

A Bibliography of Selected Articles on SODIS, July 2009.

This bibliography contains citations and abstracts to 11 SODIS studies published from January – July 2009. The bibliography will be updated on a periodic basis so please contact Environmental Health at USAID if you know of additional 2009 studies that should be added.

Environmental health bibliographies will be posted on the **EH Updates** page of the Environmental Health at USAID website at: http://www.ehproject.org/eh/eh_topics.html

1 - Acta Trop. 2009 Jun 17.

Effect of the radiation intensity, water turbidity and exposure time on the survival of *Cryptosporidium* during simulated solar disinfection of drinking water.

Gómez-Couso H, Fontán-Sainz M, McGuigan KG, Ares-Mazás E.

Laboratorio de Parasitología, Departamento de Microbiología y Parasitología, Facultad de Farmacia, Universidad de Santiago de Compostela, Campus Universitario Sur, 15782 Santiago de Compostela (La Coruña), Spain.

The solar disinfection (SODIS) technique is a highly effective process that makes use of solar energy to inactivate pathogenic microorganisms in drinking water in developing countries. The pathogenic protozoan parasite *Cryptosporidium parvum* is often found in surface waters and is associated with waterborne outbreaks of cryptosporidiosis. In the present study, a complete multi-factorial mathematical model was used to investigate the combined effects of the intensity of solar radiation (200, 600 and 900W/m² in the 320nm to 10µm range), water turbidity (5, 100 and 300 NTU) and exposure time (4, 8 and 12h) on the viability and infectivity of *C. parvum* oocysts during simulated SODIS procedures at a constant temperature of 30 degrees C. All three factors had significant effects ($p < 0.05$) on *C. parvum* survival, as did the interactions of water turbidity with radiation intensity and radiation intensity with exposure time. However, the parameter with the greatest effect was the intensity of radiation; levels $\geq 600\text{W/m}^2$ and times of exposure between 8 and 12h were required to reduce the oocyst infectivity in water samples with different degrees of turbidity.

2 - Trop Med Int Health. 2009 Jun; 14(6):620-7.

Efficacy of the solar water disinfection method in turbid waters experimentally contaminated with *Cryptosporidium parvum* oocysts under real field conditions.

Gómez-Couso H, Fontán-Sainz M, Sichel C, Fernández-Ibáñez P, Ares-Mazás E.

Laboratorio de Parasitología, Departamento de Microbiología y Parasitología, Universidad de Santiago de Compostela, Spain.

OBJECTIVE: To investigate the efficacy of the solar water disinfection (SODIS) method for inactivating *Cryptosporidium parvum* oocysts in turbid waters using 1.5 l polyethylene terephthalate (PET) bottles under natural sunlight.

METHODS: All experiments were performed at the Plataforma Solar de Almería, located in the Tabernas Desert (Southern Spain) in July and October 2007. Turbid water samples [5, 100 and 300 nephelometric turbidity units (NTU)] were prepared by addition of red soil to distilled water, and then spiked with purified *C. parvum* oocysts. PET bottles containing the contaminated turbid waters were exposed to full sunlight for 4, 8 and 12 h. The samples were then concentrated by filtration and the oocyst viability was determined by inclusion/exclusion of the fluorogenic vital dye propidium iodide. Results After an exposure time of 12 h (cumulative global dose of 28.28 MJ/m²; cumulative UV dose of 1037.06 kJ/m²) the oocyst viabilities were 11.54%, 25.96%, 41.50% and 52.80% for turbidity levels of 0, 5, 100 and 300 NTU, respectively, being significantly lower than the viability of the initial isolate ($P < 0.01$).

CONCLUSIONS: SODIS method significantly reduced the potential viability of *C. parvum* oocysts on increasing the percentage of oocysts that took up the dye PI (indicator of cell wall integrity), although longer exposure periods appear to be required than those established for the bacterial pathogens usually tested in SODIS assays. SODIS.

3 - Photochem Photobiol Sci. 2009 May; 8(5):587-95.

Solar disinfection of drinking water (SODIS): an investigation of the effect of UV-A dose on inactivation efficiency.

Ubomba-Jaswa E, Navntoft C, Polo-López MI, Fernandez-Ibáñez P, McGuigan KG.

