Solar Energy Materials & Solar Cells 117 (2013) 549–563

Contents lists available at ScienceDirect

Solar Energy Materials & Solar Cells

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

# Clean water photovoltaic sensor for solar disinfection in developing countries

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ARTICLE INFO

*Article history:*
Received 10 June 2013
Received in revised form
8 July 2013
Accepted 12 July 2013
Available online 17 August 2013

*Keywords:*
Solar water disinfection
Photovoltaic
Low cost
SODIS
UV
Sunshine duration

ABSTRACT

One of the limitations for the widespread use of solar water disinfection technologies in developing regions is the lack of low-cost clean water sensors. A new type of low-cost sensors using photovoltaic solar cells that provide information about received irradiance, temperature, UV irradiance and sunshine duration is presented. A key aspect of the design is the UV irradiance measurement. Two identical cells are used, one of them with a low-cost UV-blocking filter on top, so the total UV irradiance can be calculated as the difference between the two solar cells outputs. The first cell would be measuring UV–vis–NIR and the second only vis–NIR. The UV filter material was explored and a low-cost architectural film was selected. Materials costs for the first prototype were of approximately 4€ excluding labour. Initial testing also included experiments with real polluted water and *Escherichia coli*, showing the feasibility of the new design.



## 1. Introduction

One of the most appropriate methods for drinking water treatment (WT) in developing countries, especially in small communities or remote areas, is solar disinfection [1,2]. Solar technologies for water disinfection are clean, simple, easy to operate and maintain, suitable for domestic use, do not require electricity and have low cost. But they are environment dependent and can be used only in areas with high solar irradiance conditions all over the year. Another drawback is that in some cases, such as solar distillation, the efficiency is limited. On the other hand, most of the developing countries are located in areas with high irradiance (Fig. 1), in the so-called 'sun-belt' zone, where the use of solar technologies is feasible.

Solar water disinfection can convert the sun energy into heat to increase the water temperature for pasteurisation or distillation, or it can use directly the germicide effect of UV radiation [4], or a combination of both. Main solar technologies include solar distillation, solar pasteurisation and the SODIS method with plastic bottles. Solar distillation is based on water evaporation and condensation, but the efficiency is very low as it requires higher solar energy doses for longer periods of time to treat the water than those of any of the other solar technologies [2]. If the water is not evaporated but the temperature increase is only to about 70 °C, then it reaches pasteurisation temperature. These systems consist of containers or plastic bottles that are fully black-painted and then exposed to the sun, waiting for the water temperature to reach 70 °C (Fig. 2a). Simple reflectors made with aluminium foils or metallic materials are often used to accelerate the process. Finally, if a combination of UV radiation and temperature is used then the solar disinfection (SODIS) process [1] is followed, using clear plastic bottles directly exposed to the sun for a certain number of hours (Fig. 2b). The combination of UV and heat disinfects the water after a period of exposure.

One of the main drawbacks or limitations to the widespread use of these solar disinfection methods in developing countries is that the user has no information about when the water is safe to drink. There is a lack of low-cost sensors for natural solar disinfection to detect when the water is clean, i.e. if the treated water has received enough radiation and/or if it has reached the pasteurisation temperature. This lack of information reduces their 'usability' in remote regions. The SODIS process gives some guidelines and estimates that the water is safe to drink after 6 h of exposure if it was a sunny day, or between 2 and 3 days if it is cloudy, but sensors are not available. Scientific research has been conducted for many types of low-cost simple sensors that can provide some aid to detect when the water is clean, both for solar UV disinfection (SODIS) and solar water pasteurisation.

### 1.1. SODIS sensors

Most of the approaches are based on UV detectors, monitoring UV radiation and in some cases temperature, not measuring other parameters such as sunshine duration or global irradiance.

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http://dx.doi.org/10.1016/j.solmat.2013.07.021

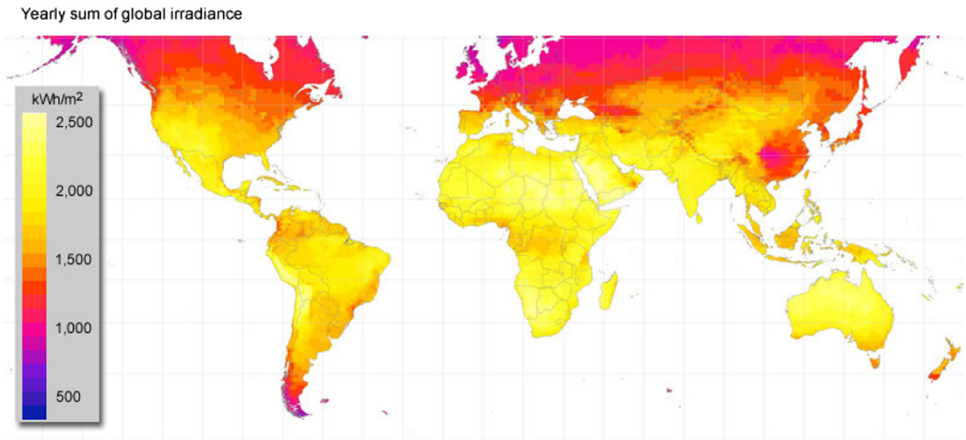


**Fig. 1.** World map showing the solar global irradiation received over the year [3]. Most developing countries are located in areas with high irradiance conditions.

