COMPARITIVE STUDY OF SENSIBLE AND LATENT HEAT STORAGE SYSTEMS INTEGRATED WITH SOLAR WATER HEATING UNIT

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Abstract

The present work has been undertaken to study the feasibility of storing solar energy using phase change materials (PCMs) and utilizing this energy to heat water for domestic applications during nighttime. This ensures that hot water is available through out the day. The storage system consists of two simultaneously functioning heat-absorbing units. One of them is a solar water heater and the other a heat storage unit consists of PCM. The solar water heater functions normally and supplies hot water during the day. The storage unit stores the heat in PCM's during the day and supplies hot water during the night and overcast periods. The storage unit utilizes small cylinders made of aluminium filled with paraffin (PCM) as the heat storage medium and integrated with a solar collector to absorb solar energy. The performance of this PCM based thermal energy storage system is compared with conventional sensible heat storage system and the conclusions drawn from them are presented.

1. Introduction

Energy is in many ways the convertible currency of technology. Today's countries and their economies are based upon abundant and reliable energy supplies. The average annual growth rate in world population is approximately 2%, and many countries exceed that level. As population grows, the need for more and more energy resources is exacerbated. Enhanced lifestyles also abet the growing demand for energy. Moreover, Global primary energy demand is expected to increase by as much as 1.5 to 3 times by 2050. Simultaneously, concern will likely increase regarding energy- related environmental concerns such as acid precipitation, stratospheric ozone depletion, etc. Energy supply and use are related not only to problems such as global warming, but also to such environmental concerns as air pollution, ozone depletion, forest destruction and emissions of radioactive substances. These and other environmental issues must be taken into consideration if humanity is to develop in the future while maintaining a healthy and clean environment. Thus an intimate connection is established between energy, the environment and sustainable development.

On remembering this crisis a society seeking sustainable development must increasingly utilize only energy resources, which cause no environmental impact. With increasing importance for environmental protection and rising energy costs, the world is turning to renewable energy systems to contribute significantly in meeting society's needs for more efficient, environmentally benign energy. In particular, solar energy, being non-polluting, clean and inexhaustible, has received wide spread attention in recent times. It also provides an abundant energy source if harnessed efficiently. Though there are many advantages, an important deterrent is that the solar energy is a time dependent energy source with an intermittent character. Hence some form of thermal energy storage (TES) is necessary for more effective utilization of this energy source. There are

https://doi.org/10.24084/repqj06.218

mainly two types of Thermal Energy Storage systems, Sensible heat storage (SHS) and latent heat storage (LHS) systems. A lot of research work was carried out on SHS materials and systems in the past and the technology for their utilization was also well developed. How ever SHS systems posses the following disadvantages: (i). Low heat storage capacity per unit volume of the storage medium and (ii). Non-isothermal behaviour during heat storage (charging) and heat release (discharging) processes. LHS system is particularly attractive due to its ability to provide a high-energy storage density and its characteristics to store heat at a constant temperature corresponding to the phase transition temperature of the heat storage substance. Previous research on LHS and SHS systems has pertained to the theoretical and experimental study of the performance characteristics of these systems, predominantly using artificial heat sources. The majority of the research on the LHS system has been performed for shell and tube arrangement, and more recently for spherical shells. A very limited number of studies are found on the thermal performance of LHS systems employing PCM in various geometries integrated with Solar heating applications. The objective of the present work is to experimentally investigate the thermal behavior and feasibility of cylindrically encapsulated PCM as a LHS medium and compare the performance of this system with SHS system.

2. Experimental Investigation

A TES tank containing latent heat storage material is constructed to analyze the performance of LHS system. The schematic of the experimental setup is shown in Figure 1. It consists of the cylindrical TES tank, which holds the PCM in a packed bed of cylindrical aluminium capsules, solar flat plate collector, flow meter, temperature indicator and a circulating pump. The photographic view of the experimental setup is shown in Figure 2.

The stainless steel TES tank has a capacity of 48 liters, capable of supplying water for a family of four. With an internal diameter of 360mm and a height of 460mm, it houses the PCM capsules and allows for heat transfer between the capsules and the HTF. It contains two plenum chambers on the top and the bottom of the tank and a flow distributor is provided on the top of the tank to maintain a uniform flow of HTF. The tank is insulated with 50mm of glass wool and is provided with an aluminium cladding. It is considered that, on an average, the family would require 60 liters of heated water for their daily needs. This energy is stored as a mixture of sensible and latent heat of PCM, and sensible heat of water within the TES tank. We assume that the PCM store two-thirds of the energy while the remaining is stored as sensible heat of water. In the case of SHS system, the same TES tank is used without having PCM shells.

