Simulation of The Effect of Libyan Sand on The Reflectance Surface of CSP

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Abstract: The reflector characteristics are negatively affected by the harsh desert weather conditions and hence the performance of the system decreases. This paper investigates the effect of two different types of moving sands "A" and "B" from Libya on the performance and safety of the solar reflectors. Samples are collected from areas that are suitable for installing CSP plants. They are in different particle sizes and chemical compositions: sand "A" with size ranges between 0.025-0.355 mm, and "B" is within 0.124-0.479 mm. The experiment outcome using sand blasting indicated that sand "A" has more influence than sand "B" as the small particles of "A" spread over a large area of the reflector. It is also noticed in the range studied that the speed variation effect has more impact than the mass quantity changing. For clean surfaces, the reflectivity is dropped by 2.2%, and the damaged surfaces increased about 1 mm in case of 0.5 g mass at 27 m/s storm speed. For 2g mass at 21 m/s storm speed, the roughness is found 3 mm.

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دراسة تأثير الرمال على الأسطح العاكسة للمحطات الشمسية التركيزية في ليبيا

عصام اندية، كريس سامسون، بيتر كوملى، هيدر المنود، الهادى الدكام و محمد عبدالنبي

ملخص: خصائص العواكس تتأثر سلبا بالظروف المناخية للصحراء القاسية وبالتالي أداء المنظومات يقل. هذه الورقة تشخص تأثير نوعين مختلفين من الرمال المتحركة نوع A و B من ليبيا على الأداء والسلامة للعواكس الشمسية. العينات أخذت من مناطق مناسبة لتركيب محطات القدرة الشمسية. فهي مختلفة في حجم الحبيبات والتركيب الكيميائي: نوع A بحجم بتراوح من 0.025-0.355 ملم

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و النوع B بحجم 0.479-0.124ملم. النتائج المتحصل عليها بإستخدام نفاث الرمال تشير إلى أن الرمل نوع A له تأثير أكثر من النوع B لأن صغر حبيبات النوع A ساهم في إنتشارها على مساحة أكبر من العاكس. كما لوحظ في مدى الدراسة أن تغيير السرعة له تأثير أكبر من تغيير كميات الرمل. بعد تنظيف الأسطح، الانعكاسية انخفضت إلى 2.2 % و خشونة السطح ازدادت بحوالي 1 ميكروميتر في حالة كتلة 0.5 جرام عند سرعة 27 متر/ث. في حالة كتلة 2 جرام وسرعة 21 متر/ث الخشونة وجدت 3 ميكرومتر.

***Keywords:** sand storm, Libyan sand, specular reflectance, damaged surfaces, reflectors, solar panels, CSP.*

1. INTRODUCTION

The Concentering Solar Power (CSP) is increasingly grown in the developing countries with high Direct Normal Irradiation (DNI) and have proven themselves to be reliable eco-friendly sources of solar energy [1] [2]. Usually such plants located in desert regions where dust and sandstorms are the most critical events. Sand particles settle on the collectors and heliostats to cause reflectivity losses, and in case storm surface erosion occurs. According to Callot et al. [3] wind velocities of 6.5m/s represent the minimum threshold velocity for dust entraining winds in Libya. Mean monthly wind speeds were generally greater than 6.5 m/s except during the winter months. A field study by O'Hara et al. [4] based on dust monitoring of three zones across Libya for one year. The findings support the view of Callot et al.[3], that the coastal area of Libya represents one of the highest emission areas of the Sahara. Indeed, in Libya, the Sahara represents a large solar potential for concentrated solar power, it is estimated by DLR that the annual technical potential of DNI level above 1800 kWh/m² per year is 139,600 TWh/y [5]. However, in another study, the total CSP potential is estimated to be 82,714 TWh/y [6]. Due to the expected installation of these technology in the Sahara region, it will be directly exposed to outdoor weathering and influenced by dirt deposition and sandstorms [4]. Recently, many studies have investigated the effect of the real and artificial environment conditions on the optical surface. Costa et al. [7] presented a comprehensive review on dust and soiling issues related to solar energy systems. Over 250 published research in the period of 2012 to 2015 are complied. They provide a useful information that has been accomplished from monitoring performance through mitigating the problems. Sansom et al [8] investigated the effect of the airborne particle size, shape, and composition on the collecting mirrors in three arid locations that are considered suitable for CSP plants, namely in Iran, Libya, and Algeria. Sand and dust has been collected at heights between 0.5 to 2.0 m.

Other studies investigated the impact of soiling on optical characteristics of CSP & PV surfaces [9-15] were found in literature. Other work were found dealing with effect dust and sandstorms on the surface of buildings, automobiles and other outdoors facilities [16-19].

The effect of dust on the transparent cover of solar collectors was considered by Elminir et al [20]. They tried to describe the factors that contribute considerably to overcome this deficit. A 100 glass samples with different tilt angle, and azimuth angle are used. They have found that the corresponding transmittance reduces roughly in the range of 52.54 - 12.38%. Almanza et al [21] presented the first aluminum-surface solar mirrors, which, after 12 years of exposure to aggressive weather conditions in Mexico City, have a reflectance decrease of only 3.5% (from 0.85 to 0.82). Sutter et al [22] worked on the prediction of the solar hemispherical reflectance losses decrease on the aluminum reflectors caused by increasing surface roughness. After two years of outdoor exposure, the average specular reflectance losses caused by corrosion and erosion in nine different sites were found in Zagora (extremely desert) is a bit higher than for the rest of the sites with a loss of 4.2 %.