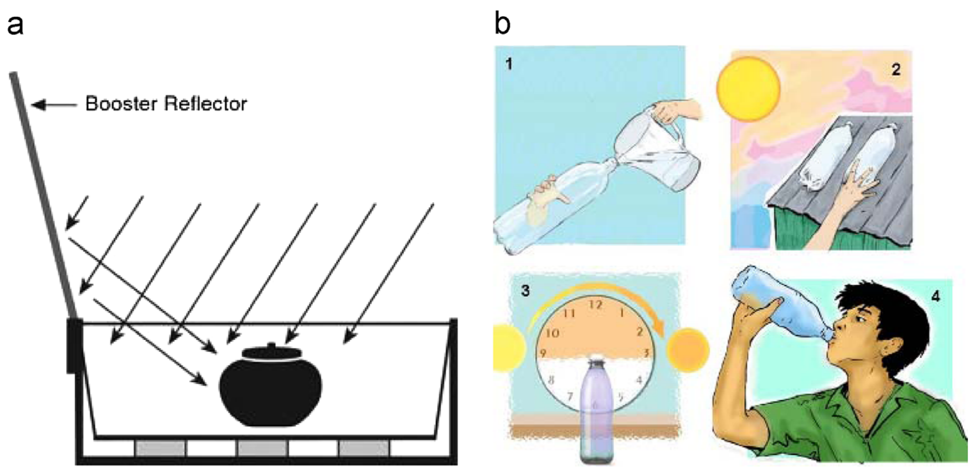


**Fig. 2.** Solar disinfection methods in developing countries: (a) solar pasteurisation [2] and (b) SODIS process [1].

In general, commercial sensors developed for both UV monitoring and artificial UV disinfection exist [5,6], but either they are too expensive for their use in developing countries or they are not suitable for natural sunlight due to spectrum differences (UVA in sunlight disinfection vs. UVC in artificial disinfection). Main findings on sensors suitable for natural solar disinfection in developing countries are summarised now.

In 1999, G. Smestad [7] patented a UV light detector for liquid disinfection units, consisting of two solid state photodetectors with different spectral responses, the first one generating in the ultraviolet–visible–infrared spectrum, and the second generating in the visible–infrared, so the UV light intensity could be calculated by differentiation of the two signals. The device connected the two parallel photodiodes output in reverse, and included the circuitry to monitor the UV level, which could activate a solenoid valve and/or alarm. The system monitored UV radiation and the sensor required power for the associated circuitry. The patent was assigned to WaterHealth International for its use in developing countries.

From this initial low cost UV photodetector intended for solar water disinfection till today there has been little research on this topic. Recent findings correspond to publications and patents from 2011 onwards. UVA dosimetric indicators (Fig. 3a) using azo dyes such as Methylene Blue or Acid Orange AO24 are other options that are currently being developed. These sensors are based on the complete discolouration of the dye when it degrades after receiving the solar radiation dose for inactivation of pathogens [8–10]. When the indicator is in dark and in the presence of oxygen, it is reoxidised back to Methylene Blue, constituting a reversible system. They measure only UVA radiation.

Another possibility is to use a passive average UV exposure sensor, consisting of an uncured ring of ultraviolet curable sealing photochromic material [11] placed around the neck and cap region of a plastic bottle, patented by Lantis et al. [12]. The main disadvantage is the inaccuracy of the measurement as it is based on colour change. UV sensors based on colour changes have been traditionally used for skin sun exposure applications [13–15], giving an overall indication of the UV content and the health hazard associated with sun exposure. In general this type of detector does not provide sufficient data for solar disinfection as it measures only an average UV dose with high uncertainty.

Finally, the Austrian company Helioz GmbH [16] has designed and patented another UV radiation sensor for SODIS, the WADIS sensor [17], consisting of a UV detector that monitors UV radiation. The integrated UV value is compared to a characteristic curve to determine the water disinfection degree, adjusted by a factor depending on the liquid temperature, which is also measured. It requires a battery, which is fed by solar cells. It is currently under development, and it measures UV radiation and temperature.

### *1.2. Solar water pasteurisation (SWP) sensors*

One type of SWP indicator is based on melting of a wax from solid to liquid and then changing shape or location, such as the water pasteurisation indicator (WAPI) shown in Fig. 3b [2,18]. The WAPI is a polycarbonate tube containing a wax at the top that