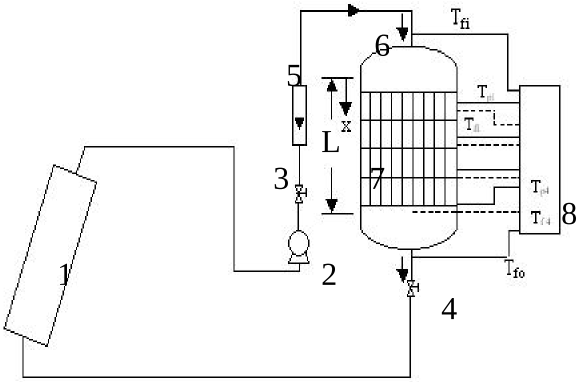

Fig. 1: Schematic of Experimental Setup
1. Solar flat plate collector; 2. Pump; 3 & 4. Flow control valves; 5. Flow meter; 6. TES tank; 7. PCM capsules; 8. Temperature indicator; T_P & T_f – Temperature sensors

3. Experimental Trial

1. During the charging process in the SHS system, the HTF is circulated through the TES tank and the solar collector unit continuously.

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The HTF absorbs solar energy sensibly and this energy is stored in the water in the TES storage tank, which is initially at atmospheric temperature. The SHS medium slowly gets heated sensibly. The charging process continues till heat transfer can no longer occur between the solar collector and the HTF as they attain thermal equilibrium. Temperatures of water in the storage tank and HTF are recorded at intervals of 10 minutes at the different locations.

Fig. 2:Photographic view of Experimental Setup

2. In the case of LHS system, during the charging process the HTF is circulated through the TES tank and the solar collector unit continuously. The HTF absorbs solar energy sensibly, and exchanges this heat with the PCM in the TES tank, which is initially at atmospheric temperature. The PCM slowly gets heated, sensibly at first, until it reaches its melting point temperature. As the charging proceeds, energy storage as Latent heat is achieved as the Paraffin melts at constant temperature (60±2°C). After complete melting is achieved, further heat addition from the HTF causes the PCM to superheat, thereby again storing heat sensibly. The charging process continues till the PCM and the HTF attain thermal equilibrium. Temperatures of the PCM and HTF at the different locations are recorded at intervals of 10 minutes. The PCM is charged through the day, whenever the user does not demand hot water during the daytime.

4. Results And Discussion

The temperature distributions of HTF and the PCM in the TES tank for different mass flow rates are recorded during charging for both the SHS and LHS systems. The cumulative heat stored and system efficiency during the charging process is studied in detail.

4.1 Latent Heat Thermal Energy Storage System

4.1.1 Charging process

Figure 3 shows the temperature variation of HTF inside the storage tank for a mass flow rate of four liter/minute and porosity of 0.51. It is observed from the figure that the temperature of HTF at all segments increases gradually until it reaches the temperature of 62 - 63°C, beyond which there is a slow decrease in the Temperature gradient.

Figure 4 represents the temperature variation of PCM during the charging process for a mass flow rate of four liter/minute and porosity of 0.51. The gradual increase in PCM temperature during the charging process is followed by a period of isothermal melting. The heating of liquid PCM shows a rapid change in temperature. It is also noted that the first layer (or segment) of PCM is completely charged within 70% of the total charging time of the storage tank. The charging process is terminated when the PCM temperature in all the segments is above 68°C. From the temperature histories of PCM and HTF, it is inferred that, for the present system, the heat transfer rate possible from the HTF to PCM in the storage tank is higher than the solar heating rate of the HTF from the solar collector. Hence, it is possible to reduce the charging time by either increasing the surface area of the solar collector, or by using one with a higher efficiency.

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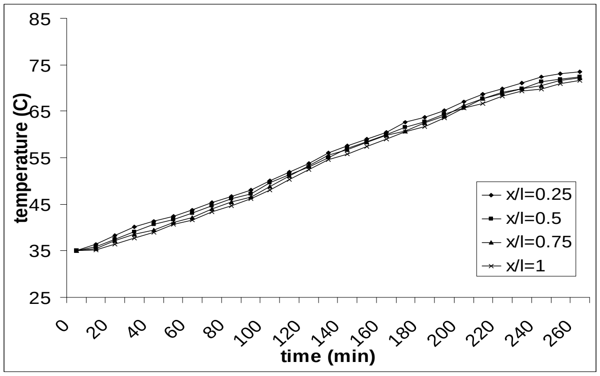

