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EE11703811-Experimental Investigation of Prototype of Sensible Type Rock Bed Thermal Energy Storage

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Abstract

Thermal Energy Storage (TES) systems are used to store the thermal energy to make it available for later use. It helps to lessen environmental impacts and makes the availability of more efficient and clean energy systems. Nowadays, TES using packed rock beds are seeking attention for storing the thermal energy available from sun. In this paper we have discussed about the sensible rock bed TES. The prototype for the samewas fabricated and experiment performed on it with the air flow from centrifugal blower having air velocity as 0.7 m/s and air inlet temperature taken as 70°C. The experiments are conducted for both the charging and discharging of the TES.

Keywords: *Thermal Energy Storage (TES), Sensible Energy, Packed Bed, Rock Bed TES.*

1. Introduction

At present, there is huge increase in the energy demands of the society. The fossil fuels on which most of the national energy systems are dependent are decreasing day-by-day. Also it is predicted that there will be huge increase in the cost of fossil fuels in coming years. Thermal Energy Storage (TES) is an important technology which can contribute to increase the energy consumption efficiency and will also help in decreasing the environmental problems.

Temporary storage of thermal energy for later utilization in the form of hot or substances is known as Thermal Energy Storage (TES). This significant technology involves use of renewable energies as well as other energy resources. It also balances between supply and demand of the energy.

TES can be stored in three forms i.e. sensible, latent and thermochemical. Latent heat is stored by changing the phase of the material without change in its temperature. The latent energy stored is given by

$$E=m\lambda \text{............ Eqn. (1)}$$

Here, E is the latent energy stored, m is the mass of the material and λ is latent heat of fusion if the material. Sensible energy is stored by causing the increase or decrease in its temperature. The stored sensible heat energy is given by

$$E=m\,C_p(T_2\text{-}T_1) \text{.......... Eqn. (2)}$$

Here, E is the sensible energy stored, m is the mass of the substance, C_p is the specific heat capacity and (T_2-T_1) is the temperature difference. Effectiveness of the sensible TES is dependent on the specific heat capacity of the substance. Also if its volume is playing an important part it is dependent on the density of the material. Sensible energy can use rocks, ground, or water for storage of energy by increasing the storage medium temperature.

There are several advantages of using sensible packed bed rock TES. Though water is easily available and having higher heat capacity and density as that of rock but to store temperature beyond 100°C we need to increase the pressure of the system which is very costly so in most of the cases rocks are used to store the energy. Also rocks are non-toxic and inflammable. They are easily available and inexpensive. Rocks can act as both heat transfer surface as well as storage media. Thus, we have selected sensible type packed bed rock TES for the analysis. Fig. 1 show the packed bed rock TES.

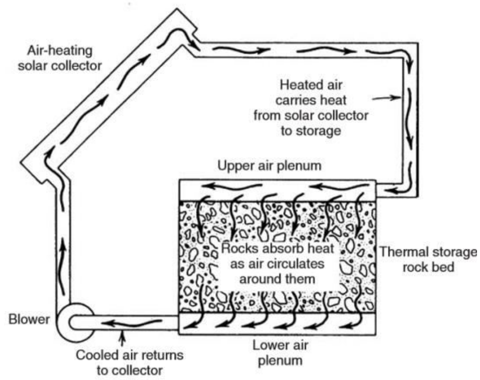

Fig.1 Sensible Packed bed Rock Thermal Energy System (Ibrahim Dincer, Marc A. Rosen)

Y. Jemmal, N.Zari, M. Maaroufi *et al* (2016) performed the Thermophysical and Chemical Analysis of gneiss rock as low cost candidate for thermal energy storage in concentrated solar power plants. In this study, geochemical composition and structural analysis of samples was studied with help of X-Ray fluorescence. Thermal density was measure with the help of Pycnometer and thermal diffusivity and thermal conductivity measured with the help of laser flash apparatus. The results obtained from analysis were:

1. Gneiss rocks have promising properties in terms of required characteristics of SHS.

2. DSC analysis indicates that it has high thermal capacity.
3. Up to 550°C it has good thermal stability.
4. It has been seen from X-Ray diffraction analysis that the rocks are totally crystalline in nature. Thus it has high heat carrying capacity. This analysis gives us the brief about the capacity of rock to store thermal energy.

