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PERFORMANCE ANALYSIS OF LATENT HEAT STORAGE UNIT WITH PACKED BED SYSTEM – An EXPERIMENTAL APPROACH

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Abstract: The increasing of the population and development of the different countries converts the energy topic in one of the most important aspects of our times. Unfortunately the global conventional fuels in reserves are running out while the world energy consumption is increasing very fast. All scientists agreed that solar energy is one of the best solutions for energy supply in many parts of the world. One of the disadvantages of this renewable energy is the fact that energy is not available all the time: the need of heat storage systems appear. The mismatch between maximum solar radiation and energy demand is a well-known problem for solar heating systems with high coverage of space heating and domestic hot water (DHW) demand. Thus, solving this is a key issue to develop efficient solar heating systems. The aim of this paper is to experimentally investigation of thermal storage system integrated with phase change material (PCM).Thermal performance of a latent thermal storage system investigated for charging at different mass flow rate of HTF and different inlet temperature of HTF. Paraffin wax is using as PCM and water is using as HTF.Packed bed system is using in experiment**.**

Keywords: Phase Change Materials (PCMs**),** Thermal Energy Storage, Charging, Heat transfer fluid (HTF)

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1. INTRODUCTION

Renewable energy supplies are steadily gaining increasing importance in all the countries. In particular, solar energy, being non-polluting, clean and inexhaustible, has received wide attention among scientists and engineers. Though there are many advantages, an important factor is that solar energy is time dependent energy source with an intermittent character. Thermal energy storage (TES) is achieved with greatly differing technologies that collectively accommodate a wide range of needs. It allows excess thermal energy to be collected for later use, hours, days or many months later, at individual building, multiuser building, district, town or even regional scale depending on the specific technology. As examples: energy demand can be balanced between day time and night time; summer heat from solar collectors can be stored interpersonally for use in winter; and cold obtained from winter air can be provided for summer air conditioning. Storage mediums include: water or ice-slush tanks ranging from small to massive, masses of native earth or bedrock accessed with heat exchangers in clusters of small diameter boreholes (sometimes quite deep); deep aquifers contained between impermeable strata; shallow, lined pits filled with gravel and water and top-insulated; and eutectic, phase-change materials. In traditional energy systems, the need for thermal storage is often short-term and therefore the technical solutions for thermal energy storage may be quite simple, and for most cases water storage

CLASSIFICATION OF THERMAL STORAGE

Thermal energy can be stored in form of sensible heat

or latent heat or combination of sensible and latent heat

SENSIBLE HEAT STORAGE

Thermal energy is stored by raising the temperature of a solid or a liquid medium by using its heat capacity. The amount of thermal energy stored in the form of sensible heat can be calculated by

$$Q = \int_{T_1}^{T_2} m \times C_P \times dT$$

Q is the amount of thermal energy stored or released in form of sensible heat (kJ), **T1** is the initial temperature (^{0}C), **T2** is the final temperature (^{0}C), **m** is the mass of material used to store thermal energy (kg), and **Cp** is the specific heat of the material used to store thermal energy (kJ/kg. ^{0}C). It is clear from that the amount of thermal energy stored in the form of sensible heat depends on mass, value of the specific heat of the material used to store the thermal energy and the temperature change. Water is known as one of the best materials that can be used to store thermal energy in form of sensible heat because water is abundant, cheap, has a high specific heat, and has a high density. In addition, heat exchanger is avoided if water is used as the heat transfer fluid in the solar thermal system. Until now, commercial applications use water for thermal energy storage in liquid based systems. Table shows a list of some materials that used for sensible thermal energy storage.

LATENT HEAT STORAGE

Latent heat storage uses the latent heat of the material to store thermal energy. Latent heat is the amount of heat absorbed or released during the change of the material from one phase to another phase. Two types of latent heat are known, latent heat of fusion and latent heat of vaporization. Latent heat of fusion is the amount of heat absorbed or released when the material changes from the solid phase to the liquid phase or vice versa, while latent heat of vaporization is the amount of thermal energy absorbed or released when the material changes from the liquid phase to the vapor phase or vice versa. Indeed, latent heat of vaporization is not paid attention for latent thermal energy storage applications because of the large change in the volume accompanied by this type of phase change. The amount of thermal energy stored in form of latent heat in a material is calculated by

$$Q = m \times LH$$

Q is the amount of thermal energy stored or released in form of latent heat (kJ), m is the mass of the material used to store thermal energy (kg), and LH is the Latent heat of fusion or vaporization (kJ/kg).It is clear from that the amount of thermal energy stored as latent heat depends on the mass and the value of the latent heat of the used material. Materials used to store thermal energy in form of latent heat are called phase change materials

