

The photo-Fenton process is a Simple Way for Enhancing SODIS. A short review

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Context of drinking water supply:

Microbial contamination of drinking water is nowadays a crucial issue, especially in isolated regions of developing countries.

Chlorination is widely used.

Limitation:

- Shortage of chemical oxidants specially in isolated regions with economical and social restrictions.
- Generation of harmful disinfection by-products (DBPs) by the bad dosing of oxidant and/or the nature of treated water.



Alternative treatments are need !

Solar Water Disinfection (SODIS)



Bacteria inactivation by the synergistic action of UV-A, B light and temperature (~50 °C)

Some drawbacks:

-Temperature > 50 °C

➔ -Small quantities of treated water (1-2 liters)

-Bacterial reactivation during subsequent storage.

Our objective: Enhancing SODIS !

. Making it independent from temperature

. Disinfecting larger quantities of water

Fenton process

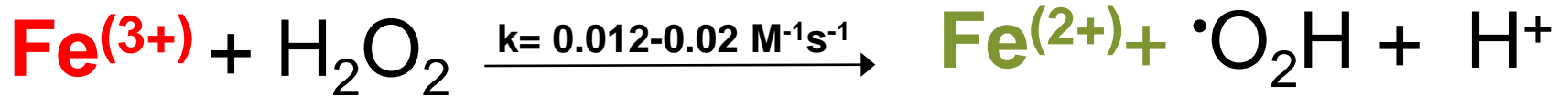
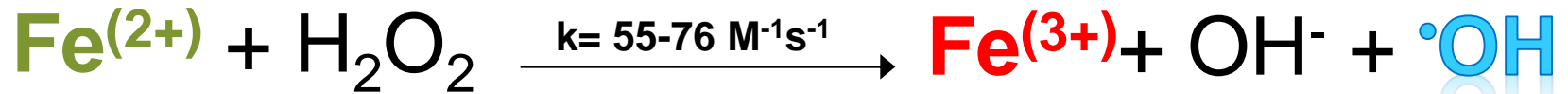
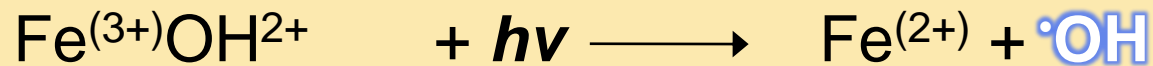
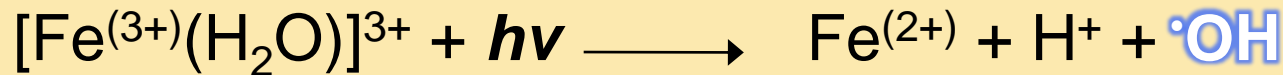


Photo-Fenton process



optimal operation: pH acid (2,5 – 3)

Photo-Fenton at Near-Neutral pH

< 2006 • Wastewater treatment at acidic pH

2006 • First photo-Fenton disinfection at neutral pH (**Rincon & Pulgarin**)

• **HOW is it possible ?**

Effect of organo-*Fe* complexes and solid Fe species

1. Solubilisation of Fe^{3+} by **NOM** at near neutral pH and
2. **Regeneration of Fe^{2+} by LMCT** with production of oxidative organic radicals (R^\bullet) that can also attack the bacteria or generate other ROS



Soluble complex at neutral pH

3. Heterogeneous-homogeneous photo-Fenton equilibrium from **solid Fe species** influenced by chemical nature, ionic strength and buffer capability of water?

Canonica, S., (2007). *Chimia* 61, 641–644.

Angela-Guiovana Rincon, Cesar Pulgarin. *Catalysis Today* 122 (2007) 128–136.

Alejandro Moncayo-Lasso, Janeth Sanabria, César Pulgarin, Norberto Benítez. *Chemosphere* 77 (2009) 296–300.

Frederic Sciacca, Julian A. Rengifo-Herrera, Joseph Wethe, Cesar Pulgarin. *Chemosphere* 78 (2010) 1186–1191.

Dorothee Spuhler, Cesar Pulgarin. *Applied Catalysis B: Environmental* 96 (2010) 126–141.

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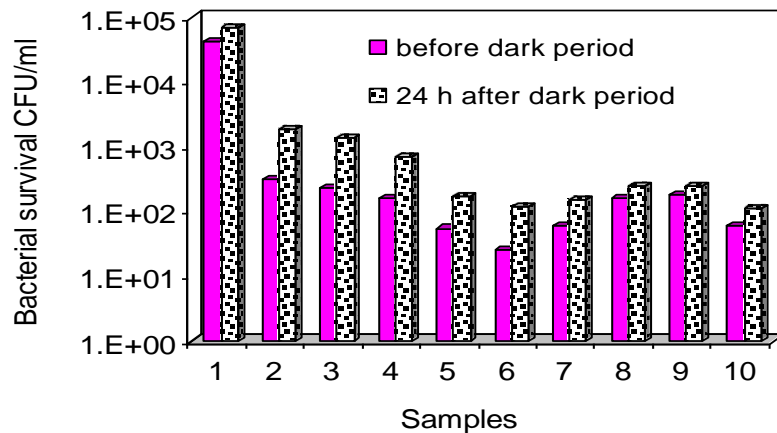
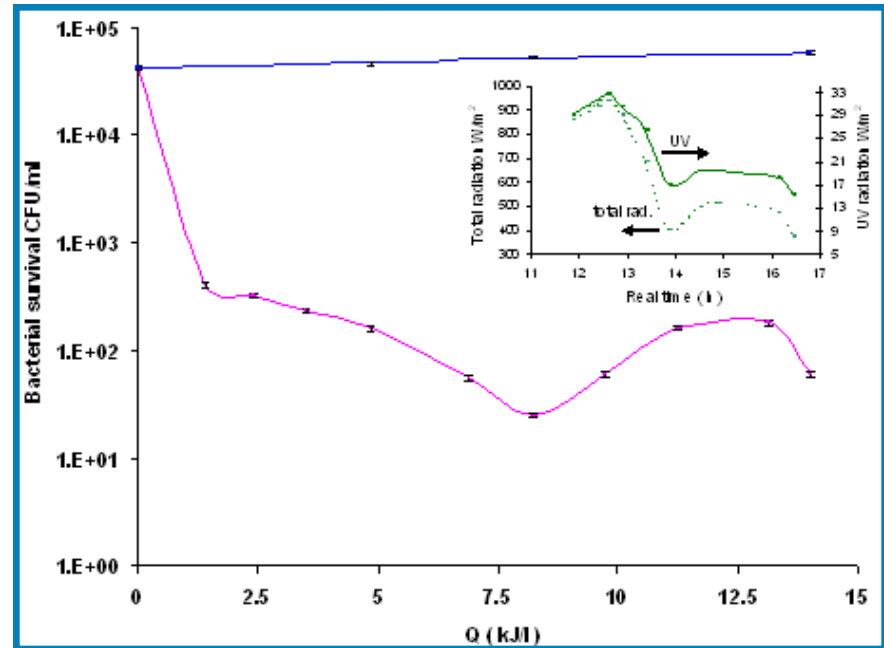
Scale up: CPC Reactor.



Type of solar photo reactor used at the EPFL, Lausanne, Switzerland and at UNIVALLE, Cali, Colombia
Compound Parabolic Collector (CPC).

