

Thermal Analysis of Fluidized Bed and Fixed Bed Latent Heat Thermal Storage System

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Abstract. Thermal energy storage technology is essential because it stores available energy at low cost. Objective of the work is to store the thermal energy in a most efficient method. This work is deal with thermal analysis of fluidized bed and fixed bed latent heat thermal storage (LHTS) system with different encapsulation materials (aluminium, brass and copper). D-Mannitol has been used as phase change material (PCM). Encapsulation material which is in orbicular shape with 4 inch diameter and 2 mm thickness orbicular shaped product is used. Therminol-66 is used as a heat transfer fluid (HTF). Arrangement of encapsulation material is done in two ways namely fluidized bed and fixed bed thermal storage system. Comparison was made between the performance of fixed bed and fluidized bed with different encapsulation material. It is observed that from the economical point of view aluminium in fluidized bed LHTS System has highest efficiency than copper and brass. The thermal energy storage system can be analyzed with fixed bed by varying mass flow rate of oil paves a way to find effective heat energy transfer.

1. Introduction

Amount of conservation of energy is more than available resources, hence there is a need substitution for non-renewable resource source and so there should be a change over to the renewable source as they can be obtained continuously. Renewable resources like wind, solar radiation are continuously emitted, but only a small amount of this energy is being used. The present work has been undertaken to study the feasibility of store up thermal energy using PCM and utilizing this energy to heat fluid for domestic applications during night time [1]. This ensures that hot fluid is available throughout the day. The PCMs are the materials which has very less sensible heat storage rather the maximum heat storage capacity is due to their latent heat capacity which is due to change in its physical phase. The storage system consists of two at once functioning heat-absorbing units. One of them is a HTF and the other a heat storage unit consists of PCM [2]. PCM which is stored inside the encapsulation material .encapsulation which is capable of transferring heat to the PCM. Encapsulation material which is in orbicular shape with 4 inch diameter and 2 mm thickness orbicular shaped product of copper, brass and aluminium are used as encapsulation materials because of its high thermal conductivity. Arrangement of encapsulation material is done in two ways namely fluidized bed and fixed bed thermal storage system [3]. The PCM and HTF are used as latent heat and sensible heat storage system respectively. The mixed sensible and latent heat storage system can overcome the negative aspect of using either one of them separately. The PCM Charging and discharging process has been carry out for both fluidized and fixed bed thermal storage system. Charging is taken for every 10 minutes from the noted initial temperature. The change in temperature of heat transfer fluid is noted for every 10 minutes. This process continues during day time. Discharging takes place during night time.



Discharging time is also noted for every 10 minutes. Discharging is taken till the HTF reaches its room temperature. Comparative study is done between charging and discharging in fixed bed and fluidized bed latent heat thermal storage system. The experiments are done to find out the way for most proficient utilize of solar energy [4]. This experiment is to find out the heat exchange rate of HTF with D-Mannitol as PCM by using different encapsulation material in fixed bed and fluidized bed latent heat thermal storage system.

2. Experimental Setup and Methodology

First and foremost step in this experiment is to setup the solar collector. Solar collector is designed to track the intermittent energy given by sun. There are many types of collector to track the energy from sun. But the literatures are proved that the use parabolic trough collector (PTC) would give the better results which also pave a way to track the solar energy in the most efficient manner [5] [6]. Initially the HTF therminol-66 is circulated through the closed loop of thermal storage system using a slow speed high temperature pump. Therminol-66 is carrying heat to the encapsulated material during charging. Circulation of oil with the optimum mass flow rate for effective heat transfer was considered for investigations [7]. Thermal storage system is intentionally made for the storage of hidden (latent) heat for extended duration [8]. Reducing losses leads to efficient storage of thermal energy which is obtained by providing glass wool for insulation [9]. Material with high heat thermal conductivity is chosen as encapsulation material. Encapsulation materials are aluminium, brass and copper. Adding PCM inside the encapsulation material is followed by melting the PCM and then pouring inside the encapsulation material. PCM which chosen for this experiment is D-Mannitol. Limited amount of PCM is poured inside the encapsulation material by ensuring sufficient space of thermal expansion of PCM [10] [11]. Before starting the experiment connection of thermocouple, flow meter and heat pump has to attach to the setup. Minimum of 12 thermocouple is needed for the system for correct measurement of temperature in all tanks. Arrangement of encapsulation material inside the tank is to be carried in two methods such as fixed bed and fluidized bed. In fluidized bed encapsulated materials are arranged randomly in a container by ensuring without any air gap between the encapsulation materials. In fixed bed position of encapsulation materials are arranged in a certain order with help of each tray. The experiment was carried out in two modes -one for charging mode and another one for discharging mode. The process of heat absorbing mode (charging mode) and heat liberating mode (discharging mode) were carried out with PCM (D-Mannitol) and also with different encapsulation material (copper, aluminium, brass).charging and discharging is to be carried out with two position fixed bed and fluidized bed latent heat thermal storage system. Above two methods is to study the heat transfer rate between HTF and PCM in fixed bed and fluidized bed.

