Mediterranean Workshop on

New Technologies of Recycling Non

Conventional Water In Protected Cultivation

Water Disinfection Using Solar Energy

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CIEMAT – Plataforma Solar de Almería

1. **Solar drinking water disinfection: *SODISWATER* project.**

2. **Solar photocatalytic disinfection of agricultural water: irrigation reuse.**

Drinking Water Needs

- 1.7 million deaths a year (mainly through infectious diarrhoea) occur world-wide due to:
  - Poor hygiene, poor sanitation, and **poor water quality**.

- 39% reduction in incidence of diarrhoea if water quality is improved (Fewtrell, L. *et al*., 2005).

- **Water is the main vehicle of distribution of many waterborne diseases.**
  - Water was responsible for **big epidemics** in the world like tiphus and cholera.

- **WHO** recognised the **disinfection** as one of the most important **barriers for protection of public health**.

Solar Disinfection

- SODIS is a water treatment method that involves making water microbiologically safe by exposure to sunlight (≥ 6 hours).
  - Synergistic effect of increase in temperature (>42ºC), direct UVA radiation and reactive forms of oxygen.
- First demonstrated by Acra *et al*., in 1980.
  - Enteric bacteria were inactivated after ≥ 6h of full sunlight.
- Variety of pathogens that have been tested.
  - Bacteria – *S. typhimurium*, *S. dysenteriae*, *E. coli*, *V. cholerae*, *P. aeuriginosa*
  - Parasites
    - Protozoa - *C. parvum* and *G. muris*
    - Helminths – not yet tested
  - Fungi and Yeast – *C. albicans* and *F. solani*
  - Viruses – *Polio.*

Solar Disinfection

- Control field trial of SODIS water in Kenya (Conroy *et al.*,1996)
  - Significant reduction in diarrhoea observed – 1.7 episodes per child in SODIS group, compared to 2.3 episodes per child in control group
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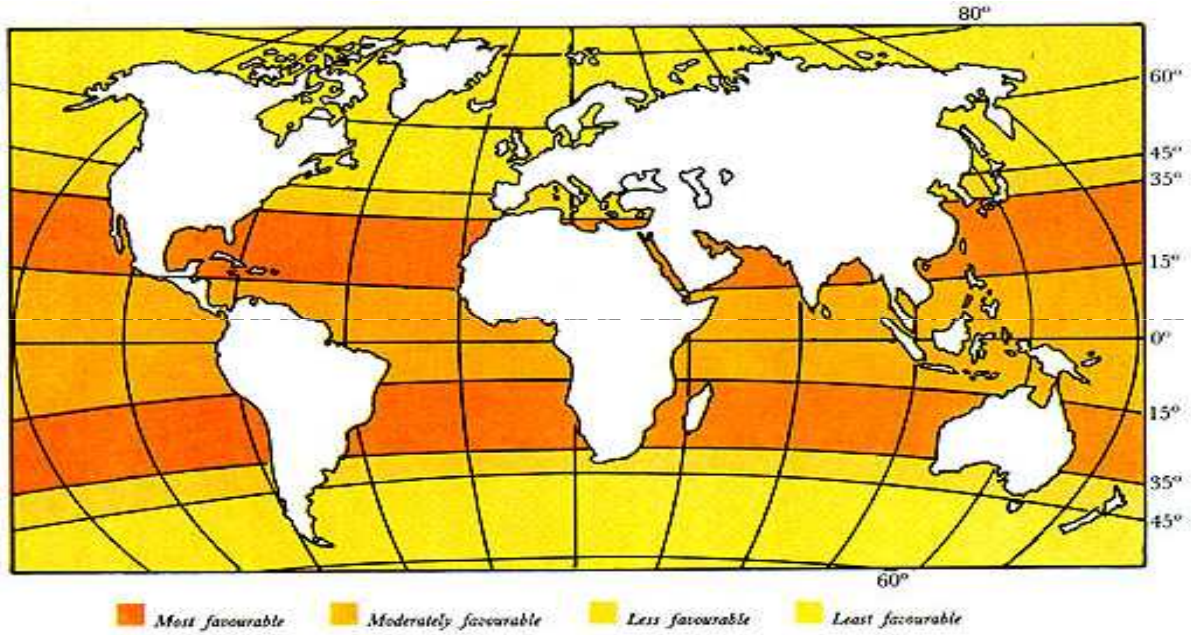
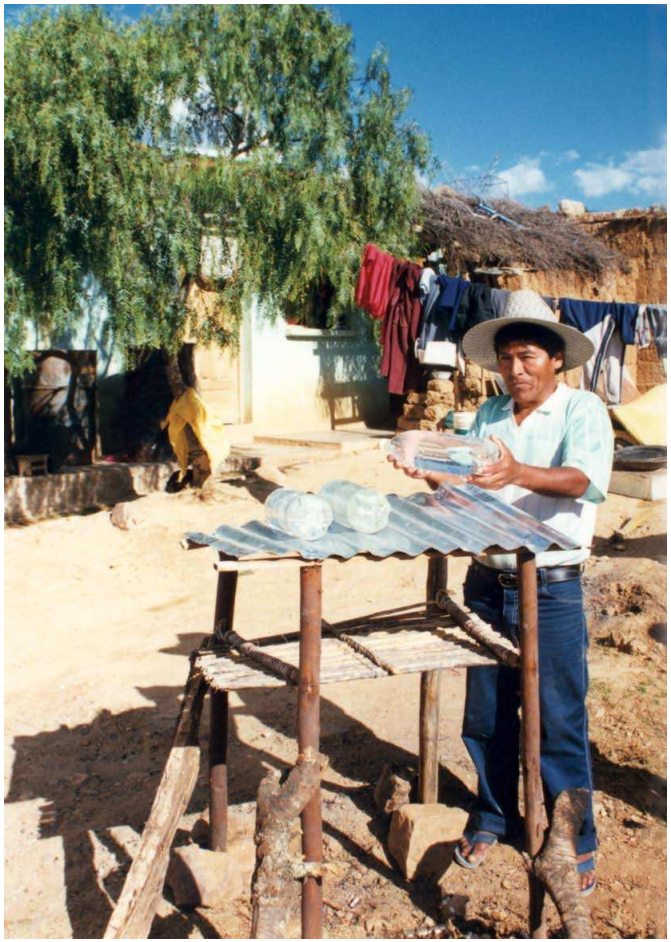
- SODIS pment goals (MDG'
  - MD
  - MD



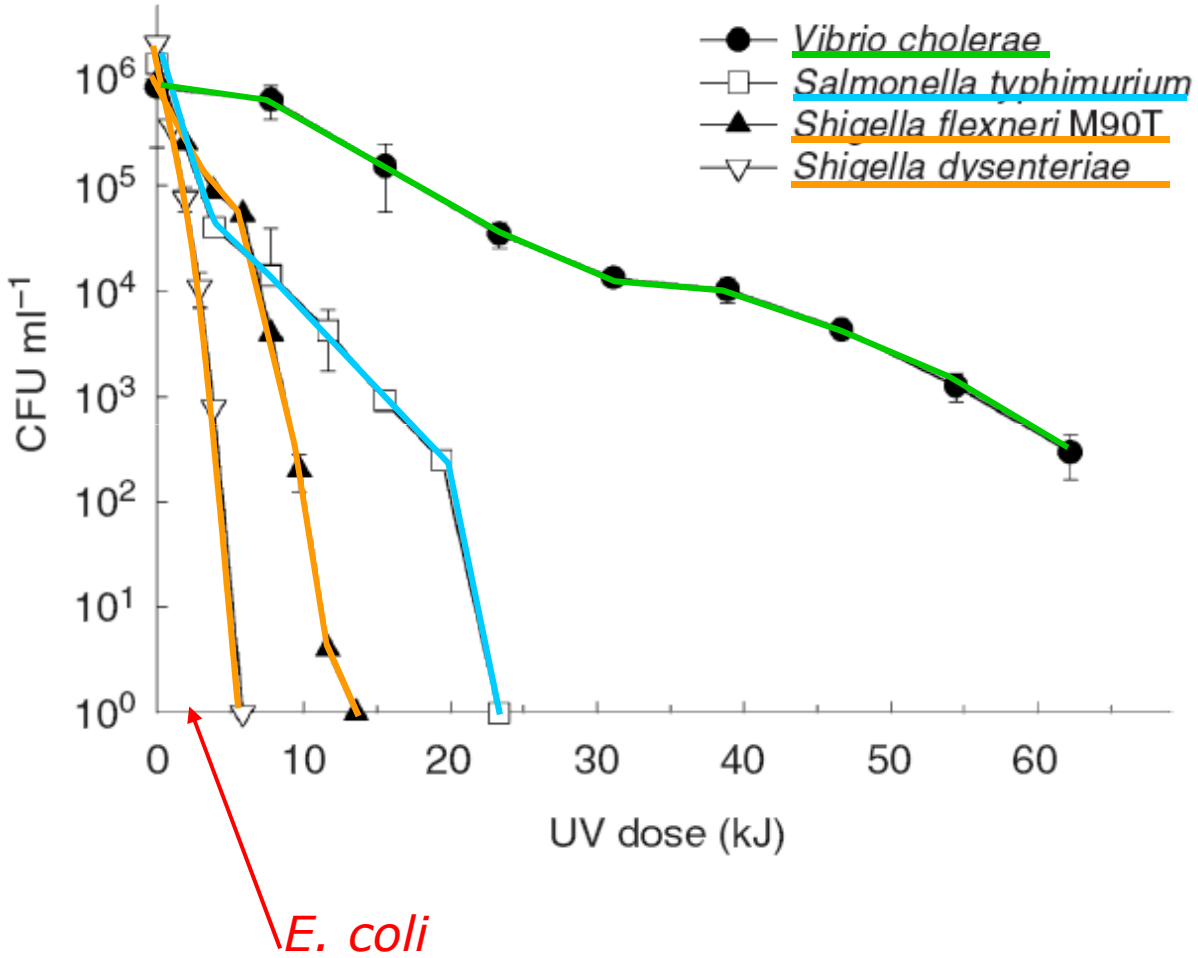
- Suitability of climate and weather conditions for SODIS
  - Countries that have a high incidence of waterborne disease also receive enough sunlight to apply SODIS