CPC Reactor

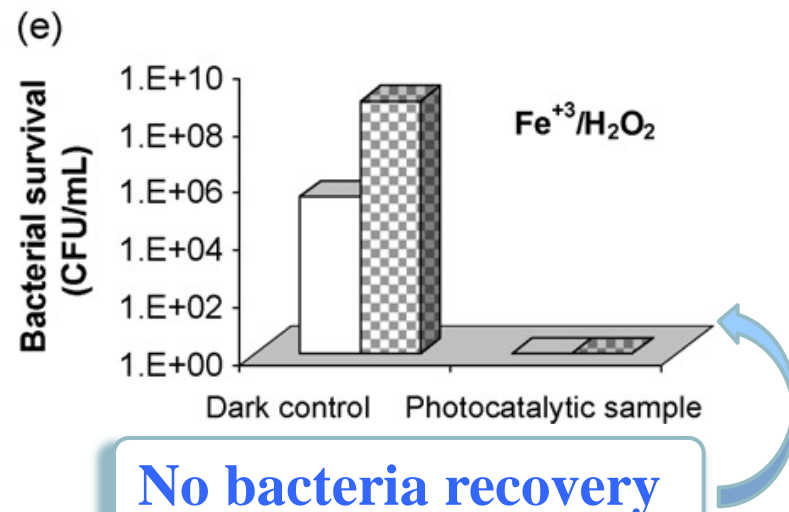
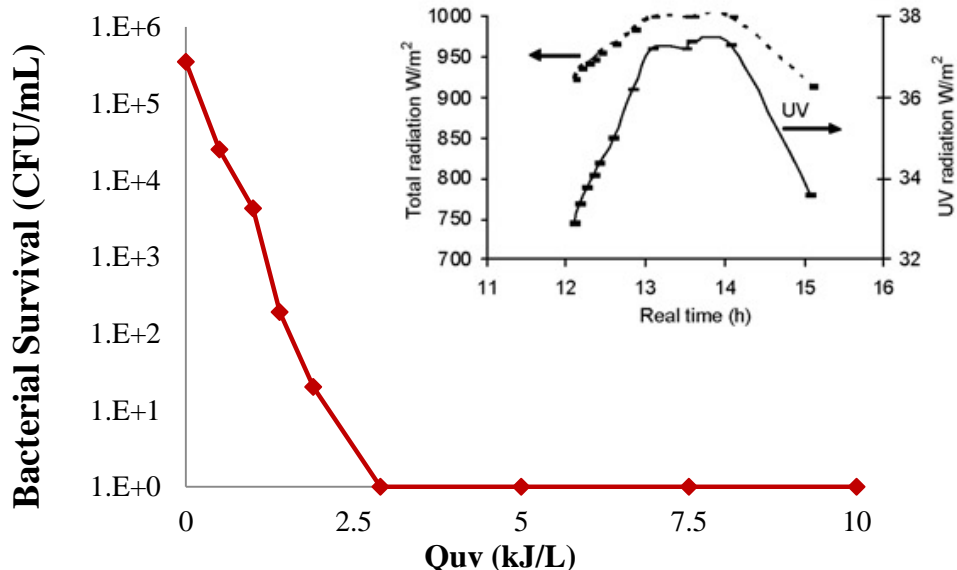
Geneva Lake Water Disinfection under only Solar light



❖ Total disinfection was not reached during illumination and bacterial recovery was observed during subsequent 24h under dark

CPC Reactor

Geneva Lake Water Under Photo-Fenton System: $\text{Fe}^{3+} + \text{H}_2\text{O}_2 + \text{Solar light}$



Natural pH: 7.5

$\text{Fe}^{3+} = 0.3 \text{ mg/L}$

$\text{H}_2\text{O}_2 = 10 \text{ mg/L}$

$V_{\text{Tot}} = 35 \text{ L}$

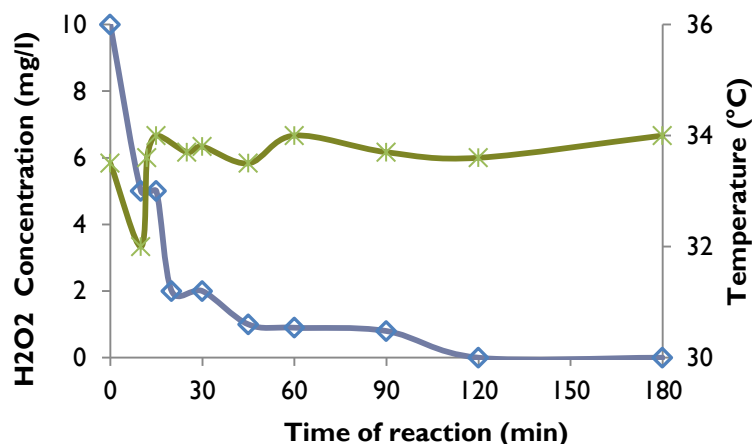


Photo-Fenton Disinfection at Near-Neutral pH

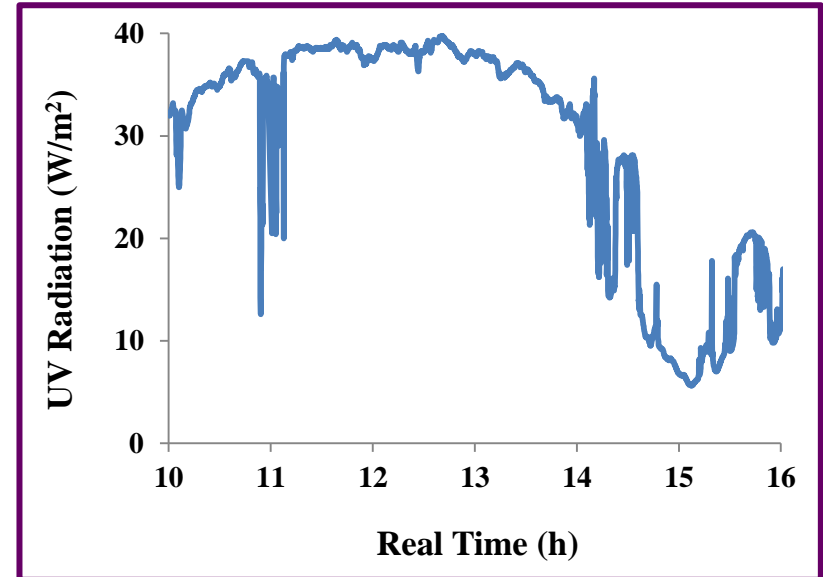
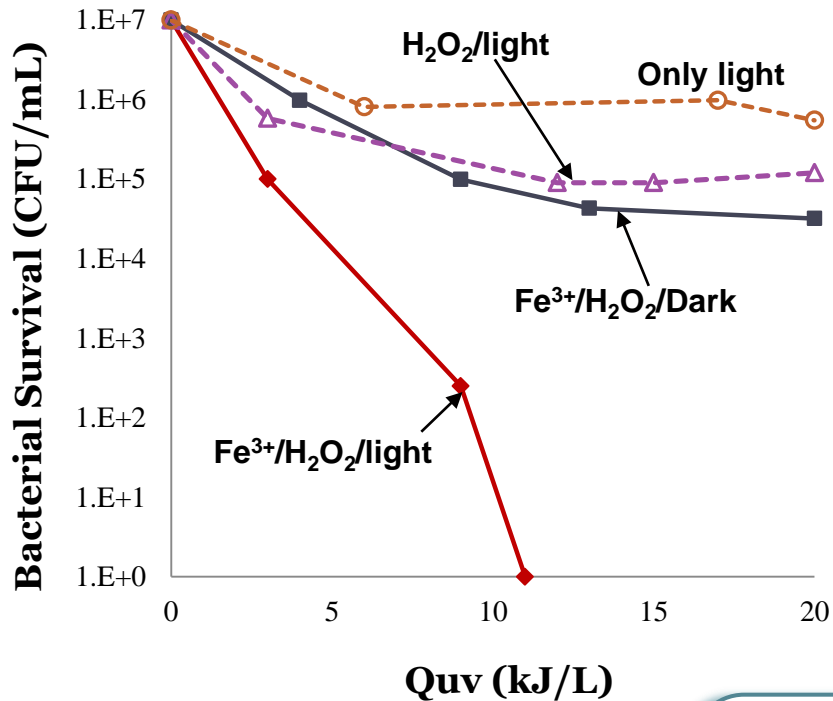
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CPC Reactor

