Experimental characterization of a Sensible Heat Thermal Energy Storage using pebbles for charging

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Abstract. In today's world, where reduction in the carbon footprints is emphasised, people are looking for alternative source of energies for power production and heat treatment of metals and alloys. One such alternative source is solar energy but due to intermittent nature a thermal energy storage (TES) is required in order to deal with heat flux that varies throughout the day so as to supply a constant power. In the present study, the characterization of the sensible heat thermal energy storage (SHTES) packed with sensible heat storage material are considered. The size of pebbles varies between 20-25mm with porosity of the SHTES as 40%. The flow rate is 40 LPM and TES was charged for 8 hours. It has been noticed that when the temperature of the inlet air is around 180°C, the temperature of the top surface of the TES is around 70°C which states that for TES high thermal conductivity materials are required so that charging and discharging can take place at faster rate. The azimuthal and axial variation of temperature is also shown and it is concluded that even after low thermal conductivity of the material azimuthal variation can be neglected for the sake of modeling the TES.

1. Introduction
To overcome the problems caused by the increase in the greenhouse gases, demand and supply gap, dwindling of fossil fuel resources, some alternate measures need to be taken one of which is to increase the use of sustainable energy. As of February 2020, India is using 86321 MW of renewable energy from various renewable sources like solar, wind, biomass gasifier, biomass power, urban & industrial waste power which is 23.4% of the total installed capacity [1]. A lot of focus is now shifting towards the use of renewable sources for energy generation mainly on solar energy because India have huge potential as it has 1700-1900 kWh per kilowatt peak for more than 300 clear sky days in a year. A target of 100,000 MW electricity production is set by Government of India till 2022 [2]. There are several hitches in implementing a solar power plant due to the inherent problems in harnessing the solar energy like intermittency, low flux density, and dependency on location.

There are several methods of harnessing the solar energy like line focussing (e.g. parabolic trough) and point focusing (e.g. parabolic dish and heliostats field based central solar tower system). In point focussing technique the heliostats focus the solar radiation on to the front surface of the absorbers which in turn heat the absorbers and the fluid passing through them.

Due to non-availability of solar radiation during night and intermittency there arises a need for the installation of thermal energy storage which can store heat during the day time and can be used during
the non-availability of the solar radiation. This also helps in smooth operation of the power plant and remove the necessity of hybridizing a solar power plant with thermal power plants. There are various types of thermal energy storage (TES) like sensible, latent and chemical thermal energy storage [3,4,5,6]. TES technologies developed for the practical applications practically exists in two main forms i.e. latent heat thermal energy storage (LHTES) and sensible heat thermal energy storage (SHTES). When it comes to store large amount of thermal energy, LHTES is given preference due to high compact energy density and potential energy supply [7,8]. There are some disadvantages associated with most LHTES materials like maximum temperature at which LHTES materials can be used is around 600°C, low thermal conductivities which results in increasing the charging and discharging time of TES and therefore some heat transfer enhancement is required which increases the cost. Apart from having low thermal conductivities, there are other problems like phase isolation, supercooling and severe degradation with thermal cycling, and thus they cannot be used effectively for long-term TES applications [9,10] and because of the mentioned problems SHTES outweigh LHTES as most of the materials are easily available and at low price point than the LHTES materials. The present experimental study is to see the integration of SHTES with concentrated solar power using naturally available materials and to see the temperature distribution in the SHTES.

2. Experimental Set up
The designed experimental set up is used to store the thermal energy of the air in the sensible heat storage materials. The rationale for choosing air as the heat transfer fluid are its free availability, non-toxic, can be heated to very high temperature. This heat energy can be used for various applications ranging from water heating, steam generation and melting and heat treatment of metals and their alloys. The schematic of the experimental set up is shown in ‘Figure 1’. The detailed working of the set-up is explained in the next sub-section.