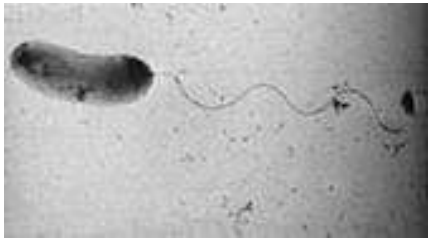
Solar Disinfection



Solar Disinfection

Inactivation of pathogenic bacteria

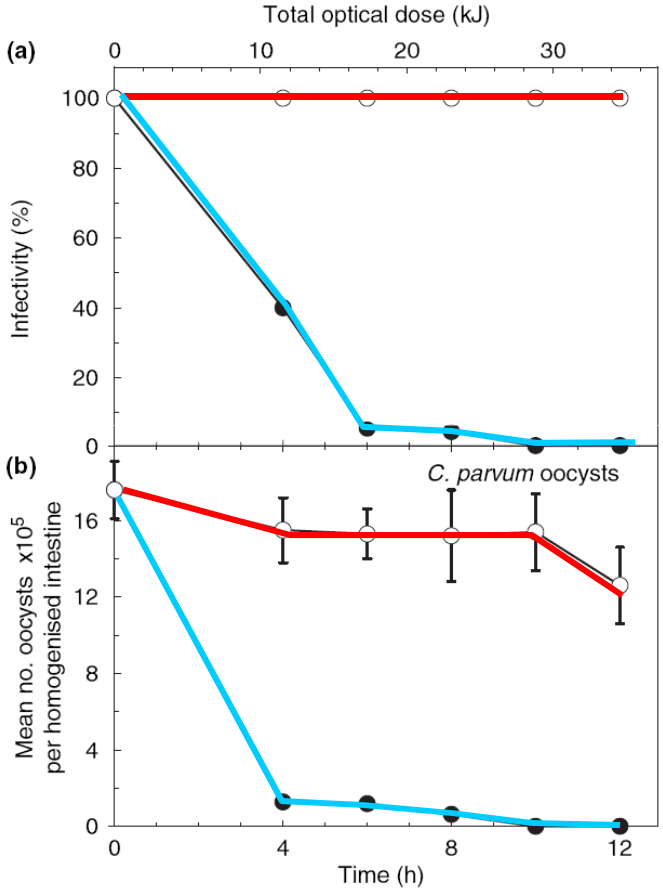




*Kehoe et al., Lett. Appl. Microbiol. 2004, **38**, 410–414.*

Solar Disinfection

Inactivation of C. Parvum oocysts



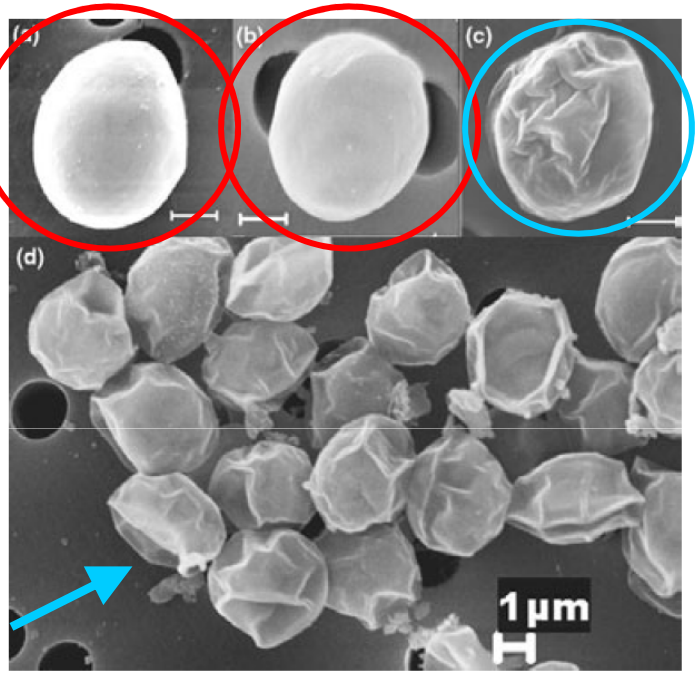


Figure 6 Scanning electron micrograph of oocysts of *Cryptosporidium parvum*. (a) *Cryptosporidium parvum* at 40°C at time = 0 h; (b) *C. parvum* at 40°C at time = 10 h; (c) *C. parvum* at 40°C + 870 W m^{-2} at time = 10 h and (d) Wide-field view of *C. parvum* at 40°C + 870 W m^{-2} at time = 10 h. Magnification is ×30 000. In each case, the scale bar represents 1 μm.

Mice Infectivity

Solar simulator: 830 W m^{-2}, 40ºC

*McGuigan et al., J. Appl. Microbiol. 2006, **101**, 453-463.*

SODISWATER project

Solar Disinfection of Drinking Water for Use in Developing Countries or in Emergency Situations (FP6-2004-INCO-DEV-031650).

Partners:

1. **RCSI (IRELAND)-coord.**
2. UU (UK)
3. CSIR (SOUTH AFRICA)
4. EAWAG (SWITZERLAND)
5. IWSD (ZIMBABWE)
6. **CIEMAT (SPAIN)**
7. UL (UK)
8. ICROSS (KENYA)
9. USC (SPAIN)

General Objetive:

The objective of this project is the development of an **implementation strategy for the adoption of solar disinfection of drinking water as an appropriate, effective and acceptable intervention against waterborne disease** for vulnerable communities in developing countries without reliable access to safe water, or in the immediate aftermath of natural or man-made disasters.

http://www.rcsi.ie/sodis/

SODISWATER project

Limitations of SODIS:

- The length of time required for inactivation.
  Cloudy day – need 2 consecutive days for inactivation

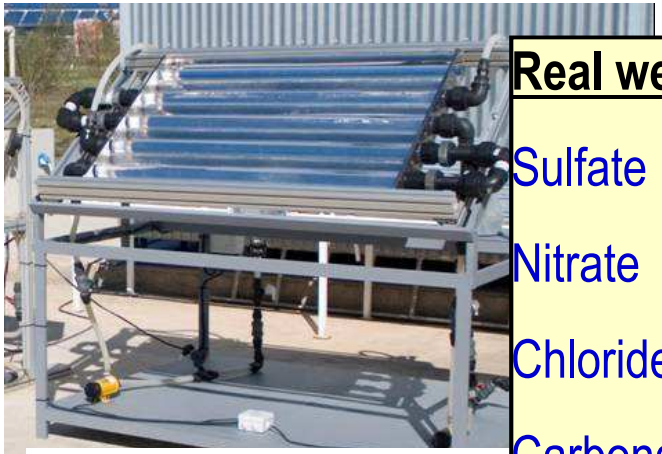
- The volume of water generated at a time during SODIS.
  Maximum 3 litres per bottle.

Technical objectives:

- Assess the SODIS disinfection process under real conditions and use of the SODIS technique to generate a larger output of water.
  Untested water pathogens, ambient temperature, larger volumes, irradiance, water quality and testing technological enhancements (solar CPC, thermal, photocatalysts, etc.).