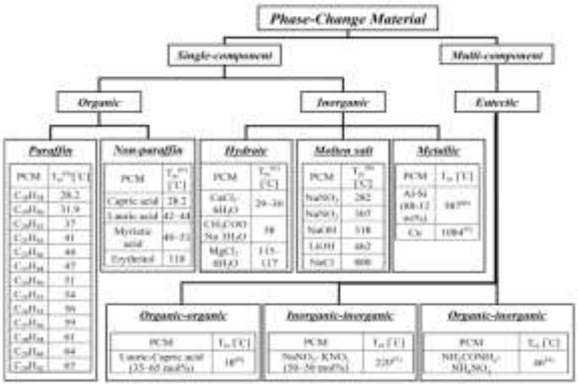
CHEMICAL HEAT REACTIONS

Heat can also be stored by means of a reversible thermo-chemical reaction. The working principle is the following one:

$$A + HEAT = B + C$$

First, in the charging period, chemical A is transformed into two new chemicals, B and C, because of heat absorption (endothermic reaction). Subsequently, the two new chemicals must be stored in separate vessels at ambient temperature. Second, in the discharging period, chemical B reacts with chemical C to form the original chemical A while releasing the stored heat (exothermic reaction). The energy of thermo-chemical reactions is the highest of all the systems introduced, and so it is the most compact way to store thermal energy. So far, there are several types of reversible thermo-chemical reactions which have been studied the most: solid-gas, liquid-gas and gas reaction.

CLASSIFICATION OF PHASE CHANGE MATERIALS



Esen et al. [1998] made numerical investigation on the thermal performance of solar water heating systems integrated with cylindrical LHS unit using various PCMs. Ismail and Henriquez [2002] presented a numerical model to simulate the process of heat transfer (charging and discharging) in a LHS system of packed bed of spherical capsules filled with PCM (Water). The effect of heat transfer fluid (ethylene glycol) entry temperature, the mass flow rate and material of the spherical capsule on the performance of the storage unit were investigated both by numerically and experimentally. Mehling et al. [2003] presented the experimental and numerical simulation results of energy storage density of solar hot water system using different cylindrical PCM modules. Their results show that adding PCM modules at the top of the water tank would give the system higher storage density and compensate heat loss in the top layer. Works in the related area are also reported by Buddhi et al. [1988], Ghoneim et al. [1989], Nallusamy et al. [2003] and Ettouney et al. [2005].

The objective of the present work is to predict the thermal behavior of a packed bed latent heat thermal energy storage unit integrated with solar water heating system which was not reported by researchers as understood from the literature survey. Parametric studies are carried out to examine the effects of HTF flow rates on the performance of the storage unit for varying inlet fluid temperatures. The performance of the present system is done during charging process.

2. EXPERIMENTAL INVESTIGATION

EXPERIMENTAL SETUP

The schematic of the experiment system is shown in fig. the experimental facility used in this study includes (1) main storage tank, (3) hot water storage tank, (4) cold water storage tank, (5) pumps, (6) Flow meters (7) thermocouples set.

During the charging cycle, the thermal energy charging process is performed on the phase change material balls integrated in the main storage tank (MST) via hot water as a heat transfer fluid (HTF); this hot water is obtained from the water heater. The hot water is pumped to the main storage tank (which contains the PCM balls) and consequently returned again to the heater in a closed loop until the temperature of the water inside the main storage tank reaches the desired value.

The main storage tank has 77 liter capacity with cylindrical shape .The hot water storage tank (HWST) has 500 liter. The cold water storage tank (CWST) has 500 liter capacity. The PCM balls were loaded inside the main storage tank. PCM balls consist of a phase change material encapsulated in a spherical shape with a shell thickness and neck at top of the sphere. The PCM is injected inside the sphere through this neck. A metallic sphere was used in encapsulated PCM as shown below in Fig

