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Analysis of Thermal Energy Storage System Using Manganese Chloride Tetra Hydrate as Phase Change Material

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ABSTRACT
In Thermal Energy Storage Systems Phase Change Material (PCM) is used to store the heat in the form of latent heat. In the present experimental investigation of hydrated salt (Manganese Chloride Tetra Hydrate) is employed as phase change material in thermal energy storage system. In the present work phase change material is filled in spherical capsules which are made of stainless steel, and water is used as heat transfer fluid. The heat transfer fluid is supply by constant heat source of constant temperature in Thermal Energy Storage Systems (TES). The present work utilizes the study of the effect of different parameters on thermal energy storage system. The experimental design is prepared by considering the parameters like flow rate, heat transfer fluid inlet temperature and PCM capsules is considered at different level. For every experimental run charging time, discharging time of Phase change material (PCM) and water temperature are recorded.

I. INTRODUCTION

Energy plays a major role in achieving economical prosperity, technological prosperity and technological competitiveness of a nation. If the requirement of the energy is fulfilled, then any nation can be considered as developed nation. This requires that a developing / underdeveloped country should concentrate on the energy technologies to ensure energy security, efficiency and environmental quality. It is observed that at present, 80% of the world's energy requirement is met by the fossil fuels (coal, oil and natural gas). It is expected to cross 90% of energy requirement of world population by 2020 leading to full exploration of fossil fuels.

The greedy nations are resorting to stock piling of these fossil fuels for the future and for the present energy requirements and also to meet the seasonal variations in the demands. This situation cannot continue forever , as the availability of fossil fuels is limited and also the environment quality is not maintained by the use of these fuels. Global warming and pollution of the environment may reach a stage challenging the existence of mankind on earth.

Shortage of energy supply is also expected and hence the industrial countries have become more conscious of their energy requirements. Hence it is necessary not only to develop economic energy usage patterns but also to conserve the available energy. This led to exploration methods to recover the waste heat and also alternate sources of energy so that the dependency on the primary fuels could be reduced.

Thermal Energy Storage (TES) is one of the key technologies for energy conservation and is used to assist in the effective utilization of thermal energy in a wide number of industrial and private applications. Thermal Energy Storage (TES) is the missing link to sustainable and reliable power generation via solar thermal energy. The use of TES will improve the overall solar thermal ability to handle the sudden increase of demand at constant sun radiation and improve the system economics by allowing larger production capacity.

TES system facilitates more effective use of thermal energy equipment and large scale energy substitutions economically. It is therefore a very alternative technology for meeting society's needs and desires more effectively and efficiently. Even though cost of TES system is higher than the fossil fuels, it has the major advantages for their limited impact on the environment and sustainability of the energy sources. The various applications of TES systems shared in the following subsections.

A Phase - Change Material (PCM) is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa. The most important difference between these materials is the phase change temperature. Each material makes its phase change at different temperature. In addition, each material has different value of latent heat and thermal conductivity. The most important feature for the selected phase change material is to have its phase change temperature fitted with the application temperature range.

The PCMs have considerably higher thermal energy densities than SHS materials. No single material with required properties can be chosen for an ideal thermal storage medium. Hence one has to use the available materials and makeup for the poor physical property by a change in system design. However, they possess low latent heat capacity and low thermal conductivity in solid phase. This is associated with reduced heat transfer rates in the solid phase, during change of phase, leading to increased time lag during charging and discharging phases.

II. EXPERIMENTAL WORK

An experimental setup is developed for conducting the experiments by varying parameters like flow rate of HTF (2lit/min), HTF inlet temperature (^{0}C) and PCM capsules shape. Total 6 sets of experiments are conducted for both charging and discharging process. This consists of the experimental setup and the experiments for the analysing charging and discharging process time for TESS.

2.1. Experimental Setup

The experimental set-up is shown in Fig. 2. This consists of an insulated cylindrical TES tank, which contains PCM stored in spherical capsules, flow meter and water storage tank. The stainless steel TES tank has a capacity of 25 litres. The storage tank is insulated with glass wool. The PCM capsules are uniformly packed in the storage tank is shown in Fig. 2. The Manganese Chloride Tetra Hydrate is used as PCM that has melting point of 58 ^{0}C and latent heat of fusion 151(kJ/kg). The PCM ($MnCl_2 \cdot 4H_2O$) is shown in Fig. 3. Water is used as both SHS material and HTF. A flow meter with an accuracy of ±2% is used to measure the flow rate of HTF and the flow rate of HTF is changed by different tap openings. The TES tank is incorporated with digital thermometers with an accuracy of ± 1 ^{o}C are placed in the TES tank to measure the temperatures of HTF and PCM stored inside the capsules. An electric water heater is used to maintain the constant temperature in the water storage tank**.** The thermo-physical properties of PCM are given in Table 3.1.

