCM modules are implemented in domestic hot water tank have been studied to reduce their size without changing the energy stored [32]. Adding PCM module at the top of the water tank proved to be a technique that finds high energy storage density [33]. The improvement in thermal performance of a domestic hot water cylinder was found with encapsulated phase change materials [34].

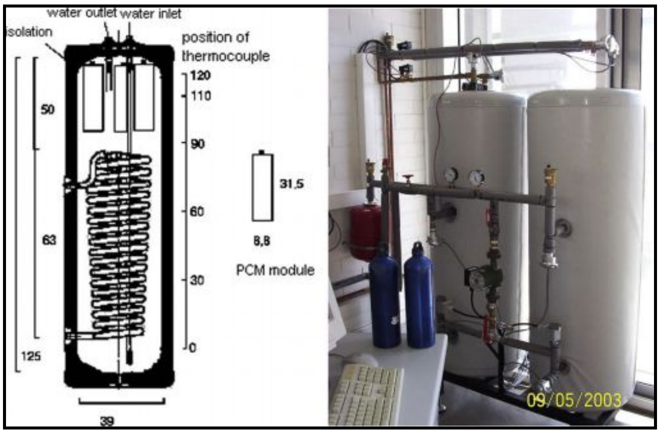

Fig. 3, Solar domestic hot water tank and the PCM module used in the experiments.

The feasibility of using PCM in the storage tank of a domestic hot water system has been evaluated based on the criterion of annual DHW system with PCM in the storage tank was compared with a similar system without PCM under the same conditions [35]. The thermal characteristics of packed bed containing spherical capsules, used in a latent heat thermal storage system with a solar heating collector has been studied. Myristic acid is selected as phase change material (PCM), and water is used as heat transfer fluid (HTF) [36]. There is an enhancement of heat transfer to the PCM when A Phase change slurry (PCS) consists of small-encapsulated PCM particles suspended in a carrier fluid A test system [37]. The time variations of the water temperatures has been studied at the midpoint of the heat storage tank and the outlet of the collector in a conventional open-loop passive solar water-heating system combined with sodium thiosulfate pentahydrate-phase change material [38].

6. Stratification and Parameters.

In solar thermal heating systems the stratification is an important phenomenon to improve the performance of the system. Stratification is the separation of hot and cold water in the thermal energy storage tank. Hot water can be stored in the top of the tank and cold water can be stored in the bottom of the tank due to buoyancy forces. The intermediate layer is called thermocline. However stratification improves the performance of the thermal energy tanks, it is affected by the factors such as mixing of water due to natural convection caused by buoyancy forces, inlet jet mixing caused by kinetic energy of water entering into the tank and thermal conduction and diffusion within the fluid itself. So it is necessary to characterize the thermal stratification in the thermal energy storage tanks. Very few of the works that have been reviewed have attempted to compare the different parameters and come up with the best parameters which evaluate thermal stratification properly experimentally from a quantitative perspective. The Dimensionless temperature distributions, Stratification number, Energy efficiency and Exergy efficiency of a domestic electric hot water storage tank heve been investigated during Static mode of operation [39]. **T**he Mean residence time, Dimensionless temperature distributions, Stratification number, Discharging energy efficiency, Discharging exergy efficiency of a domestic electric hot water storage tank heve been studied during Dynamic mode of operation [40]. **S**tratification was characterized in storage tanks and many parameters, both dimension and dimensionless, have been defined to characterize the level or probability of stratification [41]. The different parameters involved in this paper to identify stratification are Richardson Number, MIX number, Ratio H/D, Peclet number, Reynolds number and Discharging efficiency ratio. parameters such as the temperature distribution along the height at different time intervals, the charging energy efficiency, the charging exergy efficiency, the stratification number, the Reynolds number and the Richardson numbers, that characterize thermal stratification in an oil/pebble-bed TES system [42]. The performance of PCM incorporated thermosyphon solar water heating system has been examined using the flat plate collector as a heat source [43].

7. Conclusion

The current paper has been reviewed the recent developments in solar water heating systems using PCM. The information obtained about the types of PCMs have been presented and discussed. This paper also discussed about the variety of PCMs used in various storage systems with a design modification. The various PCMs applications also have been discussed. Simply PCM usage will not be a beneficial one in solar water heating. Using different combinations of PCMs with design modifications of the system, PCM container and the solar collector would be a better idea to enhance solar water heating systems.

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