REMOVAL OF DUST PARTICLES FROM THE SURFACE OF SOLAR CELLS AND SOLAR COLLECTORS USING SURFACTANTS

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ABSTRACT

One of the challenges that face the operation of solar cells and solar collectors in sandy areas is the deposition of sand particles on the glass-surface of the cells and collectors. The objective of this research is to remove the deposited particles using a surfactant with the minimum amount of water utilization. Three types of surfactants have been examined; anionic, cationic and zwitterionic. The influence of a surfactant on removal of sand particles from a fouled surface has been examined under the microscope. It is found that the most effective surfactant is the anionic, and the least effective is the cationic in case of purely sand particles. This could be due to the repulsive forces between the negatively charged sand particles and the negatively charged molecules of the anionic surfactant, which repel and remove the deposited sand particles. Cationic surfactants are positively charged, which causes adhesion to the sand particles, and no removal takes place. Another set of experiments is performed utilizing sand particles covered with carbon particles. It found that the most effective surfactant is the cationic, and the least effective is the anionic, which is opposite to the behaviour of the surfactant with purely sand particles, and that is due to the positive charge on the carbon particles. It can be concluded that the surfactant behaviour is dependent on the electrical charge of the deposited particles. The influence of the zwitterionic is between the influence of the anionic and the cationic surfactants and depends on the ph value of the water used.

INTRODUCTION

Solar cells and solar collectors in sandy areas, e.g. the Middle East and North Africa (MENA) region, are subjected to sever deposition of sand particles on the glass-surface of the cells or collectors, as can be seen in Fig. 1. The surface of the solar collectors is fouled very quickly in sandy areas, as stated by the New and Renewable Energy Authority in Egypt (2010). Fouling is defined as the deposition of foreign particles, e.g. fine sand particles, on a heat transfer surface forming an insulating layer that reduces the rate of heat transfer (Abd-Elhady et al., 2009). El-Nashar (1994, 2009) studied the influence of dust deposition on the performance of evacuated tube collectors

on a large field of collectors and found that accumulated dust on this type of collector can result in a substantial reduction in the collector efficiency. Elsherif and Kandil (2011) have measured the performance of a Photovoltaic (PV) module, i.e. an array of solar cells, installed in Cairo, and found that the efficiency of the cells has decreased by 25 % in the first two months of operation, and by 40 % after one year, as shown in Fig. 2. Fouling results in a lot of maintenance in order to keep the efficiency of the collector at an acceptable level.
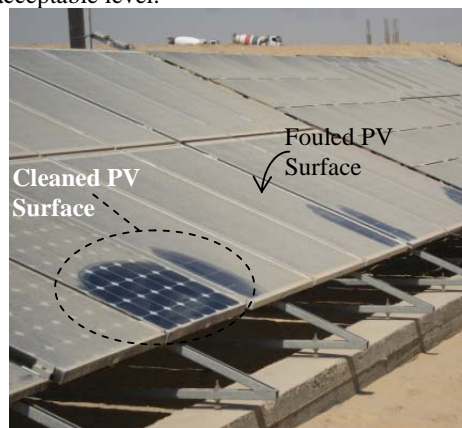

Fig. 1. Accumulation of sand particles on Photovoltaic (PV) panels installed in Cairo after two months of operation.

Precision cleaning methods are often chosen in a hit-or-miss fashion. This often leads to inadequate or inefficient cleaning systems which end up costing more in the long run. Removal of particles from surfaces has been a topic of interest to both the scientists and technological communities many years (Mittal, 1988, 1989, 1991). There are several techniques which can remove particles that are less than 10 μm in diameter, which is the particle size of importance in the presented research. These methods include: ultrasonic, megasonic, wiping, brush scrubbing, low-pressure surfactant spraying, high-pressure jet spraying, etching, and centrifugal spraying (Bardina, 1988). In the current research, the influence of low-pressure surfactant spraying on removal of sand particles from a fouled surface is examined under the microscope.
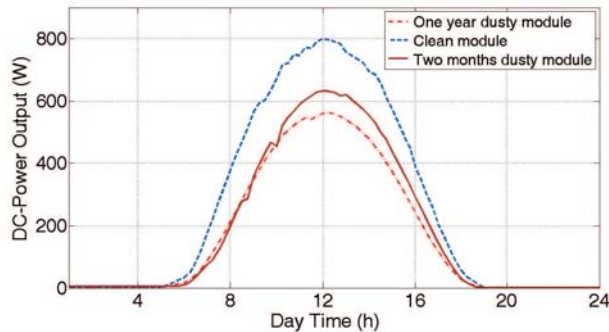
Fig. 2. Power output from a photovoltaic module installed in Cairo after two months and after one year of operation. The dashed line is the clean condition operation. Adapted from Elsherif and Kandil (2011).

