Experimental study of discharging characteristics of sensible and latent heat storage units integrated with solar flat plate collector

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ABSTRACT

The present work analysis performance of sensible heat storage (SHS) and combined storage units incorporated with solar flat plate collector. The Thermal Energy Storage (TES) unit includes Phase Change Material (PCM) of paraffin filled in spherical capsules. The water acts as Heat Transfer Fluid (HTF) to transfer the heat. The experiments are carried out to study the performance of the TES unit for mass flow rates of HTF. Discharging (heat release) experiments were conducted for discharging and batch wise discharging methods for both SHS system and combined storage system. The significance of time variation of HTF and PCM temperatures during discharging is discussed in detail. The heat storage capacity of the combined sensible and latent heat storage system is raised approximately 60% in relation to the conventional SHS system.

KEY WORDS: Thermal energy storage, sensible heat, latent heat, PCM.

1. INTRODUCTION

Solar energy is a non-polluting and clean energy source and it is time related energy source with alternating character. Thermal energy storage (TES) is important for the efficient utilization of solar energy source. More of the TES systems depend on the sensible heat of the storage medium such as oil and water and it has the drawback of less heat storage capacity per unit volume. However, the latent heat storage (LHS) has solid-liquid phase change process and it involves high heating storage capacity and isothermal behavior. The combined system removes the issues related to the SHS systems. The current work deals with the experimental analysis of combined system integrated with solar heating system.

Packed bed SHS system was studied and SHS techniques availability, selection method and environmental aspects of SHS systems were discussed (Beasley, 1984; Dincer, 1997). The combined system was discussed by the researchers viz (Sodha, 1997; Reddy, 1999). Transient heat characteristics PCM material in the form of spherical capsules was discussed (Saitoh, 1986) and in this study parameters such as diameter of capsule, flow rate, inlet temperature decrease and material of capsule were studied. 1D separate phases formulation of packed bed transient response of thermal behavior was discussed (Beasley, 1989) and air was used as heat transfer fluid. Different PCM modules were used in numerical simulation and experimental study of density of energy storage of hot water system and it gave considerable performance of the combined systems (Mehling, 2003). Water heater with LHS and without LHS were studied combined systems of uniform rate of discharging and charging of SHS system for long period (Amin, 2013) and similar works were reported in (Ettouney, 2005; Nallusamy, 2007).

2. EXPERIMENTATION

A photographic view of the experimental set-up is shown in Figure 1. This is made of an insulated tank, which has flat plate collector, pyranometer, pump and flow meter. The tank, which is 40 liters, supplies hot water for 5 to 6 persons. The tank has four segments and RTD's accuracy of ± 0.3^0C.

Figure.1. photographic view of the experimental set-up

The flat plate collector connects the tank and PCM capsules are immersed in the water. Different tests are done with different HTF flow rates.

3. RESULTS AND DISCUSSION

Charging process: The HTF is flowed through the tank continuously and exchanges the energy to PCM at start of charging process and the temperature reaches to 32^0C and it has less melting temperature. First, energy stored in PCM is sensible heat and as charging continues further PCM melts at a constant temperature and then PCM is superheated. Temperatures of the PCM and HTF at different positions of the tank as shown in Fig.2 are entered at an interval of 5 minutes. The charging process is continued until the PCM temperature reaches 70^0C. Fig. 3 shows the heat stored in the storage tank for porosity = 0.49.

