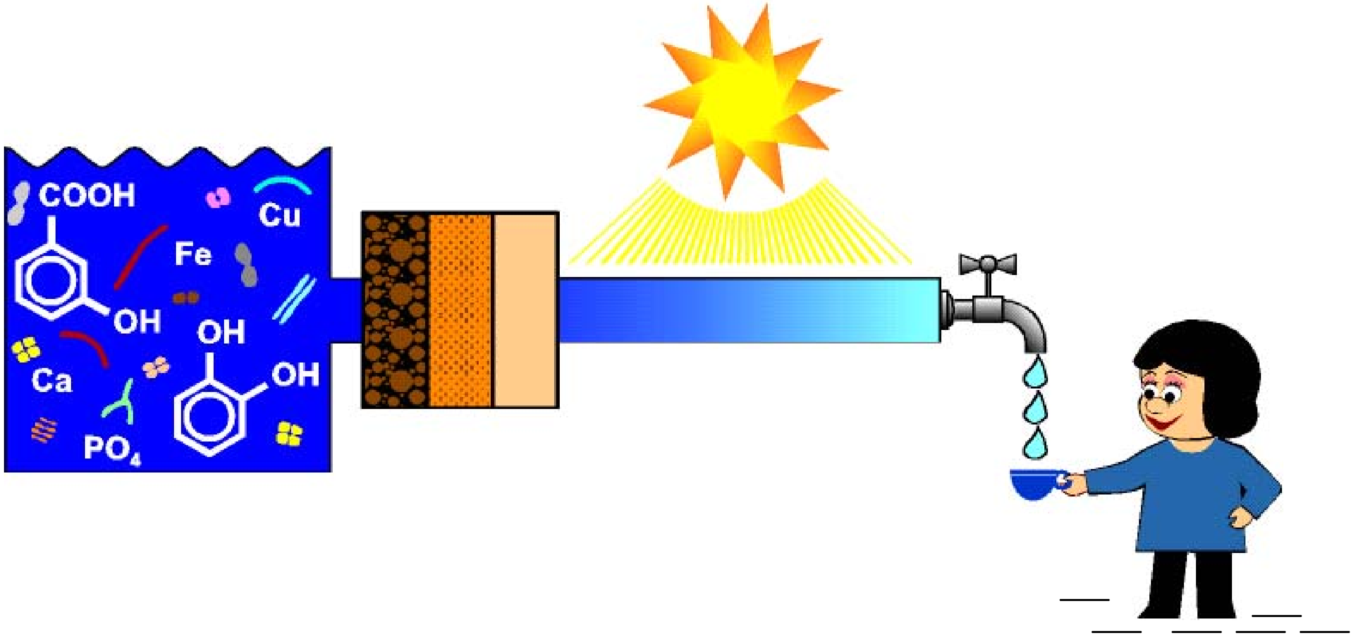
Desinfección de agua por fotocatálisis.

Aspectos básicos

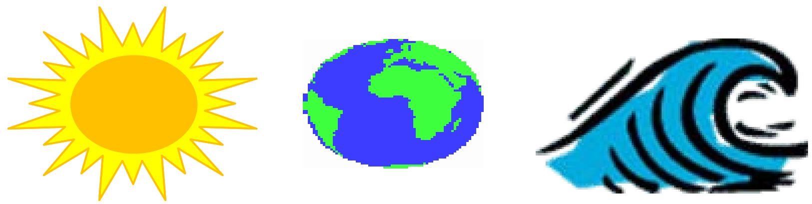


Angela-Guiovana Rincón B. y Cesar Pulgarin.

Curso « Posibilidades para la provisión de agua segura usando nuevas tecnologías ». Iguazu-Argentina, 14-10.2005.

Solar Disinfection of Water by Photocatalytic Processes.

Physico-Chemical and Biological Aspects



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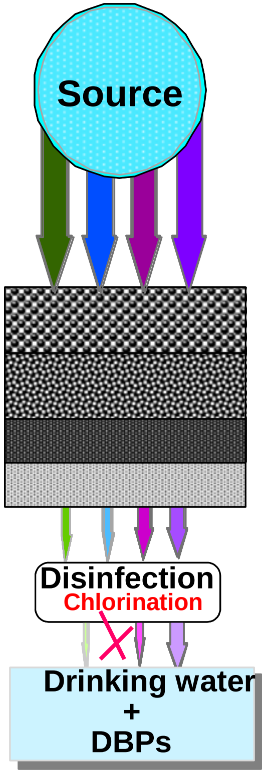
Curso « Posibilidades para la provisión de agua segura usando nuevas tecnologías ». Iguazu-Argentina, 14-15. 10. 2005.

Water disinfection



Chlorination is a widely used technique for the disinfection of water. Its bacterial inactivation effect has been proven but a great concern is that chemical risks could be enhanced due to by-products formed during the chlorination process.

Therefore, the necessity to find low cost, environmental friendly and sustainable alternatives to chlorination.

