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RESEARCH ARTICLE

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

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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 discharging 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

KEY WORDS: Phase Change Materials (PCMs), Thermal Energy Storage, Charging, Heat transfer fluid (HTF).

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

II. CLASSIFICATION OF THERMAL STORAGE

Thermal energy can be stored in form of sensible heat or latent heat or combination of sensible and latent heat

A .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

$$Q = \int_{T_1}^{T_2} m \times C_P \times dT \tag{1}$$

Q is the amount of thermal energy stored or released in form of sensible heat (kJ), T1 is the initial temperature (0C), T2 is the final temperature (0C), 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. 0C). 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.

B. 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

$$Q = m \times LH \tag{2}$$

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

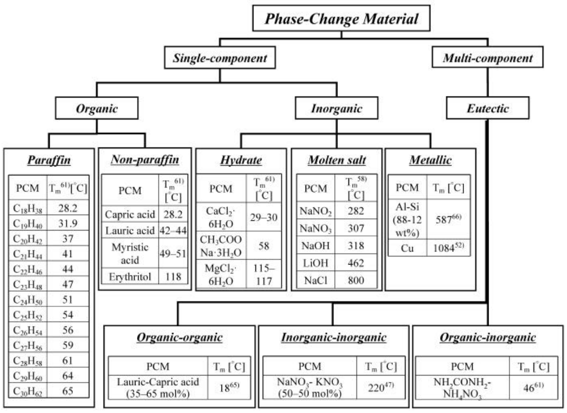
C. CHEMICAL HEAT REACTIONS

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.

III CLASSIFICATION OF PHASE CHANGE MATERIALS



PCM	T_m $^{61)}$[°C]
$C_{18}H_{38}$	28.2
$C_{19}H_{40}$	31.9
$C_{20}H_{42}$	37
$C_{21}H_{44}$	41
$C_{22}H_{46}$	44
$C_{23}H_{48}$	47
$C_{24}H_{50}$	51
$C_{25}H_{52}$	54
$C_{26}H_{54}$	56
$C_{27}H_{56}$	59
$C_{28}H_{58}$	61
$C_{29}H_{60}$	64
$C_{30}H_{62}$	65

PCM	T_m $^{61)}$ [°C]
Capric acid	28.2
Lauric acid	42–44
Myristic acid	49–51
Erythritol	118

PCM	T_m $^{61)}$ [°C]
$CaCl_2 \cdot 6H_2O$	29–30
$CH_3COONa \cdot 3H_2O$	58
$MgCl_2 \cdot 6H_2O$	115–117

PCM	T_m $^{58)}$ [°C]
$NaNO_2$	282
$NaNO_3$	307
NaOH	318
LiOH	462
NaCl	800

PCM	T_m [°C]
Al-Si (88-12 wt%)	$587^{66)}$
Cu	$1084^{52)}$

PCM	T_m [°C]
Lauric-Capric acid (35–65 mol%)	$18^{65)}$

PCM	T_m [°C]
$NaNO_3$- KNO_3 (50–50 mol%)	$220^{47)}$

PCM	T_m [°C]
NH_2CONH_2-NH_4NO_3	$46^{61)}$

Fig 1. Classification of phase change materials

IV. LITERATURE REVIEW

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 discharging process.

V. 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) Similar to the charging system, Inlet valve is opened and HTF flow from the cold water tank to main storage tank from the discharging line. The pumps on, the discharging cycle is adjusted to give the same mass flow rate this adjustment is done by using the rotameter.HTF flow from the cold storage tank to the main storage tank to the main storage tank. As a result heat is transferred from PCM ball to the cold water inside the tank. The PCM ball temperature decreases until water leaves the main storage tank. Cold water is heated up for further use. In this process the PCM material is solidified. The discharging is repeated until the thermal equilibrium is reached among temperature cold water and PCM balls (outlet and inlet temperature are same)

