Charging and Discharging Processes of Thermal Energy Storage System Using Phase change materials

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Abstract: The objective of the study is to investigate the thermal characteristics of charging and discharge processes of fabricated thermal energy storage system using Phase change materials. Experiments were performed with phase change materials in which a storage tank have designed and developed to enhance the heat transfer rate from the solar tank to the PCM storage tank. The enhancement of heat transfer can be done by using a number of copper tubes in the fabricated storage tank. This storage tank can hold or conserve heat energy for a much longer time than the conventional water storage system. Performance evaluations of experimental results during charging and discharging processes of paraffin wax have discussed. In which heat absorption and heat rejection have been calculated with various flow rate.

Keywords: Phase Change Materials, Solar Tank, Thermal Energy Storage System, Copper Tubes,

1. INTRODUCTION

Efficient and economical technology that can be used to store large amounts of heat in a reduced volume is the subject of research for a long time. PCM plays an important role in energy conservation, which is very attractive because of its high storage density with small temperature change. It has been demonstrated that the development of a latent heat in thermal energy storages system which store heat during peak power operation and release the same during reduced power operation. Phase change material is one of the thermal storage devices. Thermal energy storage system enhanced by encapsulating with suitable PCM materials, within these surfaces heat can absorb or capture solar thermal energy through natural convection. The amount of stored heat energy depends on the specific heat of the medium, the temperature change and the amount of storage material. Latent Heat Storage (LHS) is based on the heat absorption or release when a storage material undergoes a phase change from solid to liquid or liquid to gas or vice versa. This system provides a valuable solution for correcting the difference between the supply and demand of energy. Many phase change materials have been studied and tested for different practical uses by many scientists. This paper attempts to analyze the application of PCM in
thermal storage system. The present work mainly concentrated temperature profile during charging and discharging processes in thermal energy storage system. Here some relevant literature reviews are as follows: Mohammed Mumtaz A. et al., [1] discussed efficient thermal energy storage system with comprehensive evaluation of suitable PCM materials in a single-effect solar absorption system affecting its performance. Guruprasad Alva, et al., analysed [2] synthesis methods of microencapsulated phase change materials, such as physical synthesis methods like spray drying, polymerization, emulsion polymerization, interfacial polymerization, in-situ polymerization and condensation polymerization. Peizhao Lv [3] showed that the paraffin/kaolin composite with the largest particle size of kaolin (K4) has the highest thermal conductivity (0.413 W/(m K) at 20 °C) among the diverse composites. Lingkun Liu, et al., [4] discussed enhancement techniques for phase change materials for thermal energy system in domestic application. R. Al Shannaq, and M.M. Farid [5] discuss the most important methods of encapsulation applicable to these PCMs. These methods include microencapsulation in capsules ranging in size from nano- to micro-scale, encapsulation in porous particles. Kinga Pielichowska et al., [6] discussed flame retarding properties. The wide range of PCM applications in the construction, electronic, biomedical, textile and automotive industries is presented and future research directions are indicated. L.C. Chow et al [7] studied about two thermal conductivity enhancement techniques. The first technique focuses on placing encapsulated PCM of various shapes in a liquid metal medium. The second technique involves a metal/PCM composite. I. M. Bugaje [8] studied the thermal response of paraffin wax contained in plastic tubes and used in latent heat storage systems was enhanced by the use of metal matrices. R. Velraj et al., [9] in this paper a detailed investigation of the different heat transfer enhancement methods for the latent heat thermal storage system has been carried out. Enhancement has been done with fin configuration and by lessing rings are used to increase the storage capacity. Ismail et al., [10] represented a model for simulation of the process of heat transfer (charging and discharging) of a latent heat storage system of packed bed of spherical capsules filled with PCM was developed and solved numerically by using a finite difference approach and moving grid technique. The numerical grid was optimized and the predicted results were compared with experimental measurements to establish the validity of the model. V. Arun prasad Raja et al [11] developed numerical simulation method, he has enhanced heat transfer rate for water and air, computational fluid dynamics software (FLUENT) used. In which forced convection heat transfer in fully developed flow were compared with thermally developing laminar flow, it was found that heat transfer coefficients were higher due to small channel spacing and developing laminar flow. The author E. Assis et al., [12] presented the process of melting of a phase-change material (PCM) in spherical geometry has been explored experimentally and numerically. The TES unit contains paraffin as phase change material (PCM) filled in spherical capsules, which are packed in an insulated cylindrical storage tank. The water used as heat transfer fluid (HTF) to transfer heat from the solar collector to the storage tank also acts as sensible heat storage material, thermal energy storage system for the use of hot water at an average temperature of 45°C for domestic applications using combined sensible and latent heat storage concept. From the above literature a common problem in latent heat thermal storage is the poor conductivity of the phase change material. During the phase changing process, the surface heat flux decreases due to the increasing thermal resistance of the growing layer of the molten or solidified PCM. Hence, it is necessary to improve the heat transfer rate across the heating surface and phase change materials. Hence smaller diameter of copper tubes are used to improve the heat transfer rate during charging and discharging processes.

2. PHASE CHANGE MATERIALS
The Phase Change Material is the latent heat storage material. As the source temperature rises, the chemical bonds within the PCM breaks, and the material changes its phase from solid to liquid. During the charging process, the material begins to melt when the phase change temperature is reached. The temperature then stays constant until the melting process is finished. The heat that is stored during the phase change process (melting process) of the material is called the Latent Heat. It follows an isothermal behavior during the charging and discharging processes. Here, when paraffin is used as the PCM material, latent heat storage can be achieved through solid-solid, solid-liquid, solid-gas and liquid-gas phase change. However, the only phase change used for the PCM is the solid-liquid change. The PCM continues to absorb heat without a significant rise in temperature, until all the material is transformed to the liquid phase. When the ambient temperature around a liquid material falls, the PCM solidifies and releases its stored latent heat. Table 1, shows the thermo physical properties of paraffin wax.

