Peertechz

CHEMISTRY GROUP

Applied Chemistry and
Materials Science
OPEN ACCESS JOURNAL
DOI: https://dx.doi.org/10.17352/acms

Opinion

Contemporary considerations of the utility of self-cleaning coatings for solar power installations-The SolarSkin system

Nikolaos D Papadopoulos[1]*, Paraskevi Vourna[2], S Xafakis[1] and Polyxeni Vourna[1]

[1]BFP Advanced Technologies, 11633, Athens, Attiki, Greece

[2]Researcher, Laboratory of Electronic Sensors, Institute of Communication and Computer Systems, School of Electrical and Computer Engineering, Greece

Received: 28 August, 2023
Accepted: 12 September, 2023
Published: 13 September, 2023

***Corresponding author:** Nikolaos D Papadopoulos, BFP Advanced Technologies, 33 Damareos Str., 11633, Athens, Attiki, Greece, Tel: 00306932256264; Fax: 00302107010050;
E-mail: npapadopoulos@bfp-tech.com

ORCiD: https://orcid.org/0000-0002-6479-6277

Keywords: Anti-soiling coatings; Self-cleaning; Concentrated solar power; Photovoltaic

https://www.peertechzpublications.org

Abstract

Soiling of conventional Photovoltaic (PV) modules and Concentrated Solar Power (CSP) mirrors significantly affects the efficiency of the system. Although there are several soiling mitigation strategies, none of them has been widely adopted, since effectiveness in real field conditions is often disputed. Anti-soiling coatings are perhaps the most promising solution for solar power projects since they combine low cost and effectiveness. These are broadly categorized into hydrophilic and hydrophobic. Hydrophilic coatings perform better in arid climates, whereas hydrophobic coatings have a wider spectrum of functionality. Most of them however suffer from various drawbacks, such as poor durability and transmittance which restrict the extent of benefits. In addition, there are only a few reliable technologies that can be retrofitted to existing installations.

Predicting the efficiency of a given anti-soiling coating in a specific plant is difficult, therefore, the objective of this work was to identify those parameters that are critical to their performance in real outdoor conditions. Focus was given to the drawbacks of current hydrophobic coating systems and the requirements that a modern anti-soiling coating should satisfy in order to be implemented as an effective after-market solution to degraded solar systems. A prominent example of cutting-edge, high-performing self-cleaning technology, i.e. the SolarSkin system developed by BFP Advanced Technologies, is additionally presented. The latter can renovate deteriorated solar collectors, increase the energy yield of the system, and protect it from weathering effects over its expected operational lifecycle. Potential increment of the system's efficacy as well as maintenance savings are also briefly discussed.

Introduction

Soiling of solar power systems, such as CSP mirrors and PV modules, significantly affects energy yield and increases the Levelized Cost of Electricity (LCOE), which poses significant socio-economic, technological, and environmental threats [1-5]. Although the consequences of soiling are higher for concentrating systems than for non-concentrating systems, the gradual reduction of nominal power output is widely recognized as a defect mainly of PV systems. This is probably due to the fact, that a vast number of small PV installations are managed directly by individual owners.

Various reports [1-3] all over the world have revealed large decrements in efficiency due to heavy soiling (including dust, dirt, and pollen), exceeding 25% within a 6-month period, especially in areas of high industrial pollution, at seaside locales with abundant salt mist, in deserts and at areas with volcanic activities and mining.

Soiling of CSP mirrors and PV modules is a complex phenomenon. Scientific research has proven that soiling on surfaces of solar systems develops in two adjacent layers: one top layer which can be relatively easily removed by wind, rain, or cleaning action, and one sub-layer, which adheres strongly

Citation: Papadopoulos ND, Vourna P, Xafakis S, Vourna P (2023) Contemporary considerations of the utility of self-cleaning coatings for solar power installations-The SolarSkin system. Appl Chem Mater Sci 1(1): 001-007.DOI: https://dx.doi.org/10.17352/acms.000001

to the glass surface and forms a hard crust that reduces the amount of light reaching the solar cells [1]. Environmental conditions can also evoke degradation or “corrosion” of the solar panel or collector, which further adds to energy losses.

Although there are several soiling mitigation strategies, none of them has been widely adopted, since effectiveness in real field conditions is often disputed. Optimization of the system’s efficiency [6-8] is thus diligently pursued. In addition, the implementation of anti-soiling coatings has been recently intensified [9-15] representing perhaps the most promising solution in solar power projects, since effectiveness is usually combined with low application costs.

