Solar Energy Materials & Solar Cells 98 (2012) 260–266

Contents lists available at SciVerse ScienceDirect

Solar Energy Materials & Solar Cells

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

First lab-scale experimental results from a hybrid solar water purification and photovoltaic system

M. Vivar [a,*], M. Fuentes [b], N. Dodd [a], J. Scott [c], I. Skryabin [a], K. Srithar [d]

[a] Centre for Sustainable Energy Systems, Australian National University, Canberra 0200, Australia
[b] Grupo IDEA, Universidad de Jaen, Jaen 23071, Spain
[c] Particles and Catalysis Research Group, University of New South Wales, Sydney 2052, Australia
[d] Thiagarajar College of Engineering, Madurai, Tamil Nadu 625015, India

ARTICLE INFO

Article history:
Received 5 August 2011
Received in revised form
29 October 2011
Accepted 8 November 2011
Available online 30 November 2011

Keywords:
Photocatalysis
Water disinfection
Photovoltaic
Hybrid
Autonomous

ABSTRACT

A series of initial experiments to demonstrate the feasibility of hybrid photocatalytic–photovoltaic systems for simultaneous water purification and electricity generation have been conducted. Commercial TiO_2 (Aeroxide P25) suspended nanoparticles have been used as a photocatalyst and an organic dye (Methylene Blue) as a pollutant. The photovoltaic output of the hybrid system was observed to be related to MB dye photodegradation, whereby as the pollutant degraded the optical transmission to the cell improved. When the dye decolourisation was complete, the increase in photovoltaic output was between 32 and 37% depending on the initial dye concentration. The findings indicate both technologies can work simultaneously, producing drinking water and generating electricity to feed a pump, which establishes the path for a complete autonomous system.

1. Introduction

Approximately 884 million people lack access to clean drinking water according to the most recent update from the World Health Organisation [1], with almost all of them in developing regions. Of this world population without drinking water sources, 84% live in rural areas. Unsafe water and poor sanitation cause 80% of all diseases in the developing world [1]. Development of simple, cost-effective and easy to operate and maintain water purification units is a challenge that requires the application of scientific knowledge from various disciplines.

Solar water disinfection systems using photocatalysts and UV radiation have been proven as one of the most appropriate technologies for water purification [2–4], especially in remote regions of developing countries where access to electrical power is either restricted or unavailable. However, the widespread use of such photocatalytic water purification systems is hampered due to cost and technological limitations. This includes spectral limitations as most of the simple, cheap and stable photocatalysts are active only in the UV and near UV components of the solar spectrum [5] (which represents ~5% of the total solar radiation), and surface area limitations due to the relatively small available photocatalytic surface when it is coated on a support.

A new concept for a hybrid solar water purification and photovoltaic system to meet the needs for clean water and electricity in one integrated autonomous system has been recently developed [6]. The concept consists of a single unit that uses the solar spectrum more efficiently (Fig. 1), combining both photocatalysis for water purification using the UV component; and photovoltaics for electricity generation using the visible and near infra-red light components. This original concept builds on state-of-the-art technologies developed for solar photovoltaic systems and photocatalytic treatment of water, and combines both in a fully integrated compact device.

From the most generalised point of view, the proposed PWAP (Purified Water and Power) receiver comprises two devices fully integrated into a single unit, using two functionally discrete sub-modules. These two sub-modules can be assembled in two different physical arrangements: (a) one inside the other, whereby the encapsulated photovoltaic cells are embedded into the photocatalytic reactor; or (b) one above the other, whereby the photovoltaic cells are attached to the photo-catalytic reactor by means of a common encapsulation. The particular geometry of the receiver for either of the two physical arrangements can be planar or tubular. Fig. 2 shows one example of a tubular configuration comprising two concentric tubes; a main outer tube containing the photocatalyst, and an optimised internal structure containing

* Corresponding author. Tel.: +61 2 6125 1739; fax: +61 2 6125 8873.
E-mail address: marta.vivar@anu.edu.au (M. Vivar).

0927-0248/$ - see front matter Crown Copyright © 2011 Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.solmat.2011.11.012

