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Assessment of the erosion risk of sandstorms on solar energy technology at two sites in Morocco

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ABSTRACT

This multi-disciplinary research paper should help solar power plant developers to perform an advanced site assessment in arid locations where the annual irradiance levels are high, but significant quantities of airborne sand and dust increase the risk of optical energy losses due to extinction, soiling, erosion damage (also known as abrasion), etc. Due to these effects sandstorms have a direct consequence on the operation and maintenance (O&M) costs. The work presented in the following characterizes airborne sand and dust material and later focuses on the resulting erosion effects. Some important meteorological and geological parameters for sandstorm occurrence and the resulting erosive damage on glass materials by impacting windblown material are extracted from literature. The respective parameters have been measured at two locations in Morocco (Zagora and Missour). After evaluation of wind and humidity data and a comprehensive soil analysis, the erosion risk was estimated to be higher in Zagora. The specular reflectance loss of exposed silvered-glass reflectors of 5.9% in Zagora and 0.8% in Missour after 25 months of exposure verified this estimation. Additionally, a specular reflectance analysis on a mirror sample that has been exposed for nine months in Kuwait is shown. On that sample specular reflectance losses of more than 40% were measured. A checklist with seven items is given in the conclusion to help solar plant developers to evaluate the risk of component aging due to sand storm erosion.

1. Introduction

Many arid sites in the MENA-region are of high interest for solar energy plant developers because of the high annual irradiation levels. However these regions also lead to high material demands of the used components due to the increased aerosol particle loads in the atmospheric layer close to the ground (Ruiz-Arias et al., 2016). Especially the optical energy conversion process is often significantly reduced from its theoretical efficiency due to the presence of sand and dust (Sarver et al., 2013). On the one hand, this causes soiling on the respective optical surfaces that lowers plant efficiency. Cleaning can reverse the effect but requires manpower and water (Maghami et al., 2016). On the other hand, an increased presence of aeolian particles also leads to optical scattering and absorption processes in the air between the different optical components of solar power plants. This phenomenon is known as atmospheric extinction and is of special importance for central receiver concentrating solar power plants, where the spatial distance between the reflecting heliostats and the absorber can be up to several kilometers (Hanrieder, 2016). A third effect are windblown aerosol particles, which may cause possible mechanical damage when impacting on the optical components. All of the three effects lead to optical performance losses which decrease the economic benefit of a solar energy power plant. For a 50 MW concentrating solar power plant (CSP) located in Spain an annual financial loss of 0.7 M € could be calculated when the reflectance of the mirrors is decreased by 1% (Schiller and Höing, 2012). Therefore there is a strong interest of the CSP and also photovoltaic (PV) industry to develop testing procedures which are capable to estimate the lifetime of optical components as it was recently done by many groups (Humood et al., 2016; Wiesinger et al., 2016; Houmy et al., 2016; Sansom et al., 2015; Karim et al., 2015; Al Shehri et al., 2017).

The present work concentrates on the permanent mechanical damage by windblown particles causing surface abrasion (hereafter referred to as "erosion"). It was widely studied in literature on many different materials and with a variety of input parameters (Hutchings, 1992; Wada, 1992; Feng and Ball, 1999). In this study, the defects in

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Nomenclature

Symbol

α	erosion impact angle (°)
D_{soil}	mean density of soil (kg m^{-3})
N_i	number of particles in channel i (–)
V_i	mean volume of a particle in channel i (m^3)
V_a	reference air volume of EDM164 particle counter (m^3)
$\rho_{\lambda,\varphi}$	monochromatic specular reflectance at $\lambda = 660$ nm, $\Theta = 15°$and $\varphi = 12.5$ mrad (%)
λ	wavelength nm
$\rho_{\lambda,\varphi,loss}$	loss of monochromatic specular reflectance (%)
v	impact velocity m s^{-1}
u_τ	friction velocity m s^{-1}
u_τ^*	threshold friction velocity m s^{-1}
d	mean particle diameter (μm)
Θ_i	radiation incidence angle (°)
φ	acceptance half angle (mrad)
E_g	gravimetric erosion rate, mass loss of target material per impacting erodent mass (–)
E_p	particle erosion rate, mass loss of target material per impacting number of particles (g)
E_{CV}	erosion classification value (–)
K or K_c	fracture toughness (MPa m$^{0.5}$)
m_A	impacting sand mass per reflector area (g cm^{-2})
rh	relative air humidity (%)
m	mass (g)
Δm	mass loss/gain (g)
z	hight above ground (m)
z_0	surface roughness length (m)
κ	von Kármán constant (–)
H	material hardness (MPa)
w	gravimetric soil moisture (%)

