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Review Article

A Review on Rock Bed Thermal Energy Storage System for Thermal Stratification and Heat Extraction

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Abstract

The paper discusses about rock bed Thermal Energy Storage System (TES).Solar energy fluctuations are so much that it cannot be used continuously i.e. availability of solar energy varies in summer and winter. Integration of Thermal Energy Storage (TES) with solar energy has the potential to make solar energy available on demand. In TES heat can be stored using rocks in a packed bed. During charging of rock bed, temperature stratification takes place in the bed. For the thermally stratified systems, the quantity of heat extracted depends on whether it is used immediately or not. This paper reviews the technology involved in heat extraction from a charged bed. The effect of heat flow rate on quantity of heat stored and extracted.

Keywords: *Thermal Energy Storage (TES), heat extraction, rock bed, temperature stratification, air flow rate*

1. Introduction

Thermal Energy storage (TES) has only recently been developed to a point where it can have a significant impact on modern technology. In particular, TES is very important to the success of any intermittent energy source in meeting demand of energy. For example, the need for storage for solar energy applications is severe, especially when solar energy availability is least, namely, in winter. TES systems can contribute significantly to meet demands of society for more efficient, environmentally benign energy use in building heating and cooling, aerospace power, and utility applications.

Thermal energy can be stored by increasing or lowering the temperature of a substance (i.e., altering its sensible heat), by phase change of a substance (i.e., altering its latent heat) or through combining the two. Both TES forms are expected to see wider applications because of developed new energy technologies. The temporary storage of high- or low-temperature energy for later use is known as TES. Examples of TES are the storage of solar energy for overnight heating, of summer heat for winter use, of winter ice for space cooling in summer, and of the heat or cool generated electrically during off-peak hours for use during subsequent peak demand hours.

In developing countries, the major source of energy for cooking is wood fuel. Most of the time of rural women and children is spent in trekking firewood. The solar energy usage for cooking applications have several advantages that include among others: saving the rural women and children from the burden of walking long distances in search of firewood, improvement in the health of these people since they will be rarely expose to the danger of inhaling smoke caused by incomplete combustion of biomass and would reduction in the current high rate of deforestation in most parts of the world. Tremendous research has been reported on solar cookers in the past years but these solar cookers still needs some improvement for them to have a wider acceptance since the use of solar cookers are restricted to the sunny periods of the day.

Solar radiation is availability is very intermittent and it fluctuations are so much that it cannot be used continuously for cooking. For the continuous use of solar energy without any disruption by low sunshine periods, a Thermal Energy Storage (TES) is required. TES makes solar cooker competitive with the existing electrical and gas cookers.

The air-rock bed system usage for TES has the successful applications in in low temperature space heating systems. Rocks has several advantages compared to other TES materials like, rocks are cheap, readily available and the design of the storage allows cooking to be done at the top, the similar as in conventional electric and gas cookers.

The use of rock particles to store heat energy has several advantages compared to other thermal energy storage materials: they are easily available and low cost material, the technology is feasible and the storage containment design is similar to the conventional cooking oven which promotes cooking on the top part

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of the storage. In addition, when used with air at low velocities rocks have very good heat transfer characteristics and can withstand high temperatures.Studies have shown that heat can be stored in the rocks in the medium to high temperature range (200–400°C).

2. Experimental Methods

DenisOkello, Ole J. Nydal, Karidewa Nyeinga, Eldad J. K. Banda et. al., in their experimental set up used a single storage tank. The TES was constructed using two vertical co-axial cylinder using stainless steel material. The inner and outer cylinder diameters were 300 mm and 400 mm respectively. The thin, reflecting steel foils of thickness 0.3 mm were inserted between the two cylinders in order to minimize the heat loss by radiation. The bed was again insulated by fiberglass for eliminating the heat loss to the surrounding. The top plate was constructed using an aluminum plate of thickness 10 mm, and fins were attached to it made of the same aluminum material for enhancing the heat transfer from air to the top plate. By reversing the air direction the heat extraction tests were performed. The thermocouples were positioned along the bed using the hollow rod. The thermocouples were connected to NI Compact Point DAQ (Data Acquisition System). To read and record temperatures every minute a LabView program was developed. The discharge tests were performed under conditions of no airflow and under constant and varying air flow rate.