Denis Okello, Ole J. Nydal, Eldad J.K. Banda *et al* (2014) performed an experiment to investigate thermal de-stratification in rock bed TES for high temperature applications. In this experiment, comparison between two systems is done. The first TES is having 40cm as its internal diameter and 40cm as its effective length while the second TES is having internal diameter as its 30cm and the 90cm as its effective length. Charging of both the TES was done by blowing hot air from top to bottom to a known temperature profiles after that connection to input energy was removed. Sealing was done for both the inlet and outlet ports of the tank.The energy stored in the both beds then calculated. By plotting a graph of the average energy stored as a function of time duration of stay they obtained that the rate of heat loss is a function of time. The results obtained as below:
1. Thermal degradation in long and highly stratified bed: the bed was charged to capacity ratio of 0.39. Higher temperatures at the top degrade faster in highly stratified tanks. 3.8kJ/h was the average heat loss.
2. Thermal degradation in short and highly stratified tank: Charging of bed was done to capacity ratio of 0.77. The heat was lost with the average rate of 0.3 MJ/h.
3. For prevention of thermal degradation because of which there can be significant temperature reduction, we must make an attempt for avoiding high temperature gradients in the bed.

Simone A. Zavattoni, Maurizio C. Barbatto, Andrea Pedretti, Giw Zanganeh*et al* (2015) study conducts an evaluation of thermal stratification of an air based thermocline TES with low cost filler material. Total 30 consecutive cycles were analyzed in this study each cycle was characterized by 12 hours of charging time and 12 hours of discharging time. The air mass flow rate was 89.6 kg/s through the TES unit. However, especially for cycles at the start, 12 hours discharge phase gives too low temperature for the heat transfer fluid outlet.The first discharge phase was the only discharge phase which was about 10 hours and sensibly lower than 12 hours. It is observed that as the cycles proceed there was a reduction in a difference between the average stratification efficiency of charging and discharging. It almost disappears when the 19th cycle takes place as there is merging of two thermocline zones with each other and forms a single zone.

Denis Okello, Ole J. Nydal, Karidewa Nyeinga, Eldad J.K. Banda*et al* (2016) conducts the experiment for investigating heat extraction from a rock bed heat storage system for high temperature applications. In this study two vertical co-axial cylinders were used to construct the rock bed TES. Stainless steel material was used for the construction of the same. 30cm and 40cm were the inner and outer cylinder diameters respectively. For the minimization of the radiation heat loss, three thin and reflecting steel foils were placed parallel to each other. Fiberglass material was used to provide additional insulation for the bed. For performance of the discharging test, the air was blown at the bottom of the heated rock bed TES by varying the airflow conditions. The results shown that for constant airflow conditions, the rate of extraction was at the higher at the beginning but it then reduces with the time. The rate of discharging was very low without using blower.

2. Experimental Set Up

2.1 Experimental set up

The experimental set up consists of three main elements blower, heater and TES tank. The Fig.2 shows the general layout of the experimental set up.