Department of Physiology and Medical Physics, Royal College of Surgeon, Dublin 2, Ireland. eubombajaswa@rcsi.ie

The effect of solar UV-A irradiance and solar UV-A dose on the inactivation of *Escherichia coli* K-12 using solar disinfection (SODIS) was studied. *E. coli* K-12 was seeded in natural well-water contained in borosilicate glass tubes and exposed to sunlight at different irradiances and doses of solar UV radiation. In addition, *E. coli* K-12 was also inoculated into poly(ethylene) terephthalate (PET) bottles and in a continuous flow system (10 L min⁻¹) to determine the effect of an interrupted and uninterrupted solar dose on inactivation. Results showed that inactivation from approximately 10(6) CFU mL⁻¹ to below the detection level (4 CFU/mL) for *E. coli* K-12, is a function of the total uninterrupted dose delivered to the bacteria and that the minimum dose should be >108 kJ m⁻² for the conditions described (spectral range of 0.295-0.385 microm). For complete inactivation to below the limit of detection, this dose needs to be received regardless of the incident solar UV intensity and needs to be delivered in a continuous and uninterrupted manner. This is illustrated by a continuous flow system in which bacteria were not fully inactivated (residual viable concentration approximately 10(2) CFU/mL) even after 5 h of exposure to strong sunlight and a cumulative dose of >108 kJ m⁻². This has serious implications for attempts to scale-up solar disinfection through the use of recirculatory continuous flow reactors.

4 - Microbiology. 2009 Apr; 155(Pt 4): 1310-7.

Solar disinfection (SODIS) and subsequent dark storage of *Salmonella typhimurium* and *Shigella flexneri* monitored by flow cytometry.

Bosshard F, Berney M, Scheifele M, Weilenmann HU, Egli T.

Swiss Federal Institute of Aquatic Science and Technology, CH-8600 Dübendorf, Switzerland.

Pathogenic enteric bacteria are a major cause of drinking water related morbidity and mortality in developing countries. Solar disinfection (SODIS) is an effective means to fight this problem. In the present study, SODIS of two important enteric pathogens, *Shigella flexneri* and *Salmonella typhimurium*, was investigated with a variety of viability indicators including cellular ATP levels, efflux pump activity, glucose uptake ability, and polarization and integrity of the cytoplasmic membrane. The respiratory chain of enteric bacteria was identified to be a likely target of sunlight and UVA irradiation. Furthermore, during dark storage after irradiation, the physiological state of the bacterial cells continued to deteriorate even in the absence of irradiation: apparently the cells were unable to repair damage. This strongly suggests that for *S. typhimurium* and *Sh. flexneri*, a relatively small light dose is enough to irreversibly damage the cells and that storage of bottles after irradiation does not allow regrowth of inactivated bacterial cells. In addition, we show that light dose reciprocity is an important issue when using simulated sunlight. At high irradiation intensities ($>700 \text{ W m}^{-2}$) light dose reciprocity failed and resulted in an overestimation of the effect, whereas reciprocity applied well around natural sunlight intensity ($<400 \text{ W m}^{-2}$).

5 - *Parasitology*. 2009 Apr; 136(4):393-9.

Excystation of *Cryptosporidium parvum* at temperatures that are reached during solar water disinfection.

Gómez-Couso H, Fontán-Sainz M, Fernández-Alonso J, Ares-Mazás E.

Laboratorio de Parasitología, Departamento de Microbiología y Parasitología, Facultad de Farmacia, Universidad de Santiago de Compostela, Campus Universitario Sur, 15782 Santiago de Compostela (La Coruña), Spain.