The main component of the adhesion force that holds the particles together are the van der Waals force, the electrical double layer force, the electrostatic image force, and the capillary force (Bhattacharya and Mittal, 1978). The van der Waals force is the attraction any molecule has for another molecule or atom (Corn, 1961; Bowling, 1988). Electrical double layer forces are caused by electrostatic contact potentials due to differences in local energy states and electron work functions between two materials, and electrostatic image forces are caused by bulk excess charges present on the surface which produce a columbic attraction (Allen Bowling, 1985). The last component, capillary forces, exists in the presence of humidity. When a cleaning surfactant is used, only the van der Waals force needs to be taken into account. The best surfactant will quickly dissipate charges so that the static forces are overcome. When the solvent moves over the surface and the gas/solid interface disappears, the capillary force will also disappear (Stowers and Patton, 1979). The success of low-pressure surfactant spraying depends on the effectiveness of the detergent that is sprayed. The pressure of the jet itself is not nearly enough by itself to remove particles. Therefore the compatibility of the detergent with the contaminant and the surface is crucial.

Surfactants are made up of two parts: a head group and a chain (Rosen, 2010), as illustrated in Fig. 3. The hydrocarbon chain has a very weak interaction with water. It is classified as hydrophobic because of the strong interactions between water molecules due to hydrogen bonding and dispersion forces squeeze the hydrocarbon out of the water (Tadros, 1984). The head group is hydrophilic because it is solvated by interacting strongly with water through ion-dipole or dipole-dipole interactions. Whether a detergent is anionic, cationic or zwitterionic depend on the charge of its head group (Workman, 2000). The head of the anionic surfactant is negatively charged, while the head of a cationic surfactant is positively charged, as shown in Fig. 3. Zwitterionic contains a head with two oppositely charged groups. Zwitterionic surfactants are very mild, they can be anionic (negatively charged), cationic (positively charged) or non-ionic (no charge) in solution, depending on the acidity or pH of the water.

El-Nashar (2009) has demonstrated the effect of the frequency of water cleaning, i.e. daily, weekly and monthly for one whole year, on the water production of a solar desalination plant using evacuated tube collectors. The desalination plant is located near the city of Abu Dhabi in the UAE, and the evacuated tubes are cleaned by spraying water. It is found that the plant consumes about 4 % of the water produced for daily cleaning, in order to maintain the collector efficiency, which is a substantial amount of water. The objective of this research is to remove the deposited sand particles using a surfactant with the minimum amount of water utilization. Three types of surfactants, obtained from Alfa Aesar, have been examined; anionic (Sodium dodecyl Sulphate), cationic (Cetylpyridinium Bromide) and zwitterionic (Tween-80). The influence of a surfactant on cleaning a fouled surface from the deposited sand particles has been examined under the microscope, and each experiment has been repeated more than 4 times to make sure of the consistency of the presented results.
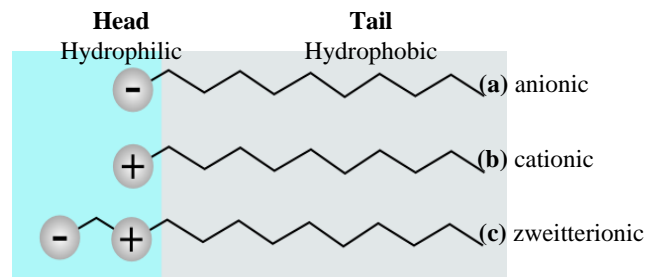

Fig. 3. Surfactant classification according to the composition of their head: (a) anionic (negatively charged), (b) cationic (positively charged) and (c) zweitterionic (two oppositely charged groups).