Disinfectants and disinfection-by products (DBPs)

apparition of chemical risk to human

- ✓ chlorine

THMs: $CHCl_3$, $CHCl_2Br$, $CHClBr_2$, $CHBr_3$
haloacetates, haloacetonitriles, haloacetaldehydes, haloketones, halofuranones, chloropicrin, chlorate aldehydes, carboxylic acids

- ✓ chlorine dioxide

Halogenated compounds, chlorite, chlorate

- ✓ chloramine

cyanogen, chloride and others generally thought to be the same DBPs as chlorine, but lower concentration

- ✓ ozone

Bromate, hydrogen peroxide bromomethanes, bromoacetates, bromoaldehydes, bromoketones, iodinated Analogs, aldehydes, carboxylic acids

- ✓ hydrogen peroxide

Carboxylic acids

UV

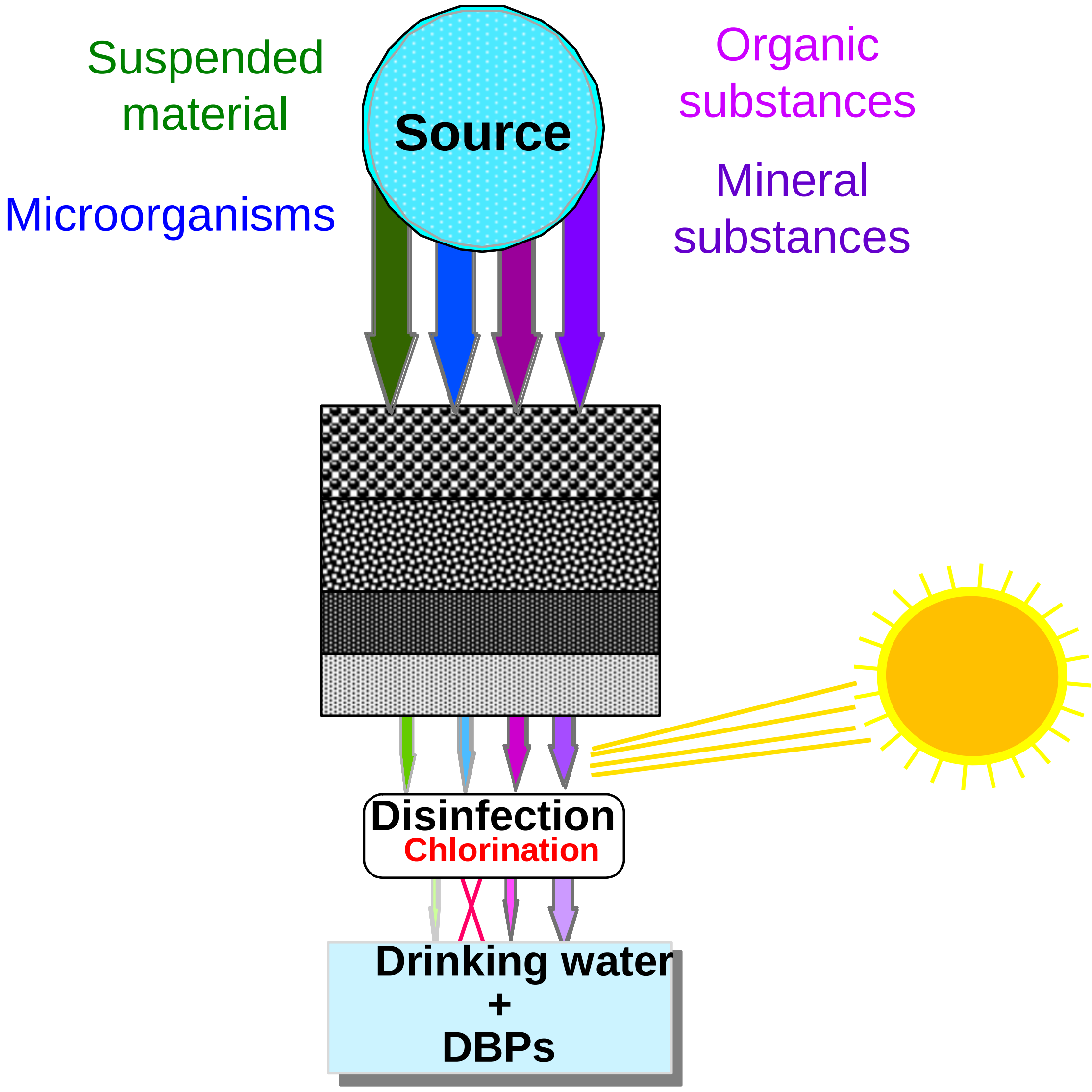
Not DBPs

Aim of the study

- To develop and assess a drinking water and wastewater disinfection process based on solar treatment as:

✓ An alternative to chlorination , by the study of sunlight influence upon the microorganisms

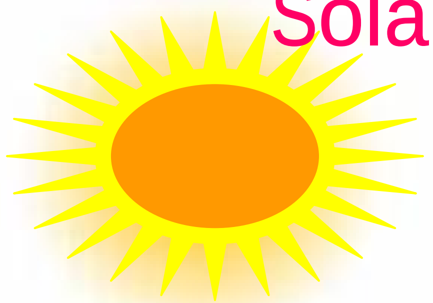
✓ A complement to chlorination, by the study of sunlight influence upon some precursors of the classical disinfection by-products



Schematic representation of the proposed disinfection system

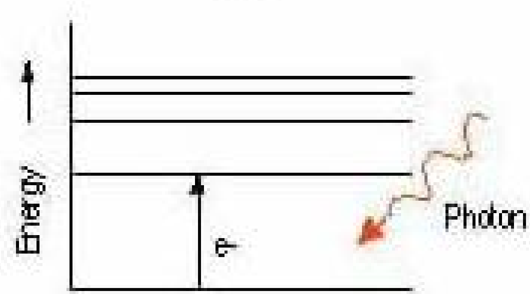
- How this treatment acts ?