Karim et al [23], were one of those who studies the methodology that focused on the analysis of influencing parameters on the mirror surface degradation. This method was implemented in two different sites in Morocco. Different erosion test rigs were proposed in the literature [24,25] these depend on the impact velocities used as recommended by the standards for airborne particles erosion testing (DIN 50 332 and ASTM G76-89). Some studies [26,27] used (MIL-STD 810 G) standard [28] as a method in evaluating the effect of sand storm aging on the surfaces.

2. EXPERIMENTAL PROCEDURE

2.1 Sand Characteristics

Sand is defined as a loose rock material of a grain sized between 63 μm and 2 mm. There are many conditions that decide on the shape and size of sand grains: material composition, age, transport mechanism and distance travelled [29]. Old sand grains are usually rounded in shape due to the effect of repeated weathering and action of external factors and their roundness make them more accentuated and static under strong wind or tidal actions. On the other hand, younger sand grains that produced artificially by crushing sandstone tend to be irregular in shape with sharp edges. Shape of sand grains can be described by two main parameters: the sphericity and angularity [30]. The two aforementioned properties (sphericity and angularity) are usually derived by examining the grains under a microscope (magnification to x25) and comparing the shape with standard chart, with numerical indices are used to express the characteristics of sphericity and angularity [31]. The eroding samples of grains used in this study were collected from two different regions in Libya: sample (A) was from (Garaboli), an area located 50 km east of Tripoli, while sample (B) was from (Jalo), a desert area in the south east of Tripoli. Both samples (A & B) are scanned, with the use of Scanning Electron Microscopy (MSE) as shown in Figure 1, it is found that:

- Both samples have different shapes, sizes, grains color and chemical compositions and that, in particular, sand "A" is more angular, friable and small in shape with camel color. Their sizes lie in the interval of 0.025-0.355 mm.

- While, sand "B" appears rounded in shape and lager in size than sand (A) with beige color, and they have size distribution lie in the range of 0.124-0.479 mm.
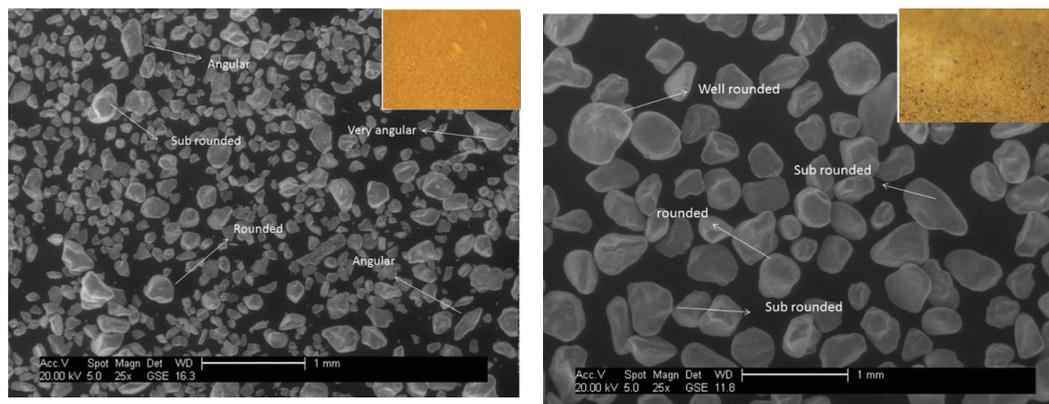
Figure (1) sands samples showing the particles shape, left : Sand A, right Sand B

In addition, they have different chemical composition as shown in Table 1.

Table (1). chemical composition of sand A and B

Atomic %	C	O	Mg	Al	Si	K	Ca	Ti	Fe
Sand A	35.4	44.63	0.5	3.1	23.14	0.74	0.38	0.225	1.9
Sand B	17.4	48.5	0.6	1.21	16.12	0.277	15.19	0.77	1.9

From Table 1, it is clear that sand (A) has higher Silica (Si) of (23.14%) than sand (B) with (16.12%). In contrast, sand (B) is higher with (15.19%) of Ca content than sand (A) with (0.38%). Therefore sand (B) is harder than sand (A) because of the calcium.

2.2 Glass Characteristics

It is a reflective glass panel manufactured by Ronda company, the layers composition and specifications are as shown in Figure 2.

Thickness	Weight (% of glass)	The reflective panels with various layers from different materials [32]
Glass: 1 mm	SiO2 72.2%	
silver: 0.076 µm	CaO 8.8%	
copper: 0.019 µm	Na2O 13.3%	
varnish: 35 µm		
adhesive: 0.2 µm		1. Glass / 2. Silver / 3. Copper / 4. Varnish / 5. Adhesive film / 6. SMC
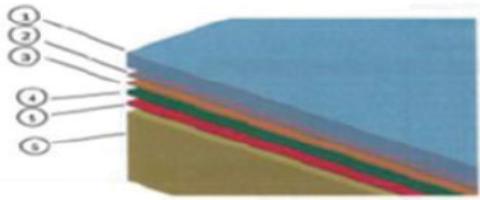
Figure (2). layers and specifications for tested reflective glass panel.