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

Fig2. PCM stainless steel capsule thermocouples set

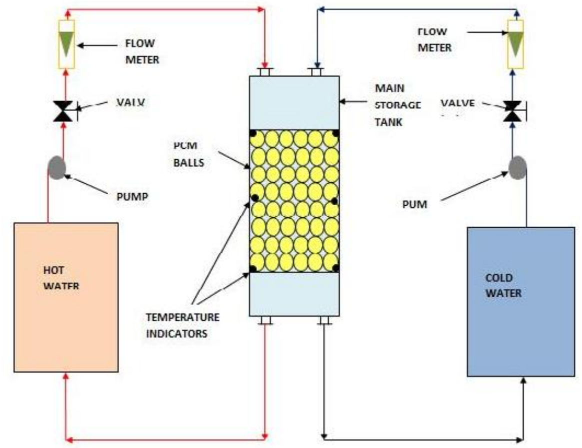


Fig 3. Schematic diagram of experimental setup

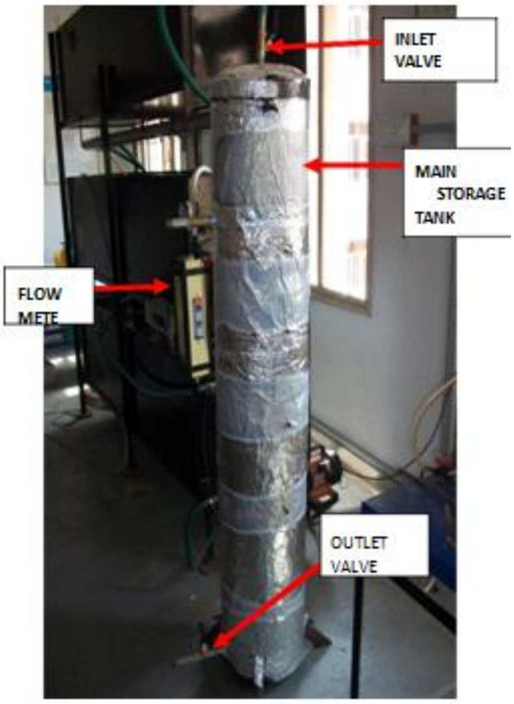


Fig 4.Photographic view of setup

VI. RESULTS AND DISCUSSIONS

During the discharging process (relishing of heat energy) of the HTF is unceasingly circulated through the system TES tank. The energy is transferred from PCM capsules to HTF and at the beginning of the discharging process, also the temperature of the PCM inside the packed bed capsules is 71 °C and temperature of HTF is about the atmospheric temperature.

When PCM extents its temperature of solidification the energy is stored in capsules as sensible heat initially. As further the discharging process is proceeds, energy appreciated is achieved at a continuous temperature by solidification the wax. Finally, the PCM converts cooled. Until the PCM temperature reaches atmospheric temperature, the discharging process is continued. The temperature histories of HTF and wax are considered at 3 parts of the storage tank (A, B, C).

1. Effect with time at planes A, B, C variation of PCM temperature

Fig shows that the PCM temperature variation through the discharging. Its mass flow rate is 6kg/min and its porosity is 0.4. In the fig., the hot water in the storage tank drops and give sensible heat due to the mixing of water at a temperature of 32 °C and the temperature drop is great until the PCM reaches its phase transition temperature. Subsequently, the temperature drop is negligible in the PCM for a long time as the PCM gives its latent heat. Its temperature starts decreasing after complete solidification of the PCM; conversely, the rate of drop in temperature is not big as staring of discharging. The reason is that is small temperature difference amongst the PCM inlet temperature and HTF inlet temperature still in system the solid PCM announcements its sensible heat.

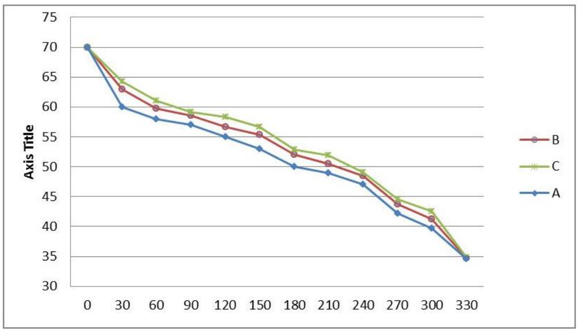


Fig 5.Vriation on PCM temperature verses time at plan A,B,C

2. Effect with time at planes A, B, C variation of HTF temperature

Fig. signifies that the HTF temperature variation in the storage tank. Its mass flow rate is 6 kg/min and its porosity is 0.4. It is seen in the fig. that is the HTF temperature at all 3 segments.

At the, beginning of the discharging process, the heat recovery rate is large and decreases with time for the reason that of the change in the thermal resistance of the solidified layer of the PCM and decrease in temperature difference between the solidified PCM and HTF parameters. The HTF outlet temperature reductions unceasingly with time in case of discharging process.

