# Performance Analysis of Sensible Heat Storage System

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**Abstract**: *The thermal energy can be collected whenever it is available and be used whenever needed with an effective application of Heat Energy Storage. Heat energy storage can be used with any heating system like electric heating, waste heat or solar system. Because of intermittent source of solar energy heat energy storage system is mostly recommended and influencing the sector. The experiment was performed at Kshitija stone crushers Pvt.Ltd., Wadgaon, Tal.-Murtizapur, Dist-Akola (M.S.), India. On thermal energy storage using Concrete block as the solid media sensible heat storage material because it is locally available at low cost and high heat storage capacity. Cooling water at high temperature flowing to radiator from Diesel engine of power generation unit is used as heat transfer fluid (HTF) in order to reuse waste heat energy. The concrete storage prototype is composed of concrete heat storage block with embedded pipe. The embedded pipe was used for transporting and distributing the heat transfer medium while sustaining the pressure. The experiment was carried in two stages i.e. charging and discharging, where energy stored while charging and retrieved while discharging. The concrete block stores the thermal energy as sensible heat. Thermal performance of Thermal Energy Storage (TES) such as charging and discharging time, radial thermal distribution, energy efficiency has been evaluated. For the charging and discharging experiment it was found that the increase or decrease in rate of energy storage and retrieval depends on the temperature and mass flow rates of HTF. The results shows that increasing the HTF flow rate increases the overall heat transfer coefficient, thereby enabling faster exchange of heat and reduces charging and discharging time. It can be conclude from this experiment that thermal energy storage can also play useful role in waste heat management system.*

**Keywords**: *Concrete, Heat Transfer Fluid (HTF), Sensible Heat, Thermal Energy Storage (TES), Waste energy management.*

## 1. INTRODUCTION

The TES can be defined as the temporary storage of thermal energy at high or low temperatures. The TES is not a new concept, an has been used for centuries. Energy storage can reduce the time or rate mismatch between energy supply and energy demand, and it plays an important role in energy conservation. Energy storage improves performance of energy systems by smoothing supply and increasing reliability. For example, storage would improve the performance of a power generating plant by load leveling.

Therefore, the design and development of efficient and economical thermal energy storage (TES) systems is of vital importance [1]. Basically, there are three methods of storing thermal energy: sensible heat storage, Therefore, the design and development of efficient and economical thermal energy storage (TES) systems is of vital importance [1]. Basically, there are three methods of storing thermal energy: sensible heat storage, latent heat storage and thermo-chemical storage. A sensible heat storage unit stores thermal energy by changing the temperature of a storage medium, either a solid or a liquid [2].

The ability of a given material to store sensible heat depends on the value of its energy density, which is the heat capacity per unit volume, and its conductivity. The economics of this mode of heat storage demands sensible heat storage material which is inexpensive.

Solid materials such as cast steel, stone, rock, sand, concrete and ceramic have usually been selected as sensible heat storage media depending on the required temperature range and specific application. The TES system using concrete as the sensible heat storage media is usually implemented by embedding the pipes heat exchanger in concrete to transfer thermal energy to or from the heat transfer fluid, air, and synthetic oil. The advantages of using a concrete system include the low cost of the thermal storage media, the high heat transfer rates into and out of concrete, the ease of handling of the material, the availability of the material, and uncomplicated processing.

## 2. DETAILS EXPERIMENTAL

### 2.1. Construction of Experimental Setup

The experimental setup composed of pipes embedded in a concrete block as shown in Fig.1. The embedded pipes are used for transporting and distributing the heat transfer medium while sustaining the pressure. The concrete stores the thermal energy as sensible heat. A special interface material grease and graphite powder mixture applied to reduce the friction between the concrete and the pipes due to the mismatch of thermal expansion. The heat exchanger is composed of 8 m long pipe of copper with the inner diameter of 0.006 m and wall thickness of 0.001 m. It is distributed in a helical arrangement with an axial pitch of 0.082 m. The storage cylinder has the dimensions of 0.28 m in diameter and 0.78 m in height. In order to record data for energy balance, the piping system was equipped with nine thermocouples. To ensure constant mass flow rate of HTF throughout system flow control valve installed on inlet of HTF pipe. The storage bed was then covered with heat insulation on all sides.

