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Heat Storing Sand Battery

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Abstract *This project aims to investigate whether India's desert sand can be utilized as a medium to store energy in a high-temperature Sensible Thermal Energy Storage System. Sand can provide a unique and eco-friendly alternative to current storage mediums, while having minimalized cost and maintenance. Oil will be heated and pumped to flow through pipes leading to the Thermal Energy Storage Element, where the sand will be thermally charged. After the desired temperature in the sand is obtained, a certain storing period will follow to determine its effectiveness. Finally, the remaining heat will be discharged and absorbed by the oil, whose heat will be utilized to generate electricity using a Peltier Element. Before proceeding into the creation of the prototype, an in-depth research on the thermal properties of India's desert sand is essential. In order to successfully design and manufacture such a project, a comprehensive analysis on the selection of standards parts as well as the design of the manufactured components is addressed. To determine the thermal distribution in the sand during the heating process, Bessel functions were used to solve the 1D heat conduction equation. Results obtained analytically were verified through ANSYS Fluent and Thermal Transient, which included flow and thermal simulations in the Thermal Energy Storage Element and the storage medium respectively. Furthermore, a realistic 3D model of the prototype is included, along with the details on its operating principle. To determine the efficiency of the system, the experiments conducted are divided into three subsections: Charging Phase, Storing Phase, and Discharging Phase. Certain constraints in designing the system are addressed along with several methods to improve the system's functionality for successful future optimization.*

***Key Words*: Thermal Energy Storage system(TES), Thermal Energy Storage Element, Charging phase, Storing phase, Discharging Phase.**

1. INTRODUCTION

*This project is geared towards finding a more cost-effective and environmentally friendly solution to storing thermal energy than contemporary methodologies can present.

* Current Thermal Energy Storage (TES) systems are facilitated by the use of molten salt. The use of this material as a storage catalyst is limited to energy storage of up to 600 °C and significantly costly

*According to a research project named "Sandstock" conducted by the Massachusetts Institute of Technology in Massachusetts, desert sand can be used in conjunction with Concentrated Solar Power (CSP) technologies to store thermal energy up to 1000 °C, approximately 400 °C higher than molten salt [2].

*Furthermore, sand's ease of availability within the country coupled with its eco-friendliness make it a worthy storage medium to frontline a new generation of thermal energy storage technology. The purpose of this project is to develop a TES system using sand as an energy storage medium in order to reduce costs, increase availability, and reduce environmental impact of presently used TES system models. To accomplish this, important storage characteristics such as charging, storing, and discharging

*India is a country that is primarily powered by coal and petrol[3]. Current predictions indicate that demand for electrical energy is set to double by 2020.

*The development of energy and cost efficient energy storage devices is a vital part of the development of solar energy based projects. However, to successfully produce electricity on demand, independently from solar intermittencies, the use of TES technologies becomes crucial. *A TES system can reduce the time or rate mismatch between energy supply and demand, thus playing a crucial role in energy conservation, and the system's reliability. In the case of power generating plants, a TES system would improve its functionality by load leveling, which ultimately results in energy conservation and cost effectiveness [4].

* It can also provide this form of energy security in an eco-friendly manner if the energy is stores is harvested renewably.

2. BRIEF SUMMARY OF UTILIZING SAND AS STORAGE MEDIUM

*To provide a powerful and yet economical solution to Indias increasing energy demands, while maintaining its interest in clean and renewable sources, innovative and environmentally-appropriate solutions must be developed and implemented.

*The proposed solution centers around the integration of sand as a storage medium for CSP plant applications. It is a high temperature sensible heat storage system with one storage tank that includes a heat exchanger along with the storage medium (sand). For the execution of testing on the sand's thermal characteristics an electric heater is chosen as the heat input.

* The heat dissipated by the heater will be transferred to the heat exchanger through the Heat Transfer Fluid (HTF), which is in the form of oil. The oil resides in an oil tank from where it is pumped through a series of pipes leading to the heat exchanger. As the oil circulates through the system, the sand's change in temperature will be monitored by temperature sensors.

*When the sand attains the desired temperature of 150 °C the end of the first phase, also known as the Charging Phase will be complete. The second phase, which is the Storing Phase, tests the storing capabilities of the TES element. Multiple tests will be conducted on the TES element to see how much thermal energy it loses across various time intervals. Finally, during the third phase, the leftover heat in the sand is recovered and converted into electricity. Cold oil will be pumped to circulate through the pipes and into the TES element, thus absorbing the sand's heat. When the heat exchange between the sand and the oil is complete, the second stage – electricity generation – will be initiated.