Fig. 1 PCM Spherical Capsules

Fig. 2 Experimental set-up

Fig.3 Manganese Chloride Tetra Hydrate ($MnCl_2 \cdot 4H_2O$)

Table: 1 Thermo physical properties of PCM

Name of the salt	Melting point (^{o}C)	Density (Kg/m3)	Latent heat (KJ/Kg)
$MnCl_2 \cdot 4H_2O$	58	2010	151

2.2. Design of Experiments

In this experiment three controllable parameters have been considered. Factors considered for the present work are

1. Flow rate of HTF (lit/min)
2. HTF inlet temperature (^oC)
3. PCM capsules

Experiments are performed according to this design and the values of charging time and discharging time, final temperature of water, and number of PCM capsules is recorded for each experimental run is shown in table 2.

Table: 2 Input factors and their levels

S. No.	Levels	Factors		
		Flow rate (lit/min)	HTF inlet temperature (^oC)	PCM capsules (no.)
1	1	2	60	30
2	2	2	62	30
3	3	2	64	30
4	4	4	60	30
5	5	4	62	30
6	6	4	64	30

2.3. Experimental data

The experiments are conducted according to the Taguchi design with three input factors, like HTF inlet temperature (60 ^oC, 62 ^oC, 64 ^oC), flow rate (2 and 4 lit/min) and PCM balls (30). For every experimental run charging time, discharging time, final temperature of water (T_W), temperature of phase change material (T_{PCM}), quantity of water with drawn (lit) from TES tank are noted in table 3.

Table: 3 Experimental layout and measured Response values Manganese chloride tetra hydrate

Experimental run	HTF inlet temp (T_{HTF}) (^oC)	Flow rate (lit/min)	PCM capsules (no.)	Charging time (min)	Discharging time (min)
1	60	2	30	30	360
2	62	2	30	32	400
3	64	2	30	36	420
4	60	4	30	28	360
5	62	4	30	32	400
6	64	4	30	36	420

III. RESULTS AND DISCUSSIONS

The present study reports the thermal performance of the PCM based Thermal Energy Storage System (TES) considering the temperature distribution of HTF (water in the TES tank that acts as a SHS material) and PCM in the TES tank, In order to establish thermal characteristics of the PCM, several experiments are conducted by varying the mass flow rates, different inlet temperatures and PCM capsules. Different parameters are analyzed and reported for the charging and discharging processes.

3.1. Charging Process

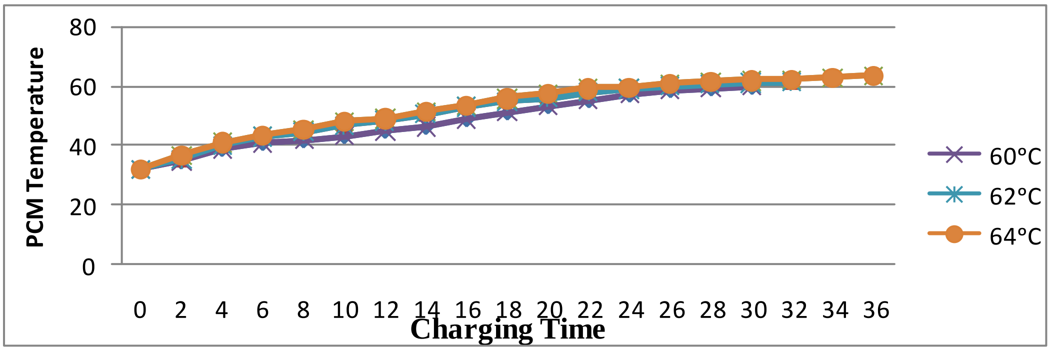
The HTF maintained at constant temperature, is allowed to flow through the TES tank continuously until temperature of PCM and HTF becomes equilibrium. The temperature of PCM is recorded at an interval of 2 minute. If PCM inside the capsule and HTF are in thermal equilibrium then the outlet value of the TES tank is closed. The tank is completely filled with HTF.

The charging experiments are conducted for the combination of various parameters of mass flow rates, HTF inlet temperatures and different number of capsules in which PCM is stored. The results of charging experiment at different levels of temperature and HTF flow rate are shown in graphs 1 and 2 below.