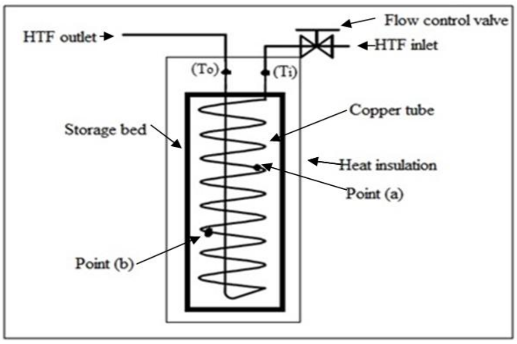


**Fig.1 Schematic of SHS**

### 2.2. Experiment Preparation and Procedure

The experimental investigation was carried out at the Kshitija stone Crushers Pvt. Ltd., At Wadgaon, Tal.-Murtizapur, Dist-Akola (M.S.), India. On 6.160 Lit. Diesel engine coupled to generator of 68 kVA capacity and cooling water from engine flowing to the radiator is taken as heat energy source for SHS setup. SHS setup connected to cooling water line. Line pressure was 4 bar and maximum temperature was 140 $^{o}$C. Additional volume increased by connecting SHS setup was compensated by additional water top up in engine cooling system. Also, working temperature of engine was monitored while conducting experiment as the designed cooling water line disturbed by connecting SHS setup as shown in Fig.2

**Fig.2 Photographic View of actual setup.**

As a startup procedure, prior to the experimental processes, most of the water contained in the concrete was expelled by heating the concrete storage block from ambient temperature to 180 °C. During the process the water evaporates and there was a buildup of vapor pressure within the concrete block which needed to be carefully monitored to avoid damage to the concrete. The mass flow rate of HTF taken 0.010, 0.012, 0.014 kg/s according to literature [8] .

The subsequent operating conditions of the concrete SHS were:

- Heat transfer fluid (water)
- Maximum internal pressure (4 bar)
- Maximum temperature: up to 140 °C
- Test temperature range between 100-140 °C
- Mass flow rate: 0.010, 0.012 and 0.014 kg/s

### 2.3 Performance Parameters

The performance parameters are charging time, energy stored, discharging time, energy recovered and exergy efficiency. They are defined as follows;

#### 2.3.1Charging time

It is the time taken for the storage bed‘s volume average temperature to reach a specified rise in temperature $\Delta T$.

#### 2.3.2 Energy stored

The amount of thermal energy stored in the different storage materials at their respective charging times is calculated using Eq. (1)

$$Q = V\rho_s \, C_{ps}( T_{(tc).} - T_{(ini).}) \qquad (1)$$

#### 2.3.3 Discharging time

The time taken by storage bed to attain a volume average temperature of Tinlet is the complete discharging time of storage bed. But after a certain time, the decrease in storage bed temperature is not significant especially when its temperature approaches to Tinlet. Thus, effective discharging time of storage bed is taken as the time till the temperature drop is significant, provided the energy recovered from the storage bed is within the design limit.

#### *2.3.4 Energy recovered*

The amount of thermal energy recovered from storage bed of different materials at their respective discharging time is calculated using Eq. (2)

$$Q = V\rho_s\, C_{ps}(\, T_{(ch)} - T_{\,(tc)}) \qquad (2)$$

where, *Tch* is the volume average temperature of the storage bed at the end of charging cycle.