SODISWATER project

- Continuous flow reactors



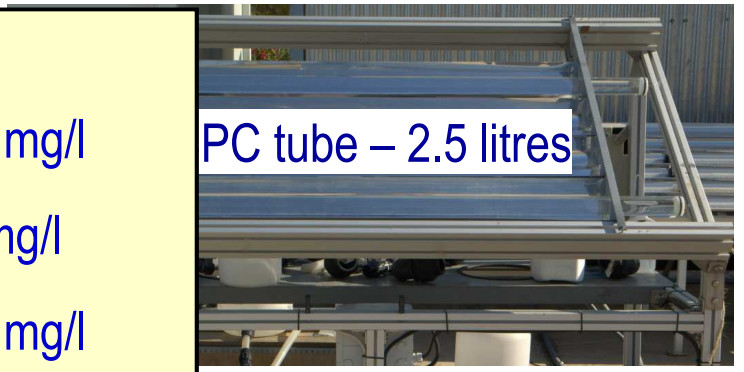
CPC Prototype 1 – 14 li

CPC Prototype 2 – 70 litres

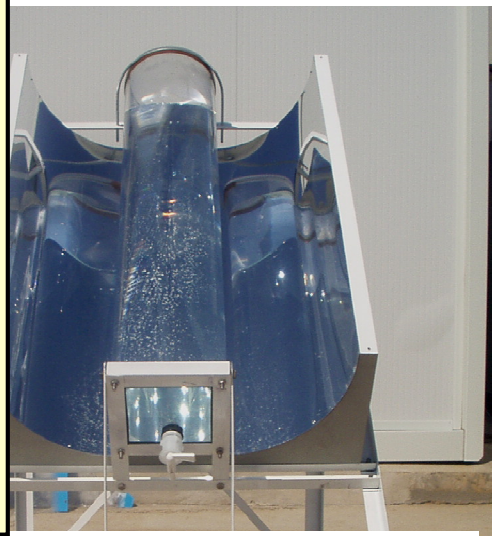
Real well-water

Sulfate	270 mg/l
Nitrate	12 mg/l
Chloride	300 mg/l
Carbonates	650mg/l
Sodium	545 mg/l
Potassium	18.5 mg/l
TOC	11 mg/l
Turbidity	5 NTU
pH	7.8

