

ON THE USE OF COLORED SAND FOR VOLUMETRIC SOLAR RADIATION ABSORPTION FOR CONCENTRATED SOLAR POWER APPLICATIONS

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ABSTRACT

Volumetric direct solar receivers have been proposed in Concentrated Solar Power (CSP) applications since they present higher efficiencies than standard surface receivers do. Silicon dioxide sand has been proposed as heat transfer and thermal storage material in Concentrated Solar Power (CSP) applications. Fluidized sand can be used in volumetric direct solar receivers; however, in this case, sand should be colored in order to improve its optical absorption properties in the solar spectrum. In this work, two methods are proposed and compared to colour the sand: Carbon Black (CB) nanoparticle coating and glucose degradation. The optical absorption is characterized using a double-beam UV-VIS spectrophotometer (Spectrophotometer Cary 500) before and after the fluidization. Moreover, colored sand shows no change in optical properties after 24 hours of fluidization, showing the practical applicability of this approach.

INTRODUCTION

Climate change is the consequence of the abuse of technologies that emit CO₂ into the atmosphere. These technologies are mainly the burning of fossil fuels for energy production. Therefore, the importance of the use and implementation of renewable energies in the world today is becoming more important, since they allow the production of energy in a clean way and at the same time take advantage of the natural resources that we have reach day by day, and inexhaustible [1]. Among the different types of renewable energy, the remarkable one is solar energy [2], and more specifically solar thermal.

Solar thermal energy is an interesting option to produce electricity in CSP plants [3]. However, due to the mismatch between production and energy demand TES materials are highly necessary in order to storage de energy. Thus, it is possible to improve the efficiency and stability of CSP plants [4]. The use of TES in CSP plants is based on the energy storage while solar radiation is abundant, and lately, when there is a high demand of energy, energy stored is released from TES. Hence, although the cost of CSP plants will be increased by the incorporation of TES systems [5], in long-term the investment becomes profitable because of electricity cost savings.

Usually, solid particle are used as thermal energy storage materials because they can act as the heat collector, heat transfer and heat energy storage media. Nowadays, molten salts are the

most solid particles used as TES [4]. Nevertheless, for some time now have been discovered new solid particles that can be used to storage energy and they have advantageous properties above molten salts. One of these particles is silica sand, better known as beach sand.

Silica sand advantages outweigh molten salts ones. Some of them are the following; silica sand is readily available in abundant quantities of it, in contrast to salts, which have to be bought commercially. This advantage lead to reduce costs of CSP plants, because of saving tones of salt you need to buy. Other advantage is that the sand is also easily movable, permitting low-cost systems to transport it. On the other hand, in terms of thermal stability sand is more stable, around 800°C [6], than molten salts 600°C, approximately [1]. This allows to reach higher efficiencies of the power cycle.

In this paper, it has been studied the size distribution and absorption spectrum of three different sand samples. One of them is raw sand and the other two, had been black colored with two different methods, and then results have been compared.

NOMENCLATURE

<i>A</i>	[-]	Absorption
<i>R</i>	[-]	Reflection
<i>T</i>	[-]	Transmission

Subscripts

<i>cs</i>	colored sand
<i>s</i>	sand

Abbreviations

<i>CB</i>	Carbon Black
<i>SEM</i>	Scanning Electron Microscope
<i>CSP</i>	Concentrated Solar Power
<i>HTF</i>	Heat Transfer Fluid
<i>TES</i>	Thermal Energy Storage

MATERIALS AND METHODS

The main material used in this paper is silicon dioxide sand. Its primary diameter is around 0,2-0,5 mm. This sand in pure state has been colored by two different methods described below: CB nanoparticles coating (method 1, CB sand) and glucose degradation (method 2, glucose sand). All the mass

measurements to obtain the samples were weighted in an analytical balance (Kern ABS, ± 0.001 mg).

Sand coloring methods

Method 1: CB nanoparticles coating

To obtain this sample, 240 ml of acetone and 3 grams of CB nanoparticles were mixed and sonicated with an ultrasound probe for 40 seconds (Sonoplus HD2200, Bandelin) at medium-high power.

Then, the 60 grams of sand were added to the previous mixture and then sonicated again, but this time for 30 seconds at high power.

Finally, thin layers of the resulting mixture were dried heating up the sample in a stove at 100°C during 15 minutes.

Method 2: Glucose degradation

In this method, 42 grams of sand, 18 grams of glucose and distilled water covering the sample were mixed. The resulting mixture was magnetically stirred during 35 minutes at 55°C . The water content of the sample was then removed by drying thin layers of the sample in a stove at 100°C .

Finally, the dry mix was introduced in an oven at 400°C during 10 minutes under inert atmosphere conditions.

Figure 1 shows the different samples evaluated in this paper.