Water from Pance River in Cali-Colombia



Natural pH: 6.2

Fe³⁺ = 0.6 mg/L

H₂O₂ = 10 mg/L

V_{Tot} = 8 L

Photo-Fenton Disinfection at Near-Neutral pH

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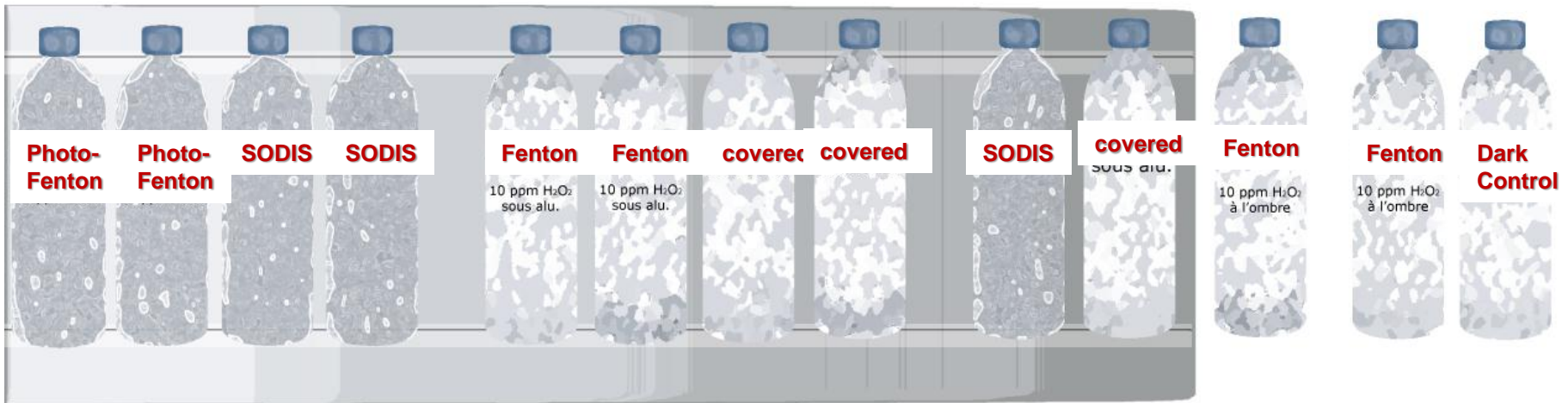
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Polyethylene Terephthalate (PET) bottles

Raw waters in Ouadadougou-Burkina-Fasso

Solar lighth exposition

Dark



Bacterial counting

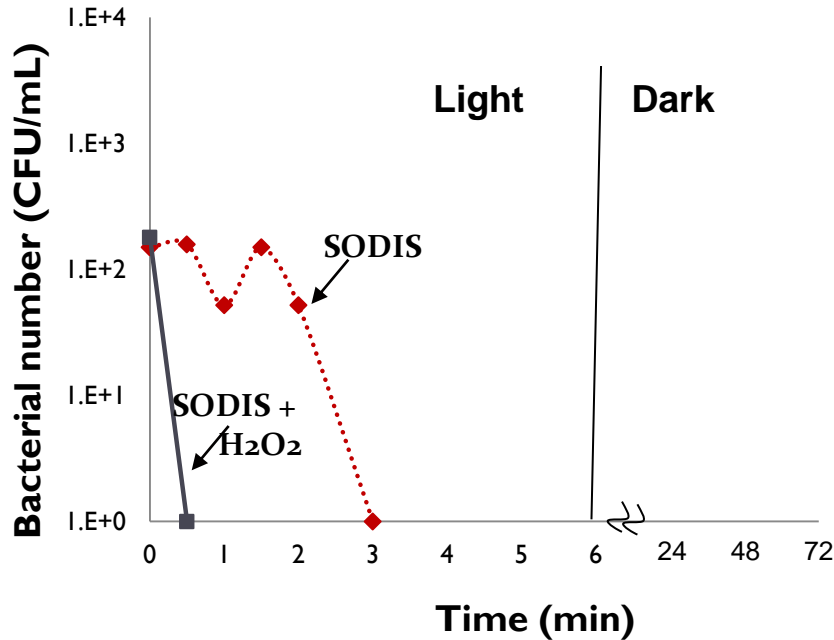
Temperature measuring

Bacterial counting

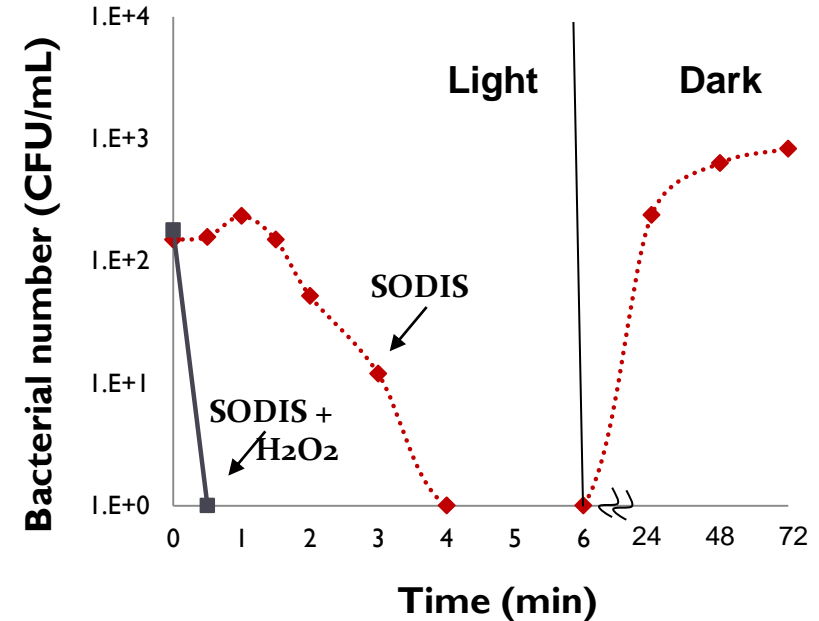
$[H_2O_2] = 10 \text{ mg L}^{-1}$

Polyethylene Terephthalate (PET) bottles

Wild Total coliforms



Wild Salmonella sp.