Although soiling rates, climate, and types of soil vary by location the application of an anti-soiling coating can benefit energy output by a non-negligible fraction. By assuming, for example, a 1.5 MWh/MWdc PV system with a power purchase agreement of 60 €/MWh, a 5% discount rate, a 0.5% annual power degradation, baseline soiling losses of the order of 5%, and two module washes per year, an increment in energy yield of at least 3% should be expected. In arid climates, this can reach 4.5%. Therefore, the application of an efficient self-cleaning coating may result in a 2.5% increment of total revenues in net present values and this calculation should be considered a rather conservative approach.

Major manufacturers of solar systems have realized the utility of coatings and more particularly, of hydrophobic coatings. Some of them have already included the application of hydrophobic coatings during production and market them as premium products. What about however for those solar power plants, which were installed 5, 10 or more years ago?

Coated surfaces accumulate dirt at a slower rate, exhibit in rainy conditions an enhanced self-cleaning effect, need less frequent cleanings, and are easier to clean. In general, anti-soiling coatings are broadly categorized into hydrophilic (water-attracting) and hydrophobic (water-repellent) [16-26]. Most hydrophilic coatings have a photocatalytic functionality being able to decompose organic matter by sun irradiation [15-18]. However, a large portion of environmental pollution is of an inorganic nature, therefore, predicting the performance of hydrophilic coatings in real outdoor conditions, especially arid climates, may be challenging. Furthermore, in areas of high humidity or frequent rainfalls water accumulation can lead to light scattering, which may degrade optical properties. On the other hand, hydrophilic coatings can be quite enduring with useful lifetimes that may exceed 5 years.

Hydrophobic anti-soiling coatings present perhaps more favorable characteristics [16,17,20-23]. It is widely accepted, that the biggest portion, i.e., at least 60%, of liquid pollution can be self-cleaned by the application of standard hydrophobic coatings. Their non-stick properties also act as soiling deterrents. Abrasive cleaners, as well as cleaning frequency and cleaning effort during regular maintenance, are minimized, too, thus reducing Operational and Maintenance (O&M) costs of the solar system.

Nevertheless, some coatings may turn ineffective, and depending on environmental conditions the power output of CSP mirrors and PV modules may decrease below the threshold of uncoated systems.

Among various commercial anti-soiling coatings, the SolarSkin coating system (SolarSkin by BFP) [27] is a prominent example of cutting-edge, high performing self-cleaning technology. Based on the patented HyDRoP system, it effectively combines the properties of both inorganic and organic materials within a multi-functional easy-to-clean, optically free, coating. The dual-activated (both chemically and mechanically) preparation of the surface promotes the development of a strong covalent bond (of about 230 Kilo-joule per mol) between the coating and the substrate, which promises superior resistance to chemicals, temperature changes, UV, and abrasion. SolarSkin brings solar glass back to its original appearance and protects it from abrasion, mineral deposits, pollution, and corrosion. Upon curing the coating, a surface-repellent charge is formed. This acts as an invisible barrier to water, soil, and stains, thus providing abrupt recovery of substrate’s transmittance after mild rainfalls. It should be also noted that the coating’s thickness has been chosen in a way that the wavelength of the incoming light and the refractive index of solar glass are effectively combined and reflection losses are minimized. SolarSkin is friendly to the environment and can be easily applied both on-site during the assembly of solar panels and collectors or directly in the field at existing plants.

Discussion

Hydrophilic coatings increase the substrate’s surface energy, thus minimizing water contact angles. Under conditions of rainfall or high humidity, thin continuous layers of water are formed which increase surface conductivity. Localization of electrostatic charges is thus prevented and the surface becomes antistatic. Water contact angles of less than 7-8^{o} can be achieved, therefore dirt may be easily washed off [21]. On the other hand, hydrophobic coatings have a low surface energy which enables the removal of dirt as water droplets roll off from the surface. Therefore, both types of coatings enhance self-cleaning properties, although by a different mode of action. Depending on the particles’ size and the water quantity and flow, the removal efficiencies may be less or more effective [28].

It should be noted that in both types of coating, the fundamental mode of action aims at reducing adhesion forces between the substrate and contaminants. Ideally, this should be achieved without compromising the substrate’s optical properties. In solar systems especially, maintaining the substrate’s transmittance is of crucial importance, since even the slightest absorption of the incoming light, either due to poor design or increased thickness of the coating may severely affect the system’s performance, especially in large solar power plants (Figure 1). In such case, the reduction of reflection losses being the result of soiling mitigation may be compromised by the restriction of transmittance.