EXPERIMENTAL WORK AND EXPERIMENTS PERFORMED

Sand particle are blown on a glass surface to simulate the developed sand layers on the surface of solar collectors and solar cells in desert areas. The fouled glass surface is taken afterwards to a light microscope. The fouled glass surface is sprayed with a surfactant and the influence of the surfactant on the fouling layer is monitored through the light microscope as shown in Fig. 4. Spraying of the surfactant is done via a dose pump, such that the droplet size and rate can be controlled. In each experiment only one droplet of surfactant is used and the diameter of the droplet is 4 mm.

Hegazy (2001) has experimentally investigated dust accumulation on glass plates over a period of 1 year in the Minia region of Egypt, also Hasan and Sayigh (1992) have monitored dust accumulation on tilted glass plate located in Kuwait for 38 days. Both found that the deposited layers were yellowish brown, and consisted mainly of quartz sand. The brown color of the deposit is due to unburned hydrocarbon resulting from engine emissions. Two types of particles are used in the performed experiments, non-metallic spherical quartz sand particles and metallic spherical carbon particles. The carbon particles have an average diameter of 5 μm with a standard deviation of ±4

μm. Two sets of sand particles have been used; fine particles of an average diameter of 10 μm with a standard deviation of ±4 μm, and coarse particles of an average diameter of 40 μm with a standard deviation of ±10 μm. The particle size distribution for the glass and carbon particles are shown in Fig. 5.
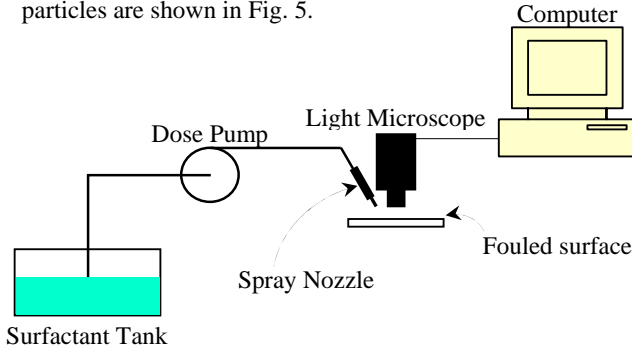

Fig. 4. Experimental setup.
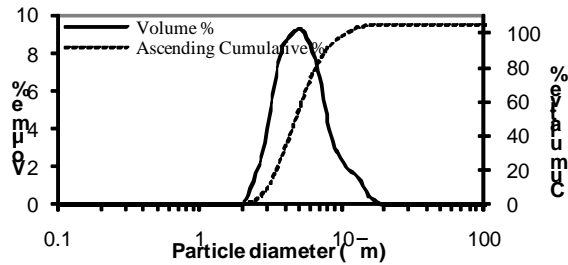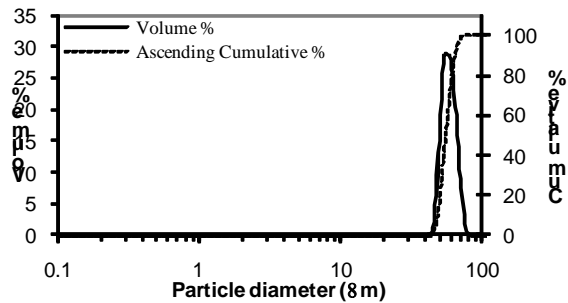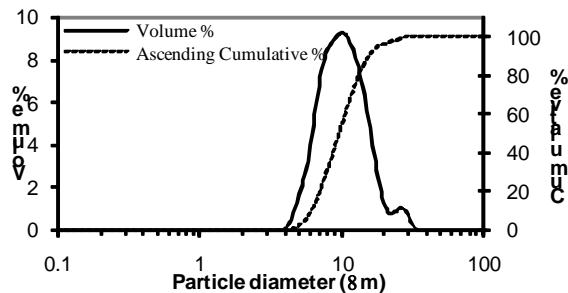

a- PSD for carbon particles; average diameter 5 μm and standard deviation ± 4 μm.

b- PSD for coarse sand particles; average diameter 40 μm and standard deviation ± 10 μm.

c- PSD for fine sand particles; average diameter 10 μm and standard deviation ± 4 μm.