Natural pH: 7.5

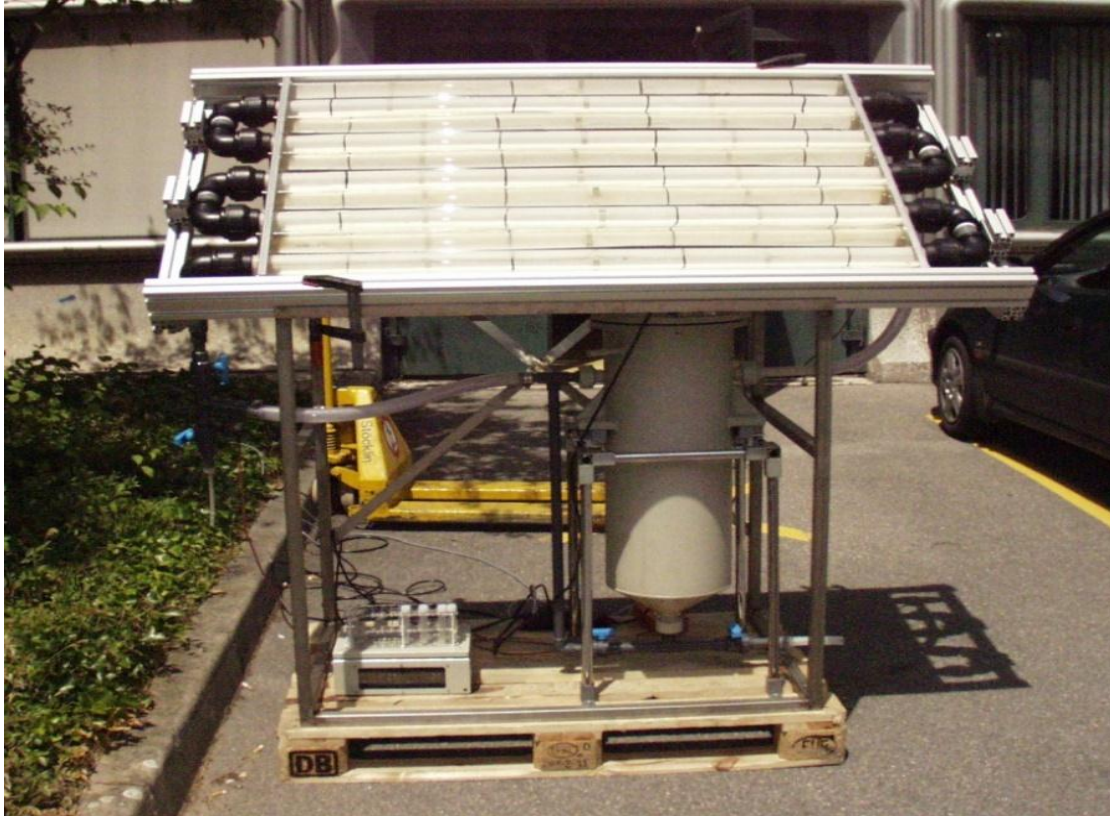
Natural iron in water= 0.3 mg/L

H₂O₂= 10 mg/L

V_{Tot}= 1.5 L

Turbidity (NTU)= 26

CPC Reactor.