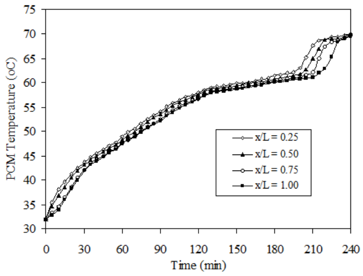

Figure.2 PCM temperature variation during charging process

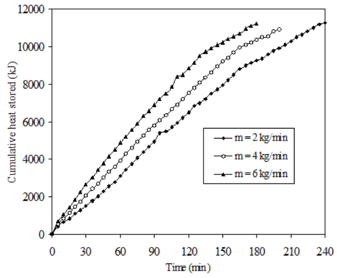

Figure. 3 Cumulative heat stored during charging process

Discharging process: The discharging process tests are done by batch wise process in that some quantity of hot water is taken out from TES tank and mixed with cold water at 32^{0}C to get the needed hot water of 20 liters at temperature of 45 ± 0.5^{0}C for direct usage and the tank is again filled with cold water of quantity equal to the amount of water taken out. Again after 10 minutes, the hot water of 20 liters are taken out. This process goes till the PCM temperature reaches 45^{0}C. The variation of HTF during continuous and batch wise processes are shown in Fig.4.

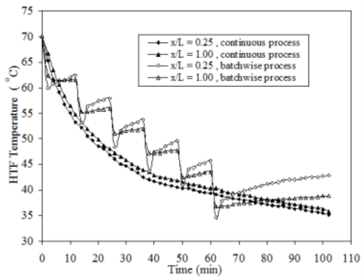

Figure. 4. Variation of HTF temperature during continuous and batchwise process

It is found that 5 batches of 20 litres of hot water at temperature of 45°C can be get in a period of 60 minutes from the TES tank. In the case of continuous discharging process, as the HTF outlet temperature decreases continuously with time, this type of process is not suitable for practical applications.

Comparison of SHS and LHS systems: In order to compare the performance of the combined storage system with the conventional SHS system, experiments are conducted with sensible heat storage tank. The storage tank used in the above experiment is used as SHS tank after unloading the PCM capsules. Fig. 5 illustrates the variation of HTF temperature during the charging process measured at x/L = 0.50, for both SHS and combined storage system, for a mass flow rate of 2 kg/min. The charging time for SHS system is less when compared to combined storage system, as the heat storage capacity of SHS system is lesser than combined storage system. For the case of combined storage system with porosity of 0.49, the quantity of water and PCM is 23 and 24 litres respectively. It is noted from the figure that in the combined storage system the increase in water temperature during the initial period of charging is higher than SHS system as the specific heat of the solid PCM is lesser than water. Once the PCM reaches its melting temperature in the combined storage system, as it absorbs more amount of heat for its phase transition, the water temperature remains almost constant during this period, whereas, in the SHS system, the temperature increases continuously with time till the end of charging process. Fig. 6 shows the cumulative heat stored (Qcum) during charging process for SHS and combined storage systems for the mass flow rate of 2 kg/min.

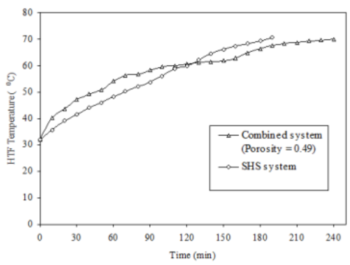

Figure. 5. Comparison of temperature profiles of HTF during charging process for both combined and SHS systems for varying HTF inlet temperature.

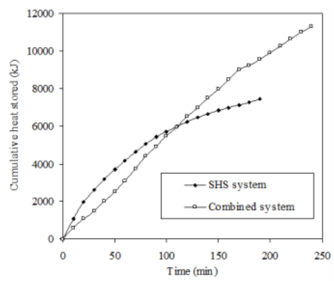

Figure. 6. Comparison of cumulative heat stored for SHS and LHS systems.

The quantity of heat stored (energy available for effective use) in the storage unit with the permissible temperature rise of 26^{0}C (i.e. 45^{0}C to 70^{0}C) is (i) for the case of SHS system, Q = 5220 kJ and (ii) For the case of combined storage system, Q = 8360 kJ. The combined storage system with porosity of 0.49 increases the heat storage capacity approximately by 60% when compared to SHS system for the same size of the TES tank and for the similar operating conditions. It is seen from the Fig. 6 that the quantity of heat stored is more in SHS system in the beginning of charging when compared to combined storage system. However most of this energy will not be available for effective use. The unavailable energy in the temperature range of 32 - 45^{0}C is estimated as 2400 kJ in the SHS system. In case of combined storage system, though the heat stored is low in the beginning of charging, the unavailable energy is only around 1835 kJ. This is due to low specific heat of solid PCM and smaller quantity of water (23 litres) present in the system.