Fig. 5. Particle size distributions (PSD) for a- carbon particles, b- coarse sand particles and c- fine sand particles.

Experiments Utilizing a Cationic Surfactant

The progress of a cationic droplet over a glass surface fouled with fine sand particles of particle size distribution (PSD) of 10 μm ± 4 μm is shown in Fig. 6, and in case of large sand partcles of PSD of 40 μm ± 10 μm is shown in Fig. 7. It can be concluded from Fig. 6 that the cationic surfactant is not capable of mixing with the fine sand particles, such that there is a clear boundary between the cationic droplet and the sand particles. The cationic droplet can easily adhere to the sand surface without further movement. This is due to the fact that the cationic droplet is positively charged while the sand particles are negatively charged as indicated by Zhang et al. (2000), such that an attraction force is developed between the sand particle and the surfactant droplet, which keeps the surfactant droplet adhered to the sand surface. A similar behavior has occurred in case of a fouling layer of large sand particles except that the surfactant was absorbed quickly by the sand layer. This is due to the high porosity of the fouling layer which constitutes of large particles, such that the surfactant is first adhered to the fouling layer and then penetrates into the layer, i.e. diffuses into the sand layer due to concentration difference. It can be concluded that a positively charged surfactant, i.e. a cationic surfactant, is not capable of removing the sand particle from the fouled surface, but it can adhere to it, i.e. it can adhere to negatively charged particles.
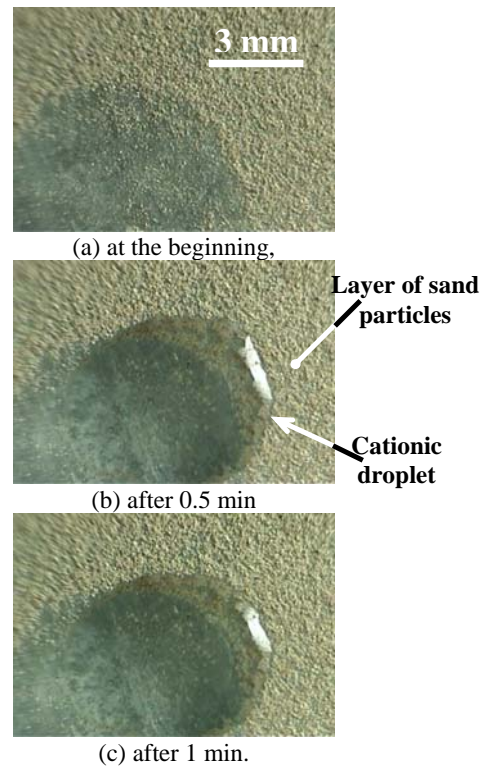

(a) at the beginning,

(b) after 0.5 min

(c) after 1 min.

Fig. 6. The progress of a Cationic droplet over a glass surface fouled with sand particles. The particle size distribution for the sand particles is 10 μm ± 4 μm.