- Batch SODIS reactors



PC tube – 2.5 litres



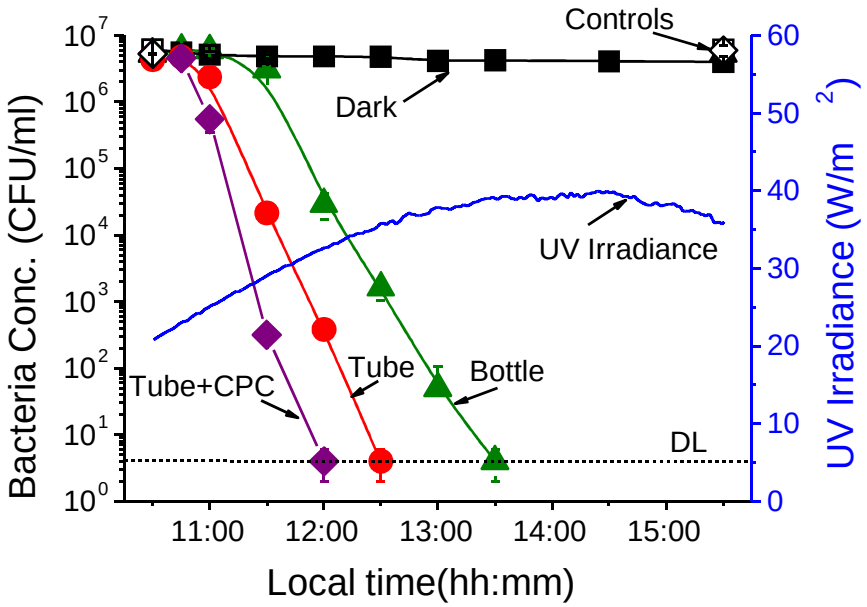
SODIS-CPC reactor – 25 litres

SODISWATER project

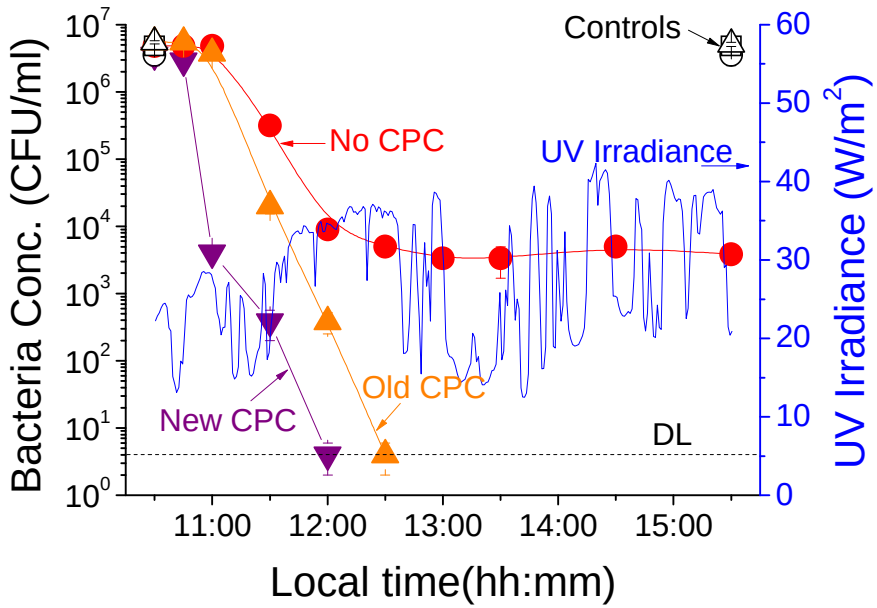
RESULTS

- CPC enhancement

Clear days



Cloudy days

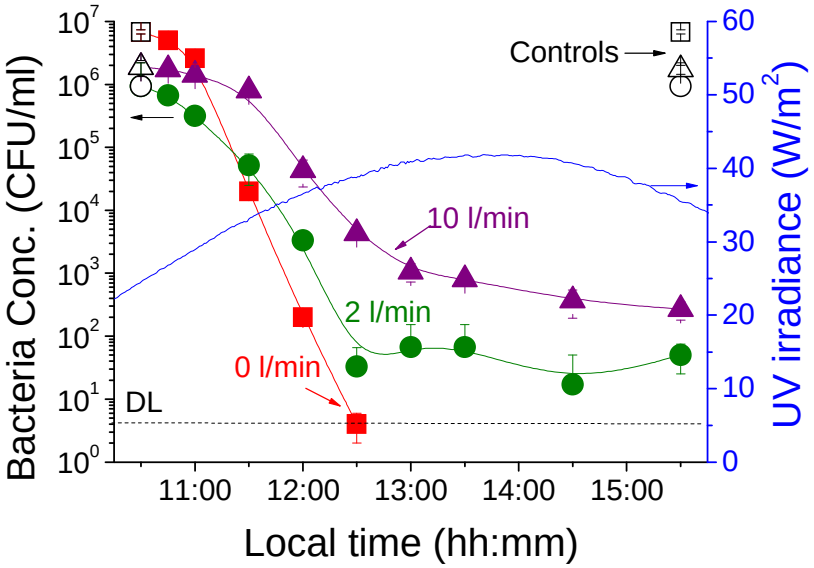


Solar Disinfection

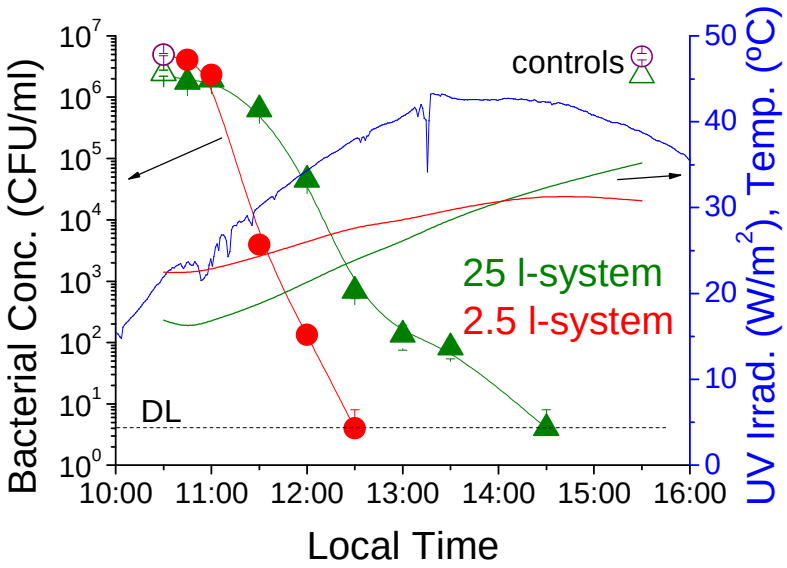
RESULTS

- Flow vs. batch reactors

Flow rate



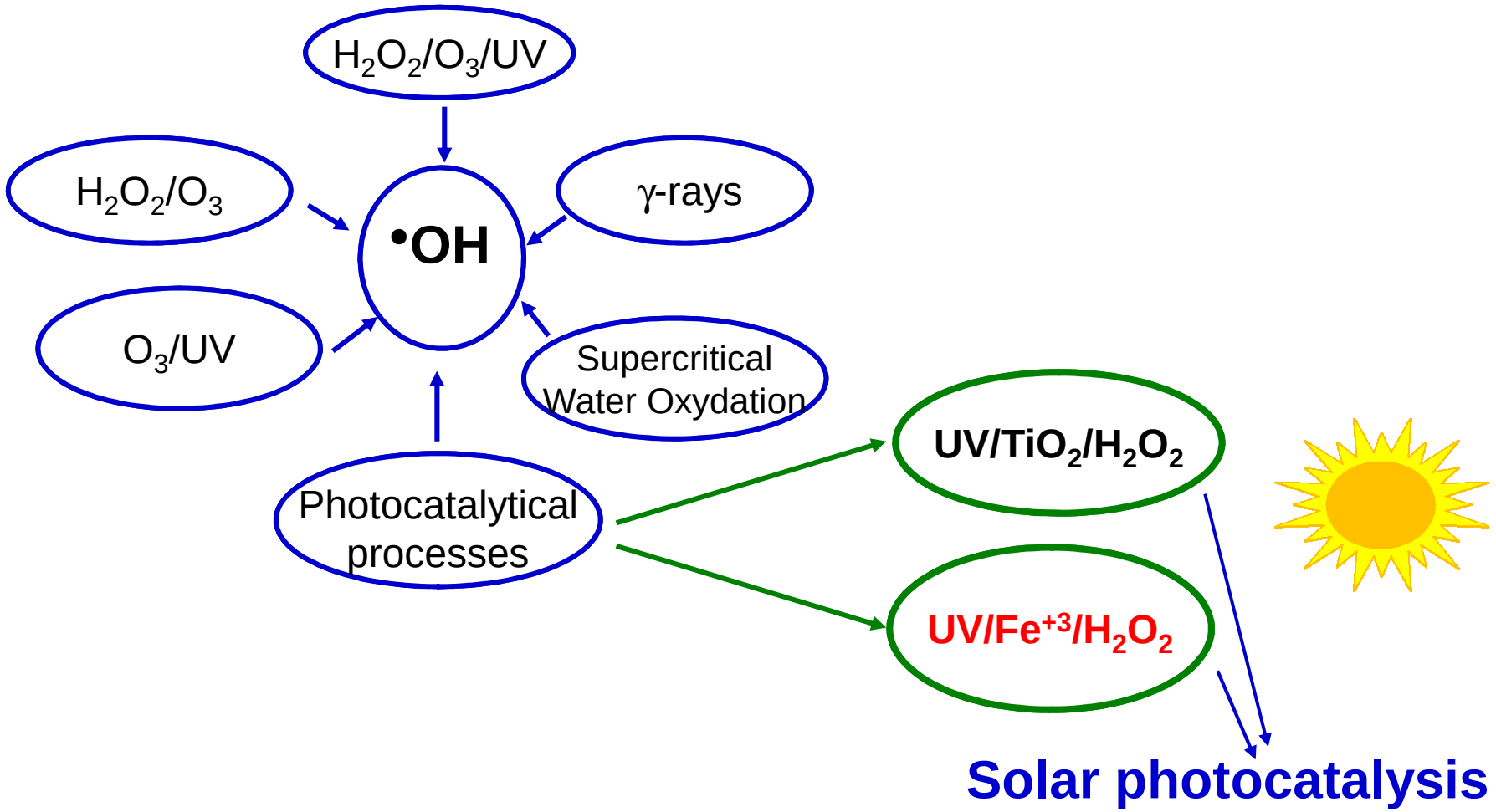
25l-batch system



1. Solar drinking water disinfection: *SODISWATER* project.

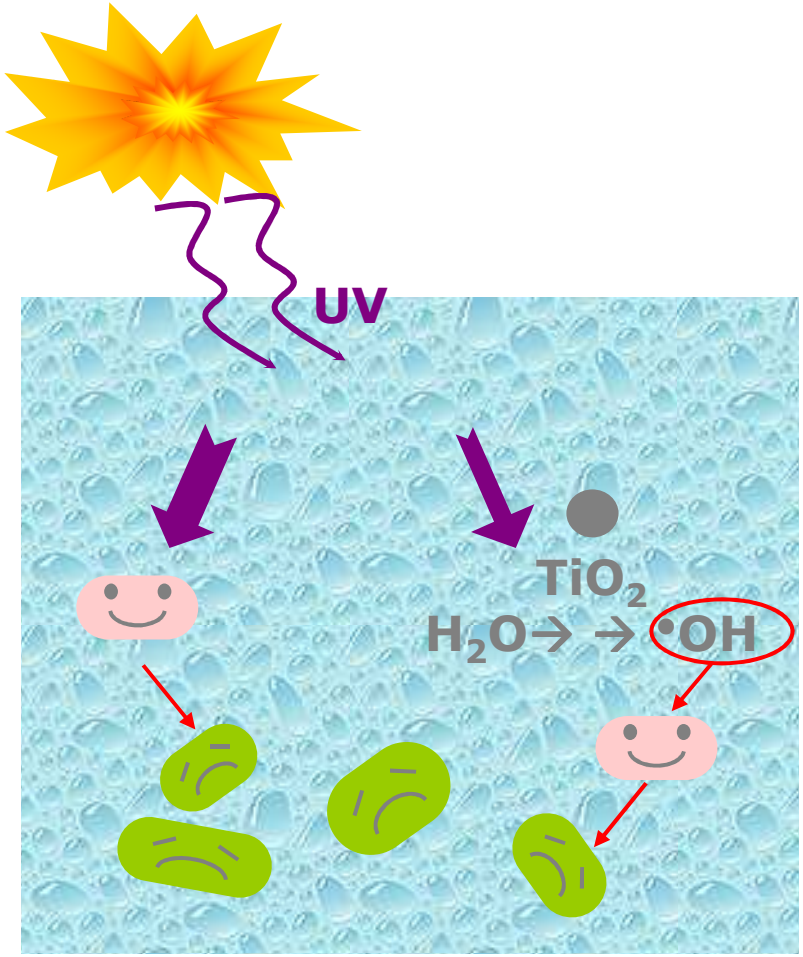
2. **Solar photocatalytic disinfection of agricultural water: irrigation reuse.**

