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Study on Characterization of River Sand as Heat Storage Medium

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Abstract

The article focuses towards the study and characterization of the river sand suitability for high temperature thermal energy storage. The study is carried out preferably on the specific heat capacity of the river sand. A river sand sample from the banks of cauvery having the smallest grain size has been chosen. The sample undergoes the tests namely; Thermal Gravimetric Analysis (TGA), Fourier Transform Infrared Analysis (FTIR) and Differential Scanning Calorimeter (DSC). Detailed analysis is carried out to observe the sample's change in weight when subjected to heating. FTIR analyzes the chemical groups present in the sample and DSC helps to identify its specific heat capacity which could justify the effect of thermal storage. TGA analysis showcased 1.013% of change in the sample weight during the first cycle of heating. However, during further heating cycle's negligible change in weight is observed. Therefore, same sample could be used for several heating cycles without the need for replacement. The reason behind the weight loss was later examined by FTIR analysis. It is observed that the carbonate compound present in the sample was missing after heating. This test justifies the absence of carbonate compound presence after the heating process. The specific heat capacity of sand was found to be 1041 J/Kg/K by DSC analysis. The observed value of specific heat capacity of sand shows its superiority over the conventionally used high temperature thermal storage medium mainly molten salt and synthetic oils. The observation shows the heated sample with agglomeration due to the presence of other impurities and a considerable color change was observed. River sand is tested for its thermal characteristics and studied for the first time to the best of knowledge which the researchers are still at the finding stage. The specific heat capacity observed in the river sand makes its suitable for high temperature thermal energy storage in Concentrated Solar Power Plants (CSP).

Keywords: Phase Change Material, River Sand, Sensible Heat Storage, Specific Heat Capacity, Thermal Characterization, Thermal Energy Storage

1. Introduction

Thermal Energy Storage (TES) is the concept of storing heat energy. It plays a key role in efficient utilization of industrial waste heat as well as renewable energy resources. It helps to reduce the cost of solar generated electricity and improve the availability of solar power plant. Technical requirements of TES system includes; high energy density, adequate heat transfer between Heat Transfer Fluid (HTF) and storage medium, mechanical and chemical stability, minimized thermal losses, complete reversibility for a large number of charge/ discharge cycle, chemical compatibility with HTF and heat exchangers. Different approaches are there for storing huge amount of heat energy under Sensible Heat Storage (SHS) and Latent Heat Storage (LHS) categories. The storage medium is decided by the temperature of the application[1]. SHS is based on the heat capacity of the storage medium by virtue of change in temperature of the storage medium. Molten salts come under LHS and are most promising storage technology for medium and high temperature storage[2].

In concentrated solar power (CSP) plants, molten salts have been the material of choice to store solar energy

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since from 1980s. Molten salts are employed in concentrated solar thermal power plants to store heat from the sun during the day and then generate electricity at night. Even though molten salts outweigh all other thermal storage options, it has certain flaws such as the high cost and diminishing energy storage capability after several usage cycles[3].

Figure 1. Sand sample collection sites located (Red spots) on the banks of Cauvery River.

Recently the researchers have been looking forward for an alternative for the next generation of CSP with storage. The main constituent of sand is quartz which is having a melting point around 1700° C. Hence it is having a high temperature withstanding capability, sand can be used for next generation CSP storage.

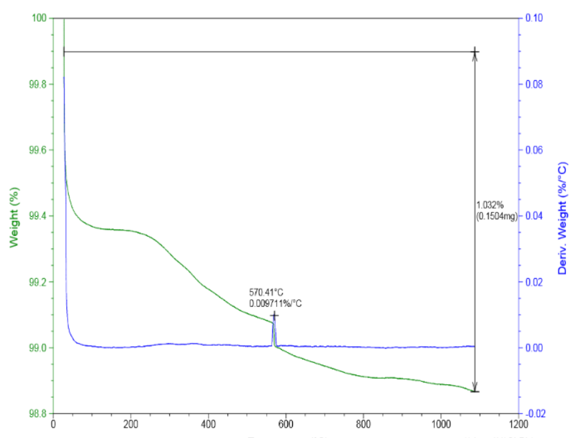

Figure 2. Plot of TGA-DSC analysis for the river sand sample.