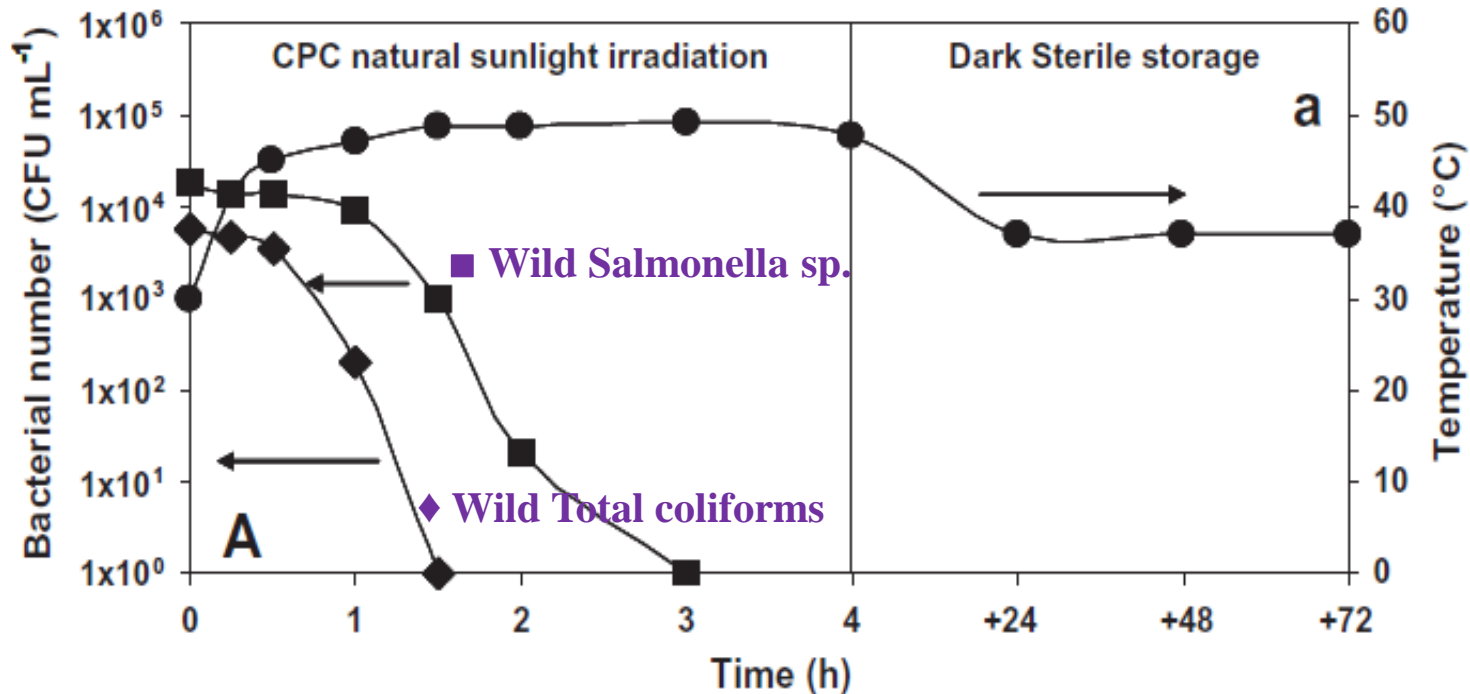


Type of solar photoreactor (CPC) used in 2ie
Ougadougou, Burkina Faso



CPC Reactor + **only** solar light **50°C** → thermic sterilization

Water from Well water of urban dam in Burkina Faso



Natural pH= 6.9

Natural iron in water= 1.2 mg/L

Without H₂O₂

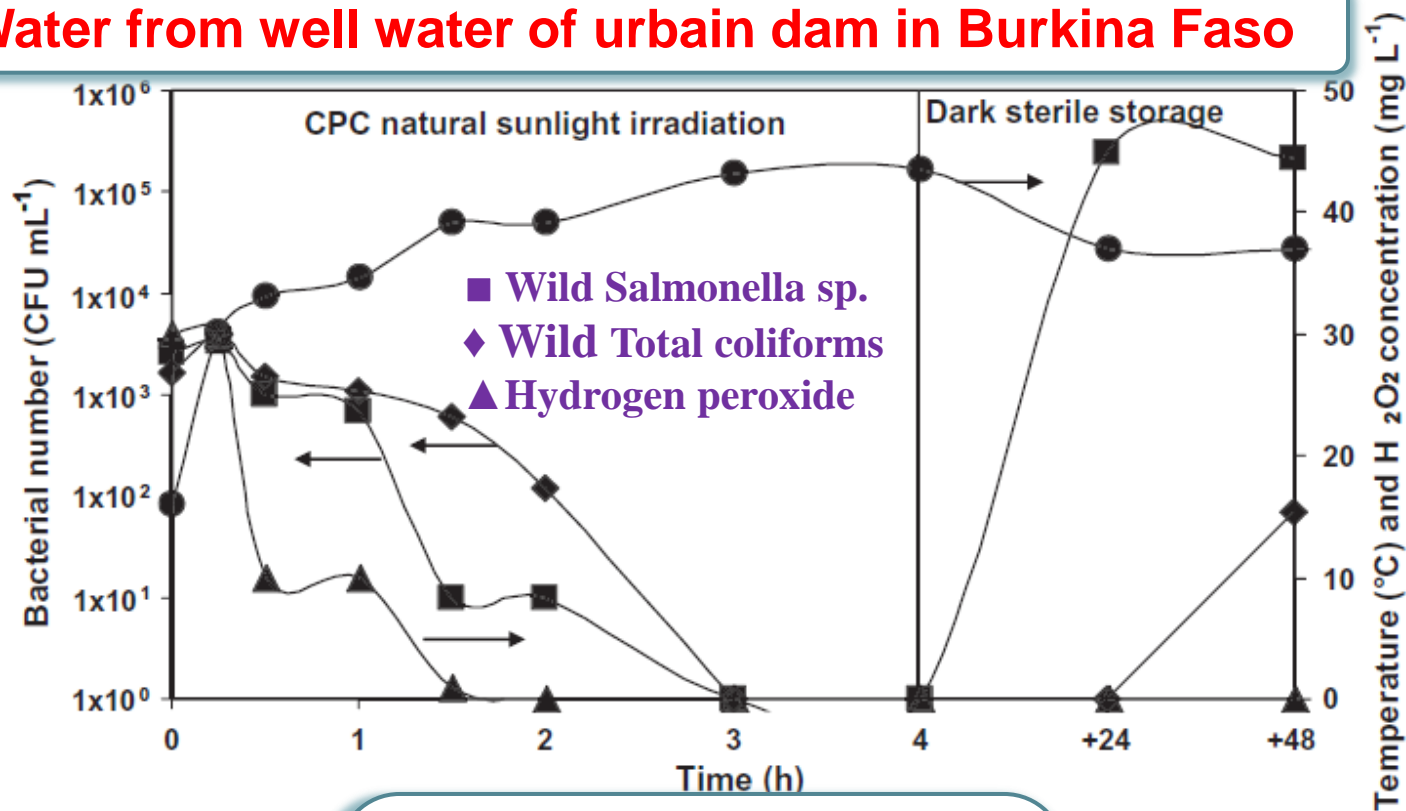
V_{Tot}= 18 L

Turbidity (NTU)= 76

Temperature: 50°C

Negative impact of H_2O_2 in CPC reactor at $42^\circ C$

Water from well water of urban dam in Burkina Faso



Natural pH= 6.9

Natural iron in water= 1.3 mg/L

H_2O_2 = 30 mg/L

V_{Tot} = 18 L

Turbidity (NTU)= 78

Temperature: $42^\circ C$

Photo-Fenton disinfection at Near-Neutral pH

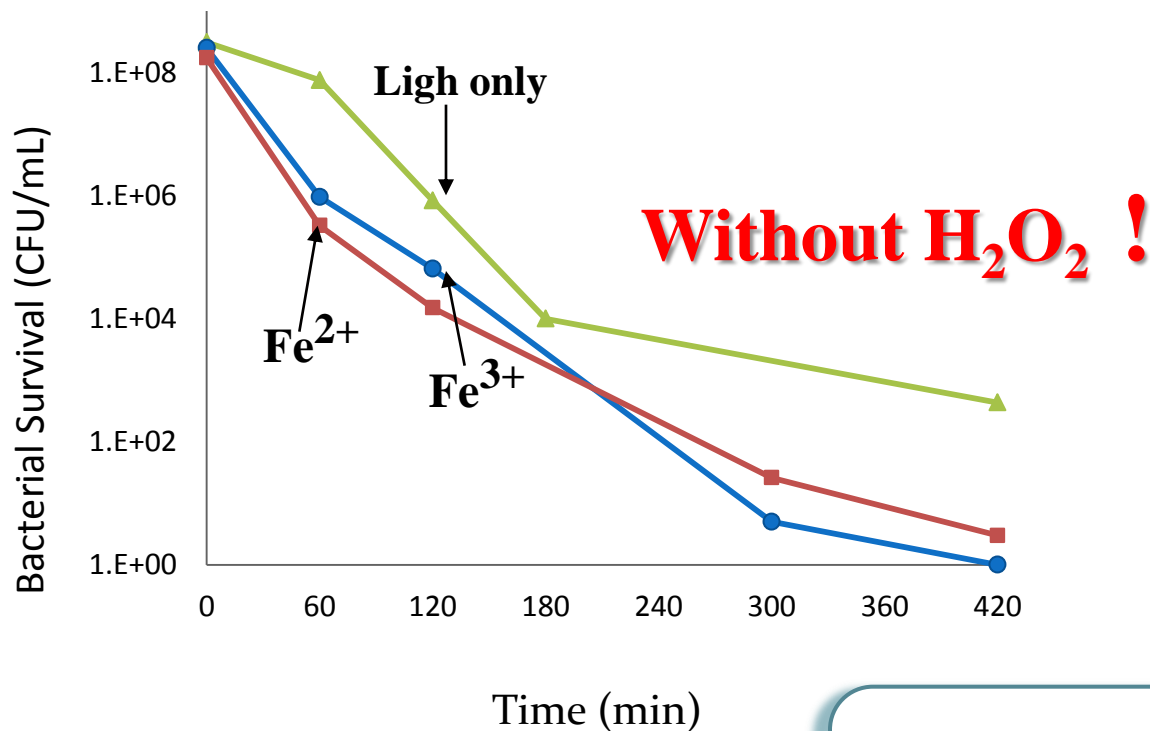
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2010-12	Spuhler et al. and Ruales	<i>E.Coli -K12</i>	Milli-Q & mineral water and Geneva Lake water
2011	Nieto-Juarez J. et al.	Virus	Carbonate-buffered saline (CBS)
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Laboratory Experiments: Solar simulator

