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Photovoltaic and disinfection performance study of a hybrid photovoltaic-solar water disinfection system

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ABSTRACT

It is the first time that flat PV (photovoltaic) cells were integrated with SODIS (solar water disinfection) to be an access to the clean drinkable water and the renewable electricity. The disinfection and photovoltaic performance of the system was evaluated by the disinfection of *Escherichia coli* (*E. coli*) and *Salmonella*. In order to enhance the SODIS process, a V-trough concentrator and low concentration H_2O_2 were adopted. The treatment time required for 8 L water that reached completely disinfection was 1.25 h and 2.5 h for the inactivation of *E. coli* and *Salmonella* respectively, when using the V-trough concentrator and 5 mg L^{-1} H_2O_2 simultaneously. Therefore, *E. coli* seems not to be a suitable bacteria indicator for SODIS. The temperature of the PV module decreases significantly because of the additional water layer, so that the power generation efficiency is improved. Although the water layer on the PV module can both reflect and absorb light, the output power of the PV module with a V-trough concentrator is about 43 W (the reference is 26.1 W), which is much higher than the whole system power consumption. Therefore, the excess power can be used for other applications.

1. Introduction

Clean water is of necessity and essentiality for every human being, there are still more than seven hundred millions people lack of access to safe drinkable water and not even the qualified sanitation by 2014. Millions of people, mostly children, die of gastrointestinal diseases caused by contaminated drinking water every year [1]. Because of economic backwardness and geographical limits, it is difficult to construct water treatment facilities in remote areas in developing countries [2]. Diseases increase local people poverty, therefore improving drinking water is an effective way to save them from poverty and reduce vulnerability.

Many researchers have proved that household water treatment can be more effective [3–5]. Lots of methods, for example, filtration, chlorination, boiling or flocculation have been used. However, each method has its disadvantages, such as high cost, taste or poor disinfection efficiency [6]. Fortunately, there is rich sunlight in many developing countries. It is a good choice using solar radiation for drinking water treatment. SODIS (solar water disinfection) had been confirmed efficiency for bacteria, fungi, protozoa, viruses and helminthes [7–9]. It was studied and promoted in developing countries for more than 30 years, which revealed a great potential to reduce diarrhea incidence [10,11]. Nowadays, there are more than 4.5 million people using SODIS to treat water in over 50 countries [7]. Nevertheless, the time needed for solar exposure is at least 6 h. If it was cloudy, this is up to 2–3 days.

The PET (polyethylene terephthalate) bottle is commonly used for SODIS, but it can only hold 2 L water [6]. Moreover, treating water by using PET bottles also faces other problems. Although results show that photoproducts, such as terephthalate compounds, do not migrate into the water and other compounds dissolved from PET bottles also below the limits setting for drinking water quality [12]. Doubts about the safety of water disinfection using plastic bottles are never end, which further obstruct the promotion of solar water disinfection.

In order to shorten the time needed for SODIS, a lot of enhanced methods had been adopted. Boosting the amount of sunlight

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Nomenclature

CFU	colony-forming unit, a single colony on culture media
LB	Luria–Bertani
PET	polyethylene terephthalate
SODIS	solar water disinfection
ROS	reactive oxygen species
DL	detection limit
P_m	the maximum output power, W
I_{sc}	short-circuit current, A
FF	fill factor

absorbed by the reactor was demonstrated to improve the efficiency of SODIS [13,14]. For increasing the radiation inside the reactors, aluminum reflectors consisted of compound parabolic, parabolic and V-groove profiles were used [15,16]. All of them enhanced the effect of the natural solar radiation. In addition, chemical additives were also demonstrated to be able to enhance SODIS process, like titanium dioxide (TiO_2), lemon, vinegar and so on [17,18]. Although TiO_2 used as a catalyst for solar photocatalytic disinfection could significantly increase the effectiveness of the SODIS. If it was used in suspension, the TiO_2 nanoparticles had to be separated before use, as the human health risks [19]. If it was supported, the cost was very high [20]. Except that, some of them could influence the taste and odor of the water, such as lemon and vinegar. Among them, hydrogen peroxide (H_2O_2) in water decomposed into water and oxygen without producing toxic by-products [21,22]. It is a suitable chemical additive to enhance SODIS process.

Bacterial disinfection is usually caused by solar UV (ultra-violet) light during SODIS process [23]. Borosilicate glass can transmit about 90% of the available UV-A as well as 45% UV-B. It is a suitable material for the use of larger solar reactors [5,24,25]. On the other hand, most of the larger SODIS systems, either continuous flow or pump circulation styles, both need electricity. However, previous studies of SODIS were limited to the disinfection efficiency and the electricity was ignored. But, remote areas that lack of clean water are also in lack of electricity.