Citation: Papadopoulos ND, Vourna P, Xafakis S, Vourna P (2023) Contemporary considerations of the utility of self-cleaning coatings for solar power installations-The SolarSkin system. Appl Chem Mater Sci 1(1): 001-007.DOI: https://dx.doi.org/10.17352/acms.000001

Figure 1: Aerial image of the 19.9MW Gemasolar CSP system, Seville, Spain [29].

Furthermore, in real-field conditions, the coating's performance, as this is reflected by water contact angles, may differ significantly from nominal values, due to environmental factors, tilt angles, cleaning strategy, etc. The reason is that physisorption or chemisorbed dirt and dust may dramatically degrade the coating's functionality.

More specifically, the upper layers of the coating are constantly exposed to the effects of the surrounding environment. Over time, dust and various contaminants are physically adsorbed on the surface. The majority of them will be desorbed by natural convection or removed by the mechanical action of wind or rainfalls, within a short period of time, e.g. within a few minutes. In the latter case, the hydrophilic or hydrophobic attributes of the coating will enhance the self-cleaning effect. However, in dry areas or regions of high insolation and humidity, some of the above physisorbed foreign material will at some point be chemically adsorbed to the surface through nucleation and growth, despite the coating's non-stick properties. Accumulation of chemisorbed contamination increases over time up to a point where it can be removed only by cleaning. This process deteriorates the self-cleaning attributes rendering the coating non-functional since water is in direct contact with the contaminant layer, not with the non-stick surface of the coating. This has a notable effect on the surface's anti-sticking properties. The initial properties of the coating can then be recovered when contamination is removed, e.g. by cleaning, so fresh layers of the coating are exposed. However, strongly adhered, i.e. chemisorbed contaminants may ultimately affect the coating's performance, since their removal may pull off the adjacent underlying coating layers as well, thus deteriorating the coating's surface.

In addition, on hydrophilic coatings contamination may form a continuous layer that blocks incoming light. On hydrophobic coatings, the contaminant layer is localized, therefore, and up to a certain point, does not have any effect on transmittivity. In real PV and CSP applications, consistent self-cleaning ability and optimum performance of the coating may be secured only by implementing an optimized cleaning strategy, based on climate/meteorology conditions and location, which will be able to remove the major part contamination before the onset of chemisorption.

Consequently, an optimized cleaning schedule coupled with the application of an optically free hydrophobic coating seems to be the most effective anti-soiling approach.

i. Hydrophobic surfaces can be developed through various approaches [30-35]. These usually employ the following materials/methods:Organofunctional silanes such as reactive alkyl- or fluoro-alkoxysilanes which promote hydrophobicity/superhydrophobicity,

ii. Preceramic materials, i.e. polysilazanes enhance mechanical stability against weathering effects.

iii. Polymeric binders functionalized with silane coupling agents. These can enhance adhesion to the substrate.

iv. Silicon oils, i.e. polydimethylsiloxanes, provide facile application, lubricity, and sufficient hydrophobicity with low hysteresis.

v. Nanocomposites comprising nanoparticles, nanotubes, nanorods, etc. improve surface hardness and provide multifunctional attributes.

vi. Polymeric films, such as PMMA are appropriately roughened (nanotexturing) and then coated with low-surface energy films. This method usually imparts superhydrophobic attributes to substrates.

In applications where maintenance of the substrate's optical properties is critical, such as PV and CSP plants, the implementation of most of the above methods, is limited either

Citation: Papadopoulos ND, Vourna P, Xafakis S, Vourna P (2023) Contemporary considerations of the utility of self-cleaning coatings for solar power installations-The SolarSkin system. Appl Chem Mater Sci 1(1): 001-007.DOI: https://dx.doi.org/10.17352/acms.000001

due to the increased thickness of the coating which may restrict transmittance or poor durability. Application complexities, such as the limited pot life of two-component coatings are additional problems.

Among the above approaches, organofunctional silanes are more advantageous for solar power applications. These can be directly deposited to substrates to promote hydrophobicity or processed further to develop superhydrophobicity. Typically, the backbone of alkoxysilanes consists of two or three hydrolysable groups that can hydrogen bond with surface hydroxyl groups forming stable silica matrixes.