3. EROSION TESTS

There are several methods for the simulation of sand storm, including the way in which the U.S. military uses to study the impact of sand on military equipment in the desert. This method ensures that the sand particles impact the tested item at velocities in the range of 18-29 m/s. The duration of test for each sample is approximately 10s. Each test represent a simulation of single sandstorm by the injection of defined mass of sand at specified velocity. In order for the particles to attain these velocities, maintain an approximate distance of 3m from the sand injection point to the test item. Use shorter distances, if the particles can achieve the necessary velocity at the target. In order to simulate the effects of a sand storm on the solar reflector surfaces, an erosion rig had to be used. It was designed and built at Cranfield University, as depicted schematically in Figure 3. The rig consists of a number of key components starting with the air compressor (C), which supplies air at high pressure to the air vessel (P). The sand is fed by a hopper system (F) into the air flow which passes along the length of the nozzle (T) to reach and impact the work holder (S), which supports the reflector glass during the experiment. The diameter of the nozzle is approximately 13mm and the distance between the sample and the nozzle is 50 mm. The erosion tests were carried out under fixed and variable parameters as listed in Table 2.
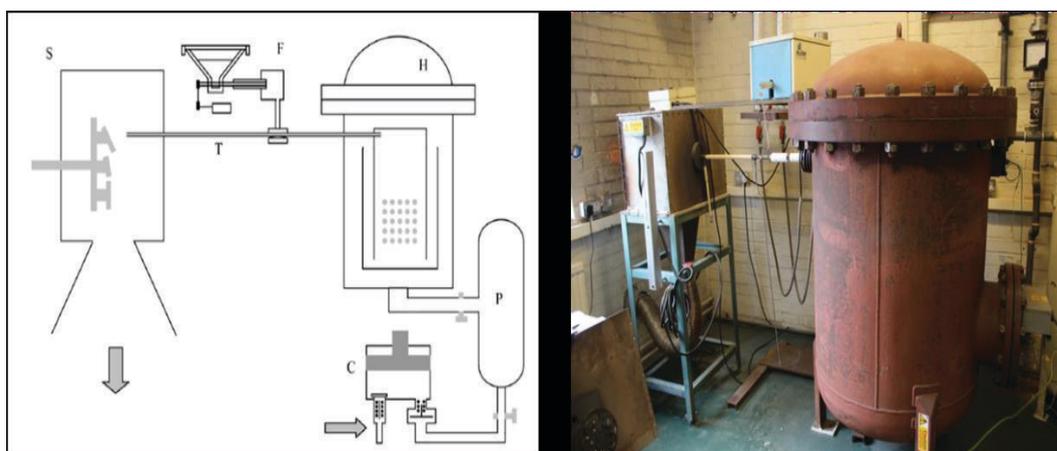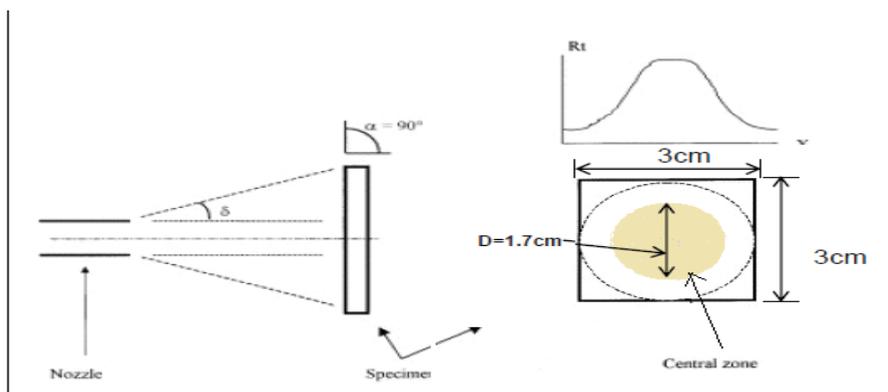
Figure (3). A schematic diagram for the erosion test rig.

Table (2). Fixed and variable parameters used in the experiment

Fixed parameters	Variable parameters
Impact angles at 90o, the tests are conducted at temperature of 25°C, ten samples of glass are considered, and distance between the pipe convergent nozzle and the samples is 50 mm.	Sand samples either sand "A" or and "B", sand particle size (washed and dried) ≈≈ sand "A" is 0.025-0.355 mm and sand "B" is 0.124-0.479 mm, Air blower velocities: 16 m/s, 21m/s, and 27 m/s, and mass of sand; 0.5 g, 1.5 g, and 2 g.

In order to simulate the effect of sand storms on the behavior of the reflective glass panel, the erosion tests were carried out using a stationary target impacted by the incident sand particles. This was carried out on two kinds of sands. The first set of tests was done with sand "A", in order to figure out the nature of their impact on five samples of reflective glass panels. The second series of tests was conducted with sand "B" on the other five glass samples. The air blower velocity was considered to be 16 m/s, 21 m/s, and 27 m/s at a constant mass of 0.5 g. The impingement angle was kept fixed at 90° and the specimen surface is perpendicular to the air flow direction.

Different sand masses were used, 0.5, 1.5, and 2 g, at a constant speed of 21 m/s. These were carried

out at a constant temperature and relative humidity; 25°C and ≈ 45% RH, respectively. The measurements of surface roughness "Ra and Sa" are carried out by the Interference Microscope (Talysurf CCI 6000) and optical reflection R(%) by Spectrometer (V-670) for each sample. The expected impact damage is measured by Olympus Lext Confocal Laser Scanning microscope.

4. RESULTS AND DISCUSSIONS

4.1 Optical Reflection

The erosion tests were carried out with and without cleaning of the reflector surfaces of the samples. The reflection spectra are measured in the visible range of 500-1000 nm, the as manufactured reflectivity of the target surface is approximately 98.4%. Referring to the tests, while the storm speed is kept constant at 21 m/s and without cleaning, it has been noticed that, the reflectivity values decrease almost steadily as the projected mass of sand increases. They reaches 90% for sand "A", and 94% for sand "B" at mass of sand of 2g, as shown in Figure 4.