Regarding the use of the solar spectrum, M. Vivar et al. [26–28] proposed the concept of integrating photo-catalytic water treatment with photovoltaic and built a fixed hybrid system to treat dye polluting water. Because TiO_2 photocatalysis mainly uses UV and near UV spectrum, which only account for about 4% in total solar radiation. At the same time, visible light is preferred by solar cells. SODIS also mainly uses UV and near UV spectrum. Compare with TiO_2 photocatalysis, catalysts are not essential for it, so the water layers have less effect on the PV modules. However, there is less study on the photovoltaic integrated with SODIS.

Escherichia coli was commonly used as the bacterial indicator for water treatment [29]. However, research works showed that this microorganism was very sensitive to solar irradiation and temperature [30,31]. In contrast, *Salmonella* sp. seems to be more resistant to SODIS, making it a far more suitable indicator for SODIS [32].

The aim of this work is to build up a highly efficient energy autonomous SODIS system. For the purpose of enhancing the SODIS process and improving the power output of the PV module, a V-trough concentrator is a good option. For it is simple to made and can realize with a geometrical of 2× concentration [33]. The electricity generated by the solar cells can be used for running the whole system. Additional electricity can charge cell phones and other daily facilities, which relieving the electricity pressure in remote areas.

A hybrid photovoltaic-solar water disinfection system with dual-axis tracking system was constructed. In order to enhance the SODIS process, a V-trough concentrator made by low cost polished aluminum and 5 mg L^{-1} H_2O_2 were used in this study. The photovoltaic and SODIS performance of the system was studied.

2. Systems and methods

2.1. The V-trough solar water treatment system

As shown in Fig. 1, the main part of the V-trough solar water treatment system includes four polished aluminum mirrors, a flat absorber and a dual-axis tracker. The mirror's dimensions are 500 × 600 × 5 mm and the angle of each mirror to the absorber plate is 120°, which can efficiently reflect UV (playing an important role in solar water disinfection) and visible spectrum (mainly used for electricity generation by solar cells). The pointing accuracy of the dual-axis tracker is less than 0.2° and the rotation angles are 100° at zenith and 220° at azimuth.

Two pumps (2.5 L min^{-1}, 6 W consumption, RS Components Ltd., China) were used for circulating water for the two systems respectively and the flat panel dual-axis tracking system used two linear actuators as shown in Fig. 2(a). Although the working power for each linear actuator was 20 W, the power consumed was very small (less than 4 W) as they worked intermittently.

Low iron tempered suede glass was used for encapsulating mono-crystalline silicon solar cells and their performance is

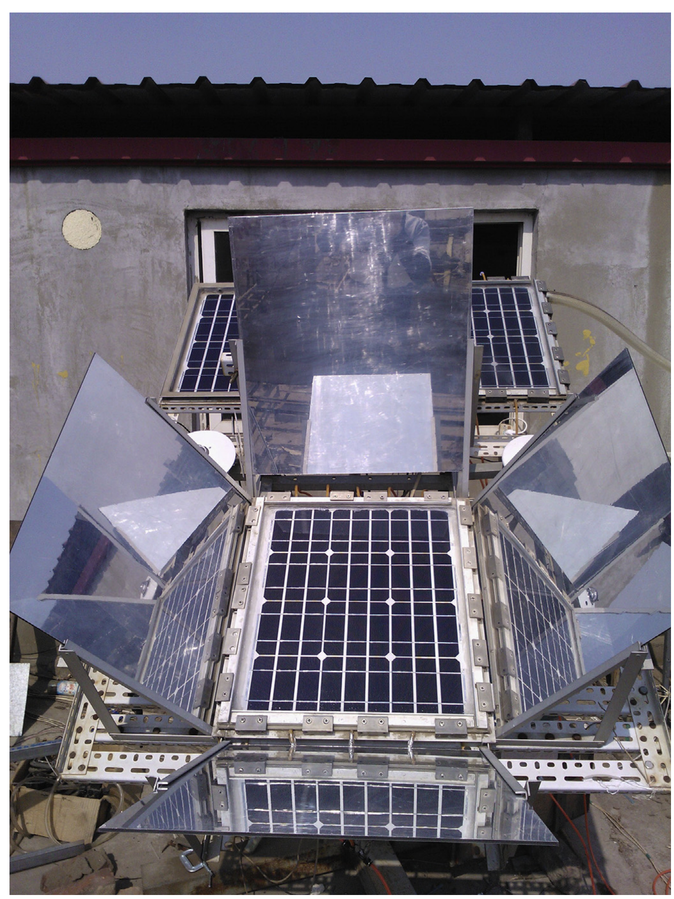

Fig. 1. The reference system, non-concentrating and concentrating systems.