![Figure 1. Schematic of the experimental set-up.](image)

2.1 Working of the experimental set up
The various components of the experimental set up is shown in Figure 2. The heating of the ambient air sucked through the inlet pipe (A) is carried out by resistance heating method, in which nichrome wire of 0.9 mm diameter wrapped over the pipe is used and placed inside the casing (B). As wrapping of the nichrome wire over the pipe result in short-circuiting therefore mica tape is wrapped over the pipe and then nichrome wire is wrapped over it which is further covered by the mica tape in order to protect the short circuiting. The power to the nichrome wire is controlled by Variac (C). Once the air picks up the heat and reaches the thermal energy storage (D) it loses its thermal energy to the pebbles present inside the SHTES and relatively cold air leaves the SHTES. This relatively cold air then passes through the bucket (F) filled with water to further cool it down which then enter the rotameter (G) and exit through the blower (H). In order to characterize the SHTES 12 k-type thermocouples were placed
at various axial, radial and azimuthal positions. Apart from these four thermocouples were placed at
the inlet and outlet of the SHTES in order to obtain the heat released by the heated air in the TES.

![Experimental set up of SHTES](image)

**Figure 2.** Experimental set up of SHTES. Components of set up is marked as .

A: Inlet pipe, B: Casing for nichrome wire, C: Variac, D: TES, E: Data logger, F: Bucket G: Rotameter, H: Blower.

3. **Characterization of thermal energy storage**

In order to characterize the SHTES the axial and azimuthal temperature distributions are recorded. The input power supply was ~ 250W at a mass flow rate of $7.5 \times 10^{-4}$ kg/s. The data are recorded for every 10 minutes. It can be seen from Figure 3(a) that at the time of starting the experiment the temperature of the pebbles inside the TES is 35°C. As the heated air comes in contact with the top surface of the pebbles it results in increasing the temperature of the pebbles and its temperature reaches to 70°C in 8 hours. It is noted that as the axial distance is increasing from 127mm to 254mm there is a drop of 8°C in the temperature and at a distance of 381mm there is a slight rise of 10°C in the temperature of the pebbles from the initial condition this is because as the heated air comes in contact with the top surface of the pebbles it is losing its heat to the pebbles present inside SHTES and even after performing the experiment for 8 hours the temperature of SHTES is rising at a very slow rate therefore, a material of high thermal conductivity is required which can be charged within 8 hours or less as the solar radiation available for the charging of the TES is available for around 8 hours. Figure 3(b) shows the azimuthal variation of temperature at theta $0^\circ$ and $180^\circ$ at a radial distance of 102mm from the centre of the TES and axial distance of 381mm from the top plate of the TES. It can be seen from Figure 3(b) that there is negligible temperature variation in azimuthal direction because of uniform distribution of the porosity in SHTES and therefore while doing the numerical simulations only axial and radial distribution of temperature needs to be considered. Figure 3(c) shows the temperature variation in the temperature of the inlet air with time. Initially, the temperature of the air rises rapidly as the power to the experimental set up is given and after 160 minutes the pace in temperature rise reduces and it achieves a quasi-steady state. Figure 3(d) shows the power released by the air in the thermal energy storage which can be calculated from [11]. It can be seen that out of ~ 250W of input power only about 94 W of power has been released by the air in the TES this suggest that a better insulation is required so that heat loss to the ambient can be reduced and more power can be delivered to the TES.
Figure 3. (a) Temperature profile of the pebbles inside the sensible heat thermal energy storage at $r = 0$, (b) azimuthal variation of temperature at $r = 102$ mm and $z = 381$ mm, (c) temperature variation of the air at the inlet of the TES, (d) power released by the air to the pebbles.

4. Conclusion
In this study, the characterization of the thermal energy storage was carried out which is filled with pebbles with diameter between 20-25mm. The characterization of SHTES was carried out in which axial and azimuthal variation of temperature is considered and it is noticed that even for low thermal conductivity materials like pebbles considered in the present study the azimuthal variation in the temperature inside the SHTES is negligible but there is a variation of 25°C in the axial direction. This shows that while modeling the TES theta (θ) variation in the TES can be neglected and 2-D study will help in saving a considerable time.

5. Reference
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