Fig. 3: Temperature variations of HTF

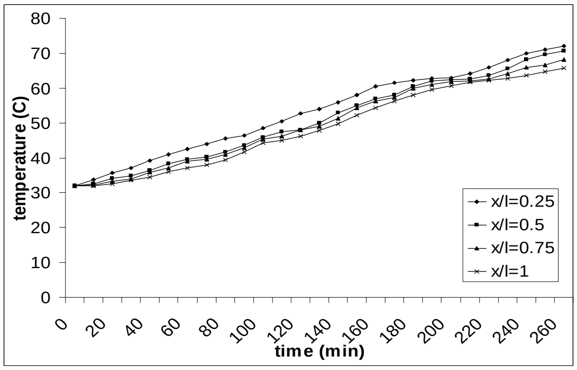

Fig.4: Temperature variations of PCM

Figure 5 illustrates the effect of varying the mass flow rate of HTF (two, four and six liters/ minute) on the charging duration of the TES tank. As the flow rate increases, we note that the time required for charging reduces. It is seen that the charging time decreases by 10.71 and 21.4% for increase in flow rates from two to four liters/ minute and two to six liters/ minute, respectively. Increased flow rates translate to increased surface heat transfer coefficients between the HTF and solar collector plate and also between the HTF and the PCM shells in the TES tank. This accounts for the shorter charging times, as more thermal energy is transferred into the TES tank by the HTF. Hence mass flow rate has a significant effect on the charging of TES tank.

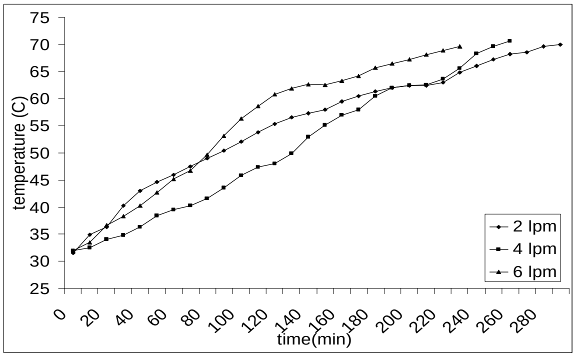

Fig. 5: Charging times for various flow rates of HTF

4.1.2 Cumulative heat stored

Figure 6 shows the cumulative heat stored in the storage tank for porosity ε=0.51. It is seen that the time required for storing 11MJ during charging is 260 minutes, 225 minutes and 200 minutes for mass flow rates of two, four and six liters/minute respectively. The avg. charging rates are estimated at 0.69, 0.724 and 1.01 KJ/ s for the corresponding flow rates in ascending order. Hence, increased mass flow rates of HTF significantly affect on average charging rate of PCM, due to higher heat extraction rates from the solar collector by the HTF.

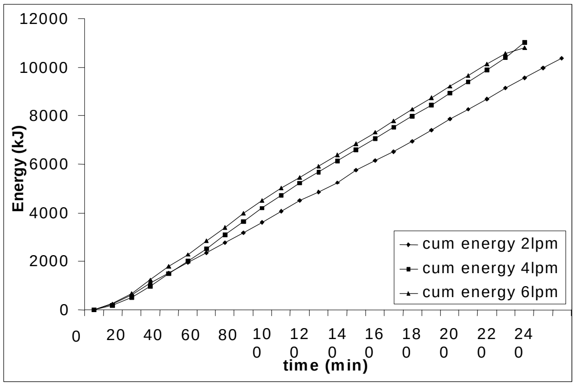

Fig. 6: Cumulative heat stored for different Flow rates of HTF

4.1.3 System efficiency

System efficiency is defined as the ratio of the amount of energy stored by the TES tank to the heat energy available from solar radiation. The system efficiencies of the TES system for the three different masses flow rates of HTF are plotted in figure 7.

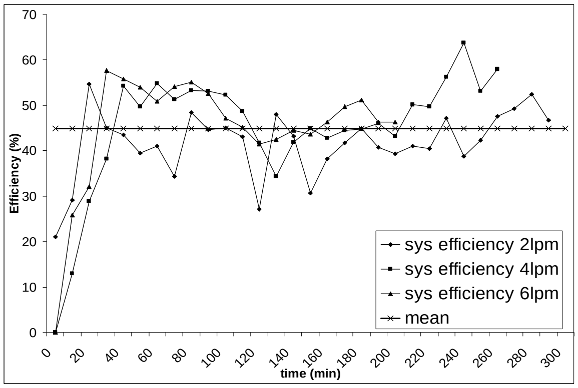

Fig. 7: System Efficiency for different mass flow rates of HTF

It is seen that the system efficiency decreases with time during the sensible heating of solid PCM, remains nearly constant during phase change period and then shows a slight increase during sensible heating of liquid PCM. The decreasing efficiency can be accredited to the increase in HTF temperature at the inlet of solar collector, which decreases the rate of heat absorption from the collector. There is also an increase in the solar intensity with time. As a result there is a gradual decrease in system efficiency. In the later periods, although solar intensity begins to reduce, the heat transfer in the tank between the PCM and HTF increases due to the melting of the paraffin, allowing more heat energy to be stored in the tank for the same flow rate. This results in a slight increase in efficiency at the latter stages of the experiment.