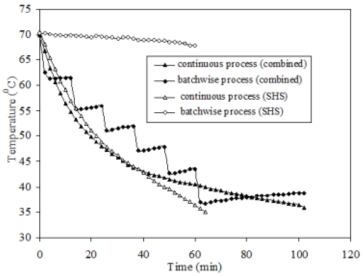

Figure. 7. HTF temperature variation during discharging process for SHS and LHS systems

The discharging experiments are carried out by both continuous and batch wise methods. Fig.7 represents the temperature histories of HTF during continuous and batch wise discharging processes for both SHS system and combined storage system. In the continuous discharge method the cold water (HTF) at 32^{0}C is circulated through the storage tank which is initially at 70^{0}C at the mass flow rate of 2 kg/min.

The batch wise discharging method employed in the combined storage system, without disconnecting the cold water flow to the storage tank, provides better performance than the continuous discharging process, as 140 litres of hot water at an average temperature of 45^{0}C is obtained for direct use in the residential premises. After the discharging process, the PCM in the storage tank is still at 45^{0}C. However, this heat cannot be utilized effectively for direct use.

4. CONCLUSIONS

A Thermal storage system is developed for the hot water to use at 45^{0}C for bathing applications using combined storage system. Charging and discharging experiments are done to study the performance of flat plate collector. The mass flow rate plays crucial role in heat extraction from the collector and combined systems reduce the size of the storage tank.

REFERENCES

Amin F.B.A, Patil A.M, Dange H.M, Comparative study of Solar Water Heater with and without Latent Heat Storage System, International Journal of Advanced Engineering Research and Studies, 2 (3), 2013, 89-92.

Beasley D.E, Clark J. A, Transient response of a packed bed for thermal energy storage, Int. J. Heat Mass Transfer, 27 (9), 1984, 1659-1669.

Beasley D.E, Ramanarayanan C, Thermal response of a packed bed of spheres containing a phase change material, Int. J. Energy Research, 13, 1989, 253-265.

Dincer I, Dost S, Xianguo Li, Performance analysis of sensible heat storage systems for thermal applications, Int. J. Energy Research, 21, 1997, 1157-1171.

Ettouney H, El-Dessouky H, Amani Al-Ali, Heat transfer during phase change of paraffin wax stored in spherical shells, Journal of Solar Energy Engg, 127, 2005, 357-365.

Mehling H, Cabeza L.F, Hippeli S, Hiebler S, PCM-module to improve hot water heat stores with stratification, Renewable Energy, 28 (5), 2003, 699-711.

Nallusamy N, Sampath S, Velraj R, Experimental investigation on a combined sensible and latent heat storage system integrated with constant / varying (solar) heat sources, Renewable Energy, 32 (7), 2007, 1206-1227.

Reddy K.S, Avanti P, Kaushika N. D, Finite time thermal analysis of ground integrated-collector- storage solar water heater with transparent insulation cover, Int. J. Energy Research, 23, 1999, 925-940.

Saitoh T, Hirose K, High performance phase-change thermal energy storage using spherical capsules, Chemical Engg. Commun, 41, 1986, 39-58.

Shimin Wang, Amir Faghri, Bergman L.T, A Comparison study of sensible and latent thermal energy storage systems for concentrating solar power applications, Numerical heat transfer, part A: Applications, 61 (11), 2012, 860-871.

Sodha M.S, Sharma A. K, Sawhney R. L, Kumar A, Experimental performance of built-in-storage solar water heating systems in laboratory and field conditions, Int. J. Energy Research, 21, 1997, 275-287.