The reflectivity, at constant mass of sand of 0.5 g and without cleaning decreases with the increase of sand flow speed to 87.8 % for sand "A", and to 92% for sand "B", at the storm speed of 27 m/s, as shown in Figure 5. However, cleaning the surfaces of the target increases the reflectivity by about 2 % with respect to the previous cases titled "unclean". Hence, the values of reflectivity, at constant speed of 21 m/s and mass of 2g, are 92.6% for sand "A" and 96.3% for sand "B", as shown in Figure 6. Whereas, the surface reflectivity, at fixed mass of 0.5 g and speed of 27 m/s, are 90.2% for sand "A" and 93% for sand "B", as depicted in Figure 7.
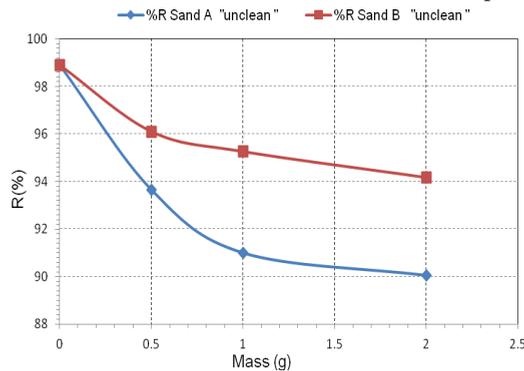
Figure (4). Variation of reflectance spectra with mass of sand at speed 21m/s (unclean)
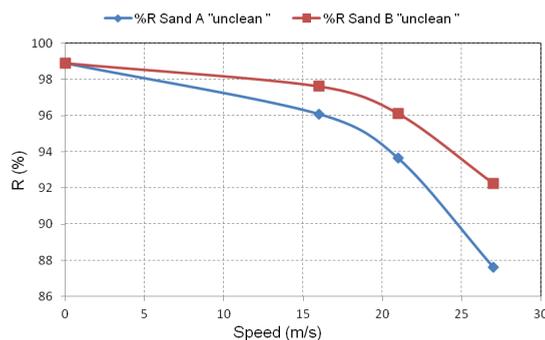
Figure (5). Variation of reflectance spectra with storm speed and mass of 0.5g (unclean).
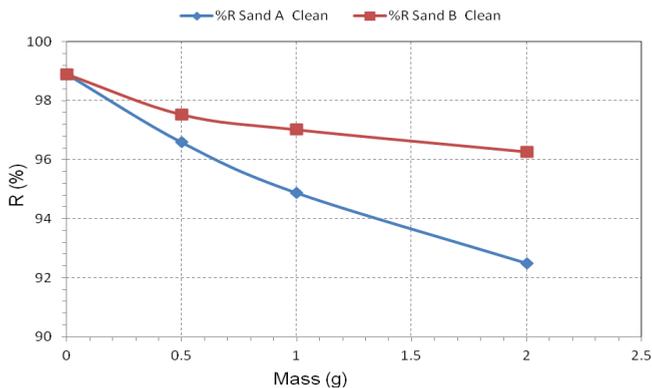
Figure (6). Variation of reflectance spectra with mass of sand at speed 21m/s (clean).
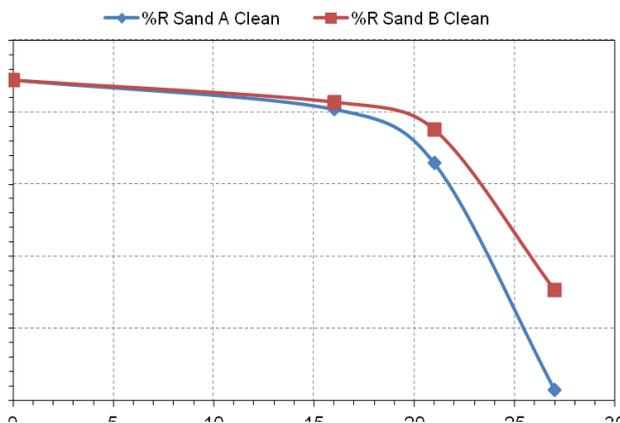
Figure (7). Variation of reflectance spectra with storm speed at mass 0.5g (clean)

Figure 8 shows the measurement of specular reflectivity loss along to the wavelength of constant speed 21 m/s and different mass.
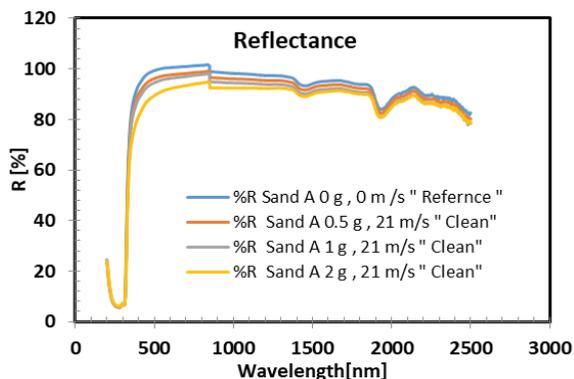
Figure (8). Specular reflectance of cleaned glass mirrors

The decrease in the surface reflectivity is mainly due to the increase of the impact damage as a consequence of the increase of the mass of sand. This is mostly true for the cases when the storm speed increases. In fact, these reflectivity losses are induced by diffusion processes of the light. It is notable from the test results that, sand "A" has higher effect on the reflection process than sand "B". This is could be attributed to the fact that, the particles of sand "A" are, smaller, and more in quantity than the particles of sand "B", and hence the light strikes more scattered surfaces due to the damage and hence diffusion process will take place widely.

4.2 Surface Roughness

Figures 9 and 10 show the effect of variation of the surface roughness as a function of both: the speed of the storm, and the mass of sand. The first set of results shows the surface roughness Sa versus the speed of the storm, in the two cases of without and with cleaning respectively. It is very clear from Figure 10 that surface roughness increases strongly until about µ m in case of mass of 0.5g in the range of speed tests.

