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Performance study of a hybrid photovoltaic and solar water disinfection system considering climatic variations over a year

N. Pichel [a,*], M. Vivar [b], M. Fuentes [a,c]

[a] IMDEA Water Institute, Alcalá de Henares 28805, Spain
[b] Department of Electrical Engineering, Universidad de Cádiz, Cádiz 11519, Spain
[c] Grupo IDEA, Universidad de Jaén, Jaén 23071, Spain

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ABSTRACT

A hybrid photovoltaic and solar water purification system (SOLWAT) was tested considering climatic variations over a year. The solar disinfection and electrical performance was assessed using natural water with wild bacteria strains of *E. coli*, total coliforms, *Enterococcus spp.* and *Clostridium perfringens* (including spores). After 6 h of sun exposure the SOLWAT system achieved the highest bacteria disinfection for *E. coli*, total coliforms and *C. perfringens* in relation to the conventional PET bottle, and *C. perfringens* was identified as the most resistant microorganism since its complete inactivation was never reached. Electrical results showed that the total energy output of the SOLWAT system designed and tested was not affected by the water disinfection reactor located above the PV module in relation to a single PV module, mainly because of the compensating effect of lower operation temperature of the PV module within the SOLWAT system vs. slightly reduced solar irradiance received. Finally, the ideal operation conditions for the SOLWAT system would be to work with high ambient temperatures and UV radiation or low ambient temperatures combined with high UV levels, being the worst conditions for its operation mild temperatures and mild/low UV levels.

1. Introduction

The concept of the SOLWAT system is a hybrid device that consists of two major parts: a water purification reactor and a photovoltaic (PV) module which improves solar spectrum utilization and minimizes space requirements integrating the functions of solar water purification (SODIS) and renewable electricity generation into a single and compact unit.

In the last decades photovoltaic technology was coupled with different water applications in an effort to reduce the high electricity costs associated with the drinking water/wastewater treatment plants or to power them in regions where electricity availability is low [1–3], and also as a promising option to make solar cells more efficient by reducing their operation temperature. Various systems configurations for numerous purposes such as domestic hot water [4–9] and photo-thermochemical reactions for hydrogen/sulphur/oxygen production [10–13] were developed. Furthermore, hybrid devices that integrate photovoltaic technology and solar water treatment have been recently investigated for the field of water purification. Vivar et al. [14] developed a photovoltaic-photocatalytic system for physicochemical water treatment and energy generation, where photocatalytic degradation (with suspended TiO_2 as photocatalyst) of organic dyes (Methylene Blue, Acid Red 26 and 4-Chlorophenol) as water pollutants was tested at lab-scale conditions [15–18] in terms of dye decolourisation and energy generation. However, microbiological water purification combined with PV technology was first presented by Pichel et al. [19] and by Wang et al. [20] in 2016 showing that bacteria inactivation and solar energy generation could work simultaneously, since energy was produced at the same time that bacteria concentration was reduced. Nevertheless, the SOLWAT system has not been evaluated yet under different operation conditions and this study constitutes the first performance analysis of the SOLWAT system considering irradiance and temperature variations along the year.

For the case of the SOLWAT system prototype developed by Pichel et al. at IMDEA Water [19], the hybrid system consists of two sub-modules assembled together, one above the other, where a 405 × 605 mm CIGS (Copper-Indium-Galium-Selenide Sulfide) PV module serves as the base of the water purification sub-module, with a water layer of 18 ± 1 mm and 4 L of capacity, which is transparent to visible and near infrared light. A borosilicate glass (320 × 430 mm) of 2 mm thickness acts as the top cover for the

* Corresponding author.
E-mail address: natalia.pichel@imdea.org (N. Pichel).

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water disinfection sub-module (Fig. 1a). Its transmittance for UV (UVB – UVA), visible and infrared spectrum can reach 90%, while the transmittance of the PET (polyethylene terephthalate) bottle (the traditional and most widespread SODIS container) is under this percentage (Fig. 2). Water disinfection occurs between the glass cover of the water purification sub-module and the PV module. SOLWAT prototype manufacturing and module characterization were previously detailed by Pichel et al. [19].

For the initial field performance assessment, and in order to assess the possible influence of the water reactor on the total energy generation and the influence of the PV module on the disinfection process, a reference system set consisting on an uncoupled system formed by two independent units was also tested. A 605 × 1205 mm CIGS photovoltaic module (as an extra 405 × 605 mm CIGS PV module was not available) and a water purification reactor with the same size and structural characteristics of the SOLWAT water sub-module, but with the photovoltaic module replaced by two borosilicate glasses with a black sheet between both glasses (Fig. 1b), were used.