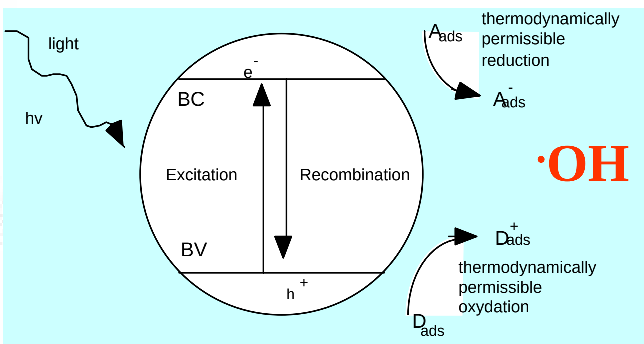
Solar irradiation



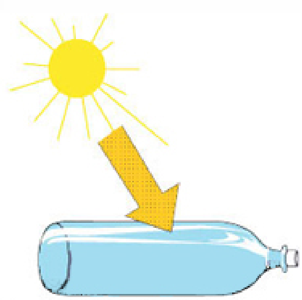
Thermochemistry

Photochemistry





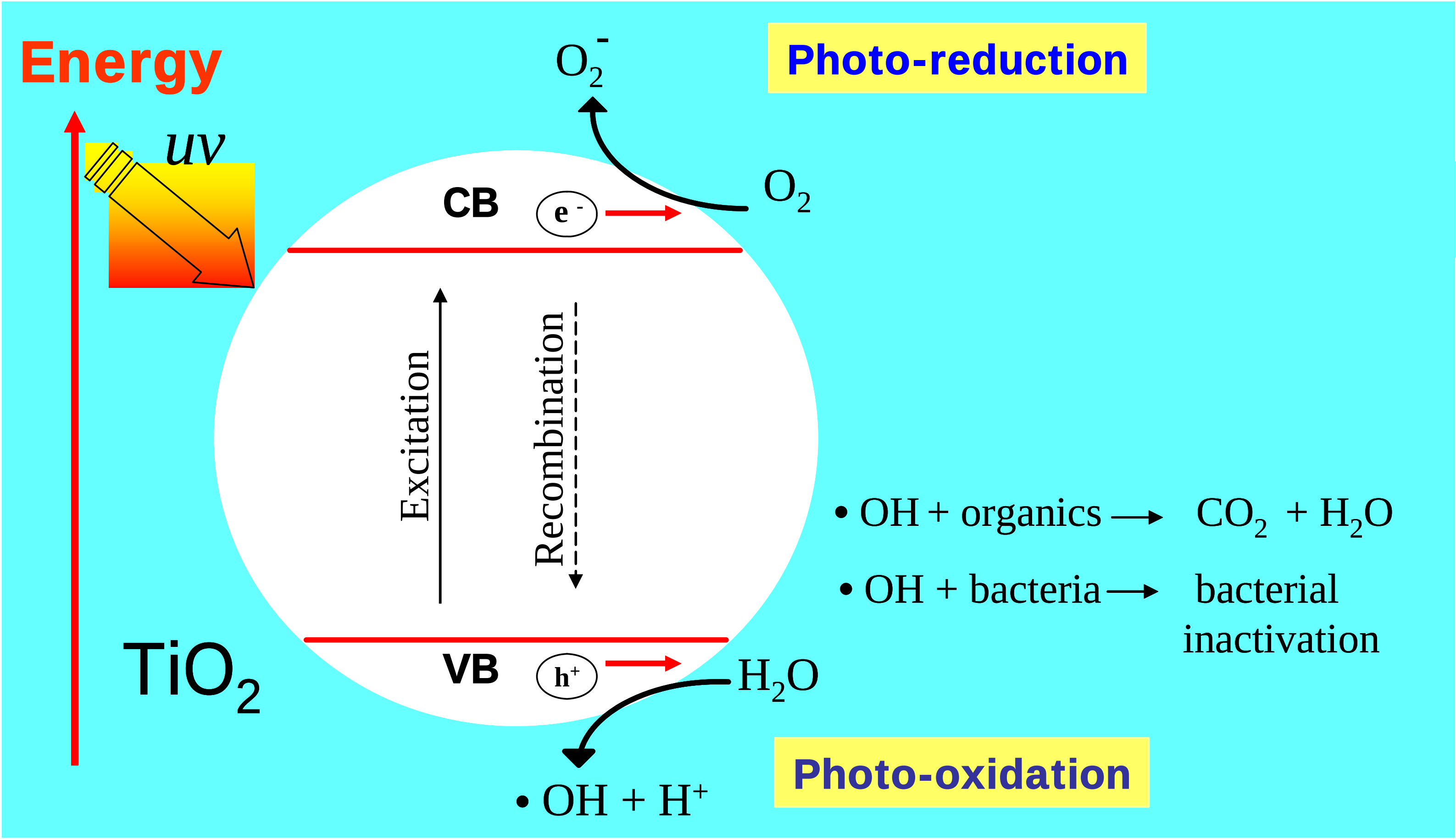
SODIS



Inactivation of microorganisms by UV-A-radiation and thermal treatment

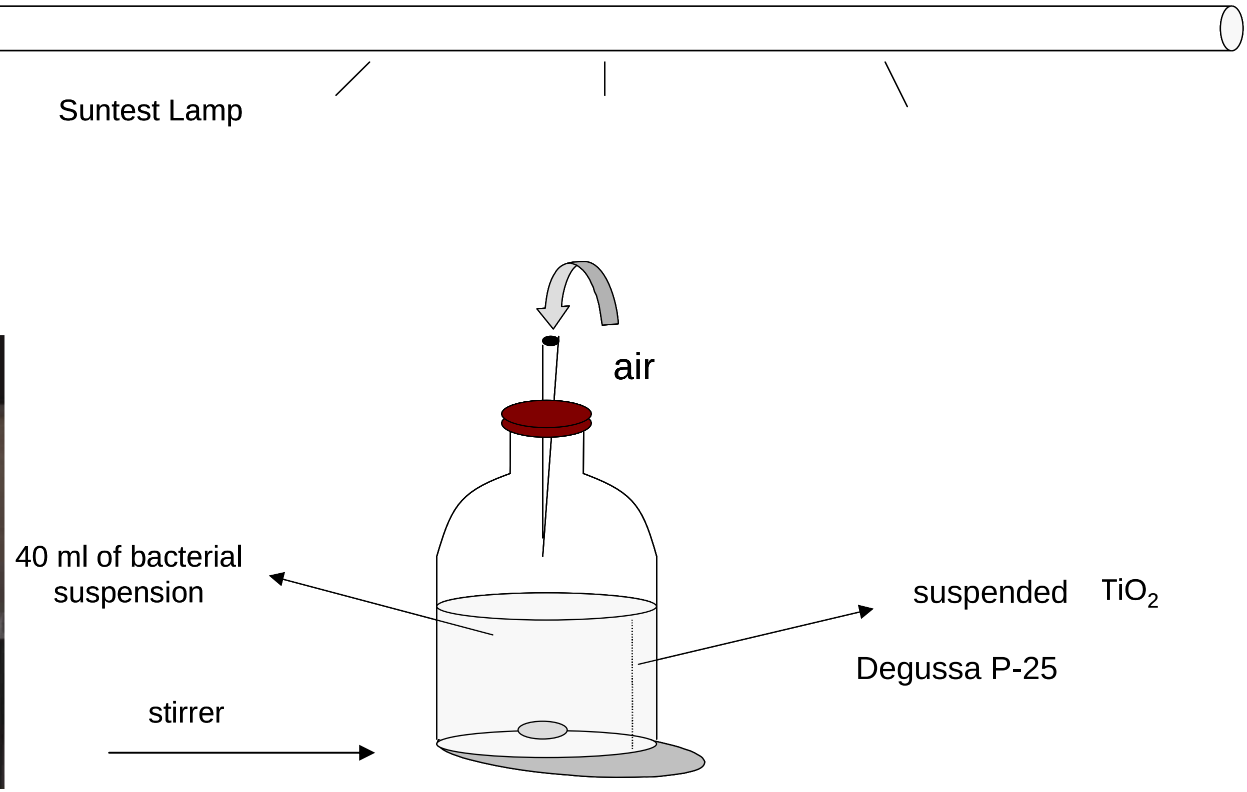
Photo-processes

TiO_2- semiconductor photocatalytic process



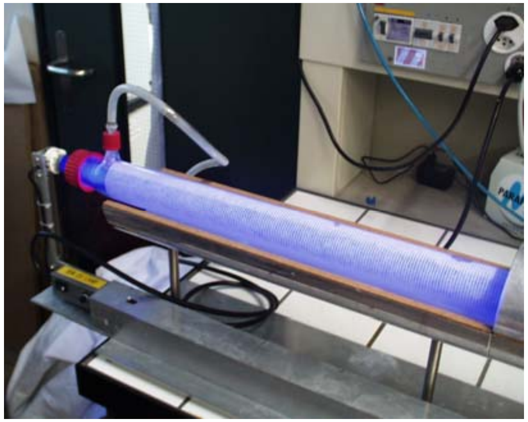
- What about the experimental tools ?

Suntest + reactor



- ✓ A Pyrex glass bottle of 50 ml was used as a batch reactor
- ✓ A Hanau Suntest (AMI) lamp was used as a simulated sunlight