Thus, organofunctional silanes are the primary material of choice in current commercial hydrophobic coatings. In real-field conditions, however, most of them suffer more or less from some of the following drawbacks:

- Poor endurance, especially with regard to abrasion, cleaning chemicals, and adverse environmental conditions such as sandstorms, sea mist, humidity, etc.
- Low overall mechanical strength.
- Reduced light transmittance.
- Low water sliding angles, despite strong static hydrophobicity values.
- Significant degradation of initial hydrophobicity after exposure to outdoor conditions.
- UV instability.
- Inadequate adhesion to the substrate, since they often do no not possess active anchoring groups or do not sufficiently follow the contour (step coverage) of the substrate.
- Short life cycle (e.g., 6 months to 2 years), which necessitates repetitive applications that shrink economic benefits throughout the service life of the system.
- Inadequate resistance to high temperatures and abrupt temperature fluctuations.
- Application difficulties, due to high curing temperatures (which can evoke the onset of diffusion of alkaline species from the substrate to the coating) and expensive equipment.
- Poor biodegradability.

There are also anti-soiling coatings for solar applications, especially for PV plants, that are marketed as both antireflective and hydrophobic. As a rule of thumb, however, water contact angles do not exceed 95 degrees and therefore, the maintenance of self-cleaning properties over time is rather questionable. This is due to the fact that after a few abrasive cycles, the water contact angle can fall below the widely accepted “easy-to-clean” threshold, which is about 80 degrees. In other words, the combination of both anti-reflection and anti-soiling properties may sound attractive, but the direct benefits in the actual transmission of the glass panels can be completely lost if soiling losses are higher than reflective losses, either due to non-uniform shading or due to location distinctiveness. Moreover, current antireflective anti-soiling coatings do not cure at ambient temperatures and their application can only be made during the assembly of new PV modules. As a result, effective protection of existing solar plants still remains problematic.

It should be noted that adhesion promoters, such as amino- or epoxy-silanes can be used to increase the coating’s abrasion resistance [36]. However, the effectiveness of this approach on hydroxylated surfaces, such as glass and mirrors of solar collectors is ambiguous since the primary bonding mechanism of silane adhesion promoters with the substrate remains the same with that of common alkoxysilanes. Thus, the best way to promote adhesion is by exposing a vast number of potential anchor sites on the substrate. On new or uninstalled hydroxylated surfaces this is achieved by thorough cleaning of the substrate. On old or already installed hydroxylated surfaces, an appropriate renovation/restoration technique is required to facilitate the exposure of an adequate number of hydroxyl groups.

Moreover, the lack of an appropriate renovation strategy, especially of heavily contaminated or corroded solar panel glass usually reduces the gains derived from the application of the anti-soiling coating. Effective practices, such as Chemical Mechanical Polishing (CMP) could restore solar glass to its original state and therefore improve its light transmittance, provided that a facile application method for existing stations, exists. In addition, a sufficient number of free active sites on which an organofunctional silane-based coating would anchor can be exposed. As a result, the latter’s adhesion to the substrate and consequently its abrasion resistance may be substantially improved. CMP applications usually employ the use of emulsions which ensure a constant presence of a liquid layer between the substrate and the polishing machine. However, these emulsions tend to be unstable over time and they need to be prepared just before use, which renders them unsuitable for after-market applications. The chemical stability of a CMP emulsion depends on parameters such as the zeta potential, pH slurry, and the iso-electric point of the polishing abrasive. Effective tuning of such parameters can increase polishing efficiency without affecting the optimum texture of solar panels and collectors.

Since ease of application and return on investment ratio are also significant factors, it is obvious that the best solution for solar power systems is a renovation and protection hydrophobic coating system, which can be easily applied and cured at ambient temperatures. Moreover, taking into account the above considerations, an efficient anti-soiling coating should ideally encompass the following characteristics and specifications:

a) High translucency.

Citation: Papadopoulos ND, Vourna P, Xafakis S, Vourna P (2023) Contemporary considerations of the utility of self-cleaning coatings for solar power installations-The SolarSkin system. Appl Chem Mater Sci 1(1): 001-007.DOI: https://dx.doi.org/10.17352/acms.000001

b) Initial hydrophobicity of 100+ degrees with minimum, linear degradation over time.

c) Maintenance of transparency upon aging.

d) Self-cleaning ability in rain. Initial hydrophobicity should be fully recovered after mild or at least, moderate rain events.

e) UV and abrasion resistance.

f) Resistance to cleaners, washing detergents, and chemicals, up to pH values of 13.

g) Resistance to extreme temperature fluctuations. Minimal degradation at repeating heating cycles of at least 120 ˚C.

h) Useful life-cycle of at least 7 years.

