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# Solar Water Purification Technologies And Photovoltaics: Is Integration Possible

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***Abstract:***

*Currently 708 million people lack access to a safe water supply, most of them in rural areas. Unsafe water and poor sanitation cause 80% of all diseases in the developing world. Development of simple, cost-effective and socially acceptable domestic water purification units is a challenge that requires the application of scientific knowledge from various disciplines.Solar disinfection is one of the most appropriate point-of-use water treatment methods in remote regions with restricted or unavailable access to electrical power and/or chemical supplies. They use the bactericidal effect of UV radiation or convert the solar energy into heat for thermal pasteurization or distillation. But their widespread is limited by the lack of low-cost sensors to detect when the water is clean, i.e. if the treated water has received enough radiation and/or if it has reached the pasteurization temperature. Additionally, for the case of natural UV photocatalytic reactors, the use of only a small fraction of the solar spectrum (5%) limits the system efficiency and increases the cost.Photovoltaic solar cells can be used to measure irradiance (from their current) and temperature (from their voltage), and can also be integrated into hybrid systems to increase their total efficiency (photovoltaic-thermal, photovoltaic-photocatalytic). This article explores the potential of the integration of solar photovoltaic in solar water treatment processes.*

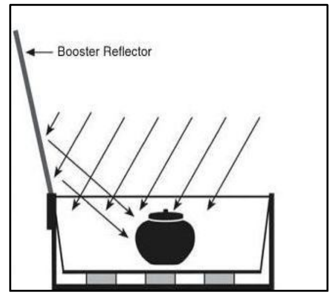
**Keywords:** *solar, water disinfection, photovoltaic, UV, electricity, hybrid, autonomous*

**Solar Water Technologies**

About 708 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. From this world population without drinking water sources, 84 % live in rural areas. In India, 1.9 million children die every year; 20 percent of these deaths result from diarrhoea-related diseases, which are usually caused by unsafe drinking water and poor sanitation [1]. On the other hand, emergency situations such as floods and earthquakes also produce lack of water supply, often in areas with limited access to infrastructure and resources [2].

Criteria for the development of a successful water treatment (WT) method in rural areas in developing countries and emergency situations are very similar: simple, low cost, appropriate for domestic use, easy to operate and maintain, low environmental impact, low energy requirements, no strong supply chain requirements, high potential social acceptance and high performance [2,3,4]. Main water treatment processes include: a) boiling, simple and efficient but it requires firewood (high energy usage); b) chlorine disinfection, very effective, simple and inexpensive, but it needs continuous chemical supply and it forms toxic gases (harmful and environmentally damaging); c) filtration, simple but not effective with all contaminants and with high maintenance; d) reverse osmosis, very effective but with very high cost and high energy usage; d) artificial UV radiation, very efficient but also, expensive and requiring specialised parts; and d) solar disinfection, clean, simple, but environmental dependent and in some cases with low performance.

Solar disinfection technologies have been proven as one of the most appropriate point-of-use water treatment (WT) methods [5,6], especially in remote regions with high irradiance conditions (most of the developing countries are located in the so-called 'sun-belt') and either restricted or unavailable access to electrical power and/or chemical supplies. They can use directly the bactericidal effect of UV radiation [7] or convert the solar energy into heat for thermal pasteurization or distillation, or a combination of both. Main technologies include (Fig. 1): natural UV disinfection using photocatalytic reactors, solar pasteurization systems reaching water temperatures of about 70ºC, solar distillation by water evaporation and condensation, and direct exposure of plastic bottles following the SODIS process for a certain number of hours using UV radiation and heat [5].