More damage is observed in case of increasing mass of sand at constant test speed of 21 m/s as shown in Figures 11-12. This is true for clean and unclean reflector surfaces. Referring to Figure 12, for both sand samples over clean reflectors, the roughness mostly doubled when the sand mass goes from 0.5 to 2g. However, for unclean reflectors, the roughness mostly tripled for the same sand mass range from 0.5 to 2g, as indicated in Figure 11.
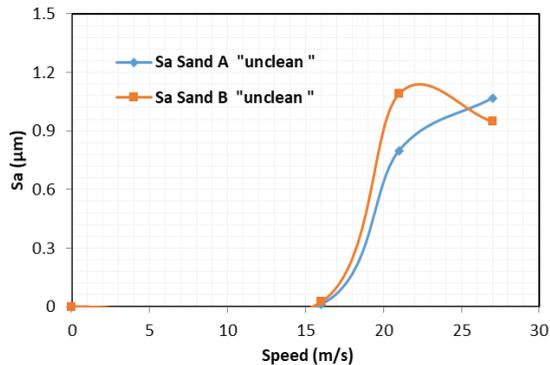
Figure (9). Evolution of the unclean-surface roughness versus storm speed at mass 0.5g.
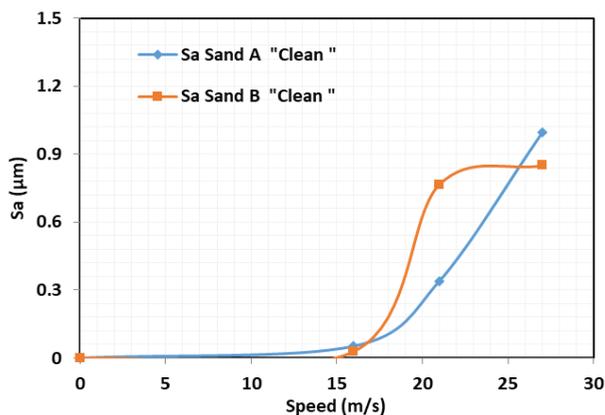
Figure (10). Evolution of the clean-surface roughness versus storm speed at mass 0.5g.
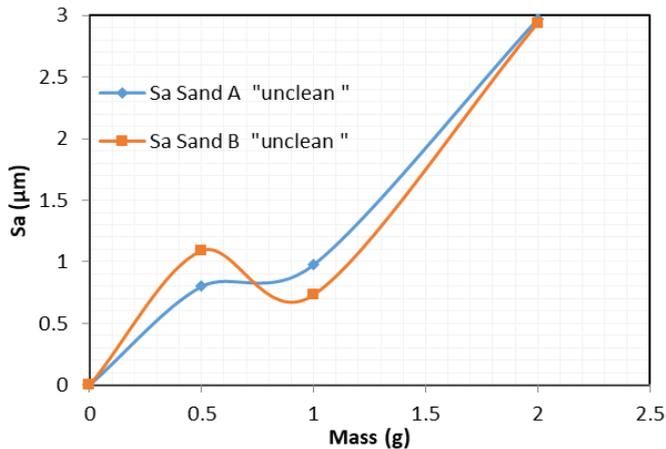
Figure (11). Evolution of the unclean-surface roughness versus sand erosion for different masses at speed 21 m/s.
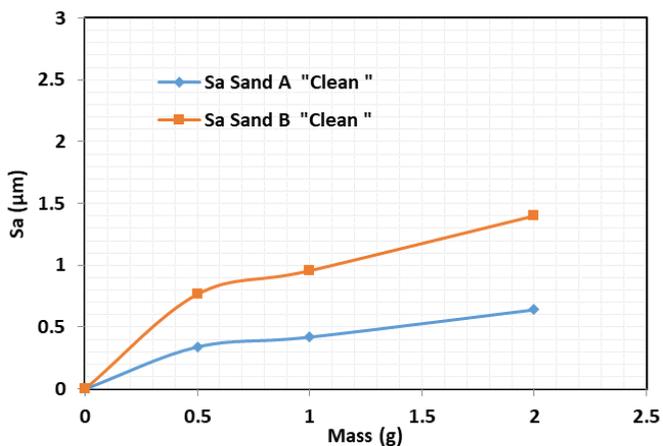
Figure (12). Evolution of the clean-surface roughness versus sand erosion for different masses at speed 21 m/s**.**

Figure 13 illustrates the measurements of the impact of sand on the reflector surface changes. It is not steady on the whole surface, in the same time the roughness of the surface increased abruptly.
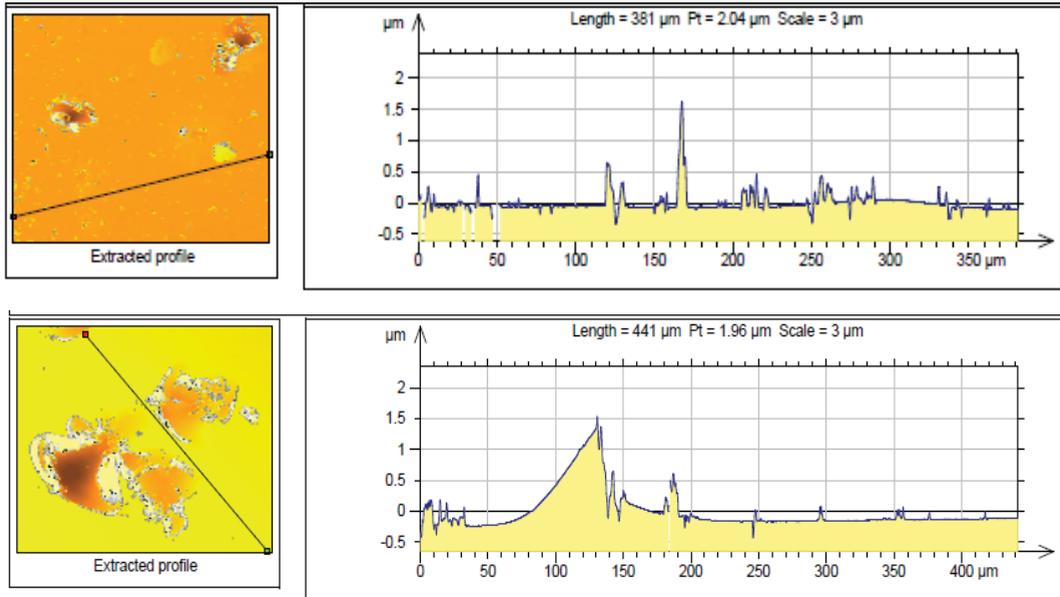
Figure (13). Profile of surface roughness (CCI) for 0.5 g, 21 m/s.(above Sand"A", below Sand"B")