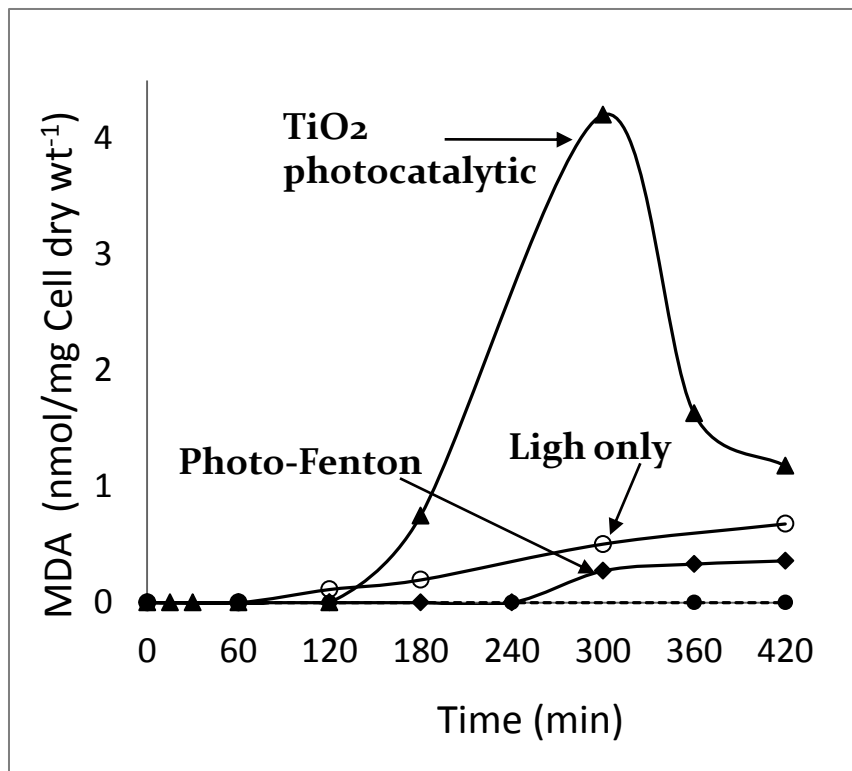
E. coli Inactivation due to Fe^{2+/3+} Treatments



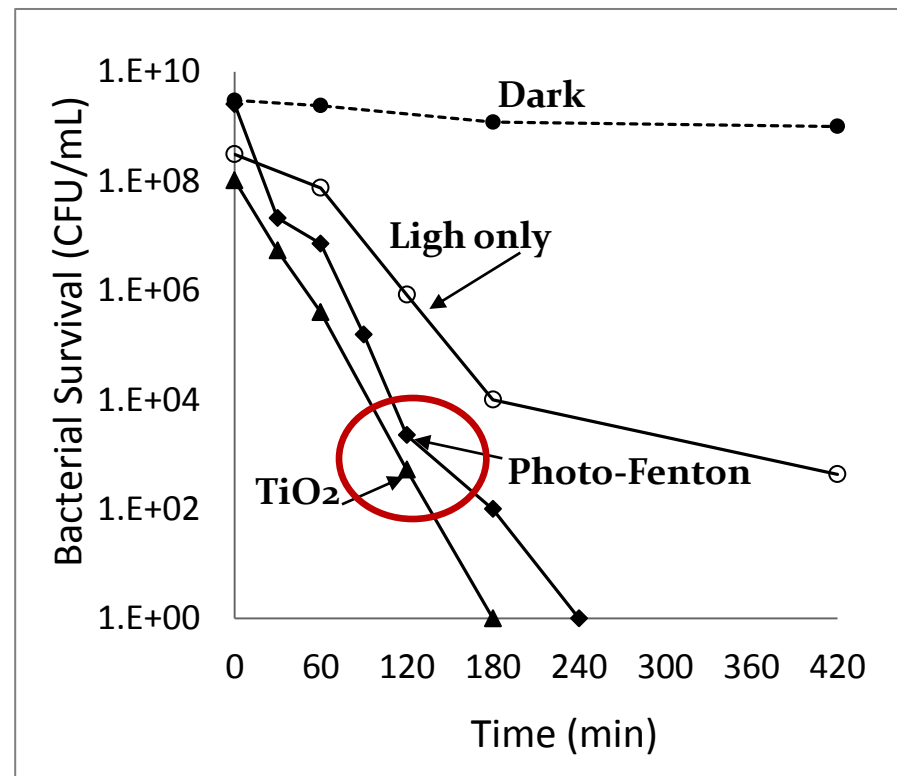
Milli-Q water pH= 6.5
Fe=28 mg/L
Vtot= 90 mL