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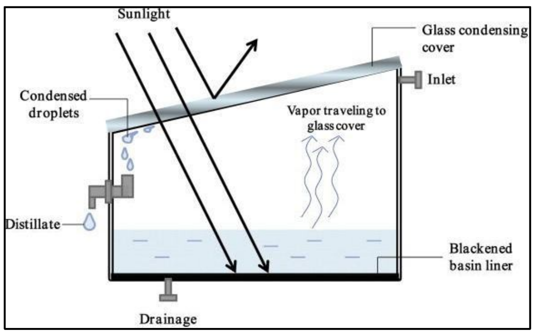


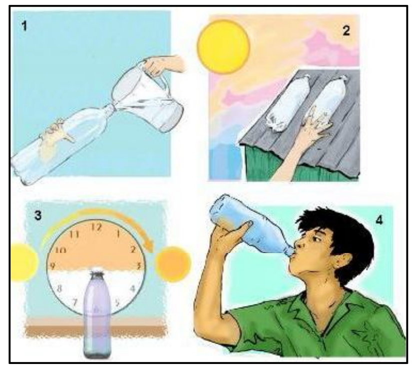

*(3)* *(4)*

*Figure 1: Solar Water Treatment (WT) methods: 1) Natural UV disinfection using photocatalytic reactors(PSA-CIEMAT, Almeria, Spain), 2) Solar pasteurization [6], 3) Solar distillation [2], 4) SODIS process [5]*

## Limitations Of Solar Wt Methods

### *Lack of sensors*

One of the main factors that affect all solar disinfection technologies widespread is the lack of low-cost sensors to detect when the water is clean, i.e. if the treated water has received enough radiation and/or if it has reached the pasteurization temperature (Figure 1). Scientific research is currently looking for all type of simple sensors that can provide some aid to detect when the water is clean, such as the current development of UVA dosimetric indicators using Methylene Blue [8], or water pasteurisation indicators based on melting of materials from solid to liquid and then changing shape or location, or materials with different thermal expansions that could interact and make a change in geometry, etc. [6]. The only technology that would not need an indicator is solar distillation, but it requires higher solar energy doses for longer periods than any of the other solar technologies [6].

*Natural UV disinfection*

Natural UV photocatalytic reactors are also limited by cost and only in the UV and near UV components of the solar spectrum (5% of the total), and photocatalyst surface area limitations due to the relatively small available surface of the receiver [6, 9]. The other drawback is that the current solar water photocatalytic technology is not autonomous and it needs some source of electricity to feed the pumps and maintain the system, which adds also more complexity. Very substantial research efforts are being conducted across the international scientific community to overcome these technological limitations. Some of the approaches include: extending the absorption of photocatalysts into the visible part of solar spectra [10,11], increasing the effective surface areas of a catalytic interface by developing new photocatalytic structures such as nanofibers, nanotubes or graphene composite particles suspended in water [9, 12], or increasing the system performance by designing hybrid systems [13]. However, there are also potential drawbacks such as the decrease in corrosion resistance of photocatalysts as spectral absorption is increased, causing an unfortunate trade-off between performance and longevity; and dispersing new nanoparticles in the water introduces an additional separation step for the removal of the nanoparticles from the purified water which is expensive, complex, and not suitable for rural areas in developing countries.

*Figure 2 : SODIS bottles under the sun showing the lack of sensors providing information about the water purification process [5]*

**Potential Of The Integration Of Photovoltaics In Solar Water Technologies**

*PV cells as sensors*

Photovoltaic (PV) solar cells can be used to measure both irradiance and temperature [14]. First, the generated short-circuit current (Isc) increases linearly as a function of the received irradiance. Therefore, a solar cell could be used to estimate the numbers of sunshine hours or the total irradiance received during a day and work as a simple light detector. This would be suitable for applications based on direct exposure of the water to the sun, such as SODIS bottles or natural UV systems. Second, the open-circuit voltage (Voc) of the solar cell decreases linearly with temperature, being generally used as an indicator of the cell temperature. This means that the cell could be also used as a thermometer, and estimate if the water on top of an encapsulated cell has reached a certain temperature or not, and for how long. Solar water pasteurization could determine if pasteurization temperature was reached, and SODIS and natural UV disinfection would have more information about the disinfection process, dependent also on the temperature. Therefore, a PV solar cell could be initially integrated in any solar water technology that requires information on irradiance and/or water temperature. Combining these characteristics with the current low cost on silicon technologies, both in PV and microelectronics, would allow the development of an efficient and inexpensive clean water sensor.

