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Laboratory simulation of the surface erosion of solar glass mirrors

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Abstract

During their functioning in concentrated solar power plant – CSP, Glass mirrors are exposed to several climate conditions that cause their degradation. Surface erosion is among mechanical degradation phenomena that can alter mirrors surface and cause a decrease of the overall performance of the CSP plant. Several parameters are influencing this degradation phenomenon, namely the impact speed, the impact angle and the erosive sand particles properties. In this study, we proceed by simulation tests to investigate the effect of surface erosion phenomenon on thin glass mirrors. In order to be representative of the natural degradation phenomenon, the inputs parameters are chosen according to collected data from two different sites in Morocco. Results of simulation tests analysis indicate that the loss in specular reflectance increases with the impact speed. By analyzing the effect of the impact angle, it was discovered that the maximum surface erosion is observed at normal impact angle of 90°. Concerning the effect of sand particles properties on optical degradation, it was found that this latter increases by increasing the sand particle's size which increase the erosion surface rate. In addition, it was shown that the sand particle's sharpness presents a precursor for surface erosion phenomenon.

Keywords: Solar mirrors erosion; Glass mirrors; Impact parameters; Sand particles

1. Introduction

Solar mirrors surfaces can be altered, during their functioning or during their maintenance in solar field of CSP plant, by erosion phenomenon (Buijs and Pasmans, 1995; Bouzid and Bouaouadja, 2000; Wang et al., 2010). This latter is caused either by mechanical contact cleaning or by direct impact of sand particles transported by wind (Zakhidov and Ismanzhanov, 1980; Caron, 2011). The present study will be focused on evaluating the effect of sand particles on mirrors' surface erosion, the phenomenon is inherent to CSP implantation plants sites, very often located in sandy deserts (Wang et al., 2010; Sansom et al., 2013).

Two main groups of parameters contribute to the mirrors' surface erosion. The first group is related to mirror's surface nature, since it was relieved that brittle materials surfaces present different behavior against erosion than ductile materials surfaces (Bouaouadja et al., 2000; Sarver et al., 2013; Gwidon and Batchelor, 2006; Alhussein, 2010). The second group is attributed to climatic and geological conditions specific to the CSP plant

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Nomenclature

CSP	concentrated solar power
ρ_s (660 nm, 15°, 12.5 mrad)	specular reflectance (%)
Ra	average surface roughness (nm)
SnH	Sharp and not Hard sand particles extracted from the site #1 (N/A)
SH	Sharp and Hard sand particles extracted from the site #2 (N/A)
RH	Round and Hard sand particles from the normalized sand (N/A)

site. The climate parameters such as wind speed and direction, determine respectively the impact velocity and the angle of sand particles during erosion. The geological parameters pertain to the erosive sand particles properties (size, shape and hardness). These parameters present an important influence on the magnitude and the characteristics of erosion generated upon mirrors surfaces (Caron, 2011; Wang et al., 2010; Sansom et al., 2013; Bagnold, 1965; Sarver et al., 2013).

To evaluate the effect of these influencing parameters on surface erosion phenomenon, several studies were conducted considering different materials surfaces by making either outdoor tests (Brogren et al., 2004; Elminir et al., 2006; Hegazy, 2001; Mastekbayeva and Kumar, 2000; Biryukov, 1999) or indoor tests (Martin, 2011; Lopez Martin et al., 2012; Gachon et al., 1999). The outdoor tests consisted of exposing sample mirrors to a natural climatic and geological conditions and documenting the observed damage upon mirrors surfaces. Besides, the indoor tests comprised the simulation of the effect of erosion phenomenon on mirrors performance at laboratory scale. They were performed using some standards developed for other domains and for which the adequacy with the CSP field was not yet confirmed (Gwidon and Batchelor, 2006; Martin, 2011). These standardized tests did not take into account the site characteristics, such as climatic and geological parameters, which justified the difference between the observed degradation in both outdoor and indoor tests.

In the present study, we investigate the effect of different parameters on mirrors surface erosion by using laboratory bench simulation tests. These tests followed a work methodology comprised of five steps:

1. Identifying, determining and collecting climatic and geological parameters that responsible for increasing the erosion rate. This study was made in two different regions in Morocco. Results are reported in a previous work (Karim et al., 2014).
2. Exposing mirrors samples in these chosen sites to follow the natural degradation that can be observed upon studied mirrors surfaces.
3. Conducting laboratory simulation tests in order to accelerate the degradation phenomenon and to study the effect of each influencing parameter separately from the others. To approach the natural exposure conditions, the used parameters for these tests are chosen according to the climatic and the geological parameters collected in the first step.
4. Correlating the obtained results from both the outdoor and the indoor tests.
5. Establishing the link that relates the erosion rate with different influencing parameters.

In what follows, the third step of the general work methodology is approached. The tests conditions, the simulation parameters and the obtained results are presented and discussed.

2. Experimental procedure

2.1. Samples

Commercially glass mirrors, commonly used in CSP solar field, were tested for this study. The glass substrate of 0.95 mm thickness is coated with a silver reflective film which is protected by three different layers, namely a copper layer and two paint layers. Mirrors samples of (7×7) cm^2 used for this study are cut from large sheets.

2.2. Test equipment

The principle of laboratory simulation of mirrors erosion consists on injecting sand particles on mirror samples surfaces and measuring the loss of the optical properties or the mass of samples. Literature review identifies, four variant laboratory benches can be distinguished. Different sensors are used to control the injected sand mass and the concentration of particles in the injected air flux. For some studies, the erosive sand is recycled (Caron, 2011). The impact angle is either fixed at 45° (Magdich, 2011) or varied from 0° to 90° (Gachon et al., 1999; Bouaouadja et al., 2000; Bouzid and Azari, 2012). Some test benches with closed air recirculation are equipped with climatic sensors to measure and control the temperature and the humidity. The table below depicts the main adjustable parameters for the reviewed erosion testers (Table 1).

In our case, simulation tests are made using a sand blower open circuit machine (Fig. 1). By using an air compressor, the erosive sand particles are passed through a