Further considerations

In general, the accumulation of foreign material onto solar panels and collectors is, over time, intensified; even rainwater often carries pollutants from the surrounding environment. Obviously, the rain itself cannot thoroughly clean uncoated surfaces from dirt and other residues. Wind-blown dust, humidity, sea salt mist, bird droppings, fungi, lichen, pollen, and various pollutants can be initially weakly adhered, i.e., physisorbed, to the surface of solar panels and mirrors. After a while, however, the sun bakes these residues to form a hard crust of dirt, which is often invisible. The latter is often difficult to remove and can significantly reduce the amount of light reaching the receiver. So, even if uncoated surfaces may seem clean, the truth is that a thin layer of dirt is always there. Regular cleaning usually removes only the upper layers of dirt which are less adherent to the adjacent layers, underneath, and thus, over time the energy yield is reduced in a non-reversible manner. In arid climates and areas of high solar insolation, the rate of soiling is even higher.

Degradation of the substrate's original texture and surface roughness due to outdoor weathering is an additional cause of power reduction. Glass panels and CSP mirrors have a specific texture the maintenance of which is critical to ensure maximum efficiency.

The implementation of a suitable renovation process, such as the 1st component of the proprietary SolarSkin system, may restore the substrate's transmittivity, which has been degraded either by strongly adhered dirt or by outdoor wear. A specially formulated aqueous emulsion of high-grade polishing powders provides high removal rates coupled with optimum surface finish.

In addition, the proprietary formula of the SolarSkin coating is based on organofunctional silanes which are pre-hydrolyzed to form highly reactive hybrid silane oligomers. Upon condensation and ambient curing, a functionalized silica matrix is formed which is mechanically robust and highly resistant to UV and chemicals. This can repel water and stains, without affecting the substrate's optical properties, which is a common malfunction of most conventional coatings. As a result, soil and dirt are not strongly adhered to and can be easily self-cleaned in rain. The mechanical forces exerted on the coating by heavy rain can sometimes have the same effect as manual cleaning since the coating's anti-sticking properties are rather pronounced. Thus, an excellent self-cleaning ability against liquid pollution is developed. What is more, the combination of marked anti-static properties with both hydrophobic and oleophobic features further reduces the impact of soiling.

Depending on environmental factors, location, the inclination of the solar system, maintenance/cleaning cycles, season, etc. the net efficiency of uncoated PV panels and CSP mirrors may be significantly restricted [37-40]. Dirty surfaces are much less effective than clean ones. It has been also shown that soiling can have a greater impact on system operators than reflection losses, which are attributed to the position of the Sun relative to the position of solar panels and collectors. Generally speaking, soiling losses can reduce energy output anywhere from 5% to 70%. Moreover, accumulated losses attributed to both substrate wear and soiling factors can be of the order of 30%.

By SolarSkin a large portion of these losses may be recovered. Testing of independently connected PV modules in variable conditions has verified the superior performance of coated PV modules. It has been estimated that coated modules by SolarSkin will yield an annual increment in module peak power of up to 4.5%, and an average 3% - 9% increment in energy over the product's lifetime. Compared to conventional coatings it has been also estimated that it can provide up to 7% more energy. Finally, the application of the SolarSkin system can reduce soiling by up to 70% (at low tilt angles). The endurance of the SolarSkin coating is key to this performance; the optimum performance of the system is retained for at least 20 years from the date of installation.

With underestimated predictions, the implementation of SolarSkin (cost of material + cost of application) at a common 100 kW grid-connected c-Si PV array located in an open field of Central Europe with modules of float cover glass of 30 degrees fixed tilt will give an annual ROI of about 80%, which means that the break-even point will come only a few months after the 1st year from the date of application.