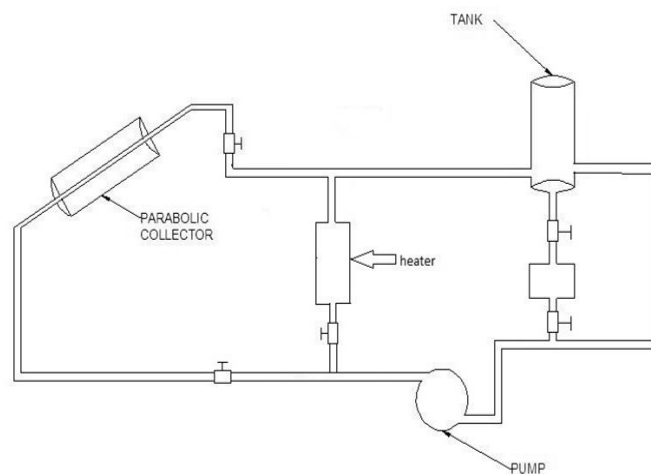


Figure 1. Experimental layout



Figure 2. PCM tank & fixed bed arrangement

Experiment setup is shown in the figure 1. The supply of oil to the remaining two tanks is closed with the help of check valve. The experimental set up consists of three thermal storage tanks, a heater and a circulating pump. The storage tank consists of both, the PCM and the HTF. Each cylindrical tank has a diameter of 256 mm and 300 mm length made of 6 mm thick MS plate. The storage tank and pipe lines are insulated with glass wool of thickness 0.10 m. A total quantity of 35 L of therminol-66 is filled in the storage tank and the circuit of pipe, and it is ensured that there is no leak in the oil flow path. An additional tank is also fabricated to house the heaters which will be used to provide the required heat energy. Valves are present at regular intervals to control the amount of HTF flow. This is used to reduce build-up of high pressure in the circuit, which could be dangerous [12]. The selection of PCM is depends on the required temperature range. The PCM chosen here is D-Mannitol, due to its stability and corresponding melting points of single tanks to use therminol-66 as HTF. Table 1 shows the properties of PCM and HTF. A gear pump maintains the HTF flow in the circuit, through the heater and storage tanks during charging and discharging process of PCM in which the heated oil i.e, HTF transfers heat to the PCM and vice-versa. The PCM is encapsulated in spherical balls of copper, aluminium and brass. The experimentation was done by altering different encapsulating material. The heater (supplementary source to the PTC) is switched on along with the pump. The temperature of HTF in all the tanks is noted after regular intervals of 10 minutes, this is called charging process of PCM. The heater is turned off, after attaining a set temperature. Keeping the flow rate on, the above process is repeated. This is the discharging process. Hence heat is subsequently stored and recovered in these processes. The above processes are conducted for all the three type of encapsulations material with D-Mannitol by using therminol-66 as HTF and the observations are noted down. PCM tank & fixed bed arrangement is shown in the figure 2.

Table 1. Properties of PCM & HTF.

PCM – D-Mannitol		HTF – Therminol 66	
Melting point (°C)	165	Density (kgm ⁻³)	1005
Latent heat (kJkg ⁻¹)	316.4	Specific heat (kJkg ⁻¹ °C ⁻¹)	1.495
Density (kg m ⁻³)	1490	Kinematic Viscosity (m ² s ⁻¹)	29.64x10 ⁻⁶
Specific heat (kJkg ⁻¹ °C ⁻¹)	2.5	Boiling Temperature (°C)	359

3. Results and Discussion

The first tank is fitted with heater and the second tank is filled with brass encapsulation. During charging heater is kept on and the heat transfer fluid temperature increase gradually as well as the temperature of PCM increases simultaneously. This process goes on during charging. In discharging mode the heater and circulating pump is turned off. Temperature of working fluid and PCM decreases slowly and the temperature of HTF is noted for every 10 minutes during charging and discharging process.