*A thermoelectric generator in the form of a Peltier Element will be used to convert the thermal energy from the oil into electrical energy via the concept of a temperature differential. This encapsulates the Discharging Phase of the system. The three-phase process explained summarizes the working principle as well as the testing procedure that will be followed.

2.1 BENEFITS OF UTILIZING SAND AS A STORAGE MEDIUM

*Sensible TES systems are currently being tested and optimized in order to provide an energy management solution with a minimal cost platform and environmental footprint. Such applications, if optimized enough, can provide a useful and well-needed progression in the technological world of TES systems.

* The Masdar Institute of Science and Technology in Abu Dhabi has been one of the frontrunners in the creation of such technologies [7]. One of their most recent experiments has been the design and construction of a thermal energy storage system that utilizes sand as the storage medium. Such a design, even its preliminary stages, has shown significant promise in its potential ability to satisfy the World's upcoming energy needs.

*The unique project offers low-maintenance requirements when compared to traditional thermal energy storages. For example, the most common storage medium, molten salt, presents plugging related issues if it is not maintained above a specific temperature (260 °C). In such a case, external heat must be added to the system in order to change the phase of the molten salt back into liquid state. Molten salt based systems are significantly costly. Specifically, for 7.5 hours of thermal storage, 28,000 tons of nitrate molten salt are required [8].

*This translates to a cost of 25.2 million dollars only for the storage medium. Alternatively, if a sand-based TES system is utilized the overall cost of such projects will be lowered by a substantial amount.

3. WORKING PRINCIPLE

- The proposed thermal energy storage system consists of the above array of components to complete the three phases; charging, storing, and discharging.
- Phase 1:charging:The first phase of the system determines the amount of time required by the sand to reach the desired temperature.
- Phase 2:storing:The second phase tests the storing capabilities of the system – in other words, the amount of heat that is lost after a certain storing period.
- Phase 3:Discharging:During the last phase the discharging capabilities of the sand as well as the electricity generating capabilities of the system are established.

3.1CHARGING PHASE

To proceed in obtaining data for the first phase of the experimental process the following practice is followed:

1. The sensors are connected to the power supply to obtain initial temperature readings of the sand and the oil
2. The gateway-valve is opened to allow the HTF to flow through the system
3. The motor that is connected to the pump is turned on
4. Both pressure gauges will indicate the operating pressure of the oil
5. The heater is connected to the power source, and the switch is turned on
6. After the light indication on the heater is turned on the experiment has officially started
7. Every minute the temperature of the oil at the outlet of the heater and the TES element's are recorded

8. When both temperature sensors reach 150°C the heater and pump are turned off

9. Pressure gauges are frequently checked for any abrupt pressure changes

3.2STORING PHASE

The end of the charging phase initiates the second phase of the system. To proceed in obtaining data for the standby phase of the experimental process the following practice is followed:

1. Since the pump and heater are turned off, the gateway valve is also turned off

2. The room temperature (22°C) is measured using a digital thermometer

3. Every two minutes the temperature read by the sensors is recorded

3.3DISCHARGING PHASE

To proceed in obtaining data for the last phase of the experimental process the following practice is followed:

1. The gateway-valve is opened to allow the HTF to flow through the system

2. The motor that is connected to the pump is turned on

3. Both pressure sensors will indicate the operating pressure of the oil

4. Every ten seconds the temperature read by the sensors is recorded

5. After a certain period, in which the temperatures measured by the two sensors are almost equal the first stage will be complete

6. The temperature of the oil tank's bottom surface is measured

7. The cooling fan is connected to a battery, in order to prepare the cooling for the Peltier

8. The Peltier element is inserted between the oil tank's hot bottom surface and the extended cold surface of the cooling mechanism

9. The temperature read by the voltmeter is recorded

10. After the voltage measurements are obtained, the pump is turned off and the gateway valve is closed

4. RESULT AND EXPERIMENTATION; CHARGING PHASE

- The temperature of the oil and sand at the start of the experiment was measured to be 30°C and 33°C respectively.
- The final temperature of 152°C for the oil, and 153°C for the sand were achieved at 58 minutes from the start of the phase

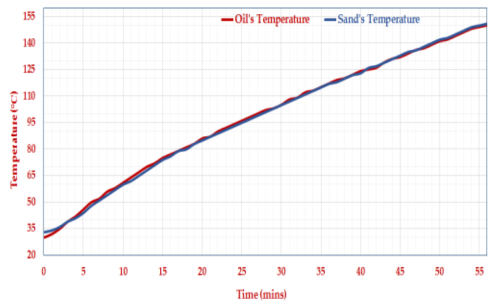

Chart 4

4.1 RESULT AND EXPERIMENTATION; STORING PHASE

- The temperature of the oil and sand at the start of the experiment was measured to be 152°C and 153°C respectively.
- At the end of the five-hour period the temperature of the oil had dropped to 50°C, while sand's decreased to 91°C. It should be noted that the storing time is measured from the end of the charging phase.