Reactors



- ✓ Simulated sunlight
- ✓ real Sunlight
- ✓ UV-A electric light

- ✓ TiO_2 P25, *E. coli*, wastewater

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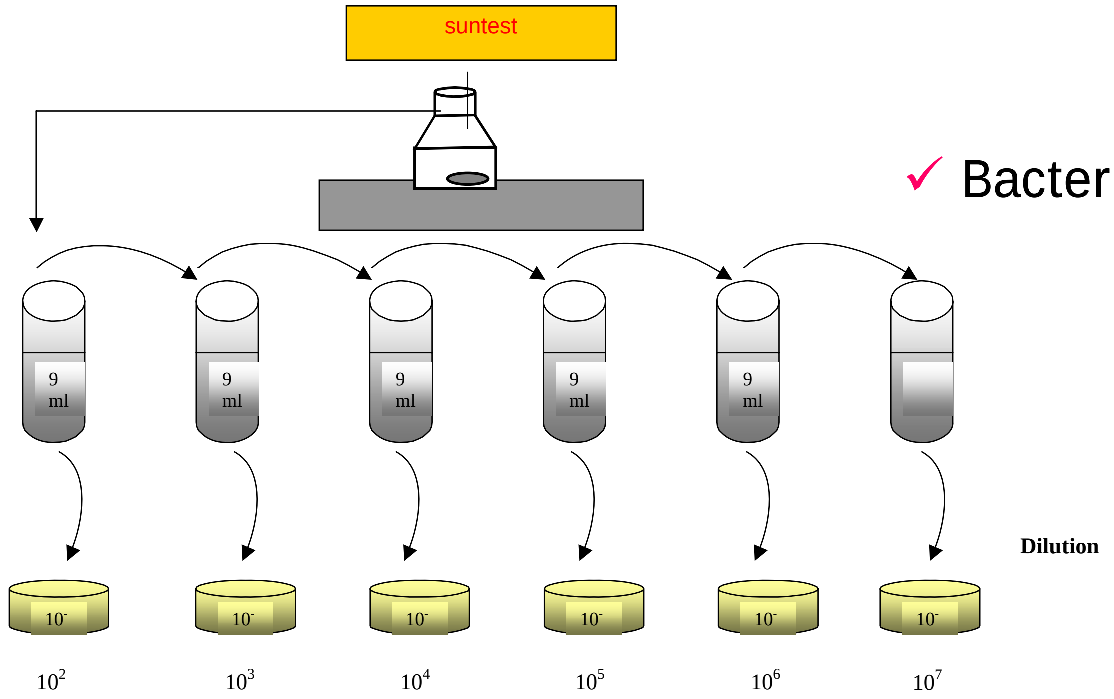
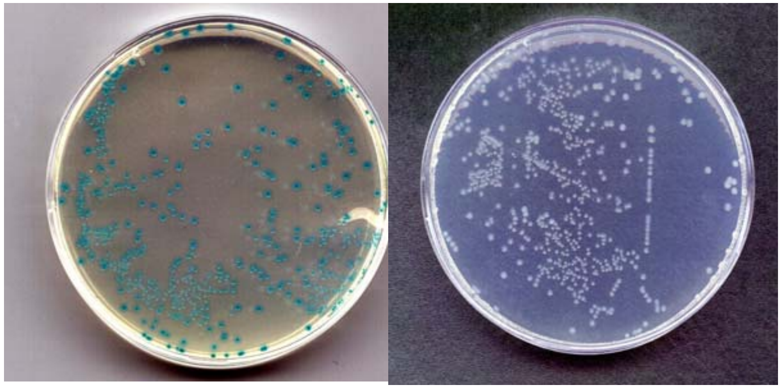
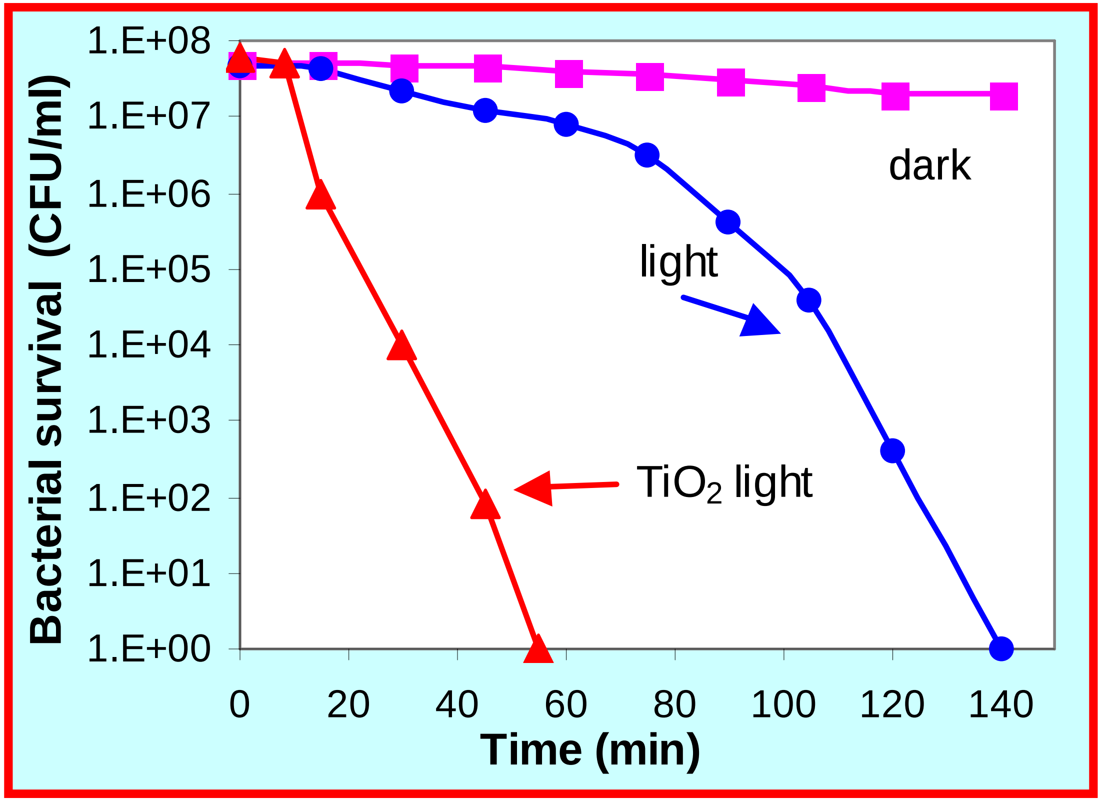
Experimental