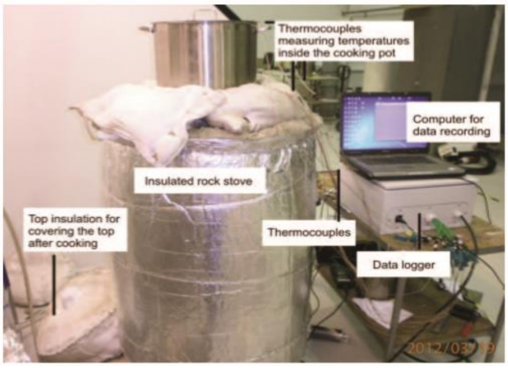

Fig.1 A rock bed system showing data logging and recording systems, top insulation for covering the top part after cooking and the thermocouples

In the experiment conducted by Denis Okello, Ole J. Nydal, Eldad J. K. Banda et. al., for analysis of thermal stratification analysis they used two different rock bed TES systems. In the first unit design, they constructed the tank using cylinder with internal diameter of 400 mm and effective storage length of 400 mm having stainless steel as a material. For providing support to the rock particles at the base the system was provided with a grid screen. The thermocouples were installed at the distances of 20, 100, 200, 300 and 400 mm from the top rock surface. In the second unit design, they used the longer unit than the first one having the two co-axial cylinders with the internal diameter of 300 mm and outer diameter of 400 mm. The total effective length of system used was 900 mm. Thermocouples installed at different locations along the height of the bed. Charging of both the TES units was done by blowing hot air from the top to the bottom to a known temperature profile after attaining the profile the air flow was stopped and the energy input connection to the bed was removed.

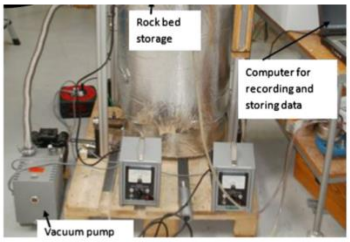

Fig.2 The larger TES with vacuum pump connected to the system and the data logger system used during thermal de-stratification tests

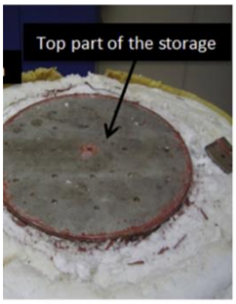

Fig.3 Top part of the storage for the shorter TES unit

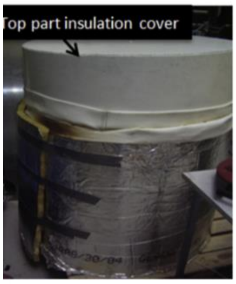

Fig.4 Complete system for the shorter TES unit

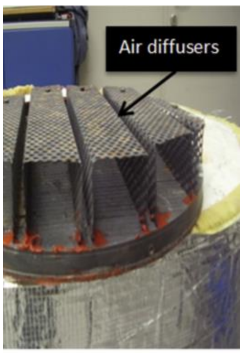

Fig.5 Air diffusers for the shorter TES unit

3. Results and Discussions

In the experiment conducted by DenisOkello, Ole J. Nydal, Karidewa Nyeinga, Eldad J. K. Banda et. al., by considering time it takes to bring a known volume of water to boiling point the cooking test was performed on the top of the rock bed heat storage. With a constant airflow rate of 4.95×10^{-3} kg/s, the variation in the temperature of water was observed and recorded. The results for constant airflow rate show that for a constant airflow rate discharging method, separation between temperature profiles after every 30 minutes are the same.

In the varying airflow rate test, the charging of bed was done with a hot air blower to nearly uniform temperature at 350 and left for stabilization for about 30 minutes. The test started with the topmost part having the temperature of the bed 320 initially which had dropped to 215 after 112 minutes. For the next time, the airflow speed was set to 2.2×10^{-3}kg/s. At the bottom cold air was blown into the storage and hot air exits through the hole at the top plate, under the cooking pot. The higher temperature at the top is observed to drop as the bed approaches thermal equilibrium.