Solar Photocatalysis



Disinfection Mechanisms

Bacterial inactivation under solar radiation



Direct action

UV absorption by DNA molecules of microorganisms

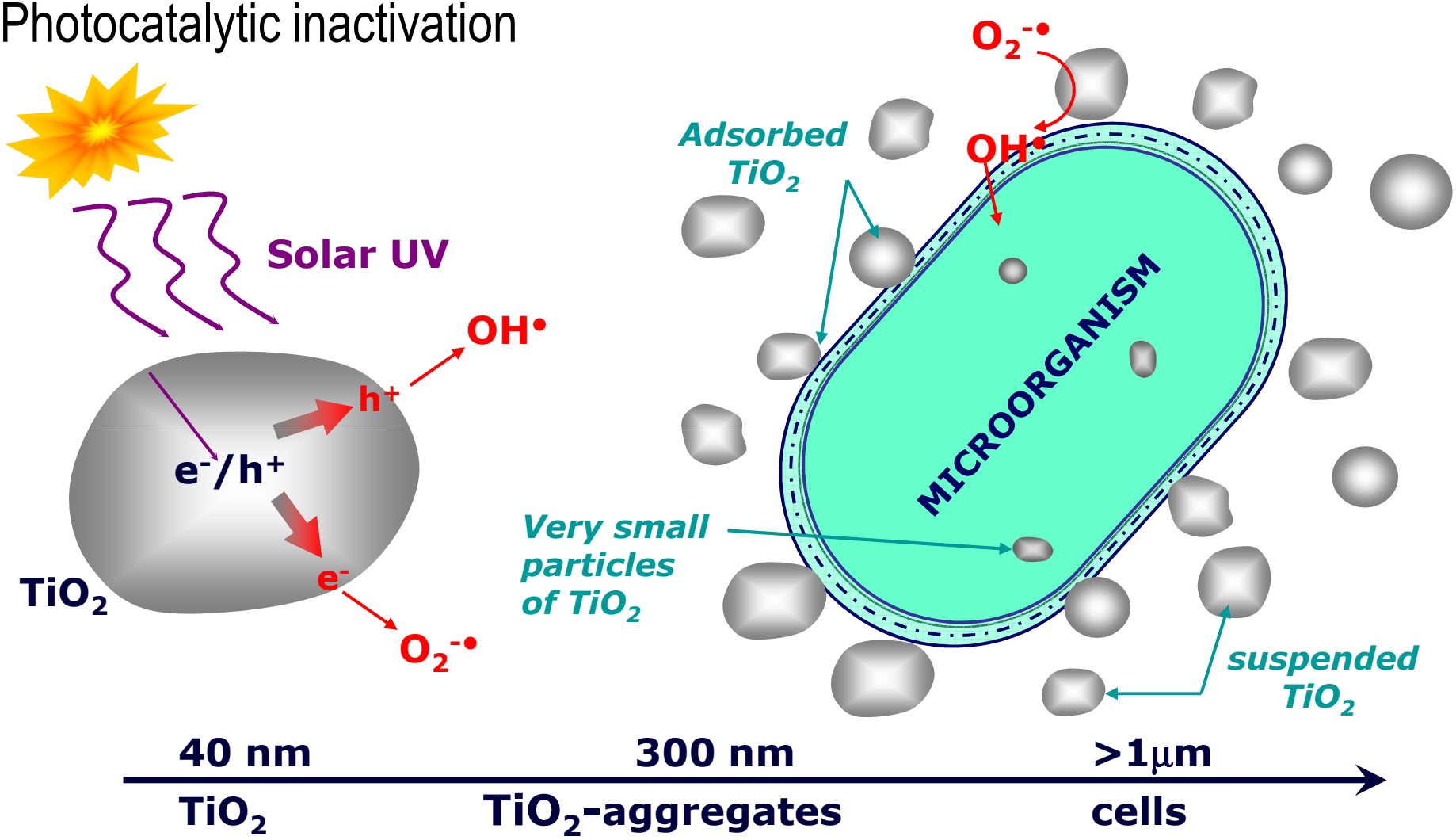
Indirect action

Photocatalytic effect of TiO_2 attacks the **cell membrane**.

Decrease of **Coenzyme-A** levels by photo-oxidation, which induces celular death.

Disinfection Mechanisms

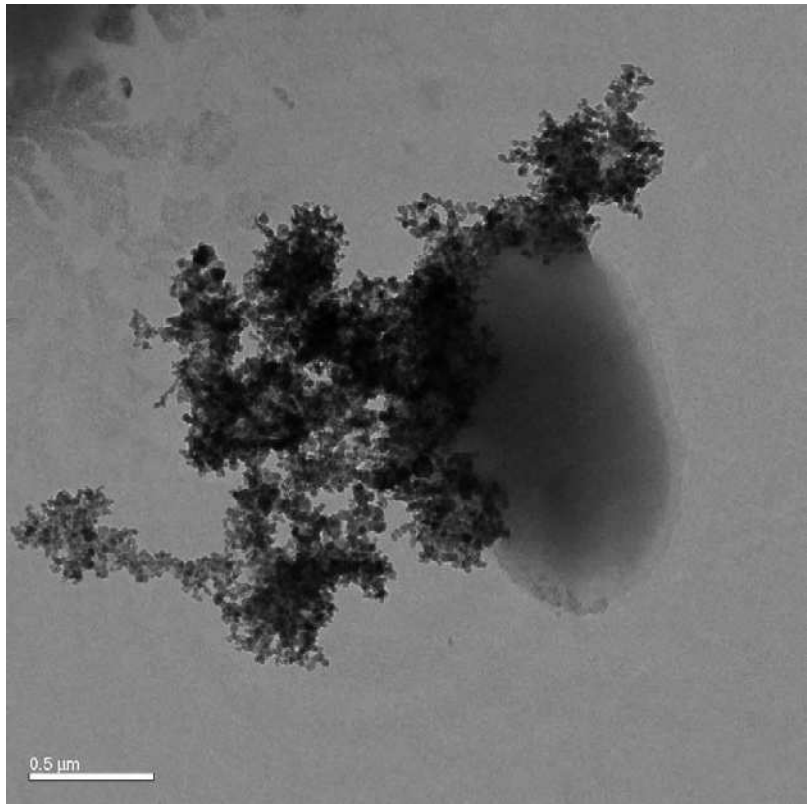
Photocatalytic inactivation



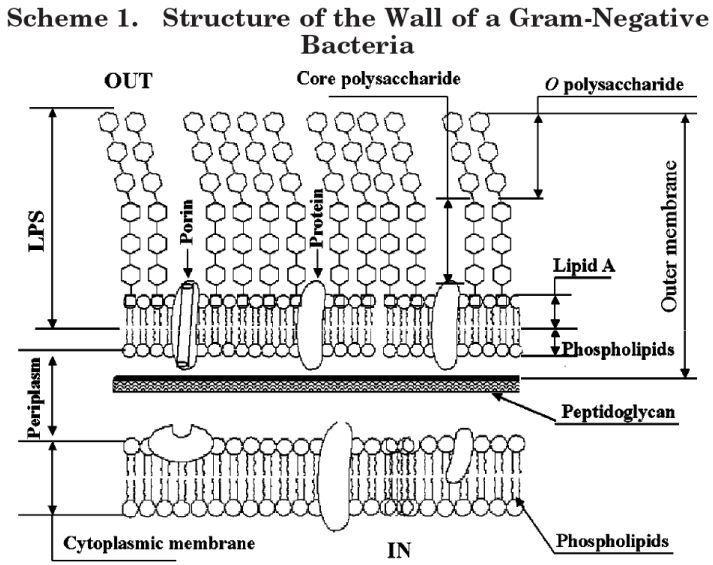
Malato, Fernandez-Ibáñez y Blanco, J. Solar Energy Engineering ***129*** *(2006) 1-12.*

Disinfection Mechanisms

Adsorption of TiO_2 on *E. coli* cells



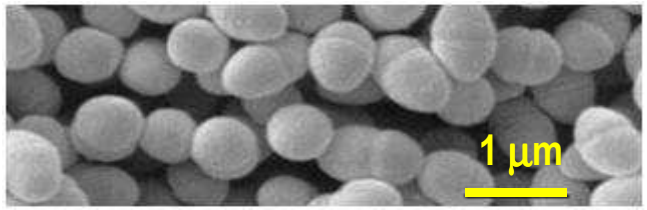
Composition of cell membrane favours contact with the catalyst.



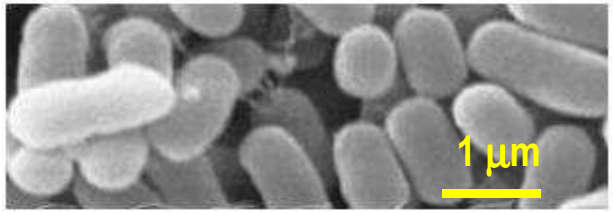
- *D. Gumy et al. Appl. Cat. B: Environ., 63 (2006) 76-84.*
- *J. Kiwi and V. Nadtochenko, Langmuir 2005, 21, 4631-4641.*

Photocatalytic Disinfection

Bacteria: *Enterococcus faecalis (Gram+)*



Escherichia coli (Gram-)



Virus and Bacteriophage: *Poliovirus* 1, *Phage MS2 (RNA-bacteriophage)*

Cancer cells: *HeLa cells (cervical carcinoma), T24 (bladder cancer), U937 (leukemia).*