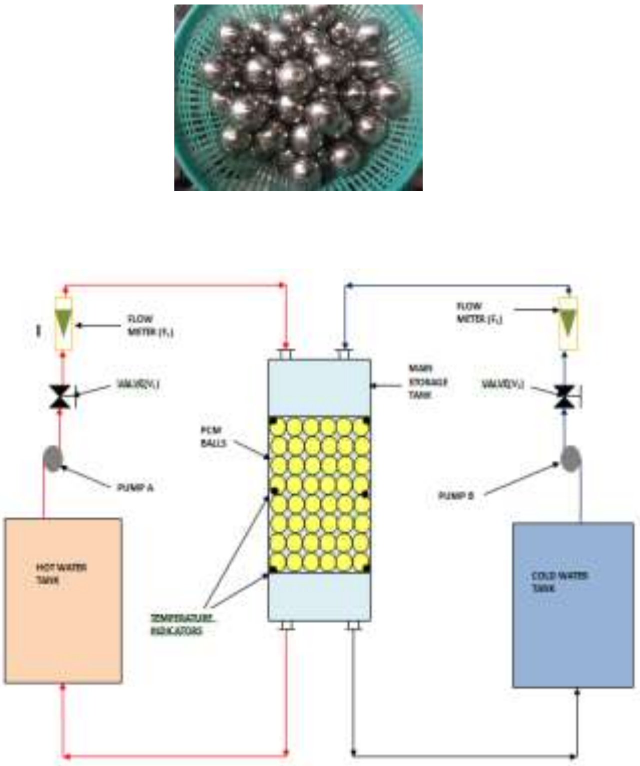


Fig 1 PCM stainless steel capsule and diagram

During the charging process (storing of heat energy) the HTF is circulated through the TES tank continuously. The HTF transfers its energy to PCM capsules and at the beginning of the charging process, the temperature of the PCM inside the packed bed capsules is 32 °C, which is lower than the melting temperature. Initially the energy is stored inside the capsules as sensible heat until the PCM reaches its melting temperature. As the charging process proceeds, energy storage is achieved by melting the PCM at a constant temperature. Finally, the PCM becomes superheated. The energy is then stored as sensible in Fig are recorded at interval of 30 min. The charging process is continued until the PCM temperature reaches 70 °C.Temperature histories of HTF and PCM. The temperature histories of HTF and PCM at 3 segments of the TES tank(A,B,C).

Fig.4.1 represents the temperature variation of PCM during the charging process for mass flow rate of 6 kg/min and porosity of 0.4. It is seen from the figure that the PCM temperature increases gradually at the beginning of the charging period, remains nearly constant around 60 °C during melting process and increases sharply during heating of liquid PCM, and that the PCM in the first segment is completely charged nearly 85% of the total charging time. The charging process is terminated when the PCM temperature in all the segments reaches 70 °C

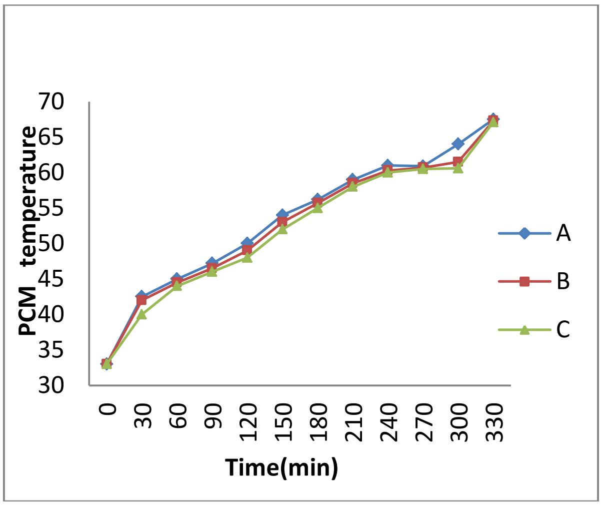


Fig 2 Effect of variation of PCM temperature with time at planes A,B,C

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Fig.4.2 represents the temperature variation of the HTF inside the storage tank for a mass flow rate of 6 kg/min and porosity of 0.4

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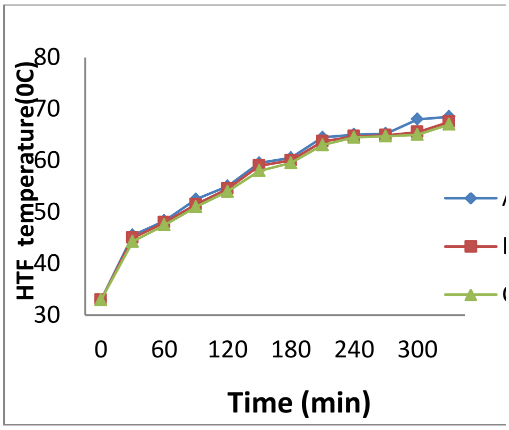

Fig 3 Effect of variation of HTF temperature with time at planes A,B,C

It is observed from Fig that the temperature of the HTF at all the segments increases gradually until it reaches the temperature of 62 °C or 63 °C and then remains nearly constant around 65 °C for a period of 30 min during which the PCM undergoes phase change at 58±1 °C. After that the HTF temperature increases up to 71 °C or 72 °C.