*Hybrid PV-UV systems*

Natural UV photocatalytic systems are limited by their poor use of the solar spectrum, only 5% of the total, and their reduced surface area for the photocatalyst, leading to an inefficient and expensive system not suitable for the households of the developing world. Photovoltaic solar silicon cells on the other hand use mostly the visible and near-infrared parts of the spectrum, and part of the UV, although very inefficiently in this region. Therefore, PV cells and natural UV photocatalysis could be integrated in a single unit that would produce clean water and electricity, using the solar spectrum more efficiently (Fig. 2), combining both photocatalysis for water purification using UV light; and photovoltaics for electricity generation using visible and near infra-red light components. The generated solar electrical power would be used to run the pumps and could be also used for the electrical enhancement of water purification using electrodes optionally positioned on the main photocatalytic module.

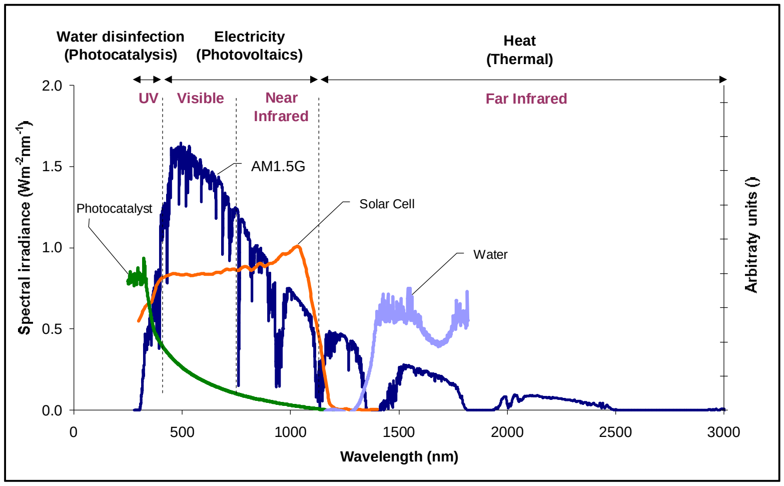


*Figure 3: Use of the solar spectrum in the new concept: UV for water disinfection using photocatalysis, and Visible and Near Infrared for electricity generation using photovoltaics. Far Infrared can generate heat that might be suitable for low grade heat applications.*

This novel concept –SolWat- for an autonomous hybrid photovoltaic-photocatalytic system for the generation of electricity and clean water was recently developed by the author [13]. It consists of a receiver comprising 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 photo-catalytic 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. 3 shows one example of a tubular configuration comprising two concentric tubes; a main outer tube containing the photocatalyst, and an optimized internal structure containing 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. 3 also shows the spectral absorbance through the different layers of materials. ***A first small-scale prototype based on a planar geometry was manufactured and tested*** by the applicant and her collaborators ***showing the feasibility of the concept*** (Fig.4), running the system autonomously by using the electricity generated by the PV cells, and simultaneously eliminating an artificial pollutant from the water [15, 16]. This first demonstration sets the path for the development of a new complete autonomous clean water system suitable for developing regions.

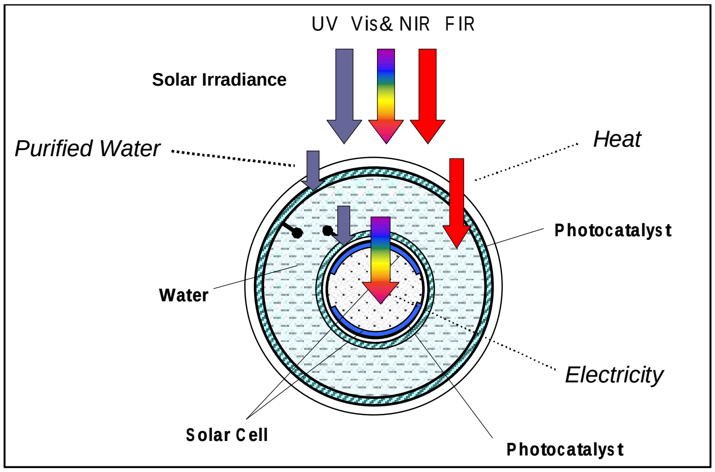


*Figure 4: Concept of a hybrid receiver: cross-sectional view showing the inner and the outer tubes, two photocatalytic layers, treated water, solar cells and electrodes; and spectral absorbance diagram: UV absorbed by the photocatalytic layers, FIR absorbed by water, Vis and NIR absorbed by solar cells.*