Fungi and Yeasts: *Saccharomyces cerevisiae, Neurospora crassa*

FITOSOL project

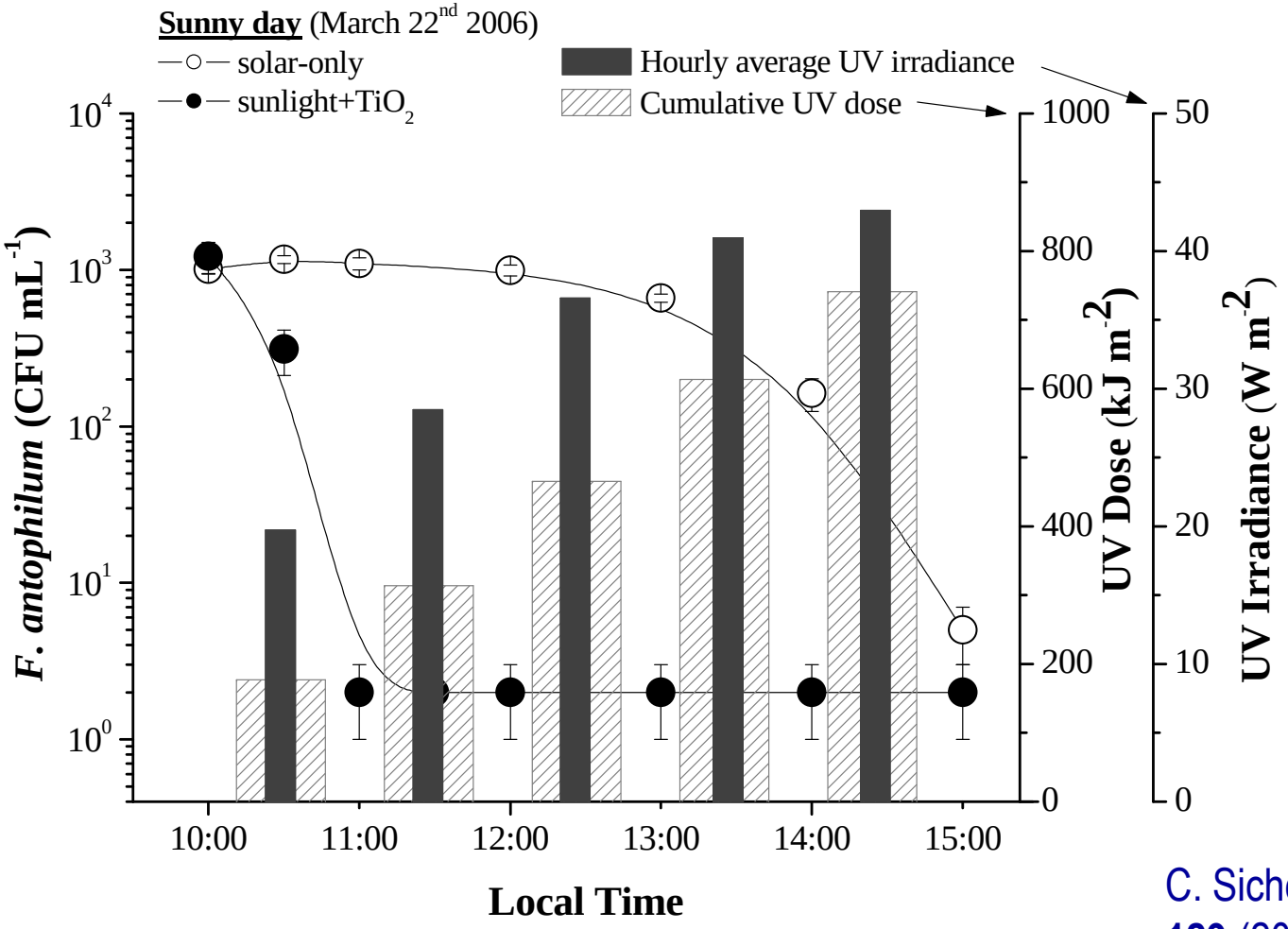
Elimination of phytopathogens in water through photocatalytic processes: application for the water disinfection and reuse in recirculation hydroponic cultures

Main objetives:

- Lab Study of solar photocatalytic elimination of model phytopathogenic microorganisms in recirculation liquid nutrient solutions in soil-less cultures.
- Design and construction of a pilot solar reactor for disinfection of water containing the mentioned phytopathogenic organisms to reuse in recirculation hydroponic cultures.
- Demonstration of the photocatalytic process ability to disinfect water from nutrient solutions of hydroponic cultures.

FITOSOL project

Solar disinfection of *F. antophilum* with slurry TiO_2



SUNNY DAY

Max. UV Irradiance: 42 Wm^{-2}

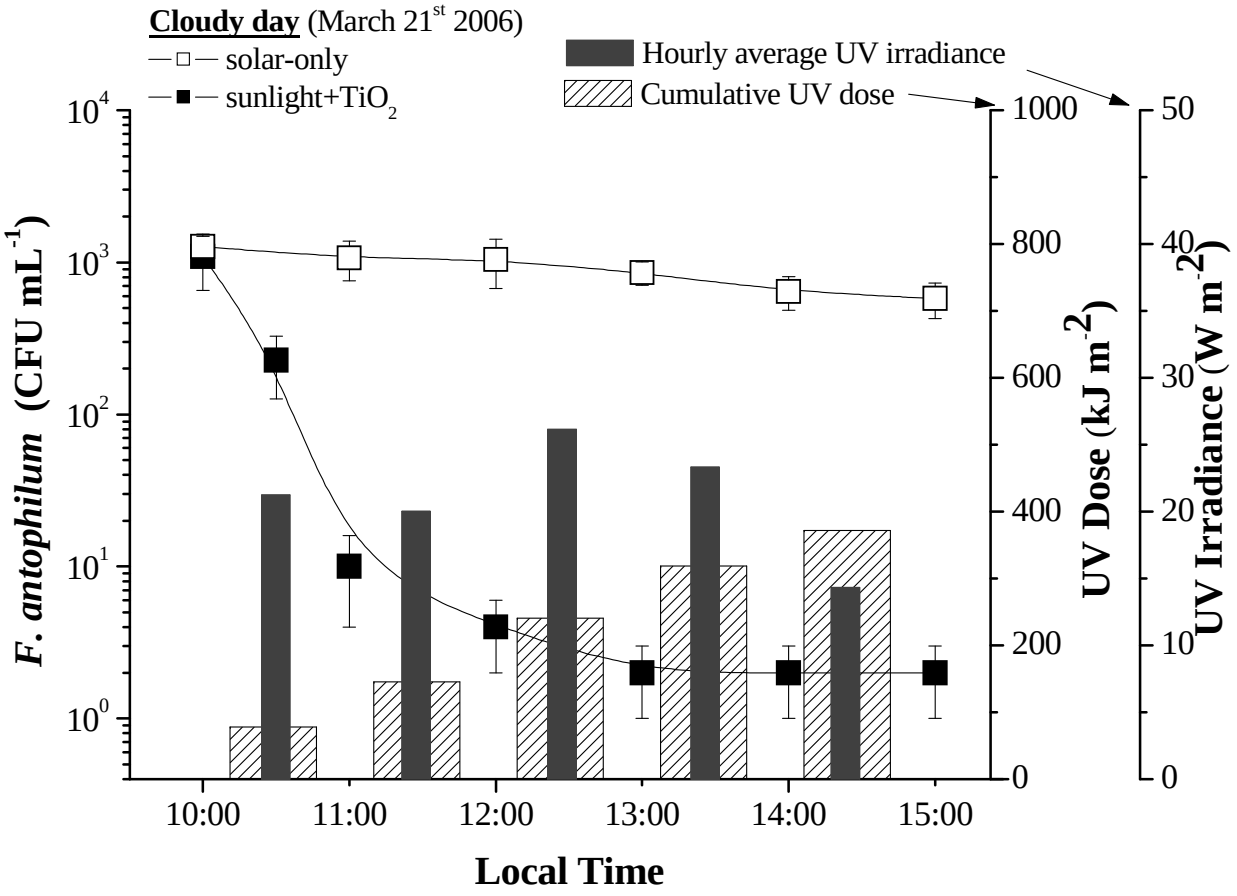
Max. UV Dose: 750 kJm^{-2}

Total volume: 200 ml.