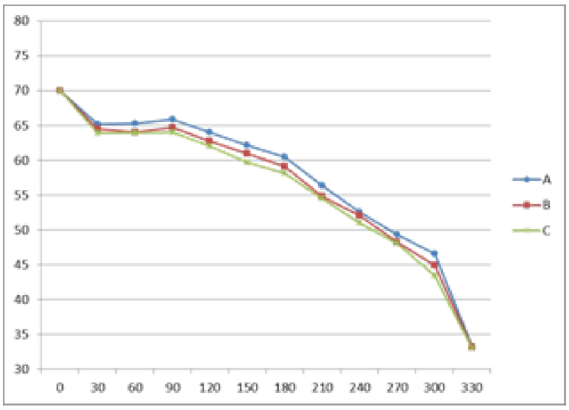


Fig 6. Effect with time at planes A, B, C variation of HTF temperature

3. Effect on temperature of PCM of different mass flow rates with time

Fig. shows the effect of varying the HTF mass flow rate (2, 4 and 6 kg/min) during the discharging of the storage tank. M1 Shows 6 kg/min, M2 Shows 4 kg/min, M3Shows 2 kg/min.

On the phase transition process of PCM, Increase in mass flow rate has large influence in manner of as the flow rate increases the time required for the complete discharging converts smaller.

The discharging time is decreased by 18% and 26% when the flow rate is enlarged from 2 to 4 kg/min and 2 to 6 kg/min is observed from the figure that respectively. This is because an increase in fluid flow rates (from 2 to 6 kg/min) interprets into an increase in surface heat transfer coefficient between the HTF and PCM capsules. Hence mass flow rate has noteworthy effect on the time for discharging the storage tank.

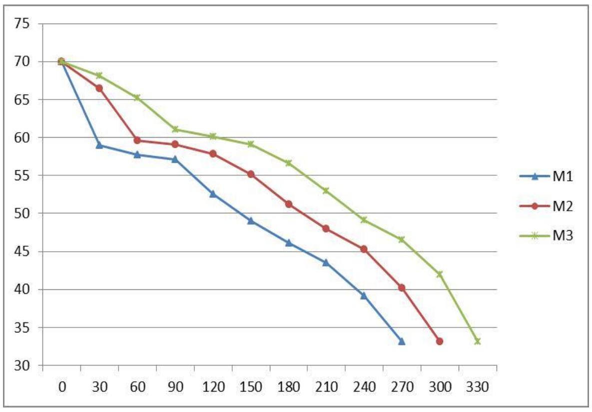


Fig 7. Effect on temperature of PCM of different mass flow rates with time

4. Effect of different fluid inlet temperature on temperature of PCM with time

The HTF inlet temperature is initiating the charging/discharging process is very important. The HTF inlet temperature depends on the heat source during the heat storage and on the surroundings during heat recovery process.

Fig.utters the effect temperature of fluid inlet on total time with the mass flow rate is as 5 kg/min. In the fluid inlet temperature, total solidification time is drastically decreased due to an increase of only 5 °C.

It is concluded from the figure that the time total for solidification reduces (approximately) by 46.05% when the fluid inlet temperature is grown up from 75 °C to 85 °C. This is due to the fact that with an increasing HTF inlet temperature, the driving force, i.e., difference between temperature of the HTF and PCM is increased. This convection heat transfer from the HTF to the PCM ball wall will increase. This increase heat transfer rates from the PCM ball wall to the PCM is because of higher heat transfer to the PCM ball wall will which is due to the convection heat transfer in the molten PCM.

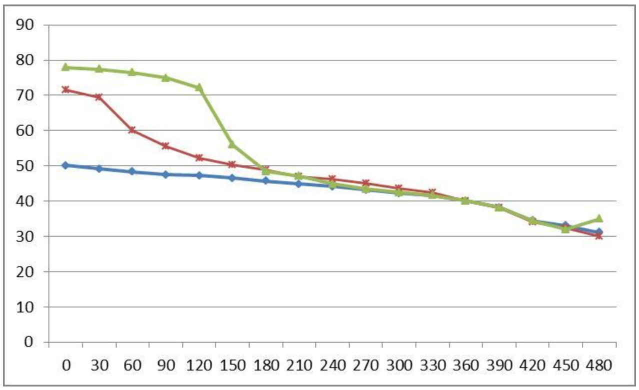


Fig 8. Effect on temperature of PCM with time of different fluid inlet temperature

VII. CONCLUSION

An LHTS unit filled with paraffin wax ball as a PCM is carried out in order to found thermal performance of an LHTS unit during an experimental analysis. A critical evaluation with time of the PCM temperature profile is carried out during this experiment. 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 relished and complete discharging process
2. The higher flow rate of system HTF, the time required becomes smaller for discharging process.

The discharging time is decreased when mass flow rate increasing. The discharging time is decreased by 18% and 26% when the flow rate is enlarged from 2 to 4 kg/min and 2 to 6 kg/min

3. The HTF temperature of inlet depended on the heat source during the heat storage and on the surroundings during heat recovery. The total solidification (discharging) time of PCM is drastically reduced due to an increase in the fluid inlet temperature.

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