Another experiment is performed with carbon particles, i.e. positively charged particles, which are placed on top of the layer of sand particles that is shown in Fig. 6. Carbon particle has a positive potential in water due to it affinity to electrical charge as indicated by Weingartner et al. (1997). The carbon particles have PSD of 5 μm $\pm$ 4 μm and the sand particles have PSD of 10 μm $\pm$ 4 μm. Figure 8 show the progress of the Cationic surfactant over the fouling layer. It can be clearly seen that the cationic surfactant has succeeded in repelling the carbon particles on the sand layer, and breaking the top carbon layer into small pieces. However, it was not possible to remove the bottom fouling layer, i.e. the sand particles. It can be concluded that the cationic surfactant can disperse positively charged particles, e.g. soot particles, and cannot remove negatively charged particles, e.g. sand particles.
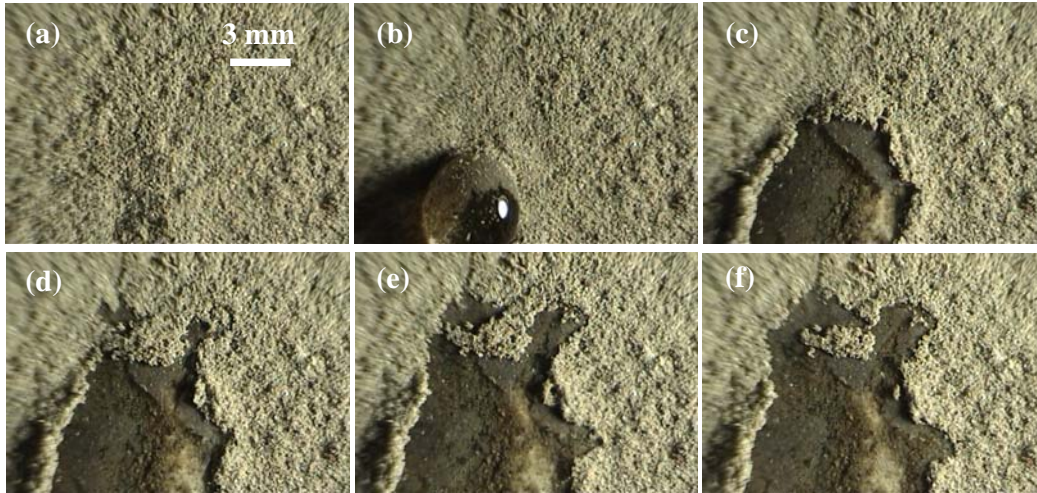

Fig. 7. The progress of a Cationic droplet over a glass surface fouled with sand particles; (a) at the beginning, (b) after 20 s, (c) after 25 s, (d) after 30, (e) after 40 s and (f) after 1 min. The particle size distribution for the sand particles is 40 μm $\pm$ 10 μm.
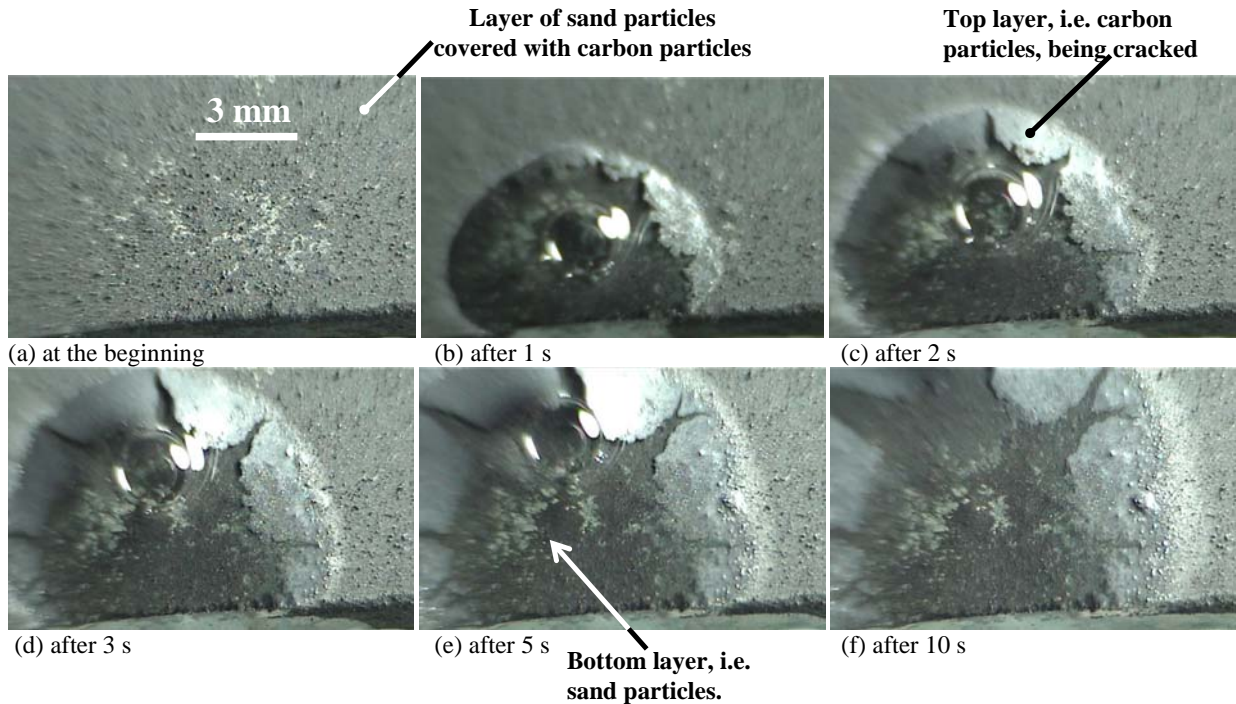