C. Sichel, et al. *Catalysis Today* **129** (2007) 152-160.

FITOSOL project

Solar disinfection of *F. antophilum* with slurry TiO_2



CLOUDY DAY

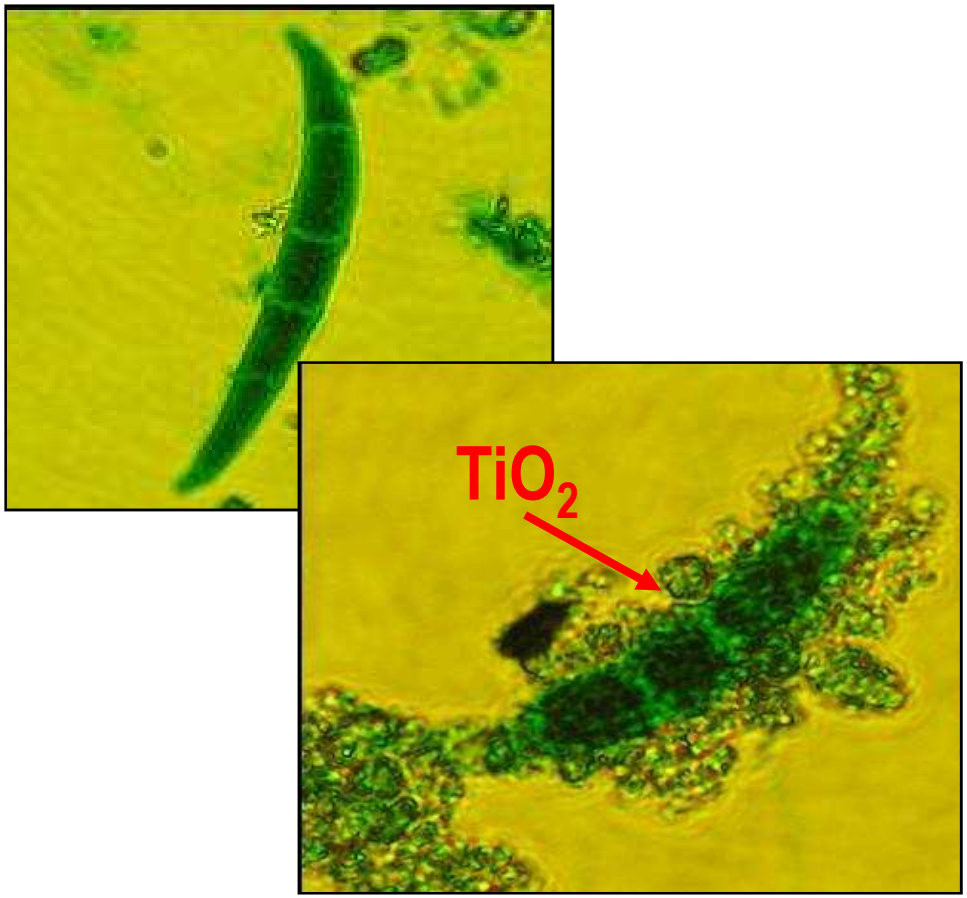
Max. UV Irradiance: 25 Wm^{-2}

Max. UV Dose: 380 kJm^{-2}

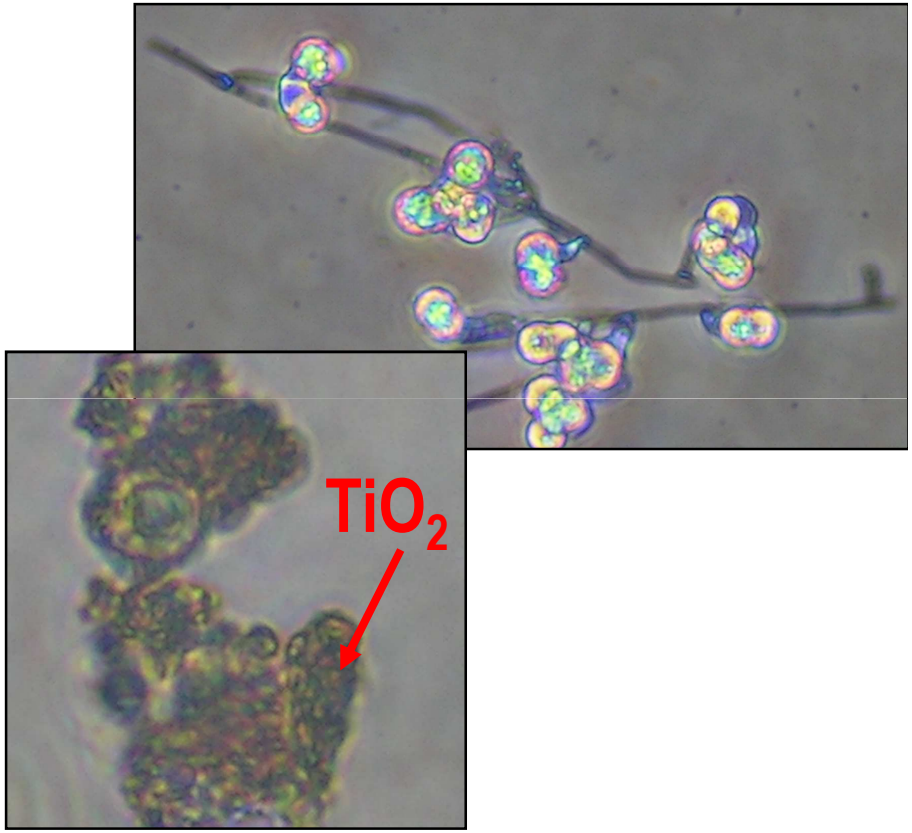
Total volume: 200 ml.

Disinfection Mechanisms

Adsorption of TiO_2 on *Fusarium* spores



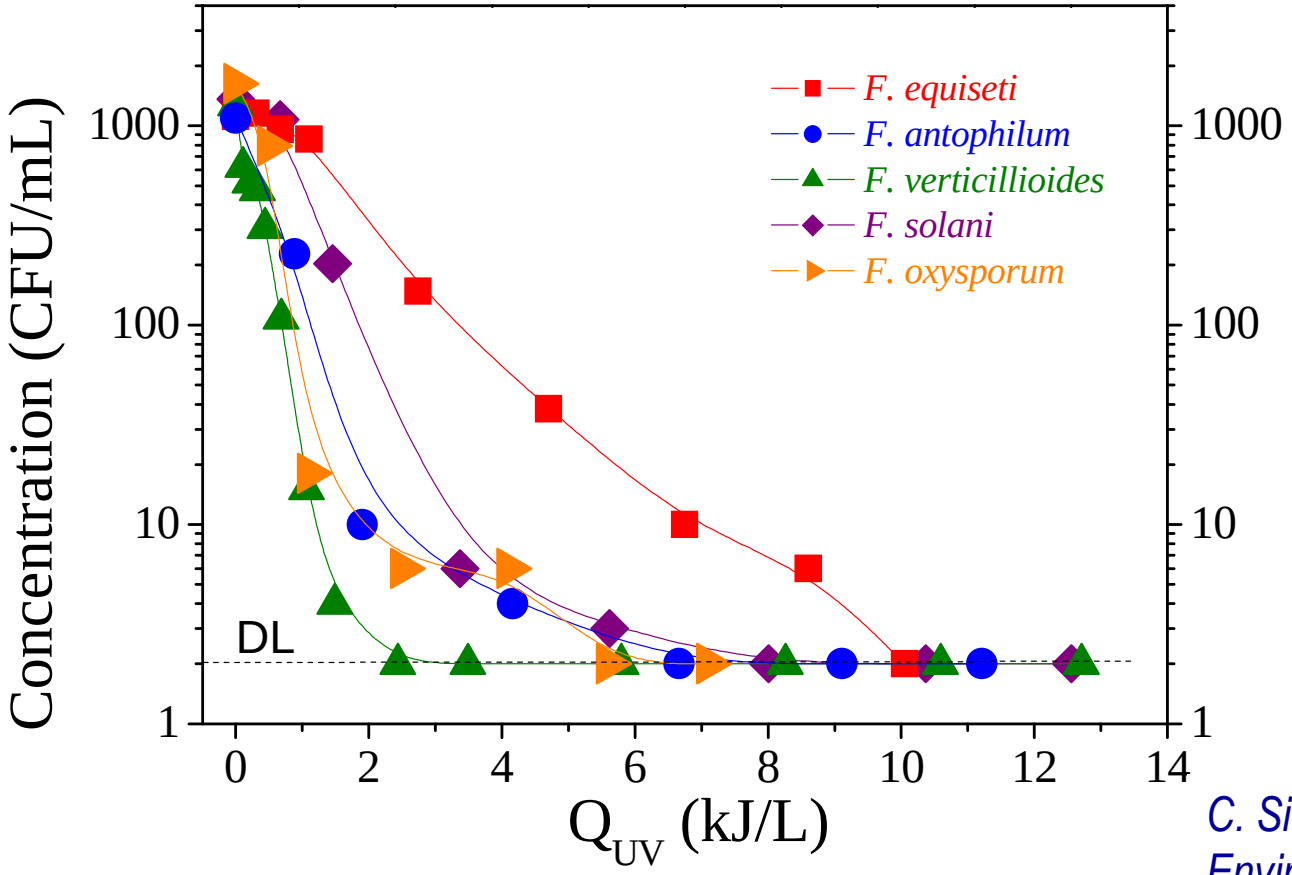
Macroconidia of *F. Equiseti* before and after the photocatalytic treatment (5h)



Chlamydospores de *F. solani* *before and after* 6h of photocatalytic treatment.

FITOSOL project

Solar disinfection of *different spores of Fusarium* with slurry TiO_2



Total volume: 200 ml.