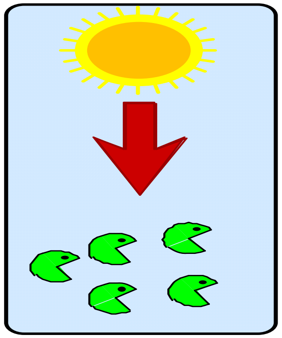


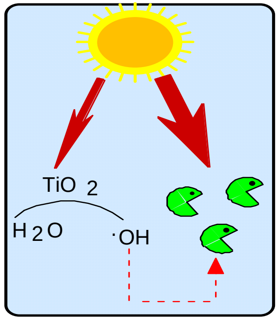
- ✓ Bacterial culturability



Inactivation of *E. coli* by sunlight







No=10^7 CFU/ml; TiO_2 0.75 g/l

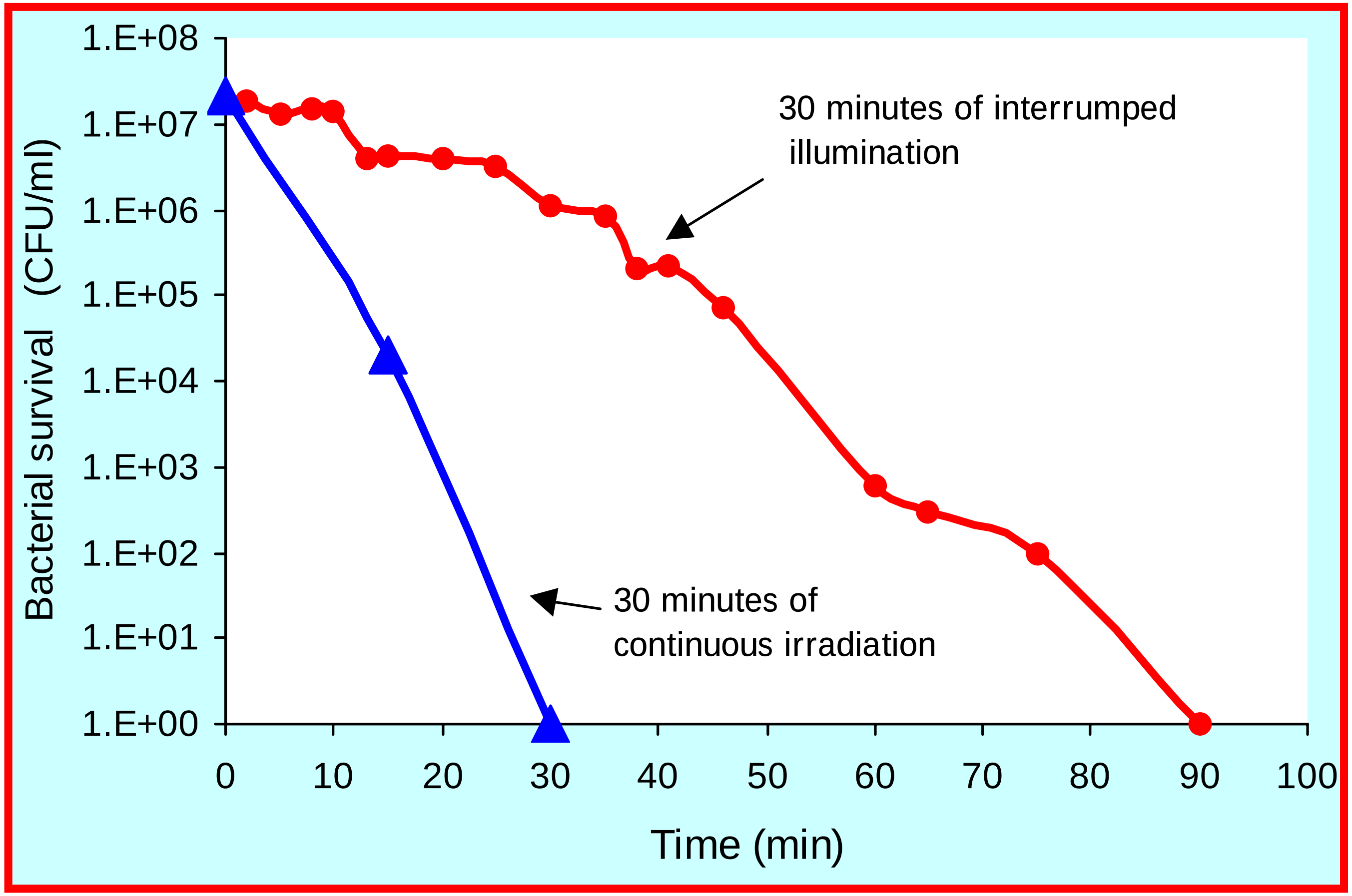
✓ *E. coli* inactivation is more efficient in the presence of TiO_2 than without TiO_2

Physicochemical and catalytical aspects

- Intermittence of illumination
- Light intensity
- Temperature
- Turbidity
- Fixation of catalyst
- Commercial catalyst
- Catalyst concentration

- What is the behavior of bacteria under intermittent illumination?

