Journal of Environmental Management 157 (2015) 160–167

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Microbial colonization affects the efficiency of photovoltaic panels in a tropical environment

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ARTICLE INFO

Article history:
Received 19 December 2014
Received in revised form
25 March 2015
Accepted 28 March 2015
Available online 20 April 2015

Keywords:
Sub-aerial biofilms
Energy production
Phototrophs
Fungi
Solar panels
Fouling

ABSTRACT

Sub-aerial biofilm (SAB) development on solar panels was studied in São Paulo. After 6, 12 and 18 months' exposure, photovoltaic panels were covered by increasing proportions of organic matter (42%, 53% and 58%, respectively). Fungi were an important component of these biofilms; very few phototrophs were found. Major microorganisms detected were melanised meristematic ascomycetes and pigmented bacterial genera *Arthrobacter* and *Tetracoccus*. While diverse algae, cyanobacteria and bacteria were identified in biofilms at 6 and 12 months, diversity at a later stage was reduced to that typical for SAB: the only fungal group detected in 18 month biofilm was the meristematic Dothideomycetes and the only phototrophs *Ulothrix* and *Chlorella*. Photovoltaic modules showed significant power reductions after 6, 12 (both 7%) and 18 (11%) months. The lack of difference in power reduction between 6 and 12 months reflects the dual nature of soiling, which can result from the deposition of particulates as well as from SAB fouling. Although 12-month old SAB demonstrated an almost 10-fold increase in fungal colonization and a higher organic content, the larger non-microbial particles (above 10 μm), which were important for efficiency reduction of lightly-biofilmed panels, were removed by high rainfall just before the 12-month sampling.

1. Introduction

The efficiency of photovoltaic solar panels is important for sustainable, renewable and environmentally friendly energy. Panels must be positioned correctly for maximum sun exposure, but further environmental effects, including biofilm formation, can reduce the amount of light reaching the photoelectrically active layer. Soiling – a complex process resulting from the deposition of particulates as well as from microbial growth – can have a large effect on efficiency, especially during periods of drought (Kimber et al., 2006), which mainly occur, in many parts of the world, during the summer, coincident with the highest solar incidence. Sea salt, pollen, and particulate matter originating from air pollution, agricultural activity, construction and other anthropogenic and natural sources accumulate on the panels, unless removed by either rain or cleaning. Sand/dust deposition impacting performance has already been addressed, and a table of recommendations has been developed as a guide for identifying cycles of cleaning and maintenance, according to prevalent climatic and environmental conditions (Mani and Pillai, 2010). Currently, many manufacturers assume a lifetime of 25 years for their installed modules, but they do not take into account the growth of microorganisms. Biofilms formed on solar collectors can impact both the efficiency of the panels by absorbing and diffusing light (Noack-Schönmann et al., 2014) and directly accelerate the accumulation of particulate matter by acting as an absorptive matrix (Gorbushina,

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http://dx.doi.org/10.1016/j.jenvman.2015.03.050
0301-4797/

2007).

Elminir et al. (2006) showed that reduced transmittance after 7 months' exposure of solar panels was strongly dependent on the density of deposited dust, which varied with the slope and orientation of the surface relative to the dominant winds in the desert region. It is recognized that microorganisms are included in this "dust", but so far they have not been characterized. The deposition of particles 0.5 to 10 microns in size tends to reduce the intensity of solar irradiation reaching the cells more rapidly than do larger particles (El-Shobokshy and Hussein, 1993) and rainfall has little or no cleaning effect on small 2–10 μm particles (Appels et al., 2013). As these dimensions exactly reflect microbial cell sizes, sub-aerial biofilms may be expected to play an extremely important role in reducing the productivity of photovoltaic systems by light-scattering or -absorbing effects.

The presence of sub-aerial biofilms produced by microorganisms is a common phenomenon on various substrates, both natural (e.g., Gorbushina and Broughton, 2009) and man-made (e.g., Polo et al., 2012; Gaylarde et al., 2011). Glass solar panels have been shown to produce microbial biofilms within a few years in Europe (Noack-Schönmann et al., 2014), but there is no information on colonization in tropical environments, where the process may be expected to be more rapid.