Species belonging to the genera *Cryptosporidium* are recognized as waterborne pathogens. Solar water disinfection (SODIS) is a simple method that involves the use of solar radiation to destroy pathogenic microorganisms that cause waterborne diseases. A notable increase in water temperature and the existence of a large number of empty or partially excysted (i.e. unviable) oocysts have been observed in previous SODIS studies with water experimentally contaminated with *Cryptosporidium parvum* oocysts under field conditions. The aim of the present study was to evaluate the effect of the temperatures that can be reached during exposure of water samples to natural sunlight (37-50 degrees C), on the excystation of *C. parvum* in the absence of other stimuli. In samples exposed to 40-48 degrees C, a gradual increase in the percentage of excystation was observed as the time of exposure increased and a maximum of 53.81% of excystation was obtained on exposure of the water to a temperature of 46 degrees C for 12 h (versus 8.80% initial isolate). Under such conditions, the oocyst infectivity evaluated in a neonatal murine model decreased statistically with respect to the initial isolate (19.38% versus 100%). The results demonstrate the important effect of the temperature on the excystation of *C. parvum* and therefore on its viability and infectivity.

6: *Water Res*. 2009 Feb; 43(3):643-52.

Solar radiation disinfection of drinking water at temperate latitudes: inactivation rates for an optimised reactor configuration.

Davies CM, Roser DJ, Feitz AJ, Ashbolt NJ.

Centre for Water and Waste Technology, Department of Civil and Environmental Engineering, University of New South Wales, Kensington, NSW 2052, Australia.
cheryl@crehleeds.demon.co.uk

Solar radiation-driven inactivation of bacteria, virus and protozoan pathogen models was quantified in simulated drinking water at a temperate latitude (34 degrees S). The water was seeded with *Enterococcus faecalis*, *Clostridium sporogenes* spores, and P22 bacteriophage, each at ca 1×10^5 mL⁻¹, and exposed to natural sunlight in 30-L reaction vessels. Water temperature ranged from 17 to 39 degrees C during the experiments lasting up to 6h. Dark controls showed little inactivation and so it was concluded that the inactivation observed was primarily driven by non-thermal processes. The optimised reactor design achieved S90 values (cumulative exposure required for 90% reduction) for the test microorganisms in the range 0.63-1.82 MJ m⁻² of Global Solar Exposure (GSX) without the need for TiO₂ as a catalyst. High turbidity (840-920 NTU) only reduced the S(90) value by <40%. Further, when all S90 means were compared this decrease was not statistically significant (prob.>0.05). However, inactivation was significantly reduced for *E. faecalis* and P22 when the transmittance of UV wavelengths was attenuated by water with high colour (140 PtCo units) or a suboptimally transparent reactor lid (prob.<0.05). S90 values were consistent with those measured by other researchers (ca 1-10 MJ m⁻²) for a range of waters and microorganisms. Although temperatures required for SODIS type pasteurization were not produced, non-thermal inactivation alone appeared to offer a viable means for reliably disinfecting low colour source waters by greater than 4 orders of magnitude on sunny days at 34 degrees S latitude.

7 - Ana I. Gomes, Vitor J.P. Vilar, Rui A.R. Boaventura,

Synthetic and natural waters disinfection using natural solar radiation in a pilot plant with CPCs,

Catalysis Today, Volume 144, Issues 1-2, Selected papers presented at the 5th European Conference on Solar Chemistry and Photocatalysis: Environmental Applications (SPEA 5), 4-8th October 2008, 15 June 2009, Pages 55-61, ISSN 0920-5861, DOI: 10.1016/j.cattod.2008.12.023.

Solar disinfection of synthetic and natural waters from the Douro River, northern Portugal was studied in a pilot plant with compound parabolic collectors. Inactivation of *Enterococcus faecalis* was slower than *Escherichia coli* possibly due to the cell wall composition of the Gram-positive and Gram-negative bacteria, respectively. The high content of peptidoglycan, teichoic acids, polysaccharides, and peptidoglycolipids, in *E. faecalis* cell wall, when compared with *E. coli*, acts as a protective coating. Higher inactivation rate constants were obtained for higher initial bacteria concentrations; however a greater dose of UV energy was required. The flow rate effect in disinfection of synthetic waters was negligible. However, for natural waters with low bacteria contamination, the effect of the mechanical stress on the inactivation increased with the flow rate. Competition for the reactive oxidant radicals was

observed in binary systems, containing similar concentrations of *E. coli* and *E. faecalis*.

No bacterial regrowth was observed for *E. faecalis* in synthetic waters. Oppositely, regrowth occurred for natural waters. This behaviour can be due to the natural water chemical composition, with the presence of various organic and inorganic species.