Laboratory Experiments: Solar simulator

Lipid peroxidation



(A) MDA formation

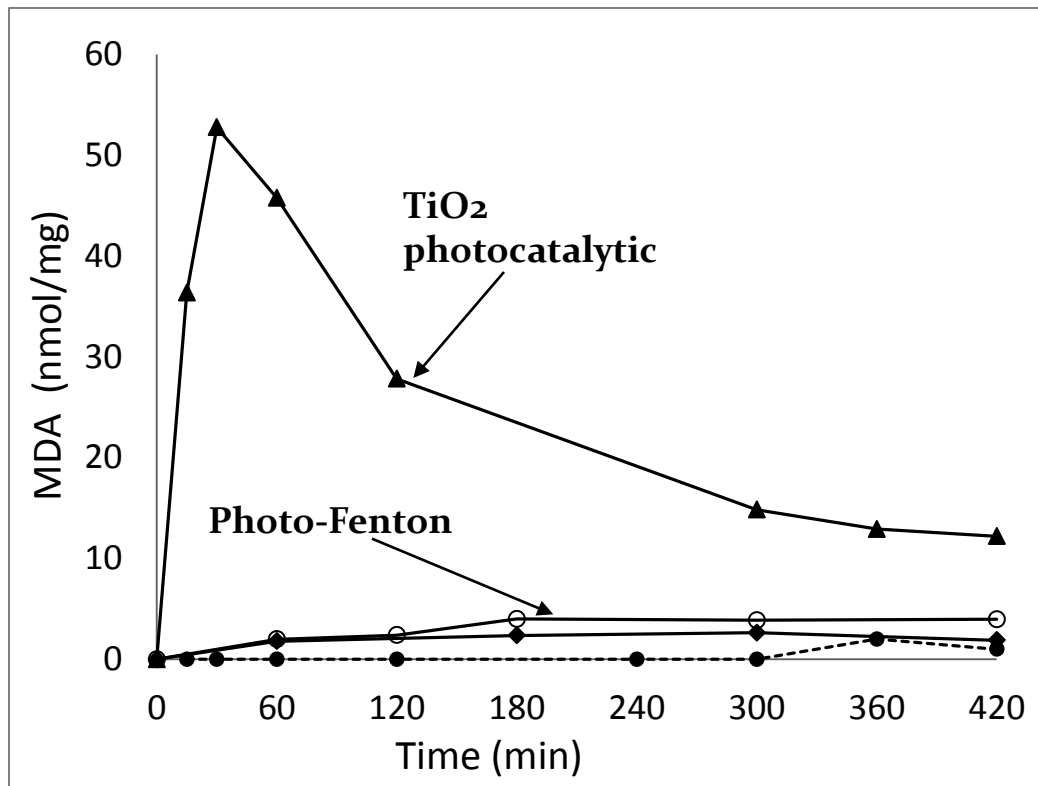


(B) *E. coli* inactivation

E. coli K-12 ~10⁷ CFU/mL pH: 6.5
TiO₂ (0.1 mg/mL)
Fe²⁺ (0.6 mg/L)/H₂O₂ (10 mg/L)

Laboratory Experiments: Solar simulator

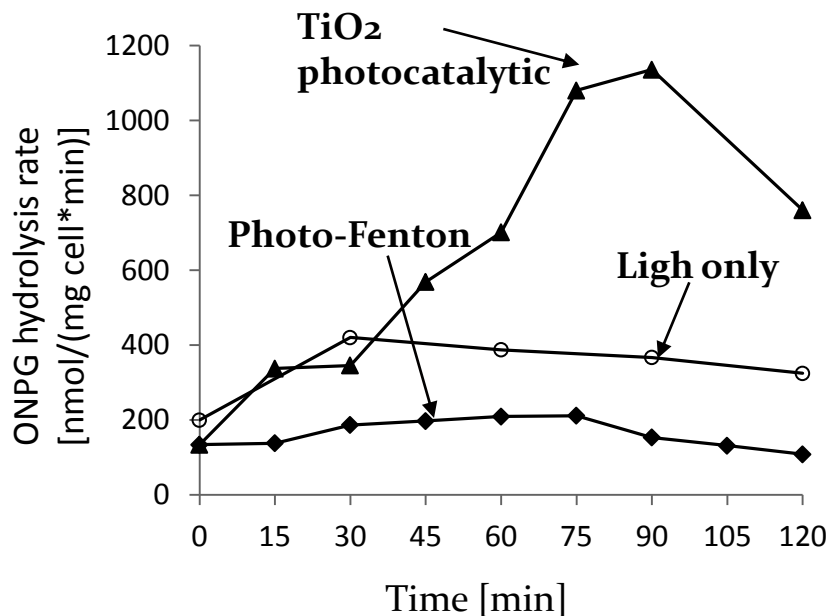
Lipid peroxidation



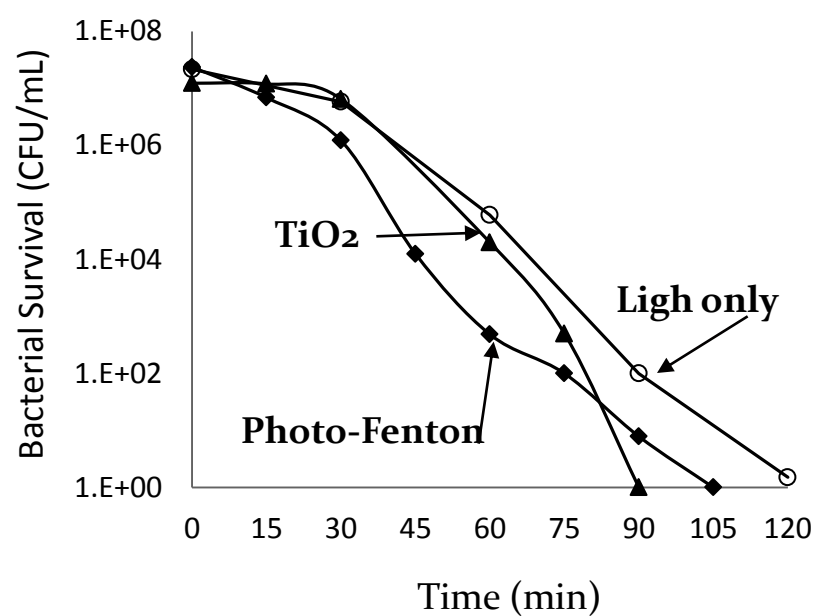
LPS (0.2 mg/mL) pH:6.5
TiO₂ (0.1 mg/mL)
Fe²⁺ (0.6 mg/L)/H₂O₂ (10 mg/L)

Laboratory Experiments: Solar simulator

Cell permeability change



(A) ONPG hydrolysis rate



(B) *E. coli* inactivation

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Photo-Fenton disinfection at Near-Neutral pH

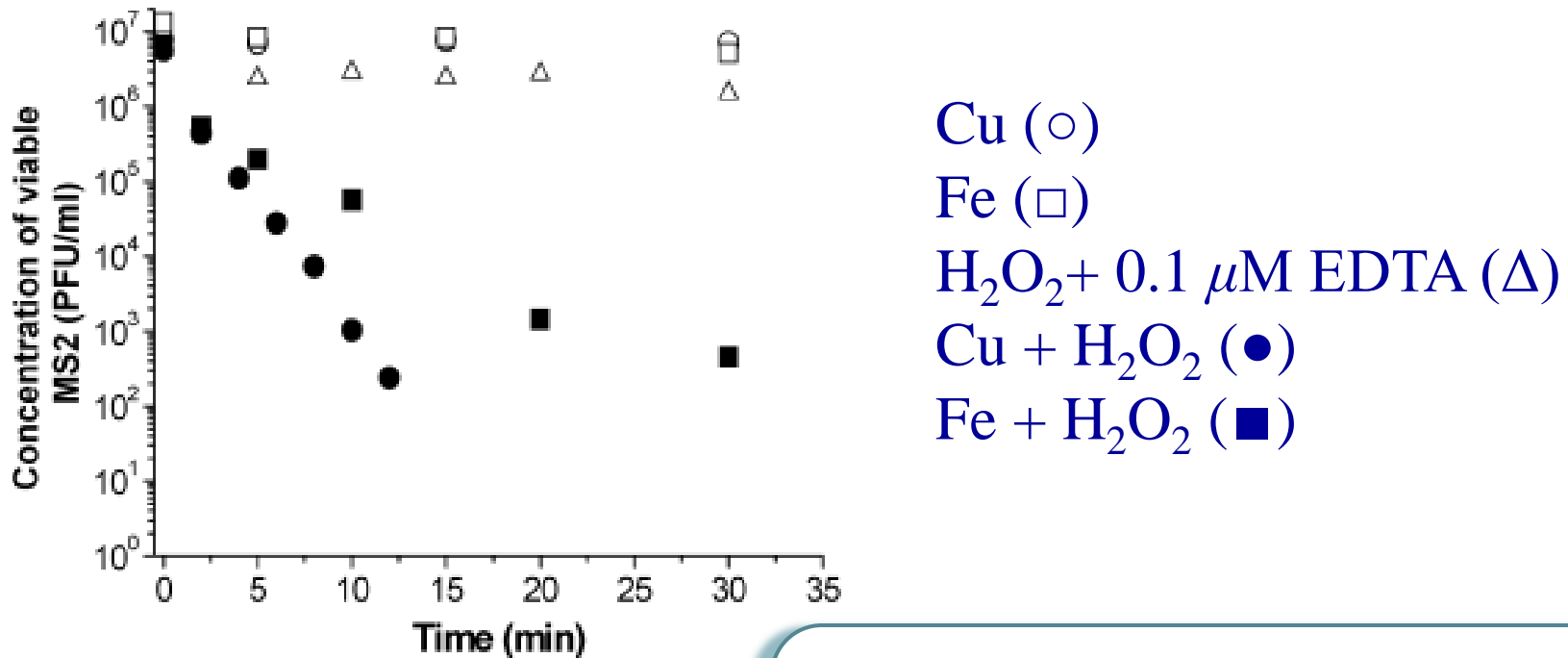
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Laboratory Experiments: Solar simulator

MS2 inactivation by Cu- and Fe- catalyzed Fenton process



In carbonate-buffered saline (CBS) pH= 6.8
Cations concentrations=5 mg/L
H₂O₂= 1.7 mg/L
Vol= 50 mL