3.1. Brass encapsulation analysis in fixed bed and fluidized LHTS system

Figure 3 shows the charging mode and discharging mode of HTF in storage tank when brass encapsulated balls are present in the tank. A comparison is made between charging and discharging in fixed and fluidized bed thermal energy storage system. The rate HTF temperature rise is quicker in both cases during charging process [13]; the heat is supplied by the external aid to the HTF. The temperature drop in both cases at slower rate in discharging process of PCM. In discharge process, the PCM liberates the heat to the HTF at slower rate. In fixed bed LHTS, the time to attain the temperature of 165°C from its room temperature is 190 minutes during charging process and in discharging process the time to attain its room temperature from 170°C is 280 minutes. In fluidized bed LHTS, the time to attain the temperature of 167°C from its room temperature is 170 minutes during charging process and in discharging process the time to attain its room temperature from 170°C is 340 minutes.

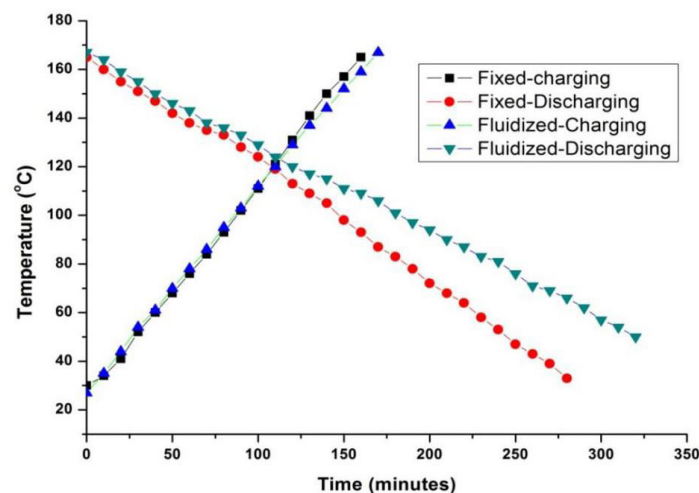


Figure 3. Brass encapsulation fixed vs. fluidized bed.

3.2. Copper encapsulation analysis in fixed bed and fluidized LHTS system

A comparison is made between charging and discharging in fixed and fluidized bed thermal energy storage system as shown in the figure 4. The D-mannitol PCM is encapsulated in copper balls are filled in the storage tank. Since copper has higher thermal conductivity property the heat absorbing and liberating of PCM was attained quickly in both cases (fixed and fluidized bed LHTS system). The time to attain the HTF temperature of 165°C from its room temperature is 160 minutes and during discharging the time to attain its room temperature from 165°C is 280 minutes in the fixed bed LHTS system. The time to attain HTF temperature of 170°C from its room temperature is 110 minutes and during discharging it's time to attain its room temperature from 170°C is 310 minutes in the fluidized bed LHTS system which shows the fluidized bed system has elevated energy density than fixed bed system [14].

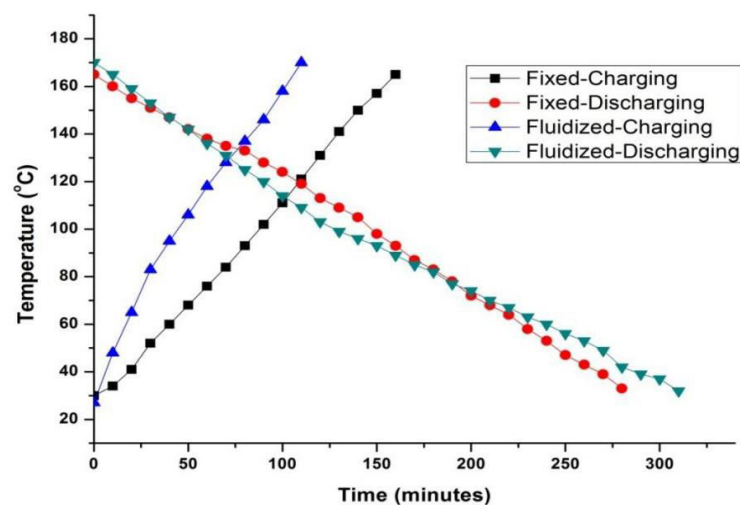


Figure 4. Copper encapsulation fixed vs. fluidized bed.