On comparison with molten salt, the sand can store energy when heated around 600˚C[4]. Moreover, this sand is cost effective and readily available. Sand can function as thermal collector, heat transfer medium as well as thermal storage[5]. Plentiful research and testing of desert sand samples from UAE were carried out to study its properties as a thermal storage medium for CSP[5]. Sand based packed bed TES system can reduce the operation cost of CSP[6]. Depending on the grain size, heat storage capability can be predicted, that is, smaller the grain size offers an excellent thermal storage potential[6]. Sand being an environmental friendly material, cheap and easily available storage medium, it can be employed even for the case of small- scale (domestic) solar energy applications such as solar dryer, solar cooker and solar based water heating systems[7].

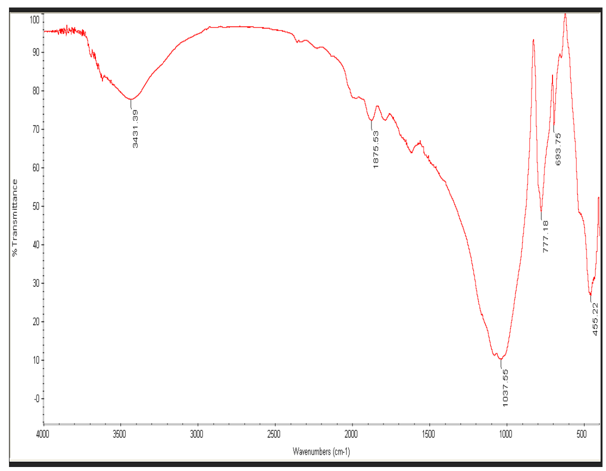

Figure 3. FT-IR Analysis of the river sand sample before TGA.

The present work emphasize on testing and characterization of the river sand samples from South-Indian region. The sand sample is analyzed for its physical, chemical, mechanical and thermal properties. The work is carried out in the following sections. Section II characterizes the sand material, Section III discusses the methods of characterization of sand material[8], Section IV presents the visual results of sand discoloration and Section V finally concludes the work.

2. Sand Material Characterization

Samples were collected from four different locations of the banks of Cauvery River in the South Indian region as shown in Figure 1. Out of the four samples collected, the smallest mean grain size was found out to be 380 μ. It is reported that the sample with smallest grain size supports for good heat storage capacity based on which the sample is chosen for this study. The specific gravity of the sand sample was found out to be 2.73 by a laboratory experiment using pycnometer.

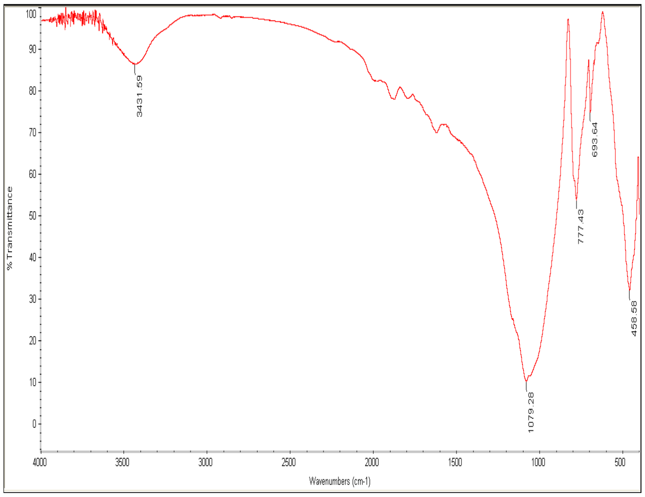

Figure 4. FT-IR Analysis of the river sand sample after TGA.

3. Methods Adopted for Characterization of River Sand Sample

The chosen sand sample of 380μ size was subjected to Thermal Gravimetric Analysis (TGA), Fourier Transform Infra-Red Analysis (FTIR) and Differential Scanning Calorimetry (DSC) to test its characterization.