8 - Ana I. Gomes, Joao C. Santos, Vitor J.P. Vilar, Rui A.R. Boaventura,

Inactivation of Bacteria *E. coli* and photodegradation of humic acids using natural sunlight,

Applied Catalysis B: Environmental, Volume 88, Issues 3-4, 20 May 2009, Pages 283-291, ISSN 0926-3373, DOI: 10.1016/j.apcatb.2008.11.014.

In this work, the disinfection of bacteria *Escherichia coli* and degradation of humic acids, using sunlight, sunlight + TiO₂ (Degussa P25) in suspension or TiO₂ supported on Ahlstrom paper (NW10) fixed around concentric tubes inside the photoreactor, were investigated in a pilot plant. The inactivation of bacteria *E. coli* proved to be more efficient (only 1 kJUV/L for 5-log decrease in concentration) when using sunlight and TiO₂ in suspension. However, true disinfection was not achieved under the conditions reported in this work. A first-order model was able to fit the photocatalytic deactivation of *E. coli* ([TiO₂] = 50 mg/L) with an inactivation rate constant of 8.21 L/kJ. A Langmuir-Hinshelwood-like model was successfully applied for modelling photolysis and supported-TiO₂ photocatalysis of bacteria *E. coli*, considering an initial latency period, a classical log-linear behaviour and a tail region. The effect of the flow rate between 5 and 15 L/min was negligible in the inactivation of *E. coli* in the presence of sunlight and supported TiO₂. The inactivation rate constant increased with the initial concentration of *E. coli*. Almost no bacterial regrowth was observed in dark conditions during 24 h after illumination of *E. coli* suspension until complete deactivation. The humic acids (HA) degradation was also investigated by solar photocatalysis with suspended and supported TiO₂ and exposure to sunlight-only, in a CPC photoreactor. Supported-TiO₂ photocatalysis of HA originated 70% concentration reduction after QUV [approximate] 14 kJ/L, whereas only 20% reduction was obtained by photolysis and slurry photocatalysis. First-order kinetic constants of 0.088 and 0.010 L/kJ were obtained, respectively, for suspended and supported TiO₂.

9 - C. Sichel, P. Fernandez-Ibanez, M. de Cara, J. Tello,

Lethal synergy of solar UV-radiation and H₂O₂ on wild *Fusarium solani* spores in distilled and natural well water,

Water Research, Volume 43, Issue 7, April 2009, Pages 1841-1850, ISSN 0043-1354, DOI: 10.1016/j.watres.2009.01.017.

Environmentally-friendly disinfection methods are needed in many industrial applications. As a natural metabolite of many organisms, hydrogen peroxide (H₂O₂)-based disinfection may be such a method as long as H₂O₂ is used in non-toxic concentrations. Nevertheless, when applied alone as a disinfectant, H₂O₂ concentrations need to be high enough to achieve significant pathogen reduction, and this may lead to phytotoxicity. This paper shows how H₂O₂ disinfection concentrations could be significantly reduced by using the synergic lethality of H₂O₂ and sunlight the first time for fungi and disinfection. Experiments were performed on

spores of *Fusarium solani*, the ubiquitous, phyto- and human pathogenic fungus. Laboratory (250-mL bottles) and pilot plant solar reactors (2 x 14 L compound parabolic collectors, CPCs) were employed with distilled water and real well water under natural sunlight. This opens the way to applications for agricultural water resources, seed disinfection, curing of fungal skin infections, etc.

Keywords: *Fusarium solani*; Solar radiation; Hydrogen peroxide; Solar reactors; Natural well water

10 - C.M. Davies, D.J. Roser, A.J. Feitz, N.J. Ashbolt,

Solar radiation disinfection of drinking water at temperate latitudes: Inactivation rates for an optimised reactor configuration,

Water Research, Volume 43, Issue 3, February 2009, Pages 643-652, ISSN 0043-1354, DOI: 10.1016/j.watres.2008.11.016.