We aimed to monitor the development of microbial biofilms on photovoltaic modules exposed to the tropical climate of Brazil, and the influence of these biofilms on the soiling and power rating of the panels.

2. Materials and methods

2.1. Photovoltaic modules (PVs) and exposure regime

In January, 2012, eighteen PVs (Conergy, Germany) were installed in the test site of the Photovoltaic Systems Laboratory, Institute of Energy and Environment (IEE), University of São Paulo (23° 33′29″ S 46° 44′1″ W), facing north and inclined at 30° (Fig. 1). PVs were analyzed (see subsequent sections) before exposure and after 6, 12 and 18 months without cleaning.

2.2. Nominal power determination

Procedures for testing of PVs were based on IEC 61215:2005: Test 10.1 Visual Inspection, and Test 10.2 Maximum power determination. Visual inspection was performed with the PV modules located in the support structure with an illumination above 1000 lux. It was carried out on all 18 modules just before the maximum power determination. Maximum power was determined under standard test conditions, irradiance across the modules of 1000 W/m2 and module cell temperature 25 °C. A commercial tunnel-type simulator manufactured by OPTOSOLAR, model Sol20 × 20, was used. This simulator is AAA class certified by TÜV Rheinland according to regulation IEC 60904-9 (IEC, 2007). The solar simulator pulse is 4 ms and irradiance stability during the pulse is <±1%. The uniformity of irradiance across the PV modules area is better than 1%. A reference calibrated device was used to ensure the same conditions in each test. After 6, 12 and 18 months of exposure they were re-evaluated in the solar simulator for analysis of nominal power.

Fig. 1. Test site with exposed PVs at IEE/USP.

2.3. Evaluation of deposited particles

2.3.1. Microscopy

Digital (HIROX KH 7700) and metallographic (Olympus) microscopes were used to image the PV surfaces after exposure, and Axioplan 2 (Zeiss) optical microscope was used for *in situ* observations. Scanning electron microscopy (SEM) of removed biofilms was carried out in a Quanta FEG (FEI) at high vacuum with a secondary electron Everhart-Thornley detector. Energy-dispersive spectrophotometry (EDS) was carried out using back-scattered electrons.

2.3.2. Thermal analysis

Samples collected as detailed below for fungi were frozen in liquid nitrogen and stored at −16 °C. They were then lyophilized and submitted to thermogravimetry. The thermal analyses were performed in a N_2 atmosphere in a thermobalance (NETZSCH, STA 409 PG) with a heating rate of 10° C/minute and final temperature of 1000 °C.

2.4. Sample collection for microbiology

2.4.1. Phototrophs

Adhesive tape samples were taken from the panels following the adhesive tape method detailed in Shirakawa et al. (2002) and Gaylarde and Gaylarde (2005), using 3 M transparent adhesive tape. Four adhesive tape samples were randomly taken from each of 5 modules at six, 12 and 18 months.

2.4.2. Fungi

Pieces (2.5 × 2.5 cm) of soft sponge were wrapped in aluminum foil and sterilized by autoclaving. The surface of each PV was wetted with 2 ml of sterile deionized water and samples were collected by cleaning the entire surface three times with three different sponges (samplings 1, 2 and 3), held in sterile forceps. Microscope inspection after cleaning showed that extremely few cells remained attached to the surfaces. Sponges were placed into tubes containing 10 ml sterile deionized water and vortexed for 5 min prior to treating in an ultrasonic bath (Thornton C/7, T7) for 10 min. Each sponge was then placed into the barrel of a sterile 20 ml syringe and, using the plunger, the liquid squeezed into the tube containing the respective ultrasonicated suspension. The volume was made up to 15 ml with sterile deionized water. All manipulations were carried out under aseptic conditions.

2.5. Identification and enumeration of microorganisms

2.5.1. Phototrophs

Tape samples were placed on solid Modified Knop's Medium (MKM; Gaylarde and Gaylarde, 2005). They were left to incubate in the light for up to 4 weeks and examined periodically with an optical microscope. Semi-quantitative assessments of density of growth, of both phototrophs and fungi growing on the agar, were