Figure 5. Formation of assemblage in the river sand sample.

3.1 Thermal Gravimetric Analysis

To study the physical and chemical properties, and the change in the sand sample the Thermal Gravimetric (TGA) analysis was performed under heat. TG Analysis was carried out on a TA Instrument, SDT Q600 machine held by a bifilar wound platinum container. Before starting the analysis, the samples were kept under the infrared lamp to remove the moisture content from it. A quantity of 14.576 mg of sand sample was subjected to a constant flow of nitrogen gas, at the rate of 100 ml/min. TGA was performed by heating the sample from an initial temperature of approximately 20˚C to a final temperature of about 1700˚C[9].

Figure 6. River sand sample before heating.

The experimental result showed that there was a notable mass loss of 1.032%, as shown in the Figure 2. However, when the same sample was analyzed again, there was no mass loss. This implies that, the same sand can be used for multiple thermal cycles. Combatively, it is observed that the sand has to be preheated for high temperature thermal energy storage applications like Concentrated Solar Power Plants (CSP).

3.2 Fourier Transform Infrared Spectrometry Analysis

Fourier Transform Infrared spectrometry (FT-IR) analysis is executed on Thermo Scientific Nicolet™ iS™ 10 FT-IR Spectrometer. The output was analyzed using Thermo Scientific™ OMNIC™ software. Analysis is performed to investigate the structural and functional groups of the sample under study. To study more about the mass loss

FTIR is performed before and after heating the sample up to 1100˚C. Figure 3 and Figure 4 indicates the FTIR analysis before and after TGA[10].

From Figure 3 and Figure 4 i.e., by performing FT-IR analysis, the presence of strong carbonyl group is found before heating. Once the sample was subjected to heating, the carbonyl content was removed[11].

3.3 Differential Scanning Calorimeter

Experiment is carried out on TA instrument USA, Q20 post processed and plotted using platinum which is a supporting software for TA instrument Q60 DSC[12,13]. The amount of heat that can be stored in sand using Differential Scanning Calorimeter (DSC) during the heating process results quartz inversion around 570˚C. This results a reversible change in the crystal structure (α to β transition). The average heat capacity value obtained from DSC analysis is 1041 J/kg/K which is significantly higher when compared to the latent heat capacity of the conventional molten salts (975 J/kg/K)[14]. Even new materials like erythritol is having a specific heat capacity of 1383 J/kg/K, which is equivalent to specific heat capacity of sand. Sand is cheaper than other newly discovered PCMs[15]. Therefore, this proves the river sand to be highly effective energy storage media when compared to molten salt.

4. Visual Testing Results of River Sand Sample

4.1 Agglomeration

It is observed that after the heating process, some of the sand particles formed an assemblage due to sintering as shown in Figure 5. Previous studies[16] states that, there is no chance of sintering of silica below 1000˚C, this agglomeration is due to sintering of impurities present in the sand sample[17]. Agglomeration may result in hindrance of flow of sand. But it can be taken away by treating the sand sample with gentle vibrations.

Figure 7. River sand sample after heating.

4.2 Colour Change

Figure 6 and Figure 7 shows the colour change of the river sand sample when subjected to heat. A notable change in color was observed after the heating process.

5. Conclusions

The selected river sand sample from the banks of Cauvery was characterized using TGA, FT-IR and DSC analysis to study its average heat storage capacity. It was observed that, when the sand sample underwent a heating process initially, there was a considerable loss in mass, but when the sample was subjected to multiple thermal cycles, there was no mass loss. This proves the sustainability of the river sand sample for multiple thermal cycles up to a temperature of 1087°C. Furthermore, the carbonyl group present in the sample also was removed in allusion to the heating process which indicates the evolution of carbon dioxide gas. From the calorimetric observation, the average heat capacity of the river sand sample was 1041 J/kg/K which makes it a suitable option for thermal energy storage.

6. References

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