5. Comparative Studies

Figure 8 depicts the cumulative heat stored in a SHS and LHS system for a constant HTF flow rate of six-liter/ minute.

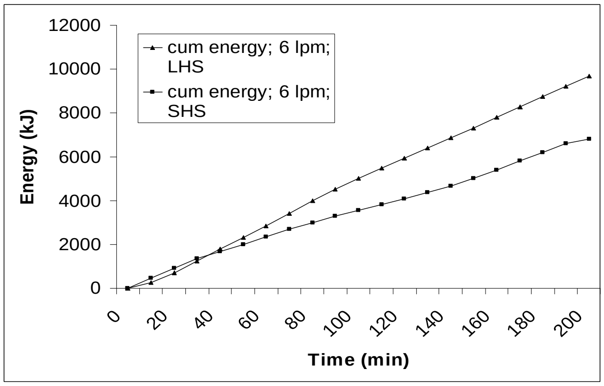

Fig. 8: Comparison of Cumulative energies in LHS and SHS systems

It can be clearly seen that the heat energy stored in LHS systems far exceeds that stored in a SHS system of the same size and volume of the storage tank. The heat stored per unit volume, when calculated, is 0.234 kJ/cc for the LHS system and is 0.144 kJ/cc for the SHS system. LHS systems can thus provide a substantial decrease in the storage volumes for the same heat stored, when compared to SHS systems. From figure 9, we can observe that the SHS system charges to the maximum temperature of 70°C 40 minutes sooner than the LHS system. On an average, the charging times in SHS systems are quicker than the LHS systems by 30-60 minutes, depending on the flow rates. The quicker charging times can be accredited to the absence of phase change materials in the SHS systems. On the other hand, heat transfer between the HTF and PCM in the Latent heat system reduces the temperature gradient of the HTF and increases charging time. Figure 10 shows the comparison of system efficiency of SHS and LHS systems for a HTF flow rate of 2 lpm. It is observed from the figure that the efficiency of SHS system is fluctuating over various periods of time, while the efficiency of the LHS system is constant over the phase transition temperatures and that it also shows a higher efficiency. Hence the LHS system is more efficient.

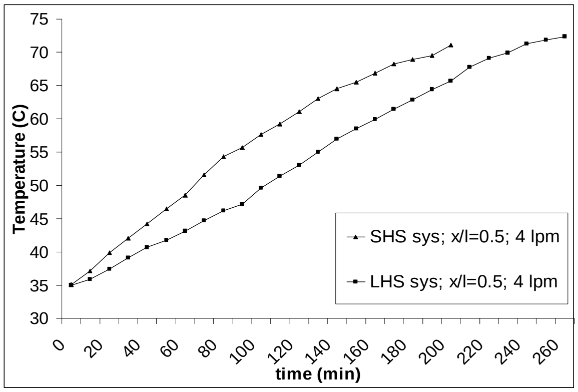

Fig. 9: Temperature histories of HTF during SHS and LHS charging process.

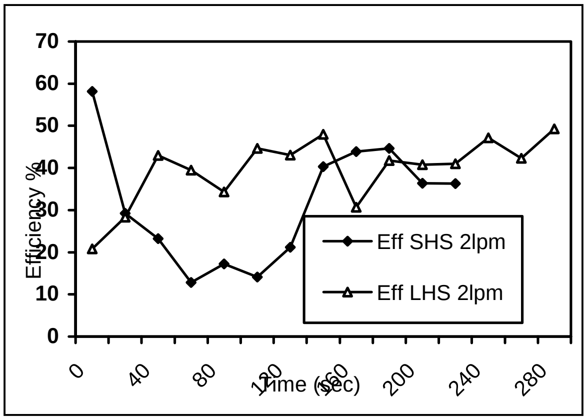

Fig. 10: Comparison of System Efficiencies for the flow rate of 2lpm between SHS and LHS.

6. Conclusions

A LHS system containing PCM in cylindrical capsules is designed and fabricated with an effective water storage capacity of about 48 liters, enough to meet the needs of a family of four. The thermal behavior of the LHS system is investigated experimentally for various operating conditions. The effects of flow rates on charging times and energy storage of the TES systems are studied. Similar studies for charging of SHS systems are also performed. The charging characteristics of the SHS and LHS systems are compared. It is concluded that LHS systems are a viable option for solar heat energy storage. Possessing considerable advantages over SHS systems, it can be used as an alternative to current domestic sensible solar water heating technologies.

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