Interruption of illumination

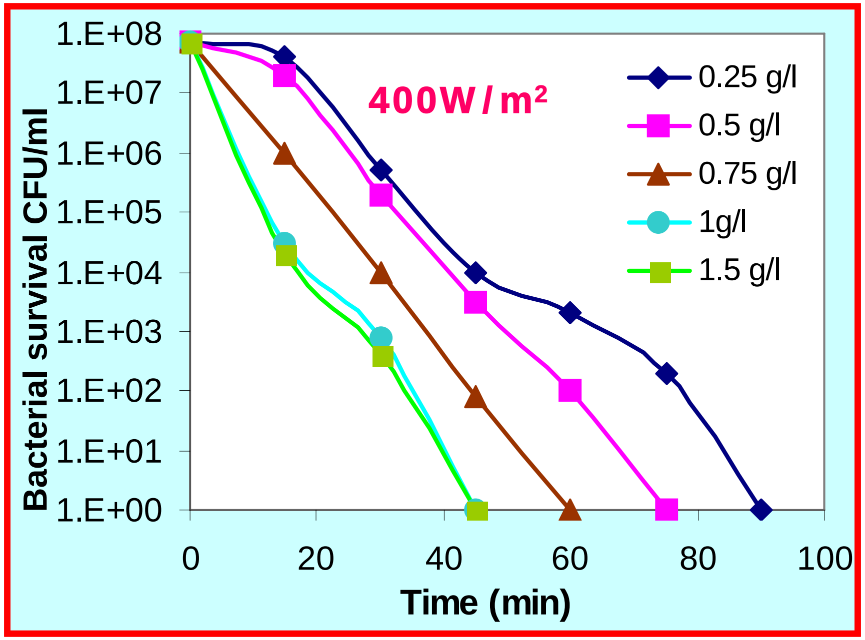


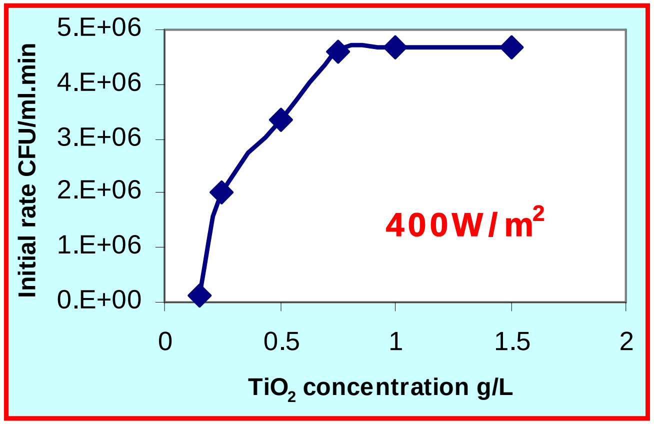
✓ Continuous irradiation was more efficient that intermittent irradiation. TiO_2 P25 1g/l

Rincón, A.G and Pulgarin C. *Appl. Catal. B: Environ.* 44 (2003), 263

- What is the optimal amount of photocatalyst?