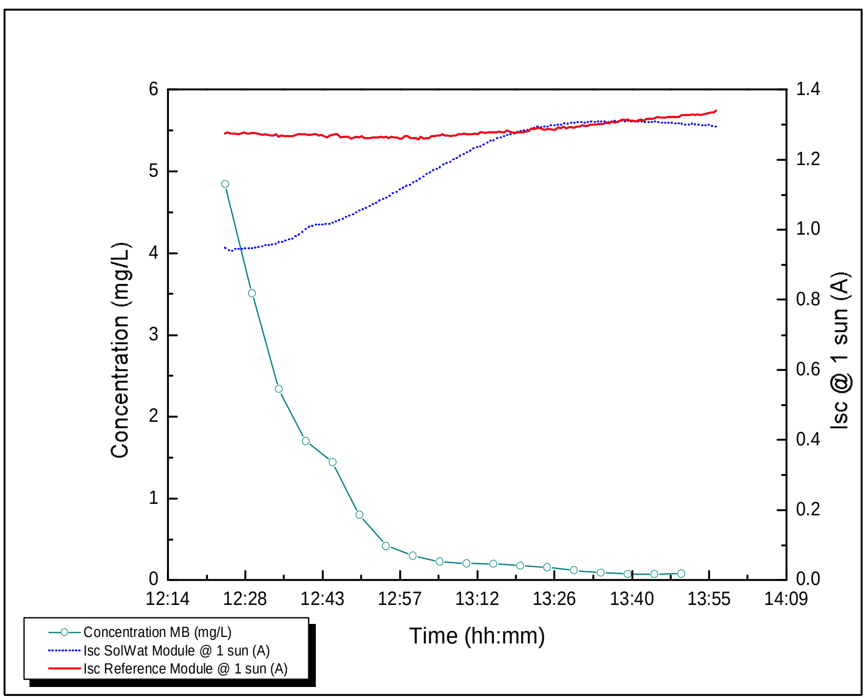


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*Figure 5: 1) Photocatalytic and photovoltaic outputs from the experiment, showing how the PV output increases as the pollutant concentration decreases. 2) Reference and SolWat receiver at the beginning and end of the experiment. The blue colour corresponds to the artificial pollutant. The final white colour shows the photocatalytic degradation of the blue dye and corresponds to the remaining suspended nanoparticles ($TiO_2$).*

**Summary**

Access to clean drinking water in developing countries is one of the toughest challenges that needs to be addressed. Currently 708 million people lack access to a safe water supply, most of them in rural areas with limited infrastructures and resources. Unsafe water and poor sanitation cause 80% of all diseases in the developing world. Development of simple, cost-effective, easy to operate and maintain, and socially acceptable domestic water purification units is a challenge that requires the application of scientific knowledge from various disciplines.

Solar disinfection technologies have been proven as one of the most appropriate point-of-use water treatment (WT) methods, especially in remote regions where access to electrical power and/or chemical supplies are either restricted or unavailable. They can use directly the bactericidal effect of UV radiation or convert the solar energy into heat for thermal pasteurization or distillation, or a combination of both. Main technologies include: natural UV disinfection using photocatalytic reactors, solar pasteurization systems reaching water temperatures of about 70ºC, and direct exposure of plastic bottles to the sun following the SODIS process using UV radiation and heat. One of the main factors that affect their widespread is the lack of low-cost sensors to detect when the water is clean, i.e. if the treated water has received enough radiation and/or if it has reached the pasteurization temperature. Additionally, for the case of natural UV photocatalytic reactors, the use of only a small fraction of the solar spectrum when using natural light (5%) limits the system efficiency and leads to a very high cost.