3.4 Microscopic Observations:

At the end of the sand erosion tests, the damaged surfaces were screened by microscopy. Figures 13-14 show a number of typical sand defect spots for both kinds of sands under different operation-related conditions. This is done into two test sets; reflective samples with different mass of sand at constant storm speed of 21 m/s, as indicated in Figure 13, and reflective panel with different speeds at fixed mass of sand of 0.5 g, as shown in Figure 14. Generally, the results show that the number of defect spots and the amount of surface damage increase as the storm speed increases, these damages also increase as the mass of sand increases.

Referring to Figure 13, which is related to constant storm speed of 21 m/s while the mass of sand takes different values, the defect spots are randomly distributed over the area of the surface. For example, for the mass of sand "A" of 2 g, the sizes of defect spots are relatively small and tend to cover the entire reflector exposed surface. However, for sand "B" with same mass of 2 g the number of spots decreases and they are far apart. Hence, from these results, it appears that sand "A" has more damage for the reflector surface than sand "B". This is most likely due to the larger amount and smaller size and more angular particles of sand "A" compared to characteristics of sand "B".

According to Figure 14 related to fixed sand mass of 0.5 g with different storm speeds, almost the same manner is observed where the defects are randomly distributed over the area of the surface. For sand "A", at speed of 27 m/s, the sizes of such spots are small and spread mostly cover all the surface. However, for sand "B" at the same speed of 27m/s, the defect spots are far apart, their number decreases while their size increases.

For the evaluation purpose to quantify the affected area, the defected areas are estimated and compared. Figure 15 shows the relation between the average impact reflector surface area and the mass for each sand. For the case of sand "A", the average impact area increases sharply with the increase of the mass of the sand. The maximum average impact of reflector surface area for mass of 2g was found to be 6050μm². However, the average impact area increases slowly with mass increase in case of sand "B". The maximum average impact of reflector surface area for mass of 2g was around 3021 μm², about half of the former amount.
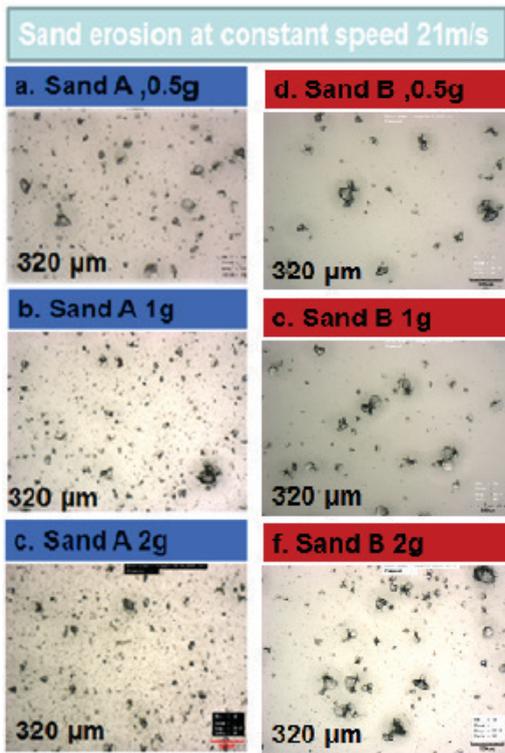
Figure 13: Samples of reflector sand erosion for different sand masses at storm speed of 21m/s (x-25).
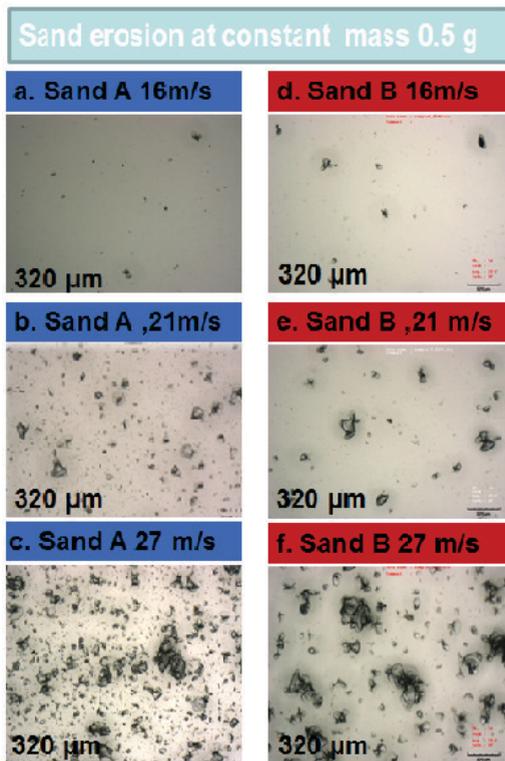
Figure 14: Samples of reflector sand erosion for different storm speeds with sand mass of 0.5g (x-25).
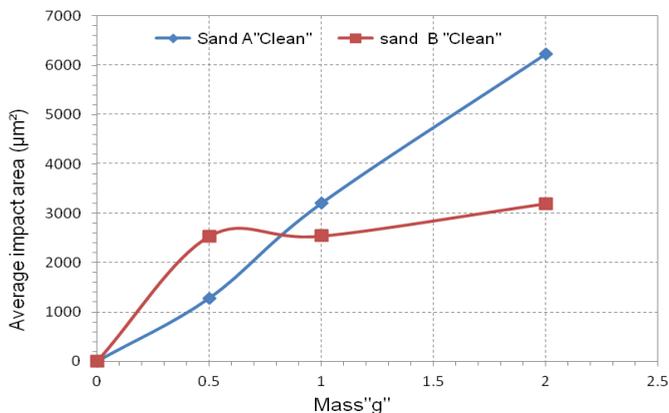
Figure (15). Variation of the average impact clean-area with the mass of the sand for a storm speed of 21m/s.