#### *2.3.5 Exergy efficiency*

Exergy efficiency is the ratio of energy recovered from the storage bed during discharging cycle to the total energy input to storage bed which is given by the Eq. (3). The total energy input is the sum of energy supplied to heat the storage bed and energy stored in the bed during charging.

$$\eta = \frac{T(ch).-T\,(tc)}{T(tc).-T\,(ini)} \qquad (3)$$

## 3. RESULTS AND DISCUSSION

### *3.1. Charging Time*

Charging of storage bed is initiated by supplying HTF through the charging tube at high temperature, $T_i$. The temperature of storage bed varies with time and space. The temperature of storage bed is averaged over the entire bed volume thus it is the function of time only. Variation of volume average bed temperature with time is shown in Fig. 3 for concrete and beds. It is seen from Fig. 3 that initially, the rise in the volume average temperature of storage beds is rapid and decreases with time. This is because of higher driving potential available for conduction during initial period of charging cycle and this driving potential reduces with time as the storage bed gains the heat of HTF. The charging rate of concrete bed is slow bed due to low thermal conductivity of concrete.

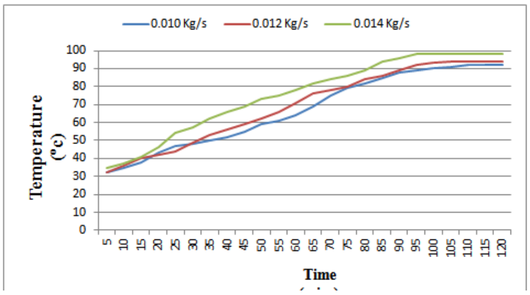


**Fig. 3.1 Average temperature of SHS block in charging experiment at given interval of time**

### *3.2. Energy Stored*

The thermal energy storage rates for the concrete bed are shown in Fig. 3 the amount of thermal energy stored in the storage materials at their respective charging times is calculated using Equation (4.6). The flow rate of 0.014 kg/s resulted in the fastest heat transfer from the pipe to the concrete, followed by the flow rate of 0.012 kg/s with 0.010 kg/s the lowest heat transfer value. The energy input at the various flow rates were 0.014 kg/s, 9.401 MJ, 0.010 kg/s, 8.557 MJ and 0.012 kg/s,8.825 MJ.

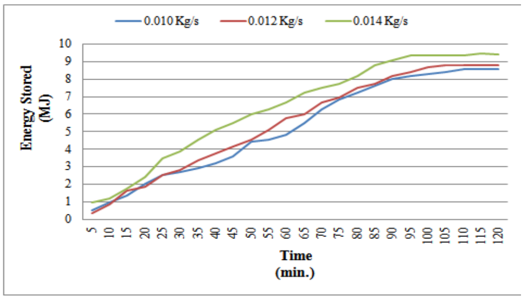


**Fig. 3.2 Energy stored during charging process at regular interval of time**

### *3.3 Radial Thermal Distribution on Charging Time*

The radial thermal distribution for thermal energy storage over charging time is shown in Fig. 5.1 and Fig. 5.2. Increasing the HTF flow rate increases the overall heat transfer coefficient enabling faster exchange of heat which reduces the charging time. At higher HTF flow rates the time required to achieve a certain temperature decreased. At the HTF flow rate of 0.014 kg/s the temperature increase over time was greatest, followed by the flow rate of 0.012 kg/s with the flow rate of 0.010 kg/s being the slowest. Fig.5.1 and Fig. 5.2 show the comparisons of thermal distribution of temperature by thermal radiation for the three flow rates through the 2 cm, and 3 cm from HTF pipe respectively.