Similarly, to assess the effect of the anti-soiling coating on CSP mirrors' performance and energy cost-reduction at a plant scale, a cost-impact analysis was performed. A study of the cost impact for a real case scenario was performed for the 50 MW Helios 1 parabolic trough power plant (Puerto Lapice, Ciudad Real Castilla-La Mancha, Spain) with A= 300000 m^2 of solar field aperture area, 2092 kWh/m^2/year ($E_{available}$ from typical meteorological year analysis) of solar resource and 16% solar-to-electricity efficiency (μ_{ele}) according to NREL [41]. A cost of 7.5 c€/kWhele (C_{ele}) was assumed based on 2020's deflated remuneration and levelized cost of electricity with the operational start year being 2012. The levelised cost of electricity assumed a 5% weighted average cost of capital and a 25-year payback period and capacity-dependent O&M costs

Citation: Papadopoulos ND, Vourna P, Xafakis S, Vourna P (2023) Contemporary considerations of the utility of self-cleaning coatings for solar power installations-The SolarSkin system. Appl Chem Mater Sci 1(1): 001-007.DOI: https://dx.doi.org/10.17352/acms.000001

(1.5% of investment cost per year), deflated from operational year 2011 by using the Worldbank's GDP deflator. By assuming an annual 1.5% soiling loss of uncoated mirrors compared to coated ones by SolarSkin and a mean application cost of the order of 2.5 €/m^2, a total revenue of approximately 2 M€ for the entire aperture area during the lifespan of the power plant should be expected.

Conclusion

In sum, a suitable glass renovation and protection coating system can substantially improve the transmittivity of PV panels and CSP mirrors and enhance the efficiency of installed solar power stations. It can increase the lifetime value of residential, commercial, and utility systems by providing substantial energy increment and soiling reduction, which translates to lower LCOE and reduced O&M costs.

The SolarSkin coating system can deliver significantly more value than conventional coatings to existing and future solar power installations. Maintenance and operation costs can be significantly reduced, while the energy yield over the expected operational lifecycle of the system is notably increased due to both the anti-soiling and durability properties of the coating.

Acknowledgment

This research has been supported under the umbrella of SOLAR-ERA.NET Cofund 2 by GSRI – General Secretariat for Research and Innovation (Greece), RIF – Research and Innovation Foundation (Cyprus), and FFG – Austrian Research Promotion Agency. SOLAR-ERA.NET is supported by the European Commission within the EU Framework Programme for Research and Innovation HORIZON 2020 (Cofund ERA-NET Action, N° 786483).