The various tests were then performed on the bed. After the bed was left to equilibrate for 13 hours, the boiling tests were again performed. The observations from the tests show that there is huge possibility to extract heat from charged rock bed storage by simply reversing the airflow direction, and the rates of extraction can be varied by simply adjusting the airflow speed.

For the thermal de-stratification experiments conducted by Denis Okello, Ole J. Nydal, Eldad J. K. Banda et. al., the tests were performed differently on the both storage units.

In a long and highly stratified bed, the bed was initially charged to a capacity ratio of 0.39 with a controlled air flow rate while monitoring temperature readings along the bed and when the temperature at the bottom was observed start rising the charging was stopped. In the tests, the observation was made that the upper section temperature of the bed decreases much faster. At the equilibrium height, the temperature was observed to remain almost constant as upper section experienced a temperature drop while the bed temperature of the lower part increases. This shows that, in a highly stratified rock bed TES;there is faster degradation in the higher temperatures at the top.

To compare the effect of bed length on the thermal degradation rate in rock bed storage, the thermal degradation test was performed in the shorter bed having the effective length of 0.4 m, with the same rocks of same type. The results from the two bed tests showed that in both the beds there is faster degradation in the upper section of the bed.

It was observed that the degradation rate decreases with decreasing temperature gradient. Much of the drop observed at the top of the bed is mainly because of heat loss due to insufficient insulation. The shorter TES is having higher rate of heat loss compared to the longer one.

High stratification occurred in the upper section of the bed and middle part of the bed did not experience much temperature change. There was slight increase in the temperature of the bottom part of the bed. In this case, at the upper section of the bed heating occurred and with the air travelling down, its temperature decreases till it equals the temperature of the mid bed. Because of heat loss to ambient there is undesirable temperature drop across the bed length.

Conclusion

Above discussed papers give us insight about the heat extraction and thermal de-stratification in the rock bed Thermal Energy Storage. From the first paper of heat extraction we get that a higher rate of energy extraction in a well stratified bed at the beginning, which then falls off the time. Discharging rate becomes much slower without usage of blower. For most of the cooking practices the method of varying air flow rates is very beneficial because we can adjust the air flow rate according to preparation methods.

In the second paper we reviewed which focuses on the thermal de-stratification in the rock bed Thermal Energy Storage we learn that in the highly stratified bed the faster decay occurred in the high temperature region. With the increase in average bed temperature the rate of heat loss from Thermal Energy System increases. For the prevention of degradation because of which significant reductions in temperature occur, we must make an attempt to avoid the higher temperature gradients in the bed.

References

DenisOkello, Ole J. Nydal, Karidewa Nyeinga, Eldad J. K. Banda (2016), Experimental investigation on heat extraction from a rock bed heat storage system for high temperature applications, *Journal of Energy in Southern Africa* ISSN:2278-0181 Vol.27 No 2, May 2016.

Denis Okello, Ole J. Nydal, Eldad J. K. Banda (2014), Experimental investigation of thermal de-stratification in rock bed TES systems for high temperature applications, *Journal of Energy Conversion and Management* Volume 86, Pg.No.125-131, May 2014.

Simone A. Zavattoni, Mauzirio C. Barbato, Andrea Pedretti, GiwZanganeh (2015), Evaluation of thermal stratification of an air-base thermocline TES with low cost filler material, *Energy Procedia*Volume 73 (2015), 289-296

G. Zanganeh, A. Pedretti, S. A. Zavattoni, M. C. Barbato, A. Haselbacher, A. Steinfeld (2014), Design of a 100 MWh packed-bed thermal energy storage, *Energy Procedia*Volume 49 (2014), 1071-1077

Jung-Wook Park, Dohyun Park, Dong-Woo Ryu, Byung-Hee Choi, Eui-Seob Park (2014), Analysis of heat transfer and heat loss characteristics of rock cavern thermal energy storage , *Engineering Geology* volume 181 (2014), 142-156