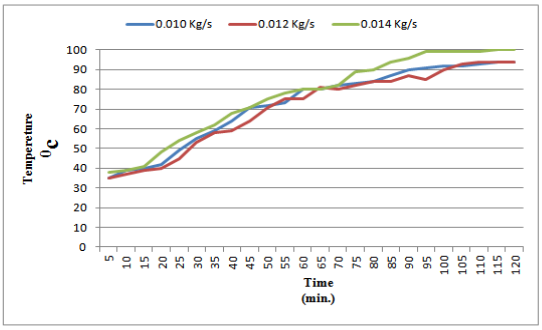


**Fig. 3.3 Radial distribution of temperature at 2 cm from HTF pipe**

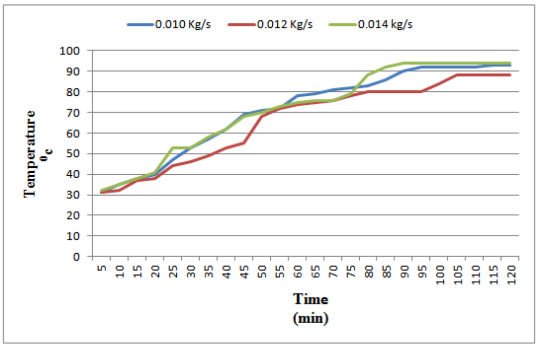


**Fig. 3.4 Radial distribution of temperature at 3 cm from HTF pipe**

### *3.4 Discharging Time*

Minimum average temperature attained by SHS bed during discharging process at respective interval of time. Discharging is initiated by supplying HTF through SHS at lower temperature possible. The temperature of storage bed varies with time and space. The temperature of storage bed is averaged over the entire bed volume thus it is the function of time only. Variation of volume average bed temperature with time is shown in Fig.6 for concrete and beds. Decrease in temperature is higher at 0.014 kg/s**.**

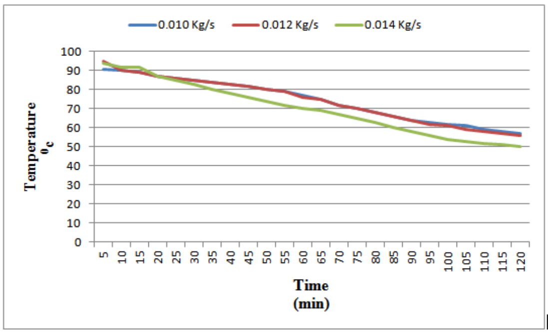


**Fig.3.5 Energy recovered during discharging process at 0.010, 0.012 and 0.014 kg/s.**

### *3.5 Energy Recovered*

The thermal energy recovery rates of the storage bed are shown in Fig.7 the amount of thermal energy recovered was calculated using Equation (2). The calculations showed that at the flow rate of 0.014 kg/s the heat transfer from the concrete into the pipe was faster than at the flow rates of 0.012 and 0.010 kg/s. The energy recovered at each flow rate was, at 0.014 kg/s, 6.418 MJ, at 0.012 kg/s, 4.947 MJ and at 0.010 kg/s, 4.662 MJ.

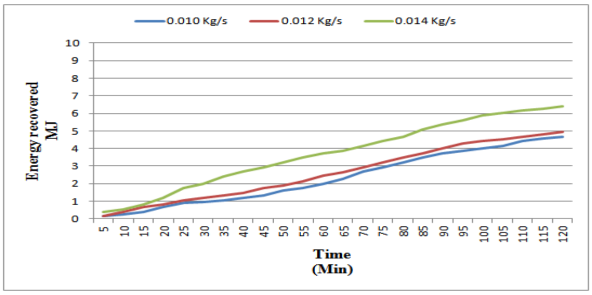


**Fig. 3.6 Energy recovered during discharging process at 0.010, 0.012 and 0.014 kg/s**

### *3.6 Radial Thermal Distribution on Discharging Time*

Heat discharge of the charged storage bed was initiated bypassing HTF at a lower temperature (Ti); The HTF receives the heat from the charged storage bed which decreases the storage bed temperature and also causes a rise in the HTF temperature along the bed. The radiant thermal distribution for thermal energy storage on discharging time is shown in Fig.8.1 and Fig. 8.2 which shows comparison of the thermal distribution of temperature of thermal radiation for the 2cm and 3 cm HTF pipes. It can be seen that the decrease in discharging time of the storage bed with HTF at the flow rate of 0.014 kg/s was faster than that of 0.012 kg/s with 0.009 kg/s being the lowest value.