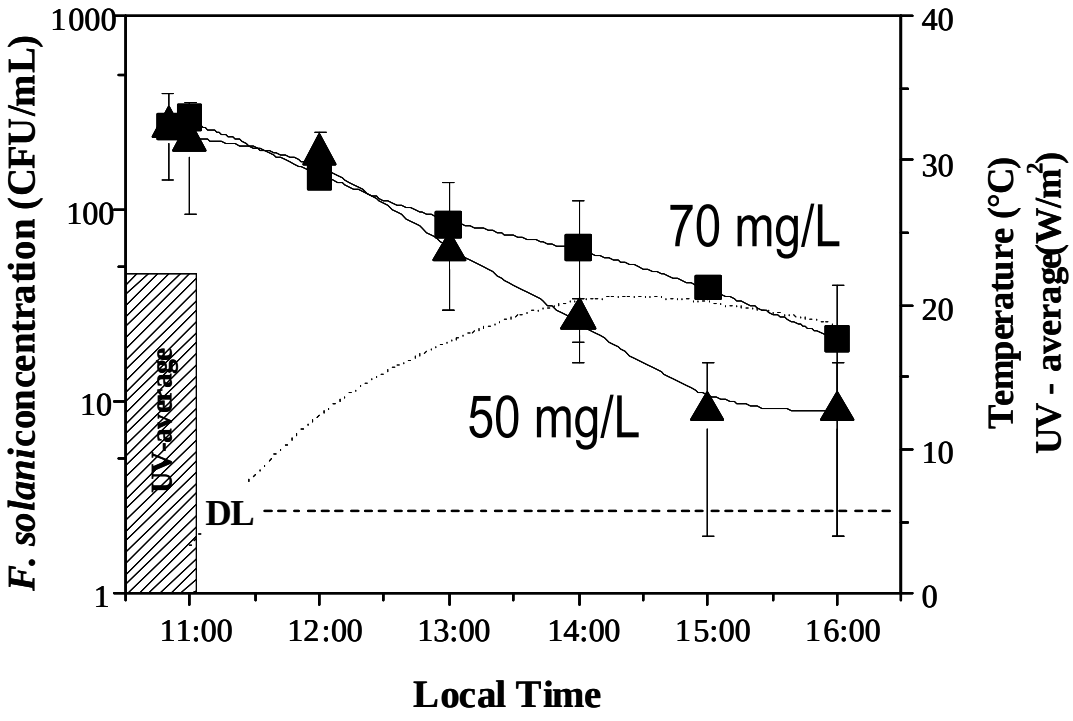
Spores of *Fusarium* can be inactivated using solar photocatalysis faster than with irradiation of natural solar light.

C. Sichel, et al. Appl. Cat. B: Environ., 74 (2007) 152-160.

FITOSOL project

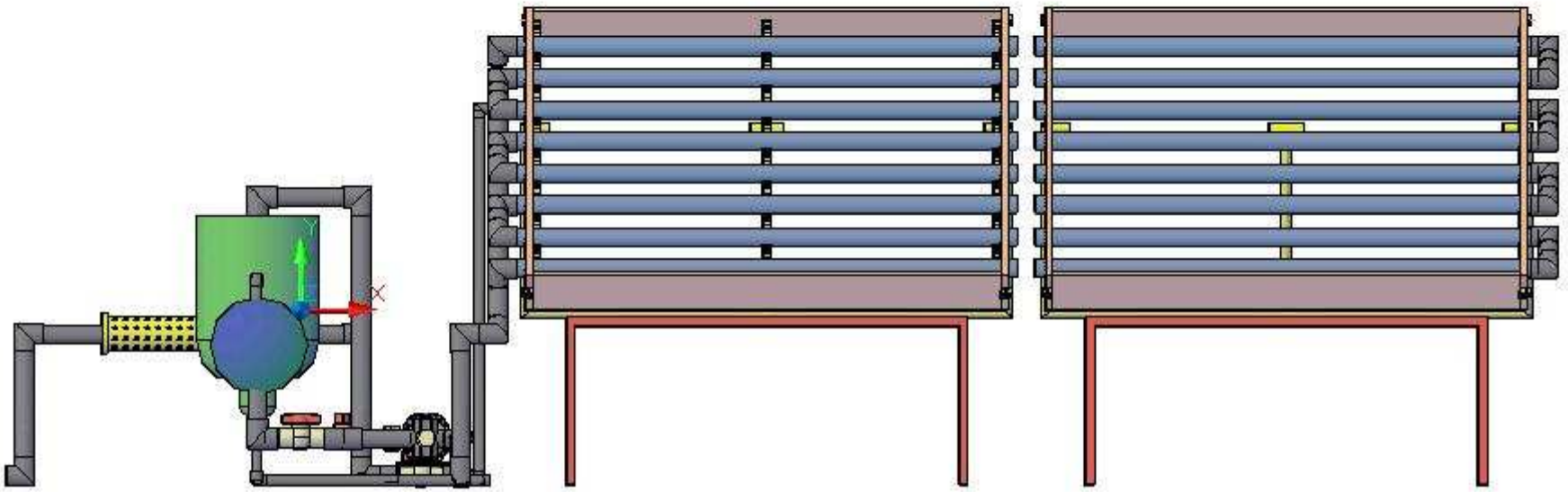
Solar disinfection of *Fusarium solani* with slurry TiO_2 in solar 14l-CPC prototype

Real well-water	
Sulfate	270 mg/l
Nitrate	12 mg/l
Chloride	300 mg/l
Carbonates	650mg/l
Sodium	545 mg/l
Potassium	18.5 mg/l
TOC	11 mg/l
Turbidity	5 NTU
pH	7.8



FITOSOL project

Design of a prototype for solar photocatalytic disinfection



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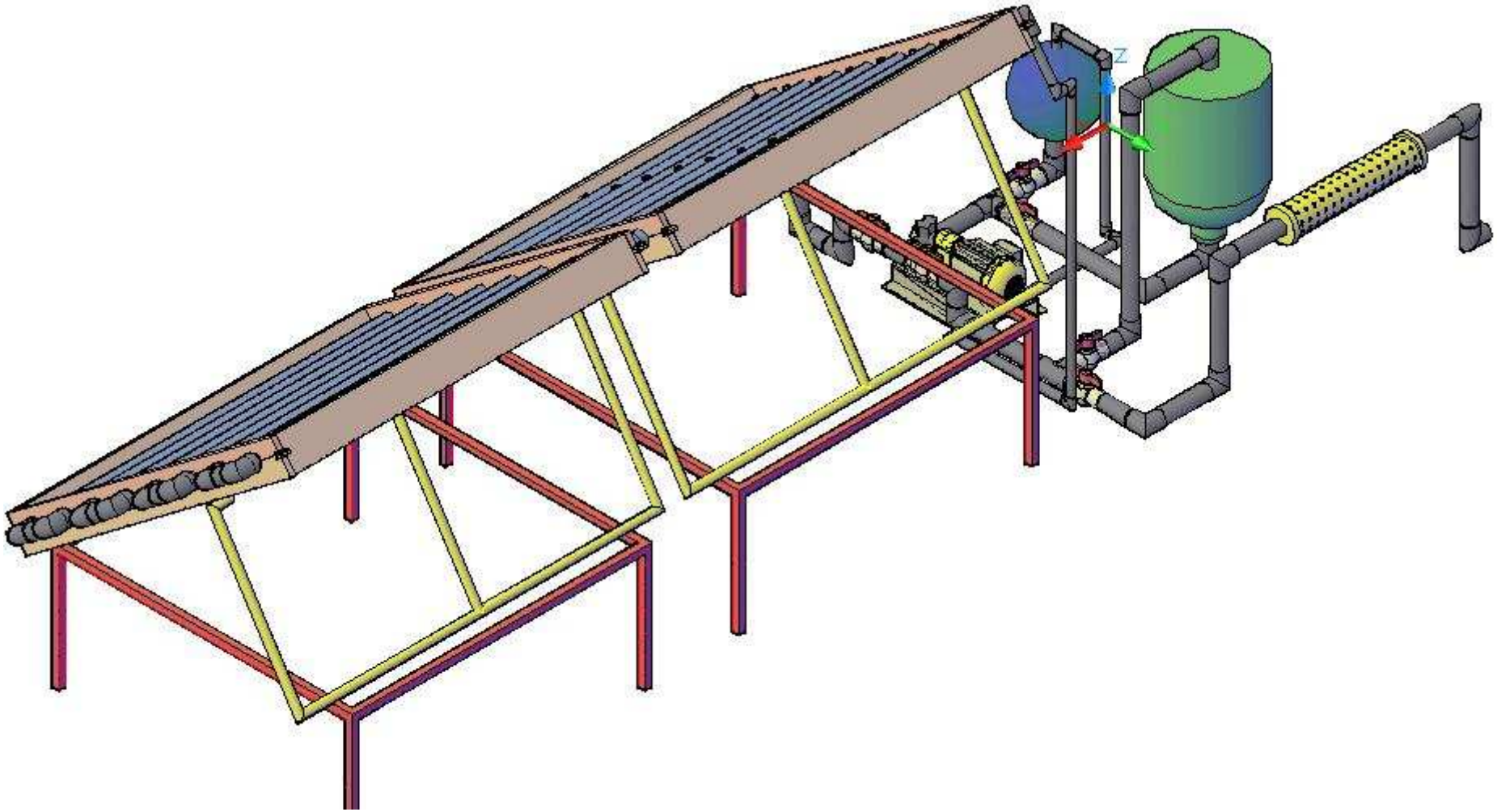

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