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Experimental study of self-cleaning property of titanium dioxide and nanospray coatings in solar applications

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ABSTRACT

Nowadays, the urgent need to replace fossil fuels with renewable energy is no secret. Therefore, researching in this area and developing the infrastructures necessary for the optimized utilization of these types of energy, are rising sharply. Among different kinds of renewable energy, due to easy access, solar energy has received special attention and extensive studies have been done, in order to increase the efficiency of the solar collectors and PV panels. One of the prime problems of solar systems in arid regions is the accumulation of dust on transparent surfaces, followed by an intensive drop in the transmission coefficient. In the present study, in a 70-day test period, up to 22% transmission coefficient loss, caused by the accumulation of dust on the surface, was observed. Thus, in order to solve this problem, Nanocoatings were deposited on glass samples to create self-cleaning property. A nanospray was used to create a hydrophobic film on the surface and TiO_2 was coated in three different thickness to create a hydrophilic film on sample surfaces. Test results showed that these surface modifications have a significant impact in the reduction of dust accumulation and the loss of the transmission coefficient. Although there was no rain during the test, for samples with surface modification, the transmission coefficient drops were noticeably reduced. After rain simulation, the results indicate that transmission loss reduced from 22% to 0.5% and dust settlement problem was almost completely solved.

1. Introduction

In recent years, global increase of energy prices in one hand and the decrease of solar system costs as well as attention to environmental aspects, has made solar energy an attractive solution to overcome the world energy demands, and in addition to creating solar power plants and solar farms, numerous projects and researchers in this field have been done (Arsalis and Alexandrou, 2015; Karaki et al., 2016; Dabaieh and Elbably, 2015; Gholami et al., 2015). Furthermore, supporting laws for developing renewable energy, which were passed in many countries, following by investment tendency, led to many techno-economical studies and various schemes to optimize photovoltaic systems (Fabrizio et al., 2010; Petersen and Svendsen, 2012; Ramadhan and Naseeb, 2011; Lacchini and Dos Santos, 2013; Nottrott et al., 2013; Shrimali and Jenner, 2013). Locally, a recent study evaluated and compared the economic aspect of increasing distributed generation capacity in Iran (Zandi et al., 2017).

Whether using solar collector or photovoltaic panel, the sun radiation should pass through a cover glass before converting to heat or electricity. So the transmission coefficient[1] of the cover glass is as important for the system efficiency as the other factors such as panel pitch (β) and orientation (γ), cell temperature, maximum power point tracking and energy conversion efficiency. Settlement of dust on a glass cover causes gradual reduction of transmission coefficient (Hegazy, 2001; Gholami et al., 2017), which then results in the overall output energy reduction.

Due to favorable radiation conditions, including high radiation power and long daylight, arid regions are more suitable for building large-scale solar installations. One of the barriers in using solar systems, either photovoltaic panels or flat collectors, in such areas, is the accumulation of dust on surfaces, which follows by reduction of transmission coefficient and total efficiency of the solar system as well (He et al., 2011; Saidan et al., 2016; Appels et al., 2013). Several factors, such as installation tilt, azimuth angle, dominant wind direction and intensity, rain and the time in which panels and collectors are exposed to outdoor conditions without cleaning, affect dust accumulation density on surface and transmittance reduction (Elminir et al., 2006; Sarver et al., 2013). In reading the literature, it can be understood that dust accumulation strongly depends on the weather conditions (Tanesab et al., 2015; Paudyal and Shakya, 2016; Ferrada et al., 2015; Abderrezek and

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[1] **Transmission Coefficient** or **Transmittance** is the ratio of the total radiant or luminous flux transmitted by a transparent object to the incident flux.

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Table 1
Deposition conditions during the coating, using radio frequency sputtering method.

Sample number	Coating thickness (nm)	Power (W)	Reflected power (W)	Chamber pressure (µbar)	Sputtering rate (A^0/s)	Substrate rotation (rpm)
1	30	89	2	3.6	2–3.4	10
2	30	91	1	5	1.5–3.9	10
3	30	90	0	4.8	2–3.4	10
4	50	94	1	4.8	2–3.9	10
5	50	92	0	4.8	2–3.4	10
6	50	91	1	4.8	2–3.4	10
7	70	92	0	4.8	2–2.4	10
8	70	92	0	5	2–3.9	10
9	70	93	0	5	2–3.4	10

Fathi, 2017), for example, a single dust storm can reduce the power output of PV modules by as much as 20% (Adinoyi and Said, 2013). Recently, Jiang et al. (2016), developed a model to estimate the cleaning frequency for dirty solar photovoltaic (PV) modules in the desert environment, based on PV module power performance, dust density and deposition velocity. They also suggested cleaning of PV modules every 20 days in desert regions.