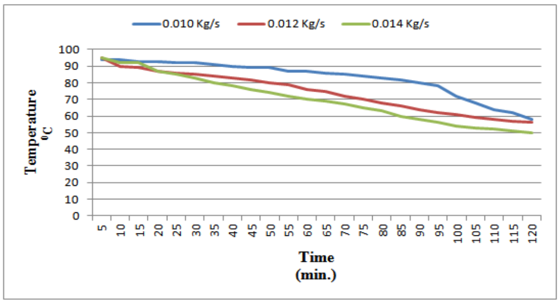


**Fig. 3.7 Radial thermal distribution at 2 cm from HTF pipe during discharging.**

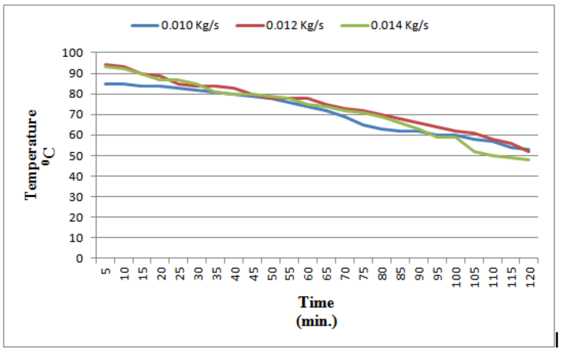


**Fig. 3.8 Radial distribution of temperature at 3 cm from HTF pipe during discharging.**

### *3.8 Energy Efficiency*

The energy was degraded in the process of storage since it was extracted at a temperature lower than that at which it was previously stored. The energy efficiency of the storage bed was evaluated using Equation 3. Fig.9 shows the energy efficiency of the thermal energy storage. For 120 minutes of operation, the energy efficiency was 56.05% at the flow rate of 0.012 kg/s while the flow rate of 0.014 gave 68.26% energy efficiency. The flow rate of 0.010 kg/s gave 54.48% for 120 minutes operational time.

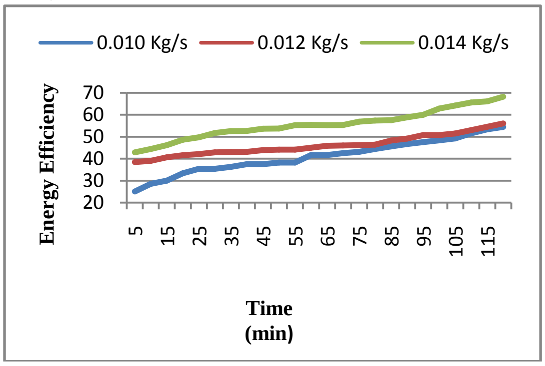


**Fig. 3.9 Energy Efficiency**

## 4. CONCLUSION

In this research, the performance analysis of thermal energy storage is presented. For the charging/discharging experiment, it was found that the increase or decrease in storage temperature depends on the HTF temperature, flow rates, and initial temperature.

The results showed that increasing the HTF flow rate increases the overall heat transfer coefficient, thereby enabling faster exchange of heat and reduces charging time.

In the charging period, the heat transfer from the flow pipes to the concrete storage medium were 8.825 MJ for flow rate of 0.012 kg/s, the fastest heat transfer rate, 9.401 MJ for the flow rate of 0.014 and 8.557 MJ for the 0.010 kg/s flow rate. The energy recovered over the discharging period was6.418 MJ for flow rate of 0.014 kg/s, the fastest heat transfer rate, 4.662 MJ for the flow rate of 0.010 and 4.941 MJ for the 0.012 kg/s flow rate. The energy efficiency at the flow rate of 0.012 kg/s dramatically increased in the first 45 minutes after which it increased gradually. For the flow rate of 0.014 kg/s, the energy efficiency increased sharply and at the flow rate of 0.010 kg/s it increased slightly and then seemed to stabilized. Over 120 minutes of operation, the energy efficiency was 56.05% at the flow rate of 0.012 kg/s while the flow rate of 0.014 gave 68.26% energy efficiency. Meanwhile the flow rate of 0.010 kg/s gave 54.48 % for 120 minutes operational time. The results from this research can be a guideline for thermal storage system design.

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