References

1. Ju X, Xu C, Hu Y. A review on the development of photovoltaic/concentrated solar power (PV-CSP) hybrid systems. Solar Energy Materials and Solar Cells. 2017; 161:305-327. https://doi.org/10.1016/j.solmat.2016.12.004
2. Renewables 2017 Global Status Report. REN21. https://www.ren21.net/gsr-2017/
3. The Power to Change Solar and Wind Cost Reduction Potential. IRENA - International Renewable Energy Agency. 2023. https://www.irena.org/publications/2016/Jun/The-Power-to-Change-Solar-and-Wind-Cost-Reduction-Potential-to-2025
4. Giri NC, Das S, Pant D. Access to Solar Energy for Livelihood Security in Odisha, India. 2023. In: Rani A, Kumar B, Shrivastava V, Bansal RC. (eds) Signals, Machines and Automation. SIGMA 2022. Lecture Notes in Electrical Engineering, vol 1023. Springer, Singapore. https://doi.org/10.1007/978-981-99-0969-8_23
5. Giri NC, Mohanty RC, Pradhan RC. Agrivoltaic system for energy-food production: A symbiotic approach on strategy, modelling and optimization Sustain. Comput Inform Syst. 2023; 40: 100915. https://doi.org/10.1016/j.suscom.2023.100915
6. Tightiz L, Mansouri S, Zishan F. Maximum Power Point Tracking for Photovoltaic Systems Operating under Partially Shaded Conditions Using SALP Swarm Algorithm. Energies. 2022; 15: 8210. https://doi.org/10.3390/en15218210
7. Zishan F, Mansouri S, Abdollahpour F. Allocation of Renewable Energy Resources in Distribution Systems While considering the Uncertainty of Wind and Solar Resources via the Multi-Objective Salp Swarm Algorithm. Energies. 2023; 16: 474. https://doi.org/10.3390/en16010474
8. Grisales-Noreña LF, Montoya OD, Cortés-Caicedo B. Optimal Power Dispatch of PV Generators in AC Distribution Networks by Considering Solar, Environmental, and Power Demand Conditions from Colombia. Mathematics. 2023; 11: 484. https://doi.org/10.3390/math11020484
9. Polizos G, Sharma JK, Smith DB. Anti-soiling and highly transparent coatings with multi-scale features. Solar Energy Materials and Solar Cells. 2018; 188:255-262. https://doi.org/10.1016/j.solmat.2018.09.011
10. Wette J, Fernández-García A, Sutter F. Water Saving in CSP Plants by a Novel Hydrophilic Anti-Soiling Coating for Solar Reflectors. Coatings. 2019; 9: 739. https://doi.org/10.3390/coatings9110739
11. Aranzabe E, Azpitarte I, Fernández-García A. Hydrophilic anti-soiling coating for improved efficiency of solar reflectors. Santiago, Chile. 2018; 220001.
12. Jang GG, Smith DB, Polizos G. Transparent superhydrophilic and superhydrophobic nanoparticle textured coatings: comparative study of anti-soiling performance. Nanoscale Adv. 2019; 1:1249-1260. https://doi.org/10.1039/C8NA00349A
13. Dahlioui D, Wette J, Fernández-García A. Performance assessment of the anti-soiling coating on solar mirrors soiling in the arid climate of Ouarzazate-Morocco. Solar Energy. 2022; 241:13-23. https://doi.org/10.1016/j.solener.2022.05.063
14. Lorenz R, O'Sullivan M, Fian A. Effects of bias pulse frequencies on reactively sputter deposited NbOx films. Thin Solid Films. 2018; 660:335-342. https://doi.org/10.1016/j.tsf.2018.06.040
15. Kim D, Kim JG, Kim T, Chu CN. Long-Lasting Superhydrophilic and Instant Hydrophobic Micropatterned Stainless Steel Surface by Thermally-Induced Surface Layers. Int J of Precis Eng and Manuf-Green Tech. 2021; 8:435-444. https://doi.org/10.1007/s40684-020-00207-5
16. Sabbah H. Amorphous titanium dioxide ultra-thin films for self-cleaning surfaces, Mater. Express. 2013; 3:171-175. https://doi.org/10.1166/mex.2013.1106
17. Banerjee S, Dionysiou DD. Pillai SC. Review Self-cleaning applications of TiO2 by photo-induced hydrophilicity and photocatalysis. Appl Catal B: Environmental. 2015; 176–177: 396-428. https://doi.org/10.1016/j.apcatb.2015.03.058
18. Spanou S, Kontos AI, Siokou A. Self-cleaning behaviour of Ni/nano-TiO2 metal matrix composites. Electrochim Acta. 2013; 105: 324-332. https://doi.org/10.1016/j.electacta.2013.04.174
19. Liang Z, Zhou Z, Zhao L. Fabrication of transparent, durable and self-cleaning superhydrophobic coatings for solar cells. New J Chem. 2020; 44:14481-14489. https://doi.org/10.1039/D0NJ01402H
20 Akustia Widati A, Nuryono N, Kartini I. Water-repellent glass coated with SiO2–TiO2–methyltrimethoxysilane through sol-gel coating. AIMS Materials Science. 2019; 6:10-24. https://doi.org/10.3934/matersci.2019.1.10
21. Ganesh VA, Raut HK, Nair AS, Ramakrishna S. A review on self-cleaning coatings. J Mater Chem. 2011; 21: 16304. https://doi.org/10.1039/c1jm12523k
22. Wu J, Tu J, Yu S. Hollow core-shell nanocoatings with gradient refractive index structure for enhanced photovoltaic performance. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 2023; 667:131424. https://doi.org/10.1016/j.colsurfa.2023.131424
23. Syafiq A, Vengadaesvaran B, Rahim NAbd. Transparent self-cleaning coating of modified polydimethylsiloxane (PDMS) for real outdoor application. Progress in Organic Coatings. 2019; 131:232–239. https://doi.org/10.1016/j.porgcoat.2019.02.020

Citation: Papadopoulos ND, Vourna P, Xafakis S, Vourna P (2023) Contemporary considerations of the utility of self-cleaning coatings for solar power installations- The SolarSkin system. Appl Chem Mater Sci 1(1): 001-007.DOI: https://dx.doi.org/10.17352/acms.000001

24. Bouvet-Marchand A, Graillot A, Abel M. Distribution of fluoroalkylsilanes in hydrophobic hybrid sol-gel coatings obtained by co-condensation. J Mater Chem A. 2018; 6: 24899-24910. https://doi.org/10.1039/C8TA10191D