Fig. 8. The progress of a Cationic droplet over a glass surface fouled with sand particles and a fine layer of carbon particles on top of the sand particles. The particle size distribution for the sand particles is 10 μm $\pm$ 4 μm, and for the carbon particles is 5 μm $\pm$ 4 μm.

Experiments Utilizing an Anionic Surfactant

The progress of an anionic droplet over a glass surface fouled with large sand particles of particle size distribution (PSD) of 40 μm ± 10 μm is shown in Fig. 9. It can be concluded from Fig. 9 that the anionic surfactant is capable of repelling and removing the sand particles. This is due to the fact that the anionic droplet is negatively charged as well as the sand particles, such that a repulsive force is developed between the sand particle and the surfactant droplet, which is capable of removing the sand particles and cleaning the glass surface from the deposited sand particles, as can be seen in Fig. 9.f. It can be seen from Fig. 9.f that the deposited sand particles have been removed such that the underlying glass surface is clear to see. A similar behavior has occurred in case of utilizing a zwitterionic surfactant, except that the zwitterionic is slower in its action compared to the anionic surfactant. The used tap water is alkaline, i.e. pH value is > 7, which results in transforming the zwitterionic surfactant to an anionic surfactant.
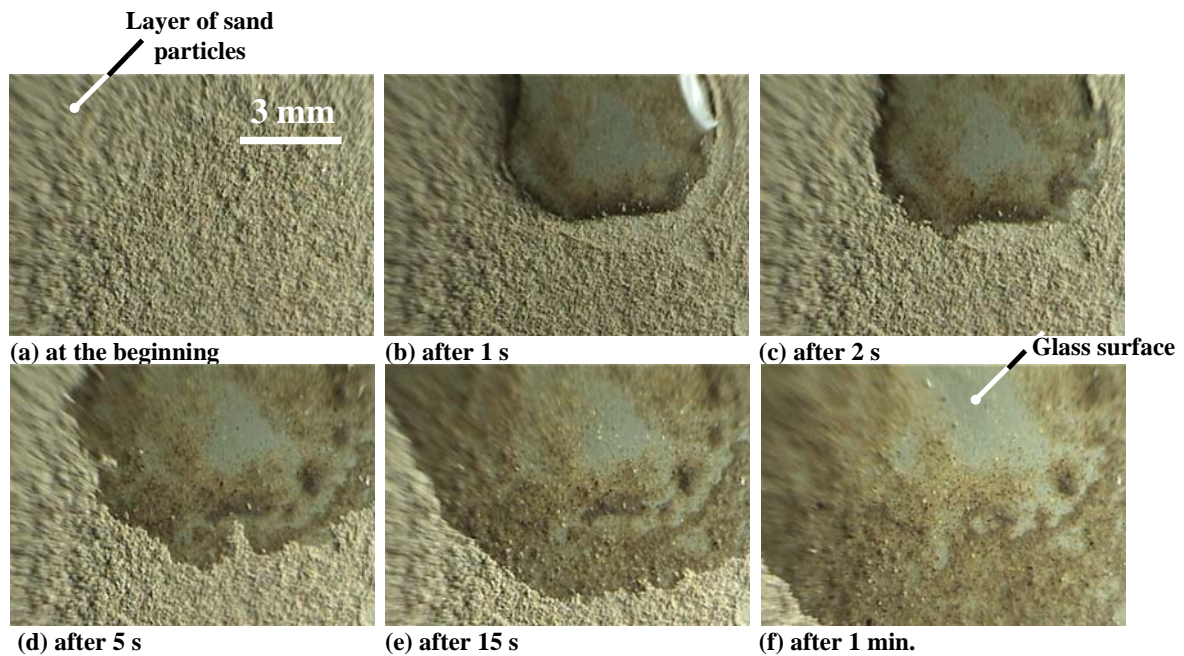