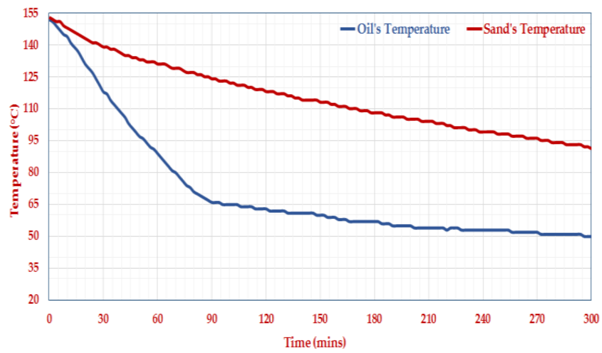

Chart 4.1

4.2 RESULT AND EXPERIMENTATION;DISCHARGING PHASE

- The initial temperature of the oil was recorded to be 50°C, while the sand's was 91°C. At the end of the first stage of the discharge phase the two mediums reached a thermal equilibrium of approximately 75°C in 7 minutes.
- After thermal equilibrium is obtained, the heat obtained back to the oil is converted into electricity through a Peltier element

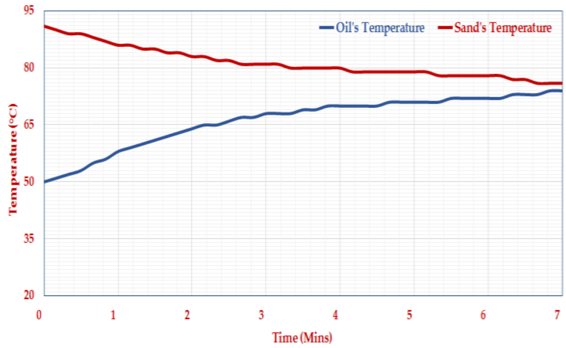

Chart 4.2

5. THERMAL ENERGY STORAGE EFFICIENCY

The effect of temperature difference in charging and discharging process on thermal conversion efficiency can be calculated from Carnot cycle efficiency ratio. It is basically the drop of the potential power generation caused by the losses in the Storing Phase

$$\eta TES,I=1-(TenvTdis/)1-(TenvTcharge/)$$

Where:

- ***Tenv*** is the ambient temperature that the system was operating in
- ***Tdis*** is the initial temperature of the sand at the Discharge Phase
- ***Tcharge*** is the final temperature of the sand at the Charging Phase

6. IMPROVEMENTS

- The components of the system should be chosen to withstand a temperature higher than the maximum operating temperature of the system.
- An insulation could be used on the pipes, TES, and oil tank to provide a stronger resistance to heat loss that the currently used insulation could not do.
- Temperature sensors should be placed inside the sand within the TES element in order to record more accurate readings of the sand's temperature over various time intervals as well as its temperature distribution.
- A Solenoid Controlled Valve Port should be added inside the TES element to limit the distribution of flow in the heat exchanger to only a fraction of the pipes.

7. CONCLUSION

Current methods used for storing thermal energy are limited to the use of molten salt as the storage medium. Molten salts are constrained by high fixed and marginal costs, due to their maintenance requirements. Furthermore, because of their incapability of withstanding high-temperatures, they cannot fuel highly efficient power cycles. India's desert sand is proven to be a more cost-effective and maintenance-free alternative for high-temperature sensible thermal energy storage. Its properties have shown to be very promising, particularly at high-temperatures with a specific heat capacity reaching that of water's. The proposed TES system includes the heat exchanger with the sand enclosed in a housing, a hydraulic gear pump to energize the flow, valves to control the flow, sensors to monitor the pressure and temperature of the HTF, as well as an oil tank to store the HTF. For the heat input, instead of a heliostat field, an electric heater was used to replicate a CSP plant's working environment. After conducting testing on the thoroughly designed, and later manufactured prototype, important characteristics of the TES element were obtained. The charging time required by the sand to reach 150°C was found experimentally to be 56 minutes. After 5 hours of storing, under insulated conditions, the sand decreased to 91°C indicating a high storing efficiency of 88.9%. In 7 minutes the oil absorbed back the heat from the sand with a discharge efficiency of 61%, followed by a voltage generation of 0.535V by the thermoelectric generator.

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