3.3. Aluminium encapsulation analysis in fixed bed and fluidized LHTS system

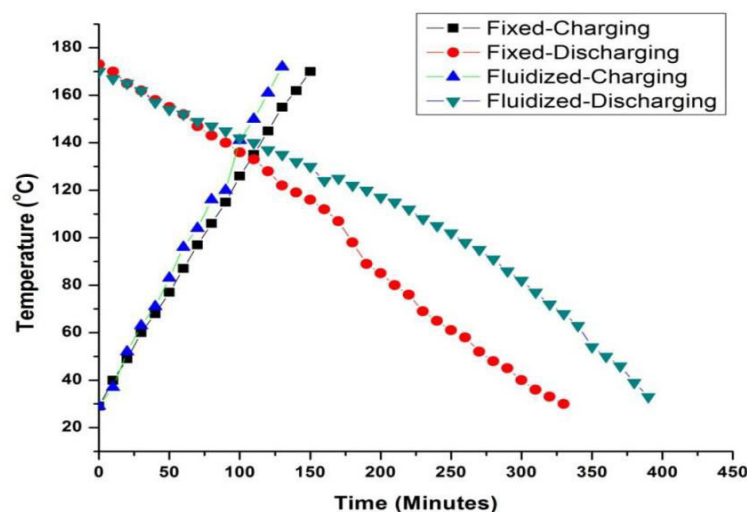


Figure 5. Aluminium encapsulation fixed vs. fluidized bed.

Figure 5 shows the charging mode and discharging mode of PCM inside aluminium encapsulations in single storage tanks. The PCM D-mannitol is encapsulated in aluminium spherical balls. In both fixed and fluidized bed LHTS system the temperature drop of HTF decreases gradually because of the higher latent heat storage capacity of D-Mannitol [15]. In fixed bed LHTS system, the time to attain HTF temperature of 173°C from its room temperature is 150 minutes in charging process and in discharging process the time to attain its room temperature from 173°C is 330 minutes. Fluidized bed LHTS system, the time to attain HTF temperature of 172°C from its room temperature is 130 minutes in charging process and in discharging process the time to attain its room temperature from 172°C is 390 minutes.

3.4. Heat transfer effect between fixed bed and fluidized bed LHTES system

Figure 6 shows the comparison between heat absorbing (charging) and heat liberating (discharging) process of brass encapsulation in fluidized bed and fixed bed thermal storage system. It shows that the mean value of heat energy transfer during charging in fluidized bed LHTS system has around 5.3 kW and during discharging around 3.3 kW. The rate of energy transfer in fixed bed LHTS system during charging and discharging is 3.31 kW and 1.332 kW respectively. The overall the efficiency of

brass encapsulation in fluidized bed LHTS is high than fixed bed LHTS system because of the more contact time between HTF and PCM in fluidized bed LHTS system.

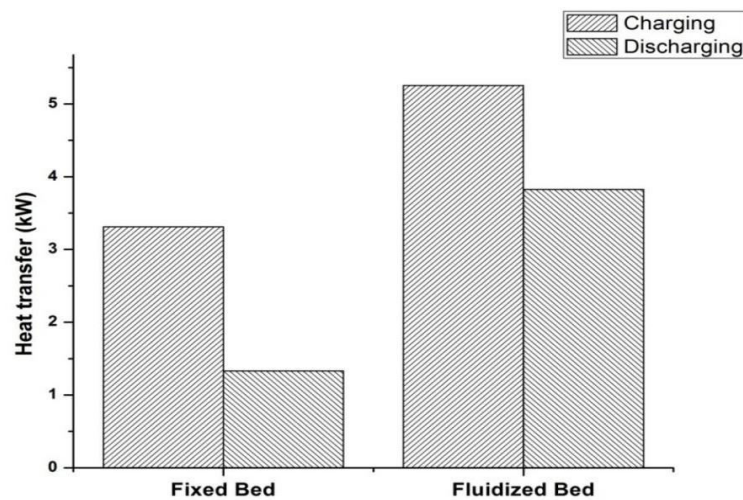


Figure 6. Heat transfer rate fixed vs. fluidized bed in brass encapsulation.