Figure 1 Pure sand, CB sand and Glucose sand (from left to right)

Sand particle size

Mastersizer 200 (Malvern Instruments) provides particle size measurement using just a few milligrams of sample. Efficient sample dispersion helps ensure that the particle size data measured by a laser diffraction analyser are both representative and relevant [12]. The equipment can give rise to errors approaching 5% for d_{10} , 3% for d_{50} and 5% for d_{90} . Measurements of the three sand samples were performed.

Coating morphology

Scanning electron microscopy (SEM) was performed in a Leica-Zeiss LEO 440 microscope equipped with digital image acquisition. Sand samples were observed so the morphology coating of the raw material were determined.

Absorption spectrum

The absorption spectrum of the sand samples were obtained by means of the transmission and reflexion spectrums measured by a spectrometer (CARY 500, Varian Dev). The measured

spectrum ranges from 400 nm to 800 nm with a spectral resolution of 0.5 nm.

The absorption spectrum can be obtained as $A (\%) = (100 - T (\%) - R (\%))$ [13]. In this work, reflection loses are taken into account in the reference spectrum measurement.

The error in the measurements is up to 0.003% due to the high accuracy of the equipment [13].

Fluidized bed

As the sand is going to be used in continuous movement, a fluidised air bed was built to study this effect in the colored sand. Figure 2 shows the fluidized bed. The sand sample is placed in a test tube and air is introduced through a thin metallic duct, which generates the sand movement. The absorption spectrums of the two colored sand samples were evaluated before and after 24 h of fluidization.



Figure 2 Fluidized bed

RESULTS

Sand particle size

Particle size distribution in number for the three sand samples is represented in Figure 3. The characteristic diameters (d_{10} , d_{50} and d_{90}) can be found in Table 1 for the different samples.

	d_{10} (μm)	d_{50} (μm)	d_{90} (μm)
Sand	22.75	294.38	575.81
CB Sand	100.60	342.83	654.58
Glucose Sand	92.40	404.95	762.94

Table 1 Characteristic diameter (d_{10} , d_{50} , d_{90}) for different samples

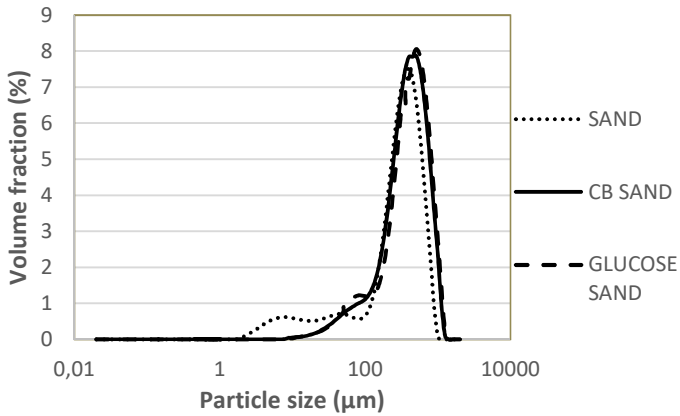


Figure 3 Size particle distribution for pure and colored sand samples

Coating morphology

Samples of the two types of colored sand were observed by SEM. One representative image of each sample is shown in this paper.

Figure 4 shows a SEM image of the sand colored by CB nanoparticles coating (CB sand). It is possible to observe that CB nanoparticles have spherical shape and a similar range of diameters. Nanoparticle clusters can be found heterogeneously surrounding the sand particles.

Averaging different SEM images, the value of the CB coating thickness is approximately 1µm.

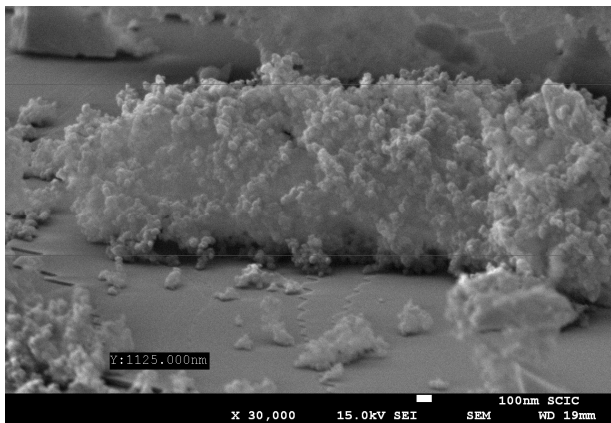


Figure 4 SEM image of CB sand

Figure 5 shows a SEM image of the sand colored by glucose degradation (Glucose sand). The layer around the sand is also heterogeneous as in CB case. In this case, the coating thickness estimated by averaging different SEM images, is around 4 µm.