Referring to the effect of storm speed on the reflector surface area damaged, Figure 16 shows the relation between the average impact of reflector surface area and storm speed for both sand types. Generally, the

average impact reflector of surface area increases with the increase of storm speed. However, the average impact reflector surface area for low storm speed is largely affected in case of sand "B" compared to sand "A", except for the storm speed of 27m/s, the opposite view has occurred, sand "A" has larger effect on the average impact reflector surface area of 5550 μm² which is a bit higher than sand "B" effect of 5000 μm².
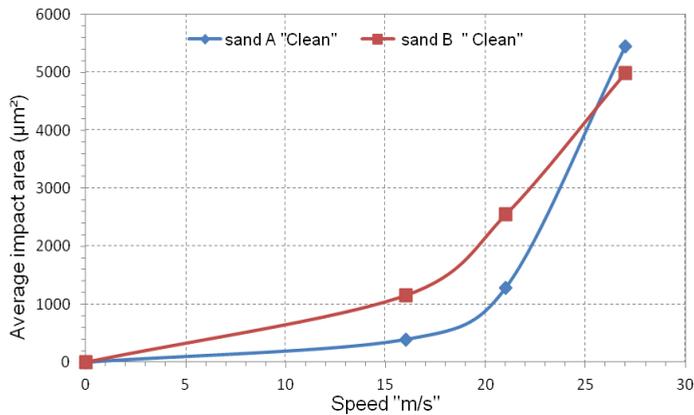
Figure (16). Variation of the average impact clean-area with the storm speed for a mass of sand of 0.5g.

5. CONCLUSIONS

This paper attempts to demonstrate the optical effect of sand storms, related to two different Libyan sand types (sand "A" and sand "B"), on a samples of reflectors (Ronda) used for concentrating solar power plants. Sand "A" is from the north part of Libya near to the coastal area and is characterized by fine camel color grains, 0.025-0.3550 mm, while sand "B" is from southern part of Libya (Desert region) and is characterized by beige color and bigger size grains, 0.124-0.479 mm. Using erosion rig, over ten samples of Ronda-type reflectors were tested at different sand masses and storm speeds. The measurements of the surface roughness are carried out by the Interference Microscope (Talysurf CCI 6000) and optical reflection by Spectrometer (V-670). The samples used are tested at wavelength of (500-1000 nm), it was found that the as-built initial state of the reflectors has a reflectivity of 98.4%.

The results have shown that using sand blaster with mass of 2 g and speed of 21 m/s, the reflectivity of un-cleaned samples with sand "A" has decreased to 90% and with sand "B" has decreased to 94% without cleaning. However, after cleaning the reflectivity of the surfaces has increased by more or less 2%, to become 92.6% for the case of sand "A" and to 96.3 for sand "B". Here, cleaning technique, probably with air, should be considered in future Sahara planned projects. More results were presented for different masses and at different speeds for both sand types.

The results of surface damage in the range of mass and speed tested in this study have shown that, the surface roughness is increased by about 1 mm in case of mass of 0.5 g and speeds up to 27 m/s. however, the damage was more obvious, up to 3 mm, in case of increasing the mass up to 2 g at speed of 21 m/s. The study has made it clear that sand storms have undesirable influence on the optical characteristics of the reflector surfaces of the CSP plants. The damage spots were occurred and well presented. Surface heat up is expected due to the accumulation of sand on the reflector surface leading to higher surface absorptivity. The expected degradation in the reflectivity of Ronda surfaces examined with Libyan sand "B" might reach to 2% yearly.

6. REFERENCES

[1]. International Energy Agency [IEA], "World Energy Resources: Solar 2016," World Energy Counc., p. 6, 2016.

[2]. G. S. Report, REN21 Secretariat, Renewables 2017 global status report. 2017.

[3]. Callot, Y., Marticorena, B., Bergametti, G., 2000. Geomorphologic approach for modelling the surface features of arid environments in a model of dust emissions: application to the Sahara desert. Geodinamica Acta 13 (5), 245–270.

[4]. Sarah L. O'Hara, Michele L. Clarke, Mokhtar S. Elatrash, (2006). Field measurements of desert dust deposition in Libya, Atmospheric Environment 40 (21) pp. 3881–3897

[5]. DLR MED-CSP, 2005. Concentrating Solar Power for the Mediteranean Region. <http://www.dlr.de/tt/portaldata/41/ Resources/dokumente/institut/system/projects/MED-CSP Full report final.pdf>

[6]. M. Moser, F. Trieb, and T. Fichter, "Potential of Concentrating Solar Power Plants for the Combined Production of Water and Electricity in MENA Countries," J. Sustain. Dev. Energy, Water Environ. Syst., vol. 1, no. 2, pp. 122–140, 2013.