Photo-Fenton disinfection at Near-Neutral pH

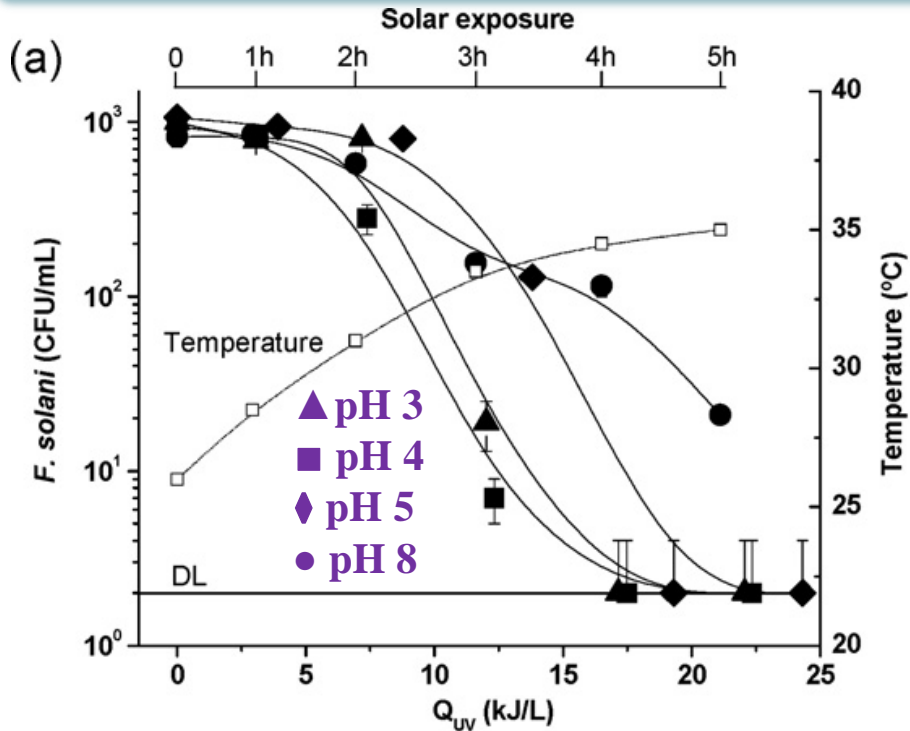
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Laboratory Experiments: Solar simulator

F. solani microconidia inactivation

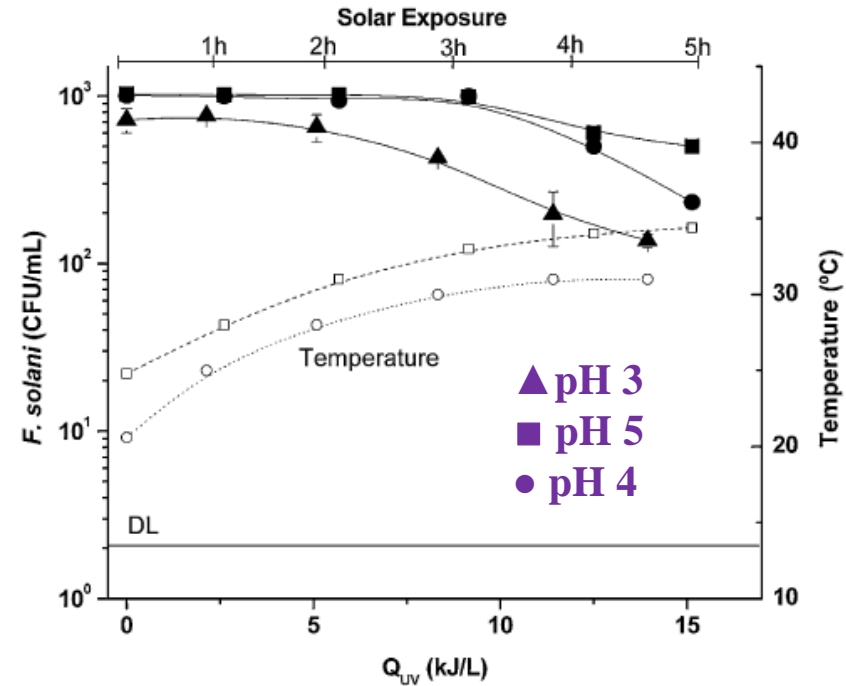


Fe=5 mg/L

H₂O₂= 10 mg/L

pH 5: **DOC reduction: 19%**

Simulated
municipal effluents
 V_{Tot} = 250 mL



Fe=10 mg/L

H₂O₂= 20 mg/L

pH 5: **DOC reduction: 30%**

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Main Pulgarin-Group activities:

- ▶ Mechanistic study of Advanced Oxidation Processes (AOPs) in degradation of chemical and microbiological pollutants in water. Coupling of AOPs and biological systems
- ▶ Development of supported self-cleaning and self-disinfecting (photo) active materials
- ▶ Household helio-photocatalytic water disinfection for isolated regions from Latin America and Africa.
- ▶ Coordinator (16 years) EPFL-UNIVALLE cooperation

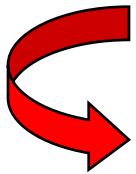
<http://projets-cooperation.epfl.ch/index/view/lang/en/document/72>

New coordinator EPFL-UNIVALLE Plan biannual Dr Luc Patiny:

luc.patiny@epfl.ch

Main results of the EPFL-UNIVALLE program 1994-2012

- Projects for around 6-7 millions CH Francs specially on environmental topics
- 25 Ph. D. and post Ph. D.
- 30 masters
- 17 undergraduate studies
- 33 trainings



- 80 papers in international scientific journals and congress
- World most cited work in 1) TiO₂ photo-assisted bacterial inactivation in water 2) Coupling of photochemical and biological processes for pollutant degradation



Main results of the program (2)

Some examples of Ph. D. thesis

- ◆ **Angela Guiovana Rincon:** Solar disinfection of water by photocatalytic processes: thèse 3050 (2005)
 - ◆ **Rodrigo Jimenez:** Development and application of UV-visible and mid-IR differential spectroscopy techniques for pollutant trace gas monitoring, these 2944 (2004)
 - ◆ **Elizabeth León:** Système d'indicateurs environnementaux pour évaluer les impacts principaux de l'exploitation du pétrole en Colombie, thèse 2861 (2003)
 - ◆ **Victor Manuel Sarria:** Coupled Advanced Oxidation and Biological Process for wastewater treatment, thèse 2785 (2003)
 - ◆ **Luis Borda:** Apport des systèmes d'information géographiques (SIG) pour la surveillance et l'évaluation de la qualité des eaux côtières, thèse 2724 (2003)
 - ◆ **Sandra Parra:** Coupling of photocatalytic and biological processes as a contribution to the detoxification of water: these 2470 (2001)
 - ◆ **Norberto Benitez:** Cadmium speciation and phyto-availability in soils of the Swiss Jura hypothesis about its dynamics, these 2066, (1999)
-



Acknowledgements

- Swiss National Science Foundation (**SNSF**): Ongoing **Project No IZ70Z0_131312/1-2**.
- Universidad del Valle (**UNIVALLE**), Colombia
- Ecole Polytechnique Fédérale de Lausanne (**EPFL**)
- Swiss Agency for Development and Cooperation (**SDC**): support to two previous projects with Colombia and one other going on with Burkina Faso
- **COLCIENCIAS**, Colombia
- European Commission (**EC**): two projects in South America and North Africa
- Cooperation & Development Center, EPFL (**CODEV**): several seed money projects.



EPFL

**I express my gratitude to
Ph. D. students and collaborators
from C. Pulgarin Group (GPAO)
<http://gpao.epfl.ch/>**



Thank you for your attention