The energy exchange rate of aluminium encapsulation in fixed and fluidized bed thermal storage system is exposed the figure 7. During charging, the fluidized bed LHTS system is 2.8 kW higher than fixed bed LHTS system. During discharging process, the fixed bed LHTS 0.83 kW higher than fluidized bed LHTS system.

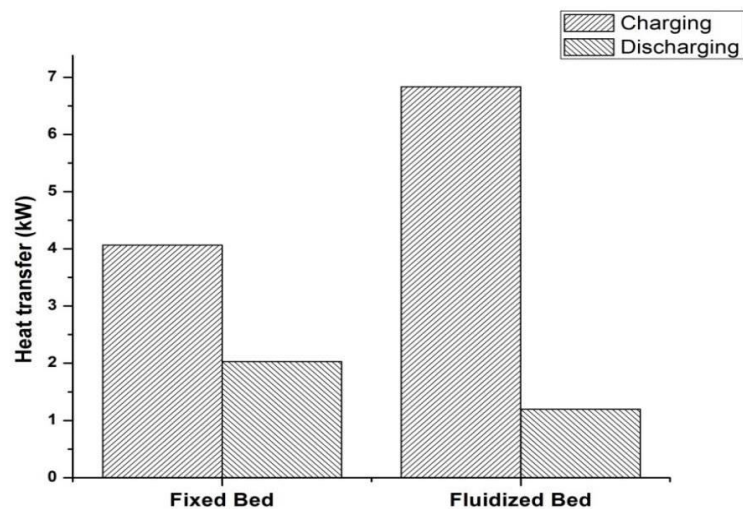


Figure 7. Heat transfer rate fixed vs. fluidized bed in aluminium encapsulation.

The mean energy transfer rate copper encapsulated PCM in fixed and fluidized bed LHTS is shown in the figure 8. The fixed bed LHTS is 3.65 kW and 2.73 kW during the process of heat absorption and liberation respectively. In fluidized bed LHTS system the heat energy transfer rate is about 5.98 kW during charging process and 2.81 kW in the case of discharging process of PCM. The results clearly show that the heat transfer rate in fluidized bed LHTS is always higher in magnitude when compared to fixed bed LHTS system. The end result of the experimentation has proved that the fluidized bed LHTS system have superior energy density than fixed bed, thus the overall effectiveness of the fluidized bed LHTS system is always high.

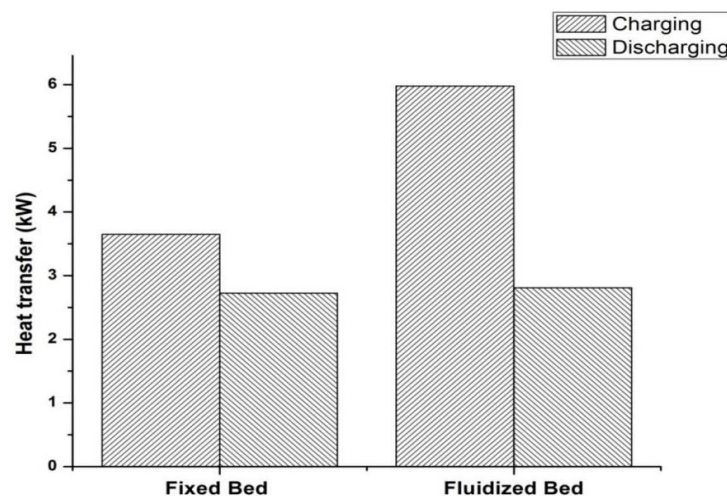


Figure 8. Heat transfer rate fixed vs. fluidized bed in copper encapsulation.

4. Conclusion

Thermal analysis of fluidized bed and fixed bed latent heat thermal storage system with the use of D-mannitol as PCM has been studied and analyzed. Comparison was made between the performance of fixed bed and fluidized bed with different encapsulation material namely copper, aluminium and brass. It is observed that from the economical point of view aluminium in fluidized bed LHTS System has highest efficiency than copper and brass. With the use of aluminium encapsulated PCM in fluidized bed LHTS system showed that the cost per kW of energy stored is around Rs. 1.8 which is 33.33 % and 22.22 % less than copper and brass respectively. The mean energy transfer rate of aluminium encapsulated PCM in both cases is about 12 % less than copper 10 % higher than brass encapsulated PCM. Thus the use of PCM in fluidized bed LHTS would give the better results of energy transfer than fixed bed LHTS system, but need to care about the HTF flow pressure drop in the storage tank.

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