Fig.4.3 illustrates the effect of varying the mass. flow rate of HTF (2, 4 and 6 kg/min) during the charging of the storage tank. Increase in mass flow rate has large influence on the phase transition process of PCM.

As the flow rate increases the time required for the complete charging becomes smaller. It is seen from the figure that the charging time is decreased by 16% and 24% when the flow rate is increased from 2 to 4 kg/min and 2 to 6 kg/min respectively.

This is because an increase in fluid flow rates (from 2 to 6 kg/min) translates into an increase in surface heat transfer coefficient between the HTF and PCM capsules. Hence mass flow rate has significant effect on the time for charging the storage tank.

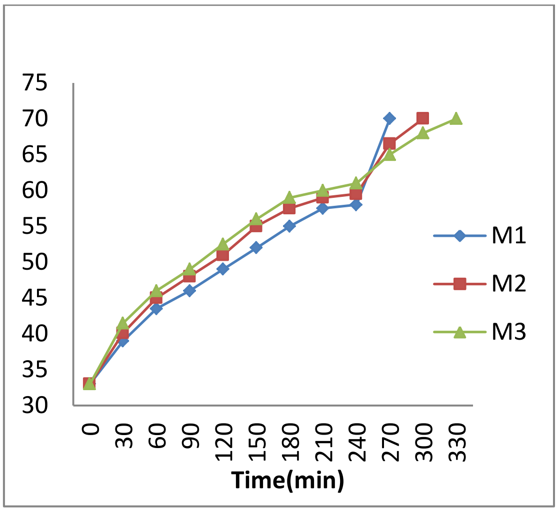

Fig 4 Effect of variation of HTF temperature with time at planes A,B,C

Fig.4.3 illustrates the effect of varying the mass. flow rate of HTF (2, 4 and 6 kg/min) during the charging of the storage tank. Increase in mass flow rate has large influence on the phase transition process of PCM. As the flow rate increases the time required for the complete charging becomes smaller. It is seen from the figure that the charging time is decreased by 16% and 24% when the flow rate is increased from 2 to 4 kg/min and 2 to 6 kg/min respectively. This is because an increase in fluid flow rates (from 2 to 6 kg/min) translates into an increase in surface heat transfer coefficient between the HTF and PCM capsules. Hence mass flow rate has significant effect on the time for charging the storage tank.

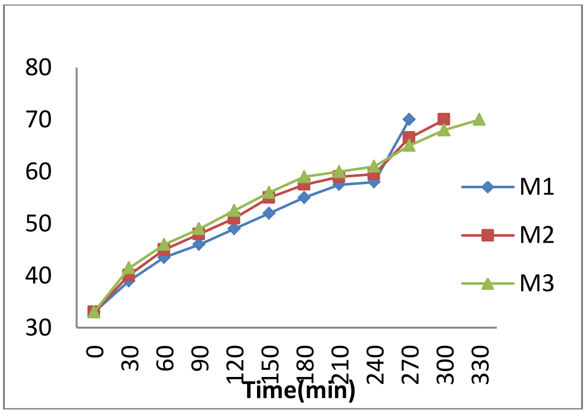

Fig.5. Effect of different fluid inlet temperature on temperature of PCM with time

CONCLUSIONS

An experimental investigation on an LHTS unit filled with paraffin wax ball as a PCM is carried out in order to establish thermal performance of an LHTS unit. A critical evaluation of the PCM temperature profile with time is carried out. Based on the thermal parametric studies the following conclusion can be drawn,

1 The inlet temperature and mass flow rate have strong influences on the heat stored and complete charging process.

2. The higher flow rate of HTF, the time required for the complete charging becomes smaller. the charging time is decreased by 16% and 24% when the flow rate is increased from 2 to 4 kg/min and 2 to 6 kg/min respectively

3 The inlet temperature of the HTF depends on the heat source during the heat storage and on the surroundings during heat recovery. The total melting time is drastically reduced due to an increase in the fluid inlet temperature.

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