Once the feasibility of the concept has been demonstrated by previous works, the aim of the present work is to assess the behaviour of the SOLWAT system considering climatic variations along the year under different UV and temperature conditions, with the final objective of evaluating the climatic conditions effects of a temperate climate on the SOLWAT water purification and electricity generation performance.

2. Materials and methodology

2.1. Experimental set-up

An annual campaign of tests was conducted at the rooftop facilities of IMDEA Water (Alcalá de Henares, Spain) over different weather seasons of the year including summer, autumn, winter

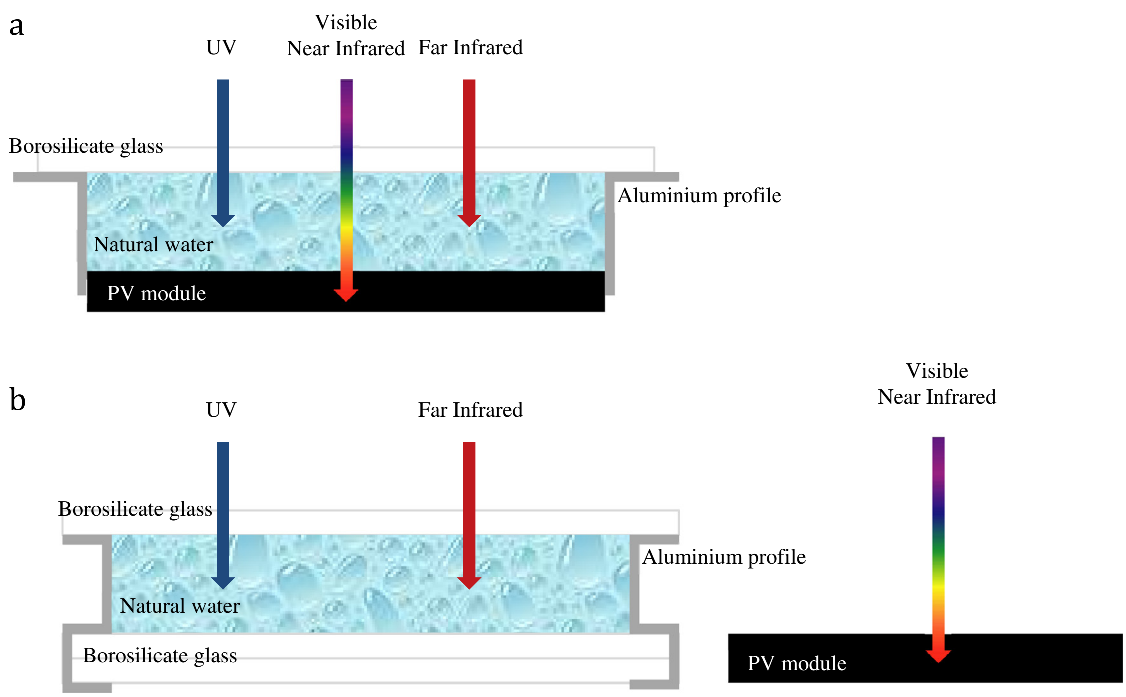

Fig. 1. Schematic diagram of the (a) SOLWAT system and (b) reference system set, where the integration of the PV module on the bottom and the water reactor on the top can be observed for the SOLWAT system (including the different materials); and the two independent units including the water reactor and the PV module are shown for the reference system. It can also be observed the use of the solar spectrum in the new concept: UV and far infrared for water disinfection and visible and near infrared for electricity generation.

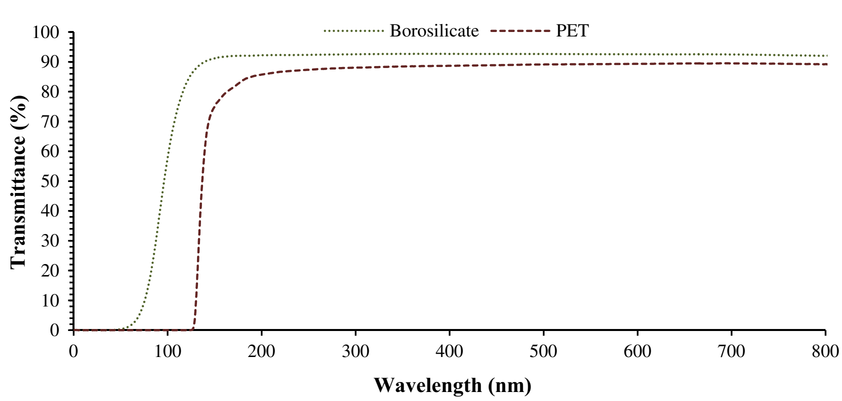

Fig. 2. Transmittance (%) of light through a 2 mm thickness borosilicate glass and PET (polyethylene terephthalate) in the UV and visible range.