Fig. 9. The progress of an anionic droplet over a glass surface fouled with sand particles. The particle size distribution for the sand particles is 40 μm ± 10 μm.

Another experiment is performed with carbon particles placed on top of the fouling layer shown in Fig. 6, i.e. the sand particles. The carbon particles have PSD of 5 μm ± 4 μm and the sand particles have PSD of 10 μm ± 4 μm. The progress of an anionic droplet over the fouling layer is shown in Fig. 10. It can be clearly seen that the anionic surfactant has failed to remove the deposited particles, i.e. the sand and the carbon particles. The anionic surfactant moves over the fouling layer without affecting the fouling layer, as can be seen from Fig. 10. This is attributed to the fact that the anionic surfactant is negatively charged and the carbon particles are positively charged, which causes the carbon particles to become neutralized as soon as the surfactant passes over the carbon particles. Neutralization of the carbon particles diminishes any repulsive forces to develop causing the surfactant to pass over the fouling layer without any resistance as can be seen from Fig. 10. A similar behavior occurred while utilizing a zwitterionic surfactant in alkaline water.
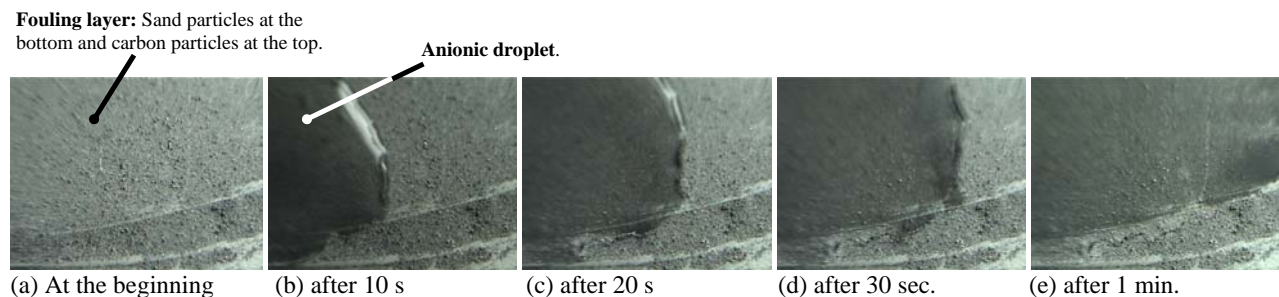

Fig. 10. The progress of an aionic droplet over a glass surface fouled with sand particles and a fine layer of carbon particles on top of the sand particles. The particle size distribution for the sand particles is 10 μm ± 4 μm, and for the carbon particles is 5 μm ± 4 μm.

Experiments Utilizing a Mixture of an Anionic and Cationic Surfactant

The influence of mixing surfactants together on cleaning is examined in this experimnet. A new surfactant is made, which is a mixture of the anionic and the cationic surfactants used in the previous experiments. The mixing ratio is 1:1. The influence of the mixed surfactants on cleaning a glass surface fouled with sand particles and a fine layer of carbon particles on top of the sand particles is shown in Fig. 11. The particle size distribution for the sand particles is 10 μm ± 4 μm, and for the carbon particles is 5 μm ± 4 μm. It can be concluded that the mixed surfactants succeded in removing both the sand particles as well as the carbon particles, such that the underlying glass surface becomes clean and clear to see. It can be concluded that the best cleaning effect can be attained by using a mixture of the anionic and the cationic surfactants, such that the anionic part removes the negatively charged particles while the cationic part removes the positively charged particles.