25. Papadopoulos ND, Falara PP, Vourna P. A versatile approach towards development of easy-to-clean transparent nanocoating systems with pronounced anti-static properties for various substrates. AIMS Mater Sci. 2023; 10 (1): 139-163. doi: 10.3934/matersci.2023008

26. Papadopoulos ND, Vourna P. Proposing a sustainable strategy for the fabrication of robust anti-soiling coatings with enhanced antibacterial attributes for non-absorbent substrates. Int J Nanomater Nanotechnol Nanomed. 2022; 8:001-004. https://doi.org/10.17352/2455-3492.000047

27. BFP Advanced Technologies. BFP Advanced Technologies. 2023. https://bfp-tech.com/site/e-shop/

28. Jang GG, Smith DB, List III FA. The anti-soiling performance of highly reflective superhydrophobic nanoparticle-textured mirrors Nanoscale. 2018; 10: 14600 https://doi.org/10.1039/C8NR03024C

29. Under permission of Shutterstock, Inc. Stock Image: 1630760365.

30. Purcar V, Rădițoiu V, Rădițoiu A. Preparation and Characterization of Some Sol-Gel Modified Silica Coatings Deposited on Polyvinyl Chloride (PVC) Substrates. Coatings. 2020; 11: 11. doi:10.3390/coatings11010011.

31. Gong X, He S. Highly Durable Superhydrophobic Polydimethylsiloxane/Silica Nanocomposite Surfaces with Good Self-Cleaning Ability. ACS Omega. 2020 Feb 19;5(8):4100-4108. doi: 10.1021/acsomega.9b03775. PMID: 32149238; PMCID: PMC7057699.

32. Sutar RS, Gaikwad SS, Latthe SS. Superhydrophobic Nanocomposite Coatings of Hydrophobic Silica NPs and Poly(Methyl Methacrylate) with Notable Self-Cleaning Ability. Macromol Symp. 393; 2000116. doi:10.1002/masy.202000116.

33. Syafiq A, Vengadaesvaran B, Rahim NAbd. Transparent Self-Cleaning Coating of Modified Polydimethylsiloxane (PDMS) for Real Outdoor Application. Progress in Organic Coatings. 2019; 131: 232-239. doi:10.1016/j.porgcoat.2019.02.020.

34. Chen Z, Li G, Wang L. Strategy for Constructing Superhydrophobic Multilayer Coatings with Self-Cleaning Properties and Mechanical Durability Based on the Anchoring Effect of Organopolysilazane. Materials & Design. 2018; 141: 37-47. doi:10.1016/j.matdes.2017.12.034.

35. Zheng H, Pan M, Wen J. Robust, Transparent, and Superhydrophobic Coating Fabricated with Waterborne Polyurethane and Inorganic Nanoparticle Composites. Ind Eng Chem Res. 2019; 58: 8050-8060. doi:10.1021/acs.2iecr.9b00052.

36. Arkles B. Silane Coupling Agents: Connecting Across Boundaries; Gelest Inc. 3: 2014.

37. Klimm E, Lorenz T, Weiss KA. Can anti-soiling coating on solar glass influence the degree of performance loss over time of PV modules drastically? 28th European PV Solar Energy Conference and Exhibition. 30 September - 4 October, Paris, France. 2013.

38. Pedrazzi S, Allesina G, Muscio A. Are Nano-Composite Coatings the Key for Photovoltaic Panel Self-Maintenance: An Experimental Evaluation. Energies. 2018; 11: 3448. https://doi.org/10.3390/en11123448

39. Fathi M, Abderrezek M, Friedrich M. Reducing dust effects on photovoltaic panels by hydrophobic coating. Clean Techn Environ Policy. 2016; 19: 577-585. DOI 10.1007/s10098-016-1233-9

40. Wette J, Sutter F, Garcia AF. Evaluation of anti-soiling coatings for CSP reflectors under realistic outdoor conditions, Solar Energy. 2019; 191:574-584. https://doi.org/10.1016/j.solener.2019.09.031

41. Helios I. Concentrating Solar Power Projects. NREL. SolarPACES National Renewable Energy Laboratory. 2023. https://solarpaces.nrel.gov/project/helios-i.

Citation: Papadopoulos ND, Vourna P, Xafakis S, Vourna P (2023) Contemporary considerations of the utility of self-cleaning coatings for solar power installations-The SolarSkin system. Appl Chem Mater Sci 1(1): 001-007.DOI: https://dx.doi.org/10.17352/acms.000001