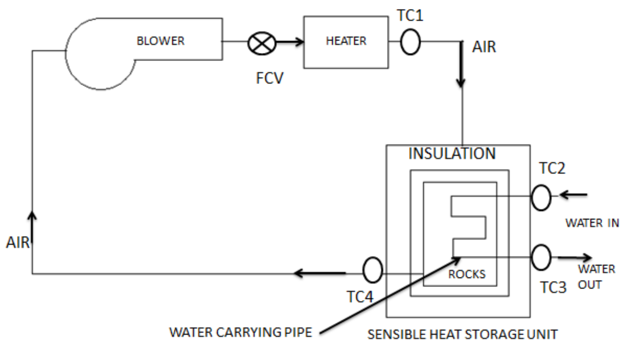

Fig.2 Layout of experimental set up

The centrifugal blower of 1 HP and 3000 RPM is used for the experiment. The RPM of the blower varied according to required air flow rate. For heating of incoming air from the blower plate type heater wounded around the pipe having capacity of 1 kW is used. The total length of the heater is 300 mm. Material used for the storage are the rock pebbles with the specific capacity ranging between (0.84-0.94) kJ/KgK and density of the pebbles is 1600 kg/m^3. In the fig.3 are shown the components of the set up and they are:

Fig.3 Experimental Set up 1. Centrifugal blower: 1HP, 3000RPM 2. U tube manometer for pressure measurement 3. Plate type air heater of 1kW capacity

4. Air inlet pipe 5. TES Tank 6. Air outlet pipe 7. Temperature indicator

The TES tank consists of two concentric cylinders outer one having 500 mm diameter and inner one having 450 mm diameter. The effective height of the tank is 500mm. material used for fabrication of the tank is mild steel. Tank cover is in the conical shape having one inlet and one outlet port. Height of the cover is 150mm and diameter as same as that of the tank. Both tank and cover are insulated with rock wool as an insulating material. Copper coil tube with the height of 300mm, coil diameter as 150mm and wire diameter i.e. diameter of the tube as 20mm is used for the water flow. Water is used for the extraction of heat from the tank. The inlet and outlet pipe diameter is taken as 40mm.

For measurement of the air velocity anemometer is used. K-type thermocouples are used for temperature measurement in the whole system. Total 11 thermocouples were used. Thermocouples are then connected to temperature indicator for reading the values. U tube manometer is used to measure the temperature at inlet and outlet of the tank. water flow rate is measured by drawing an unknown volume of water in the container for 1 minute and then measuring the volume of the water in the container.

2.2 Arrangement of thermocouples in the system

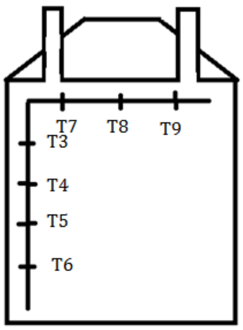

Fig.4 Arrangement of thermocouples in the TES Tank

Fig.4 shows the arrangement of thermocouples inside the TES tank. In the whole set up the thermocouples are used as follows at various locations for measuring the temperatures at various locations:

T1: used to measure air inlet temperature to heater from the blower.

T2: used to measure heated air temperature inlet to the TES tank.

T3-T9: used to measure temperature at various locations in the tank diagonally and axially.

T10: water inlet temperature to copper coil tube.

T11: water outlet temperature from the copper coil tube outlet.

3. Experimental Procedure

The experimental procedure is followed as below:

1) Before turning on the blower and air supply inside the system. Heater is turned on and allowed to heat up to certain temperature.
2) Blower is turned on and the airflow with velocity of 0.7m/s is allowed inside the system and the tank for 2 hours. 5 cycles of this charging are performed and average of temperature at each point is taken.
3) Heat in the air is taken away by the rock pebbles inside the TES tank and air is escaped through the outlet. Temperature after equal intervals of time is recorded at each location.
4) After following this procedure for certain time the air supply is turned off. And tank is allowed stay for a certain period of time. Temperatures at the end of the cycle will give us the heat stored in the tank.
5) Water supply is allowed in the system with the flow rate of 2LPM for half an hour. Temperature of the water after equal intervals is measured. And then water supply is turned off.
6) After turning off the water supply the temperature of the tank is again measured which will give us the remaining heat in the tank.