Table 1 Thermo physical Properties of paraffin

| Properties       | Paraffin wax |
|------------------|--------------|
| Melting point    | 58 °C        |
| Latent Heat      | 200-210 kJ/kg|
| Density          | 920 kg/m³    |
| Heat capacity    | Solid 2 kJ/kg·K |
|                  | Liquid 2.5 kJ/kg·K |
| Thermal conductivity | 0.2 -1.7 W/m·K. |

3. FABRICATION OF PCM STORAGE TANK

The fabrication of PCM storage tank is a concentric cylinder with height of 80 cm in length. The inner cylinder is 35 cm and the outer cylinder is 40 cm in diameters with capacity of 45 litres. It is made with stainless steel. The tank contains numbers of copper tube each tube filled with PCM materials. The storage tank is well insulated and thermally sealed by filling the annulus with glass wool. The solar tank has 100 litres capacity; the solar collector contains 15 numbers of evacuated glass tubes. The length of evacuated glass tube is 138cm, a breadth of 100 cm, and a 4cm clearance. The height of the solar tank from the base of the collector was ensured to be 80 cm. The maximum permissible working pressure maintained in the evacuated tube collector was 0.4kg/cm². The outer surface of the inner glass tube is coated with a special solar selective coating, which absorbs and converts the maximum amount of solar radiation into heat. The space between the outer and inner glass tubes is evacuated and permanently sealed off, and the vacuum acts as an excellent insulator. The PCM storage tank has integrated with the solar tank. PCM storage tank received hot water from solar tank. Solar energy has absorbed and stored in PCM storage tank as latent heat. Large quantity of solar energy can be stored in a day time and same heat can be retrieved for later use. The tank was instrumented to measure inlet and outlet water temperature at eight different levels with R20-Thermocouple arrangement. Flow meters were used to vary the flow rate.

4. EXPERIMENTAL WORKING MODEL
The experimental set-up consisting solar tank with a capacity of 100 litres and PCM storage tank with a capacity of 45 litres; the tank have instrumented to measure the HTF and PCM temperatures with a thermocouple arrangements. Flow meters were fit across the pipe line to measure the flow rates by adjusting the valve position, proper inlet and outlet pipe connections are ensured, as shown in Figure 3. Here, water is used as the Heat transfer fluid and paraffin used as phase change materials. To analyze the temperature variation of the HTF and PCM in the copper tube, the length of the copper tube is divided into four divisions or segments (levels) from the base, each division of in and out of the copper tubes is connected to thermometers with sensors. Inside the copper tube the PCM is presented, and outside the copper tube the HTF is circulated. Hence, we can read the temperature for both the HTF and the PCM at all levels. During the active phase of the sun light the heat energy can be stored in the solar tank through the evacuated glass tube collector. The Heat Transfer Fluid (HTF) from the solar tank is allowed to the PCM storage tank. Then the PCM and HTF temperature are noted every 10 minutes at four levels. During discharging process the cold water is allowed to the PCM tank with ambient temperature again the HTF and PCM temperature are noted every 10 minutes at four levels. The experiment is completed when the PCM and water temperatures are the same. The same procedure is repeated for different mass flow rates.

Figure 1. Experimental working model

5. RESULTS AND DISCUSSION

5.1. Charging and discharging process of paraffin wax

The charging process was carried out by applying HTF at 76°C with a different flow rate of 6 kg/min, 4kg/min, and 2kg/min to the PCM storage tank. During the charging process the HTF is circulated continuously through the PCM storage tank. The Heat Transfer Fluid (HTF) exchanges its energy to
At the beginning of the charging process, the temperature of the paraffin inside the tubes will be ambient temperature, which is lower than the melting temperature. Initially the energy is stored inside the tubes as sensible heat until the paraffin reaches its melting temperature. As the charging process proceeds, energy storage is achieved by melting the paraffin at a constant temperature and stored as latent heat. Then the charging process is continued until the paraffin temperature reaches the value of 76°C energy is stored as sensible heat in liquid paraffin. The discharging processes were carried out by applying the cold water at ambient temperature, which is circulated continuously through the storage tank to recover the stored heat energy. The following Figures 4 and 5 show the charging and discharging processes of paraffin wax with respect to time and temperatures.

The observation made from the experimental results that charging process takes 160 minutes and discharging process takes 200 minutes when the flow rate has 6kg/min. Likewise for 4kg/min charging process takes 180 minutes and discharging process takes 210, and for 2kg/min the charging process takes 200 minutes and discharging process takes 220 minutes. The above results indicate that when flow rate is increase time consumption has decreases. However due to the smaller diameter of copper tube...
arrangement, the discharging time is reduced significantly compared with commercial thermal storage system.

6. CONCLUSION

It is concluded from the experimental results that the Phase Change Materials (PCM) plays an important role in energy conservation, which is very attractive because of its high storage density with small temperature change. Phase change material is one of the thermal energy storage materials. It has been demonstrated that the development of latent heat in thermal energy storage systems, which stores heat during peak power operation and releases the same during reduced power operations. In the fabricated storage tank heat can transfer from the HTF to the PCM as well as from the PCM to the HTF during charging and discharging processes. During the discharging process heat can be retrieved after a long interval, without losing any considerable losses. Summation of charging and discharging processes of latent heat storage material of paraffin wax has considerably higher thermal energy storage densities materials, and able to absorb or release large quantities of energy at a constant temperature by undergoing a change of phase.

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