Fouling layer: Sand particles at the bottom and carbon particles at the top.

Glass surface

(a) After 3 s,   (b) after 6 s,   (c) after 9 s,   (d) after 12 s,   (e) after 15 s.
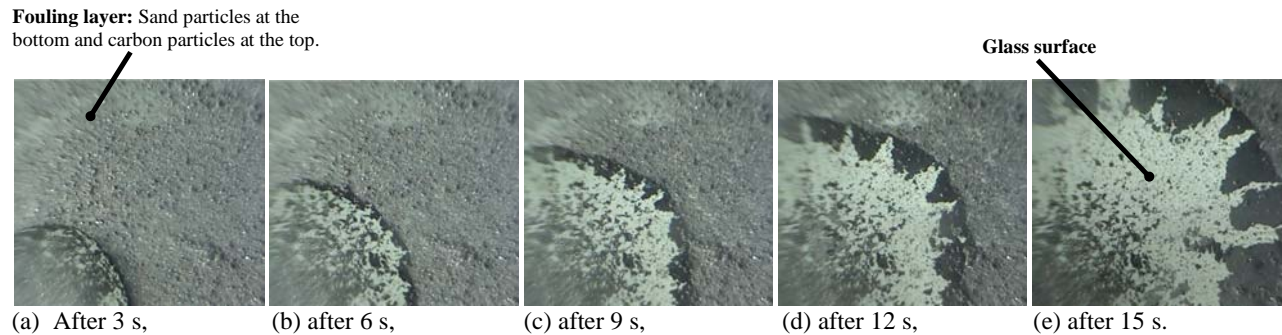
Fig. 11. The progress of a droplet of mixed cationic and anionic surfactants over a fouled glass surface. The glass surface is fouled with sand particles and a fine layer of carbon particles on top of the sand particles. The particle size distribution for the sand particles is 10 μm ± 4 μm, and for the carbon particles is 5 μm ± 4 μm.

CONCLUSIONS

The objective of this research is to remove deposited sand particles on a glass surface using a surfactant with the minimum amount of water utilization. Three types of surfactants have been examined under the microscope; anionic, cationic and zwitterionic. It can be concluded from the performed experiments that:

1- If the deposited particles are purely sand then the most effective surfactant is the anionic, and the least effective is the cationic. This could be due to the repulsive forces between the negatively charged sand particles and the negatively charged molecules of the anionic surfactant, which repel and remove the deposited sand particles. Cationic surfactants are positively charged, which leads to adhesion to the sand particle and no cleaning action takes place.

2- If the deposited sand particles are covered with a layer of soot particles, i.e. carbon particles, which is likely to happen in rural areas near highways, then the most effective surfactant is the cationic, and the least effective is the anionic. The behaviour of the surfactant in this case is different than in case of purely deposited sand particles. This could be due to the repulsive forces between the positively charged carbon particles and the positively charged molecules of the cationic surfactant, which repel and remove the deposited sand particles. Anionic surfactants are negatively charged, which leads to adhesion to the sand particles and no cleaning action.

3- A mixture of anionic and cationic surfactants leads to the best cleaning action irrespective of the surface charge of the deposited sand particles.

4- The surfactant behaviour is dependent on the electrical charge of the deposited particles.

5- The influence of the zwitterionic is between the influence of the anionic and the cationic surfactants, and depends on the ph value of the used water.

6- One droplet of a mixture of an anionic and cationic surfactants, was capable of cleaning the fouled glass surface, which surely can save a lot of water especially in desert belt countries like in the MENA region. A quantitative analysis will be made in the future to determine how much water will be saved in case of using and not using a surfactant in the cleaning water.

NOMENCLATURE
MENA   Middle East and North Africa
PV   Photovoltaic
PSD   particle size distribution

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