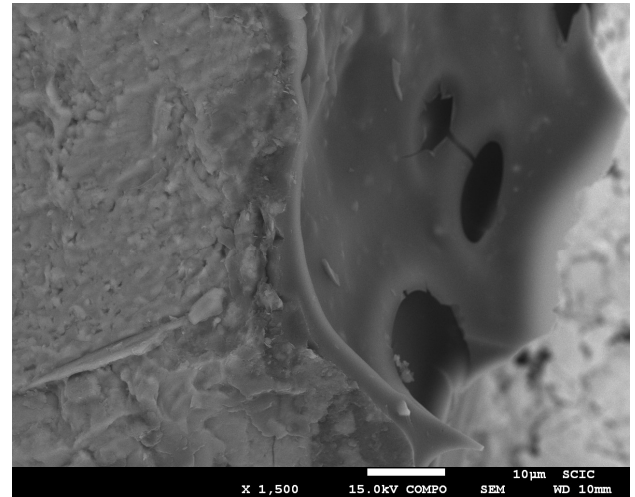


Figure 5 SEM image of glucose sand

These values of coating thickness are in accordance with the diameter increment obtained in sand particle size measurements.

Absorption spectrum

The absorption spectrums of the two colored sand samples were evaluated before and after 24 h of fluidization.

Figure 6 shows the absorption spectrums for the initial sand and the two colored sand samples before the fluidization.

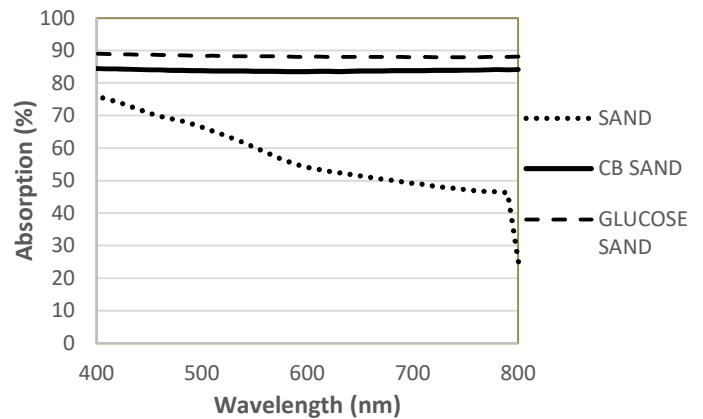


Figure 6 Sand absorption spectrums before fluidization

In both cases, the absorption of colored sand is higher than that of the initial sand. Also, the absorption for both colored samples is more homogeneous for different wavelengths. Higher absorptions are obtained for the sand colored by glucose degradation. Averaging the data along the measured wavelengths, the CB sand increases 47.57% their absorption with respect to the initial sand and the glucose sand increases 54.52%.

Figure 7 shows the comparison of absorption spectrum for the initial sand and the two colored sand samples after 24 hours of fluidization

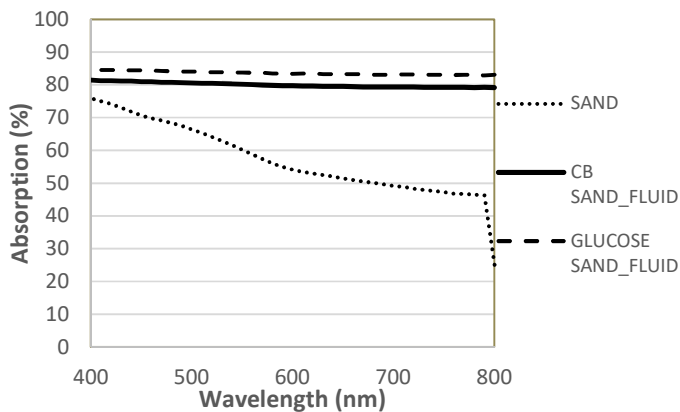


Figure 7 Sand absorption spectrums after fluidization

In both colored samples, the absorption spectrum after the fluidization decreases. In the case of the fluidized CB sand only a 19% and in the case of the Glucose sand 16.38%.

Anyway, with both coloring methods, the fluidized colored sand importantly increases the absorption spectrum with respect to the initial sand: 40% in the case of CB sand 46.85% in the case of Glucose sand.

CONCLUSION

Two types of colored sand have been synthesized and characterized, one based on CB nanoparticle coating and the other on glucose degradation. The preliminary results indicate that the colored sand presents better radiative properties than the initial sand, as the absorption increases between 47.6% and 54.5% depending on the sand coloring method. The sand colored by glucose degradation method presents better absorption results than that colored by addition of CB nanoparticles. This can be an important advantage in using colored silica sand as a direct solar solid absorber medium in solar harvesting applications. Additionally, the coloring of the sand is only slightly affected by a 24 hours fluidization, as the absorption measurements show decreases between 16% and 19% in each colored sample. Although further fluidization periods should be performed, this initial result is a good indicator of the sand coloring stability.

Further characterization and tests are needed and will be done in future works.

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