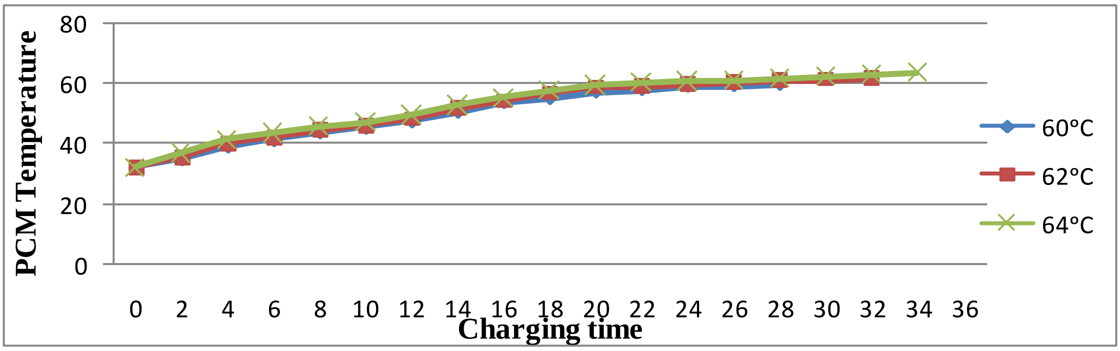
3.2. Discharging Process

In this process a certain amount of hot water (say 2 lit and 4 lit) is withdrawn from the TES tank and same amount of water is fed into the TES tank and the temperature of withdrawn water is noted. The water is withdrawn from the TES tank for every 20 minutes. This entire process is called batch process. The same procedure is repeated for all experiments. The discharging process is continued until the temperature of withdrawn water (T_W) reached to 28 ^oC. The results of discharging experiment at different levels of temperature and HTF flow rate are shown in graphs 3 and 4 below.

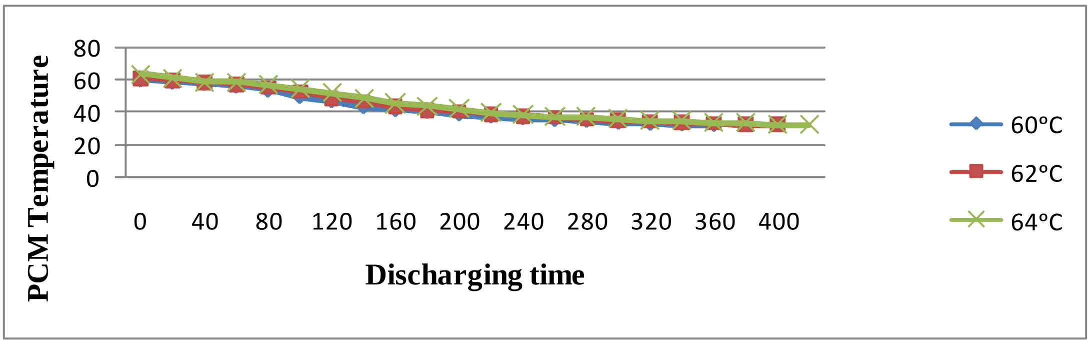
Graph .1 Varying of PCM Temperature at 2 lit/min flow rate (Charging)



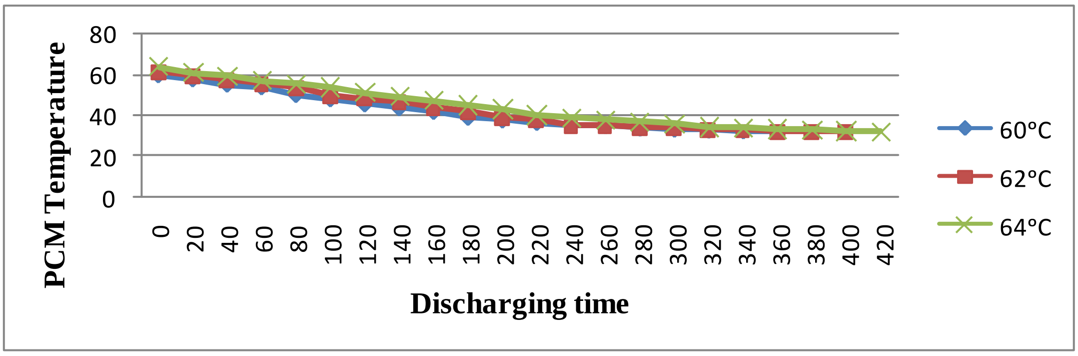
Graph .2 Varying of PCM Temperature at 4 lit/min flow rate (Charging)



Graph .3 Varying of PCM Temperature at 2 lit/min flow rate (Discharging)



Graph .4 Varying of PCM Temperature at 4 lit/min flow rate (Discharging)



IV. CONCLUSIONS

From the results, the following conclusions are drawn:

- An indigenous experiments setup has been built to carry out TES system during charging and discharging process using PCM.
- The set of six experiments are conducted according to various input factors like flow rate, HTF temperature PCM capsule shape.
- By conducting experiments, it is observed that effect of water flow rate of HTF 4 lit/min, HTF inlet temperature at 64^{o}C give the best results for charging and discharging time with spherical shape PCM capsule.
- Hence it is concluded that higher flow rates, higher inlet temperatures of HTF recommended for spherical shape PCM capsule.

V. SCOPE FOR THE FUTURE WORK

However this work can be extended further by considering the following.

- The melting point of PCM (manganese chloride tetra hydrate) is 58^{o} C and easily achieved during sunny days, hence it is recommended that, this PCM might be used in solar energy storage applications like solar water heating systems.

VI. REFERENCES

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