STUDY OF COMBINED SENSIBLE AND LATENT HEAT SOLAR THERMAL ENERGY STORAGE SYSTEM

Ph.D. THESIS

by

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ABSTRACT

The global fossil fuel resources are dwindling with the world ever-increasing energy demand and concern for environmental sustainability has attracted the attention of researchers towards the use of renewable energy resources and waste heat resources. The major technological bottleneck for preventing the effective deployment and efficient use of renewable energy resources is their intermittent nature and so the energy supply and demand have not been balanced in time. In order to minimize the discrepancy between energy supply and demand and to ensure continuous energy supply, an integration of thermal energy storage with the solar thermal systems is one of the promising technology. The thermal energy storage system plays a major role in effective utilization of resources in improving the efficienty of solar thermal systems. The use of efficient and inexpensive thermal energy storage systems can enhance the performance of solar thermal systems, as well as the widespread usage of solar energy.

Thermal energy storage in a packed bed system with air as a heat transfer fluid, offers an attractive and efficient approach for storing the solar thermal energy. The thermal energy storage comprises of storage media in a storage container through which the heat carrying fluid (air) is passed to transfer thermal energy from air to the storage media. The energy stored can be retrieved by pumping the atmospheric air through the packed bed. Generally, sensible heat and latent heat storages are the two main technologies used for storing the thermal energy. The sensible heat storage system accumulates the energy by changing the internal energy without phase change and for latent heat storage, the energy is stored by changing the phase of a material.

The latent heat storage system draws more attention than the sensible thermal storage system because of their high storage density and prolonged discharge time. However, the latent heat storage has a major drawback of lower thermal conductivity, which results in a lower heat transfer rate. To increase the heat transfer rate of the system, researchers have implemented heat transfer augmentation techniques which can increase the cost and compliance of the system. Both sensible and latent heat thermal energy storage systems have their disadvantages. From the literature, it was found that most of the studies are focused on individual sensible and latent heat thermal energy storage systems. A very few studies are available on hybrid sensible-latent heat storage systems, particularly experimental studies. In

view of these issues, the major concern about the design of the thermal energy storage system is to deliver larger quantities of thermal energy for a longer duration, minimize the thermocline degradation and to maximize the heat transfer rate. To mitigate the drawbacks of individual sensible and latent heat thermal energy storage systems, a novel combined sensible-latent thermal energy storage system has been proposed. Under the present study, the performance of combined sensible-latent heat storage system with different proportions of storage medium is proposed to investigate experimentally and compare its performance with individual system performance.

In order to achieve these objectives, a test set up of thermal energy storage system was designed and fabricated. Three different thermal energy storage systems i.e sensible, latent and combined sensible-latent TES systems were considered and experimentations were performed to generate the data for analyzing the thermal performance of the systems. The sensible thermal energy storage system is packed with concrete spheres in the entire tank, while in case of latent thermal energy storage system the tank is filled entirely with encapsulated capsules having same diameter of 38 mm as of concrete spheres. The combined sensible-latent heat storage system constituted a sensible storage section with a packed bed of concrete spheres and a latent storage section with an encapsulated phase change material on top of the sensible storage material having a size of 38 mm diameter.

The experiments were conducted on sensible and latent heat thermal energy systems for collecting the data to analyze the performance of the systems having similar storage tank and storage element geometries. The void fraction of 0.4 is obtained by packing the storage elements randomly in a storage tank for the considered thermal energy storage systems. A comparative performance assessment of sensible and latent thermal energy storage systems has been carried out for different values of mass flow rates during charging and discharging process. Further, a combined sensible-latent thermal energy system has been investigated and results were compared with the sensible and latent thermal energy storage systems under similar system and operating parameters.

In order to investigate the effect of volume fraction of PCM on the performance of the combined sensible-latent thermal energy system, four different values of volume fraction of PCM ranging from 20% to 80% have been considered in this study. The performance parameters in terms of instantaneous and cumulative energy transferred, energy stored and extracted, pumping energy, thermocline degradation, storage efficiency, charging and discharging time are analyzed during charging and discharging process.

The heat transfer and pressure drop have significant effect on performance of the system. Based on the experimental results, better heat transfer was observed in sensible and combined sensible-latent TES as compared to the latent TES. This is because of the existence of higher thermal conductivity of sensible storage materials than the case of PCM. The latent TES system is found to have 8.69% and 16.81% higher charging and discharging time as compared to the combined TES systems. Whereas, 10.7% and 73.56% higher charging and discharging time has been found in comparison with the sensible TES systems. The charging and discharging time of sensible TES is found to be reduced by 30.35% and 18.30%, whereas for combined and latent TES systems, it is reduced by 29.03%, 16.58% and 21.22%, 27.99% respectively as the mass flow rate is increased from 0.024 kg/s to 0.038 kg/s.

The energy transfer, energy recovery, energy storage, storage density and storage efficiency are the important performance parameters for evaluation of system performance. The cumulative energy transferred by HTF in sensible, latent and combined sensible-latent TES systems are found as 1.05 kWh, 1.92 kWh and 1.39 kWh, respectively during charging for a given flow rate of 0.172 kg/s. Whereas, the corresponding cumulative energy retrieved by HTF is found to be 0.61 kWh, 1.81 kWh and 1.22 kWh, respectively. Based on the experimental study, it is found that 1.98 times more energy was stored and 2.1 times more energy has been recovered in combined sensible-latent TES than the sensible TES. Whereas, in comparison with the latent TES, the storage and recovery of the energy has been lowered by 0.52 times and 0.50 times, respectively.

Based on the comparison of different volume fractions of PCM, 80% and 60% volume fraction PCM systems are found to have better overall storage efficiency in comparison to the 40% and 20% volume fractions of PCM respectively. The 80% volume fraction of PCM has 20.7%, 66.36%, 118.25% higher storage capacity than the case of 60%, 40% and 20% volume fraction of PCM, respectively. Further, 80% volume fraction has more energy recovery by 24%, 64.4%, and 134% than the case of 60%, 40% and 20%, respectively. It shows that system with 80% volume fraction of PCM exhibits better storage and recovery capacity. An attempt has also been made to carryout an economic analysis of three considered TES systems. For the considered size of storage tank of the three TES systems, it is found that the sensible TES system has 64.8% and 41.95% lesser installation cost than the latent and combined sensible-latent TES respectively. The results show that the combined sensible-latent TES system is more expensive than the sensible TES, but cheaper than the latent TES system.

Based on the study, it is found that variation in volume fractions of PCM has a significant influence on the system performance. The combined sensible-latent heat thermal energy storage system has higher discharging time, lower thermocline degradation, more energy delivered for a longer duration, reasonable capacity cost over sensible heat thermal energy storage and lower charging time, higher heat transfer over the latent heat thermal energy storage system. The system having 60% volume fraction of PCM showed minimum installation cost and better energy density, charging and discharging time, overall storage efficiency over the system having other considered volume fractions. Accordingly, it has been found that a combined sensible-latent heat thermal energy storage system with 60% volume fraction has better performance in comparison to the individual sensible and latent heat thermal energy storage systems.

This study may be useful for the implementation of thermal storage systems for different solar thermal energy applications like solar dryers, solar air heaters and other low temperature applications.