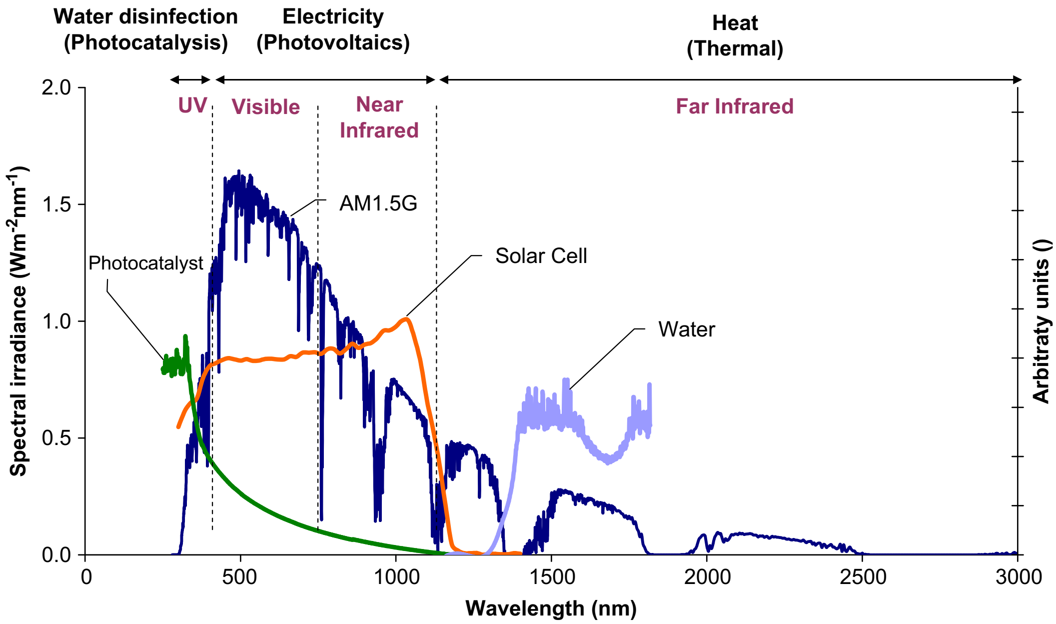

Fig. 1. Use of the solar spectrum in the new concept: UV for water disinfection using photocatalysis, and visible and near infrared for electricity generation using photovoltaics. Far infrared can generate heat that might be suitable for low grade heat applications.

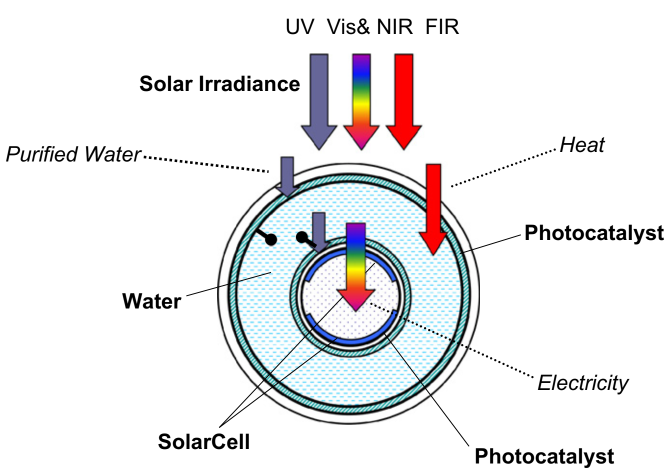

Fig. 2. The concept of a hybrid receiver: cross-sectional view showing the inner and the outer tubes, two photocatalytic layers, treated water, solar cells, cooling liquid and electrodes; and spectral absorbance diagram: UV absorbed by each of the photocatalytic layers, far IR absorbed by water, visible and near-IR absorbed by solar cells.

the encapsulated solar cells. Both the internal surface of the outer tube and the external surface of the inner structure are suitable for supporting a photocatalyst; almost doubling the effective surface area, which is a primary limitation of photocatalytic water purification systems.

Fig. 2 also shows the spectral absorbance through the different layers of materials. The system uses the UV for photocatalysis and the visible and the near-IR light for the solar cells, with the far-IR absorbed by the water, as shown in Fig. 1. The generated solar electrical power is used to run the pumps and can also be used for the electrical enhancement of water purification using electrodes [7–9] optionally positioned on the main photocatalytic module. Additional thermal energy generated from light absorption in the far-IR could be also used in combination with a heat exchanger for hot water domestic applications.

This concept explores new methods for splitting the solar spectrum using simple materials and processes. Careful adaptation of the refractive indices between the various interfaces and materials is required to minimise optical losses, as well as match spectral responses of the photocatalyst (a nano-particulate semi-conducting material such as a mesoporous titanium dioxide film) and the photovoltaic solar cells. The innovative use of the split spectrum for the two different applications also needs to be studied to develop an understanding of the inter-relationship between the two technologies and the benefits and limitations arising from their integration.

This article presents the results from the first lab-scale experiments conducted at The Australian National University (ANU) on PWAP receivers, coupling photovoltaics (PV) and photocatalysis (PC) in one optically adapted receiver. These experiments show that the integration of both technologies is feasible and there is scope for further development into complete autonomous PV/PC modules.

2. Materials

For this set of tests, two small planar prototypes were manufactured, comprising photovoltaic solar cells located below a photocatalytic reactor as shown in Fig. 3. The photocatalytic reactor consisted of a Pyrex glass petri dish. The solar cells were encapsulated in clear silicone beneath the reactor.

Suspended TiO_2 particles (commercial Aeroxide P25, surface area 50 m^2/g) were used as the photocatalyst at a concentration of 0.2 g/L. To simulate the pollutant, an organic dye (Methylene Blue (MB), Sigma-Aldrich) with an absorption peak at 665 nm was selected, with initial concentrations ranging from 0.005 g/L to 0.01 g/L. A magnetic stirrer was used to ensure that the suspended photocatalyst did not settle to the bottom of the reactor.

The photovoltaic component of the solar receiver consisted of four small monocrystalline solar cells connected in series with a total short-circuit current of approximately 105 mA at 1 sun (1000 W/m^2).

3. Experimental procedure

The PWAP receiver was set up under natural sunlight along with a control sample (Fig. 4). The control sample, having the same configuration as the PWAP receiver, was used to isolate