Subscript

p	erodent particle material
t	target material

Acronyms

Acetube	Accelerated Erosion Tube (for artificial sandstorm aging experiments)
CSP	Concentrating Solar Power
CFD	Computational Fluid Dynamics
EDM164	Environmental Dust Monitor 164 of Grimm
EDX	Energy Dispersive X-ray Spectroscopy
GHI	Global Horizontal Irradiance
MENA	Middle East and North Africa Region
PSD_{num}	Numerical Particle Size Distribution
PV	Photovoltaic
SEM	Scanning Electron Microscope
TSP	Total Suspended Particles
DNI	Direct Normal Irradiance
D&S	Devices & Services Portable Reflectometer 15-USB

glass reflectors provoked by air-borne particles at two representative sites in Morocco (Zagora and Missour) are analyzed. Because glass, with technology-appropriate surface coatings, is the state of the art material to maintain high efficiency of CSP as well as PV systems, the findings of the present work are relevant for both technologies (Fernández-García et al., 2010; Humood et al., 2016). Depending on the respective site differences a measurable optical performance loss could be detected. A comprehensive outdoor study undertaken by Wette et al. (2016) who exposed samples on seven outdoor sites, found massive erosion defects only in Zagora. In addition to the Moroccan sites, an outdoor exposure campaign undertaken by the company TSK (Gijón, Spain) of glass reflectors in Kuwait is presented. They also show a significant performance loss due to the presence of sandstorms. Their finding is consistent with the extensive literature addressing the severe sandstorm activity in the Kuwait region (Subramaniam et al., 2015).

Within this work, the erosion determining factors are discussed, the critical sand movement principle is explained and resulting data from the investigated outdoor sites are shown. The differences between the varying reflectance losses at the distinct sites can be mainly explained by the particle size distribution of the soil, the mineralogical composition of the soil, the wind velocity in combination with relative humidity, the prevailing wind direction with respect to the solar collector orientation, and the characteristics of the local landscape.

1.1. Defects on brittle materials

From the mechanical point of view, glass can be classified as a brittle material which forms erosion pits and cracks when exposed to harsh solid particle impacts. It has been shown in literature that defects caused by sandstorms on various construction materials is as real as on exposed glass samples for solar energy applications (Wiesinger and Sutter, 2016; Karim et al., 2015). Within the present work, further evidence from a field exposure in Morocco and Kuwait will be given as well in order to emphasize the actuality of the issue of glass erosion. This is due to the low fracture toughness K (or critical stress intensity factor, sometimes also labeled K_c) of glass. Depending on K the overall

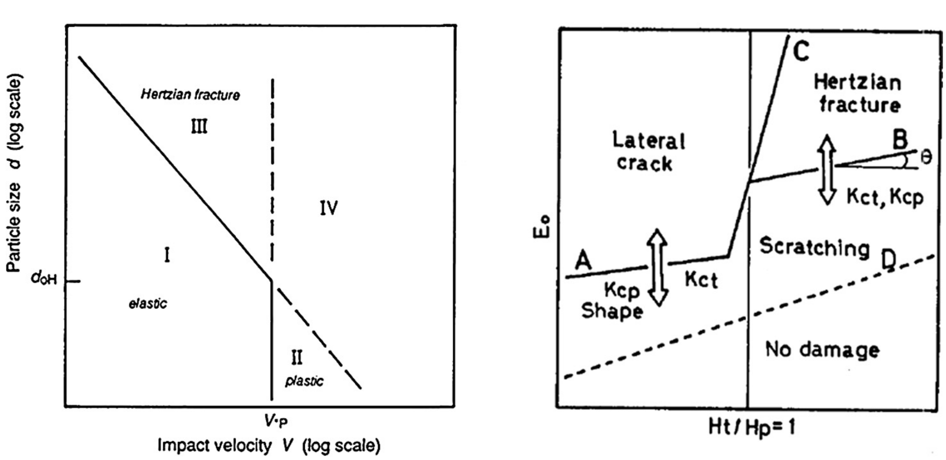

Fig. 1. Two examples of erosion maps of brittle materials: Hutchings (1992) (left) points out four regimes of erosion in dependence on the impact velocity and the particle size. Wada (1992) (right) describes four different regimes by combining particle size and the impact velocity to the impact energy E_0 on the y-axis and the ratio of the hardnesses on the x-axis. The indices p or t stand for particle and target, respectively.