In order to receive the optimum sunlight during a year, installation tilt is usually set the same as the location latitude. Furthermore, in the northern hemisphere, solar collectors and PV panels are typically faced toward south (Duffie and Beckman, 1991). Wind and rain conditions are also depending upon the climate and cannot be controlled. So it seems that the only way to prevent the transmission coefficient drop is to remove the dust from the surface.

Transparent surfaces can be cleaned manually, automatically and naturally (Sayyah et al., 2014). Wind power, gravitational force, and rain are included as the natural ways which could take settled dust away from the surfaces. Gaier et al. (1990), Gaier and Davis (1992), studied the validity of this method on Mars which has huge dust storms each year. They reported that if panels could be oriented in such a way that the angle of attack and wind speed are proper, wind will clear off the dust from the surface of a photovoltaic array. Since the installation tilt angle of panels on earth is usually set by the latitude of the site, the proper angle of attack may not be obtained. Furthermore, it is difficult to rotate large arrays of solar panels, and this may lead to energy consumption and reduction of total efficiency of the system. In another work, William et al. Williams et al. (2007), studied the vibration characterization of self-cleaning solar panels with piezoceramic actuation. Usually, due to high-power consumption, difficulties and expenses relating to the machinery maintenance, using mechanical methods, such as brushing, blowing, ultrasonic excitement and vibration, to remove dust from the surface of the solar panels, are not efficient.

Electrostatic dust removal method was studied by Clark et al. (2007), in order to reduce the dust level on the surface, in the lunar application. The most famous electro dust removal method, based on the concept of electric curtains, was developed by F.B. Tatom and collaborators at NASA in 1967. In this method which later was developed by Masuda at Tokyo University in the 1970s, electrostatic and dielectrophoretic forces are used to shift and move dust particles. In recent years, this technology has been used for space applications in the moon and Mars (Calle et al., 2008, 2009; Atten et al., 2009; Sharma et al., 2009; Bock et al., 2008; Liu and Marshall, 2010).

Perhaps the most optimal method to remove dirt from surfaces is to modify the surface to obtain self-cleaning properties. Self-cleaning nanofilms which could be coated on the surface for this purpose should be transparent and they are usually either super-hydrophobic or super-hydrophilic. Most researchers about super-hydrophobic and hydrophilic surfaces, are mainly focused on either reducing or increasing the wetting properties, and still, the question remains that whether it is possible to use these self-cleaning nanofilms for solar applications or not. In the current study, to overcome dust accumulation problem, TiO_2 nano-coatings and nanospray were used on some of the glass samples and in a 70-day period, the dust surface density and the transmission coefficient loss for the coated and uncoated glass samples, were measured and compared. In the following parts, first, selected coatings will be introduced briefly. Then, after reporting the climate conditions of test region, basic specifications of the experiment and the results will be explained.

2. The hydrophobic and hydrophilic coatings

Super-hydrophobic surfaces such as lotus leaves, show extremely low wetting property and greatly high hydrophobicity. Nanostructures of these surfaces could enhance contact angle over 150°. So the raindrops, immediately after reaching the surface, would roll on it and wash away dust particles (Park et al., 2011).

In the current study, the hydrophobic property was added to the surface of seven glass samples, using a nanospray prepared by Nanospadan company. To do so, first the glass surfaces were washed by water and alcohol solution, then the hydrophobic solution was sprayed on the glass surface. The time required for the stability was 24 h.

The most famous super-hydrophilic film is titanium dioxide which, in addition to the hydrophilic property, also has a photocatalytic characteristic. This self-cleaning method has two steps. The first phase is a photocatalytic process, in which titanium dioxide under the effect of ultraviolet radiation breaks down organic dust. Then in the next step, due to the super-hydrophilic property, raindrops, rather than gathering in one place, spread over the entire surface and wash away the dust particle (Park et al., 2011).

To coat TiO_2 on the surfaces, the equipment at the Laser and Plasma Research Institute of Shahid Beheshti University were used. TiO_2 was coated on each sample, using radio frequency sputtering method, which is considered as a physical vapor deposition under vacuum method. Deposition conditions in the laboratory are given Table 1. It should be noted that the nanospray is a less permanent surface modification than titanium dioxide and need to be recoated every two years.

3. Climatology of the test region

Test apparatuses were located on the roof of mechanical engineering department in Isfahan university of technology at 32°43′00″ north latitude and 51°31′45″ East longitude. Therefore required climate and weather information was extracted from the closest weather station (32°47′00″ north latitude and 51°67′00″ East longitude).

Due to the rainfall decline in recent years, 84 percent of Isfahan province is experiencing drought, which 15.8 percent is severe drought. In addition, by comparing the amount of dust in recent years and the long-term annual average, a significant increase in the region and the country becomes apparent (The National Weather Service, 2014-15), which emphasizes more on the importance of this study.

4. Experimental basic specifications

Given that in the northern hemisphere in order to receive the most