[7]. Costa S. C. S., Diniz A. C., Kazmerski L. L., Dust and Soiling issues and impacts relating to solar energy systems: Literature review update for 2012-2015, Renewable and Sustainable Energy reviews, 63 (2016) 33-61.

[8]. C. Sansom, H. Almond, P. King, E. Endaya, and S. Bouaichaoui, "Airborne sand and dust soiling of solar collecting mirrors," AIP Conf. Proc., vol. 1850, no. June, 2017.

[9]. H. Pedersen, J. Strauss, and J. Selj, "Effect of Soiling on Photovoltaic Modules in Norway," Energy Procedia, vol. 92, pp. 585–589, 2016.

[10]. R. B. Pettit and J. M. Freese, "Wavelength Dependent Scattering Caused By Dust Accumulation on Solar Mirrors.," Sol. energy Mater., vol. 3, no. 1–2, pp. 1–20, 1980.

[11]. D. J. Griffith, L. Vhengani, and M. Maliage, "Measurements of mirror soiling at a candidate CSP site," Energy Procedia, vol. 49, pp. 1371–1378, 2013.

[12]. A. A. Merrouni, F. Wolfertstetter, A. Mezrhab, S. Wilbert, and R. Pitz-Paal, "Investigation of Soiling Effect on Different Solar Mirror Materials under Moroccan Climate," Energy Procedia, vol. 69, pp. 1948–1957, 2015.

[13]. A. O. Mohamed and A. Hasan, "Effect of dust accumulation on performance of photovoltaic solar modules in Sahara environment," J. Basic Appl. Sci. Res., vol. 2, no. 11, pp. 11030–11036, 2012.

[14]. M. Guerguer, M. Karim, S. Naamane, Z. Edfouf, O. Raccurt, and C. Delord, "Soiling deposition on solar mirrors exposed in Morocco," AIP Conf. Proc., vol. 1850, 2017.

[15]. R. Conceição, H. G. Silva, and M. Collares-Pereira, "CSP mirror soiling characterization and modeling," Sol. Energy Mater. Sol. Cells, vol. 185, no. May, pp. 233–239, 2018.

[16]. N. P. Woodruff, "Wind-blown soil abrasive injuries to winter wheat plants.pdf," Agron. J., pp. 499–504, 1956.

[17]. D. V Armbrust, "Recovery and nutrient content of sandblasted soybean seedlings," Agron. J., vol. 64, no. October, pp. 707–708, 1972.

[18]. Q. Jianjun, H. Ning, D. Guangrong, and Z. Weimin, "The role and significance of the Gobi Desert pavement in controlling sand movement on the cliff top near the Dunhuang Magao Grottoes," J. Arid Environ., vol. 48, no. 3, pp. 357–371, 2001.

[19]. Z. Wang, L. Liu, X. Li, and L. Zhao, "An experimental method for analyzing environmental effects of blowing sands on glass abrasion," Procedia Environ. Sci., vol. 2, no. October 2015, pp. 207–217, 2010.

[20]. H. K. Elminir, A. E. Ghitas, R. H. Hamid, F. El-Hussainy, M. M. Beheary, and K. M. Abdel-Moneim, "Effect of dust on the transparent cover of solar collectors," Energy Convers. Manag., vol. 47, no. 18–19, pp. 3192–3203, 2006.

[21]. R. Almanza, P. Hernández, I. Martínez, and M. Mazari, "Development and mean life of aluminum first-surface mirrors for solar energy applications," Sol. Energy Mater. Sol. Cells, vol. 93, no. 9, pp. 1647–1651, 2009.

[22]. F. Sutter, J. Wette, F. Wiesinger, A. Fernández-García, S. Ziegler, and R. Dasbach, "Lifetime prediction of aluminum solar mirrors by correlating accelerated aging and outdoor exposure experiments," Sol. Energy, vol. 174, no. September, pp. 149–163, 2018.

[23]. Karim M., Naamaneetal S., 2014, Towards the prediction of CSP mirrors wear: Methodology of analysis of influencing parameters on the mirrors surface degradation: Application in two different sites in Morocco, Solar Energy,

Vol 108, pp 41-50.

[24]. C. Holze and A. Brucks, "Accelerated lifetime modeling on the basis of wind tunnel analysis and sand storm aging," *Energy Procedia*, vol. 49, pp. 1692–1699, 2013.

[25]. F. Reil, I. Baumann, J. Althaus, and S. Gebhard, "Evaluation of current standards and practices for the simulation of wind-blown sands and their applicability as accelerated ageing tests for PV modules," *Conf. Rec. IEEE Photovolt. Spec. Conf.*, pp. 1537–1541, 2013.

[26]. P. H. Shipway and I. M. Hutchings, "Influence of nozzle roughness on conditions in a gas-blast erosion rig," *Wear*, vol. 162–164, no. PART A, pp. 148–158, 1993.

[27]. P. Chevallier, A. B. Vannes, and A. Forner, "New parameters in erosion for study of bulk materials and coatings," *Wear*, vol. 186–187, no. PART 1, pp. 210–214, 1995.

[28]. MIL-STD 810 G, 2008. Test Method Standard: Environmental Enginnering consideration and laboratory tests, United States Department of Defense. <http://www.dtc.army.mil/publications/MIL-STD 810 G.pdf>

[29]. http://www.sand-atlas.com/en/shape-of-sand-grains/

[30]. Ajit Jillavenkatesa, Stanley J. Dapkunas, Lin-Sien H. Lum, Particle Size Characterization, National Institute of Standards and Technology Special Publication 960-1, 2001

[31]. Baker, Stephen W. Rootzones, Sands and top dressing materials for sports turf. STRI, 2006.

[32]. Data sheet Ronda High-Tech reflective panels "Technical data sheet, material characteristic"