Solar radiation-driven inactivation of bacteria, virus and protozoan pathogen models was quantified in simulated drinking water at a temperate latitude (34[degree sign]S). The water was seeded with *Enterococcus faecalis*, *Clostridium sporogenes* spores, and P22 bacteriophage, each at ca 1×10^5 m L⁻¹, and exposed to natural sunlight in 30-L reaction vessels. Water temperature ranged from 17 to 39 [degree sign]C during the experiments lasting up to 6 h. Dark controls showed little inactivation and so it was concluded that the inactivation observed was primarily driven by non-thermal processes. The optimised reactor design achieved S90 values (cumulative exposure required for 90% reduction) for the test microorganisms in the range 0.63-1.82 MJ m⁻² of Global Solar Exposure (GSX) without the need for TiO₂ as a catalyst. High turbidity (840-920 NTU) only reduced the S90 value by <40%. Further, when all S90 means were compared this decrease was not statistically significant (prob. > 0.05). However, inactivation was significantly reduced for *E. faecalis* and P22 when the transmittance of UV wavelengths was attenuated by water with high colour (140 PtCo units) or a suboptimally transparent reactor lid (prob. < 0.05). S90 values were consistent with those measured by other researchers (ca 1-10 MJ m⁻²) for a range of waters and microorganisms. Although temperatures required for SODIS type pasteurization were not produced, non-thermal inactivation alone appeared to offer a viable means for reliably disinfecting low colour source waters by greater than 4 orders of magnitude on sunny days at 34[degree sign]S latitude.

11 - L.M. Flendrig, B. Shah, N. Subrahmaniam, V. Ramakrishnan,

Low cost thermoformed solar still water purifier for D&E countries,

Physics and Chemistry of the Earth, Parts A/B/C, Volume 34, Issues 1-2, Sustainable Water Solutions, 2009, Pages 50-54, ISSN 1474-7065, DOI: 10.1016/j.pce.2008.03.007.

Solar distillation mimics nature's hydrologic water cycle by purifying water through evaporation (using solar energy) and condensation (rain). It is one of the most basic purification systems available today to obtain high quality drinking water and can remove non-volatile contamination from almost any water source. This low-tech technology should therefore be ideally suited for developing and emerging countries where sun shines in abundance. In the past century numerous designs have been realised with footprints ranging from 0.5 m² to thousands of square meters. Despite

all efforts, this intriguing technology has not been applied widely yet. Among the challenges that remain are: (1) its low yield, (2) obtaining local commitment to operate/maintain large scale systems properly, and (3) relatively high initial investment costs. The objective of this study has been to address challenges 1 and 3 by using standard plastic thermoforming technology to realize a small scale single slope solar still for personal use (2-4 l per day) with adequate efficiency and at low production costs.

Materials and methods

The solar still consists of two parts: a basin that holds the dirty water and a transparent tilted cover onto which the clean water vapour can condense. The basin has a footprint of 1.34 m² and is made of a 3 mm thick sheet of black high-density polyethylene (HDPE) which is thermoformed using standard equipment for making fish-ponds. This allows for the incorporation of detailed features, like reinforcements and a clean-water collection gutter, at no extra cost. The transparent cover is made of UV stabilised low-density PE-foil which is under a slope of 10[degree sign] to transport condensed water droplets to the lower located collection gutter.

Throughput and purification performance were evaluated in duplicate at our Bangalore R&D facilities in India, over a short term (5 day) period. Solar radiation was measured using a Pyranometer. The system was loaded with 40 l of laundry rinse water. Results At an average solar radiation of 12.95 MJ/day/m² the average yield of purified water was 3 l/day. This resulted in a calculated overall system efficiency of 39%. Purification performance (contaminated versus purified water) of the solar still loaded with the most contaminated water source was: Total dissolved solids (TDS) from 2925 ppm to 40 ppm, pH from 9.6 to 5.5, conductivity from 6130 mS/cm to 26 mS/cm, turbidity from 394 NTU to 0.4 NTU, total viable count (TVC) from 314 million cfu/ml to <10 cfu/ml.

Conclusion

Thermoforming allowed for the realisation of a single slope solar still that can sustainably produce high quality drinking water at point of use from waste water with an above average efficiency and at a manufacturing price (in The Netherlands) of below [euro]25-per system. Next step should focus on a long term evaluation (months, instead of days) to access the full potential of the solar still to produce safe drinking water at point of use in an economical and reliable way.