Photovoltaic solar cells can be used to measure irradiance (based on their current) and temperature (based on their voltage), and can also be integrated into hybrid systems to increase their total efficiency (photovoltaic-thermal, photovoltaic-photocatalytic). This article has explored the initial potential of the integration of solar photovoltaic technology in solar water treatment processes, which could be done by: a) using solar cells as inexpensive clean water sensors measuring irradiance and temperature suitable for different solar WT systems (SODIS, solar pasteurisation, natural UV); and b) developing hybrid photovoltaic-photocatalytic systems in a single unit that uses the solar spectrum more efficiently, combining both photocatalysis for water purification using UV light; and photovoltaics for electricity generation using visible and near infra-red light components. This innovative approach could lead to low-cost clean water sensors suitable for all solar disinfection technologies, and to high efficient, autonomous hybrid systems that could be used in rural areas with no access to electricity and/or in emergency situations. The total cost of the hybrid system and the social acceptance will also need to be explored as the main drawbacks that could affect the deployment of such system.

**Reference**


1. 1.WHO-Unicef JMP, update on 'Progress on Drinking Water and Sanitation', 2012.
2. S. Loo et al., Emergency water supply: a review of potential technologies and selection criteria, *Water Research* 46 (2012), pp. 3125-3151.
3. D. M. Johnson et al., Feasibility of water purification technology in rural areas of developing countries, *Journal of Environmental Management* 88 (2008), pp. 416-427.
4. WHO, 'Guidelines for drinking-water quality', 4th edition, 2011.
5. K.G. McGuigan, et al., Solar water disinfection (SODIS): A review from bench-top to roof-top, *Journal of Hazardous Materials* (2012), http://dx.doi.org/10.1016/j.jhazmat.2012.07.053
6. C. Ray, R. Jain (eds.), *Drinking Water Treatment,* Strategies for Sustainability, 2011, Springer, New York.
7. M. Boyle et al, Bactericidal effect of solar water disinfection under real sunlight conditions, *Applied and Environmental Microbiology* 74, No. 10 (2008), 2997-3001.
8. R. Copperwhite, C. McDonagh and S. O'Driscoll, A camera phone-based UV-dosimeter for monitoring the solar disinfection (SODIS) of water', *IEEE Sensors Journal* 12 (2012), pp.1425-1426.
9. K. Nakata et al., Photoenergy conversion with TiO2 photocatalysis: New materials and recent applications, *Electrochimica Acta* (2012), In Press, http://dx.doi.org/10.1016/j.electacta.2012.03.035.
10. M. N. Chong et al., Recent developments in photocatalytic water treatment technology: A review, *Water Research* 44 (2010), 2997-3027.
11. M. Pelaez et al., A review on the visible light active titanium dioxide photocatalysts for environmental applications, *Applied Catalysis B: Environmental* 125 (2012), pp. 331–349.
12. L. Pastrana-Rodriguez et al., Advanced nanostructured photocatalysts based on reduced graphene oxide–$TiO_2$ composites for degradation of diphenhydramine pharmaceutical and methyl orange dye, *Applied Catalysis B: Environmental* 123-124 (2012), pp. 241–256.
13. M. Vivar et al., A Concept for a Hybrid Solar Water Purification and

Photovoltaic System, *Solar Energy Materials and Solar Cells* 94 (2010) 1772-1782.

**14.** A. Luque, S. Hegedus (Eds.), Handbook of Photovoltaic Science and Technology, Wiley, Chichester, 2003.

**15.** M. Vivar et al., First Lab-Scale Experimental Results from a Hybrid Solar Water Purification and Photovoltaic System, *Solar Energy Materials and Solar Cells* 98 (2012), pp. 260-266.

**16.** M. Fuentes et al., Results from a first autonomous optically adapted photocatalytic-photovoltaic module for water purification, *Solar Energy Materials and Solar Cells* 100 (2012), pp. 216-225.