4. Results

4.1 Heat addition cycle

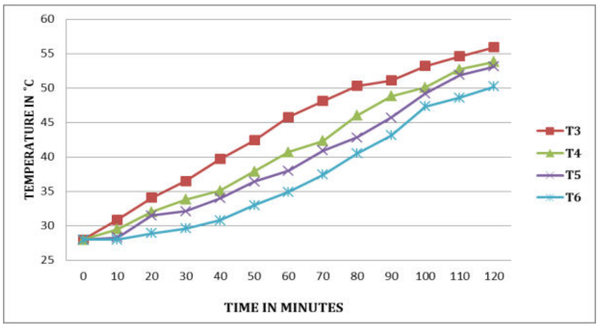

Fig.5 Temperature variation in the TES tank in axial direction

It is seen from the fig.5 that as the time precedes the temperature in the bed increases. The temperature reaches average of 55°C in hours of air supply at 70°C inlet temperature. The temperature rise is higher at the top of the bed and is lower at the bottom of the bed. This happens because rock pebbles are porous media. Also from fig.6 we can see the temperature variations in the diagonal directions. It varies higher at the inlet side of the bed as compared to that of outlet side of the bed. Heat stored in the bed id given by

$$Q=m\,C_p(T_2-T_1)$$

Here, T_1 is the average temperature at the start of the charging cycle. And T_2 is the average temperature at the end of the charging cycle. Thus the total heat stored in the bed is average 2.6kJ. the bed is then allowed to stay for 30 minutes the bed temperature in that period drops down to 53.1°C.

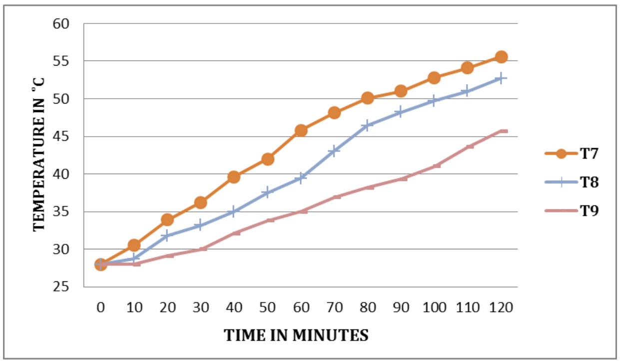

Fig.6 Temperature variation in the TES tank in the diagonal direction

4.1 Heat extraction cycle

Water is allowed to flow through copper tube coil in the bed with initial temperature of 25°C with the flow rate of 2LPM. From fig.7 it is seen that there is not much rise in temperature in the water. The water temperature increases up to 26.2°C. the bed temperature decreases with increasing time thus availability of heat goes on decreasing as the heat is been extracted from the bed. After 30 minutes the temperature reaches to 33°C which is almost near to the initial bed temperature which means that there will be no further extraction of heat from the bed.

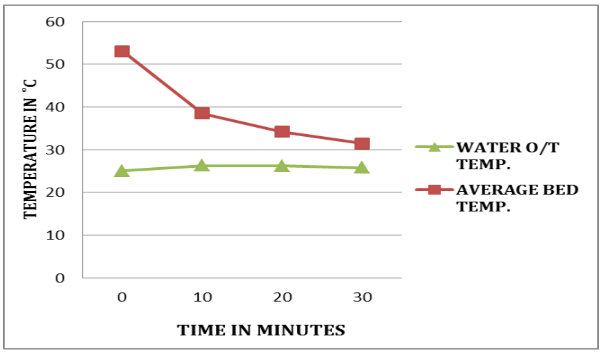

Fig.7 Temperature change in heat extraction cycle with time

Conclusion

This paper examines the charging and heat extraction from the TES tank at the particular temperature. The conclusion drawn from the above experiment is given below.

1) For storing large amount of the heat in the tank inlet air temperature must be increased.
2) The time for which heat is supplied must be increased in order to increase the storage of heat.
3) For the heat extraction cycle, water flow rate must be reduced in order to get higher outlet temperature.
4) Change in inlet and outlet directions will also give the higher outlet temperature as there is extra heat stored at the top of the bed.

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