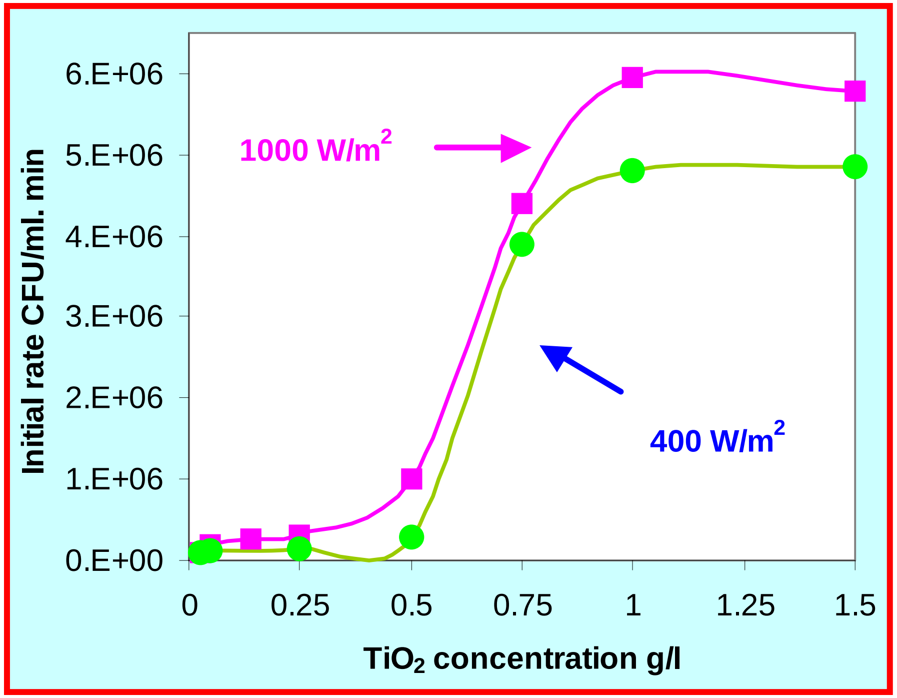
TiO_2 concentration

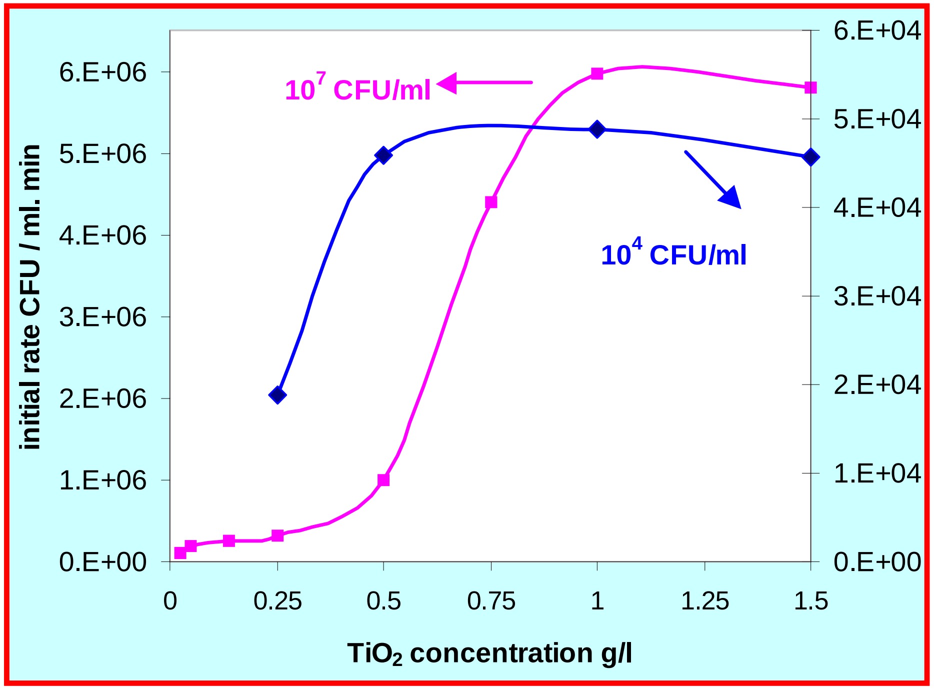




✓ The initial rate increases with the amount of catalyst up to a level corresponding to complete absorption of the incident light by TiO_2 (screen effect)

TiO_2 concentration





✓ The initial rate increases with the amount of catalyst up to a level corresponding to complete absorption of the incident light by TiO_2 (screen effect)

✓ The optimal TiO_2 concentration varies as a function of light intensity and initial bacterial concentration

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Physicochemical and catalytic aspects

- Direct germicidal action of light with the addition of TiO_2 is more efficient than the action of light alone.
- Intermitency of irradiation decrease the bacterial inactivation rate
- It is necessary to overpass a threshold of TiO_2 concentration before to observe a significant bacterial inactivation.
- The optimal TiO_2 concentration depends on different parameters as initial bacterial concentration, light intensity and the chemical composition of water. In our condition, the optimal values are generally ranged between 0.5 and 1 g/l.

- The chemical substances present in the water have an effect on the disinfection?

Chemical parameters

- Natural inorganic substances: (+) (-)
- Effect of synthetic and natural mixtures of organic and inorganic substances (+)(-)
- H_2O_2, O_2 (+)
- Specific organic substances (-)

Rincón, A.G and Pulgarin C. *Appl. Catal. B: Environ.* 51 (2004), 283-302

Rincón, A.G et al. *J. Photochem Photobiol. A: Chem.* 139 (2001), 233

Biological aspects:

- Influence of physiological state of bacteria and number of transfers
- Influence of initial bacterial concentration
- Definition of the effective disinfection time (EDT)
- Post irradiation events
- Response of natural bacterial community to photocatalytic treatment

EDT

- « Efficient Disinfection Time » is defined as the the treatment time required to prevent any bacterial regrowth during the subsequent 24 or 48 h in the dark, after stopping the phototreatment.

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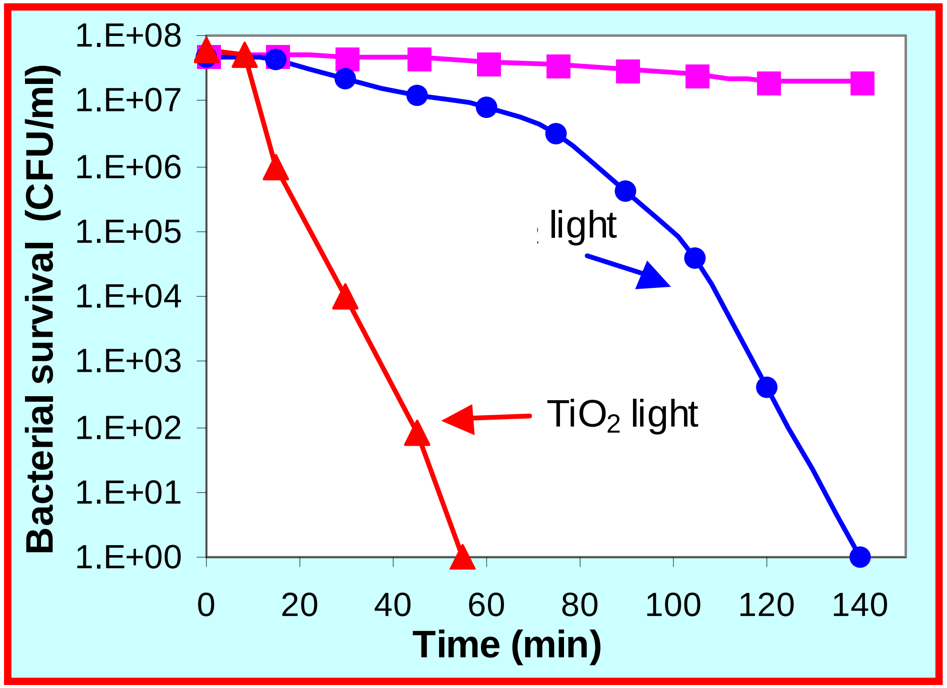
Post irradiation events

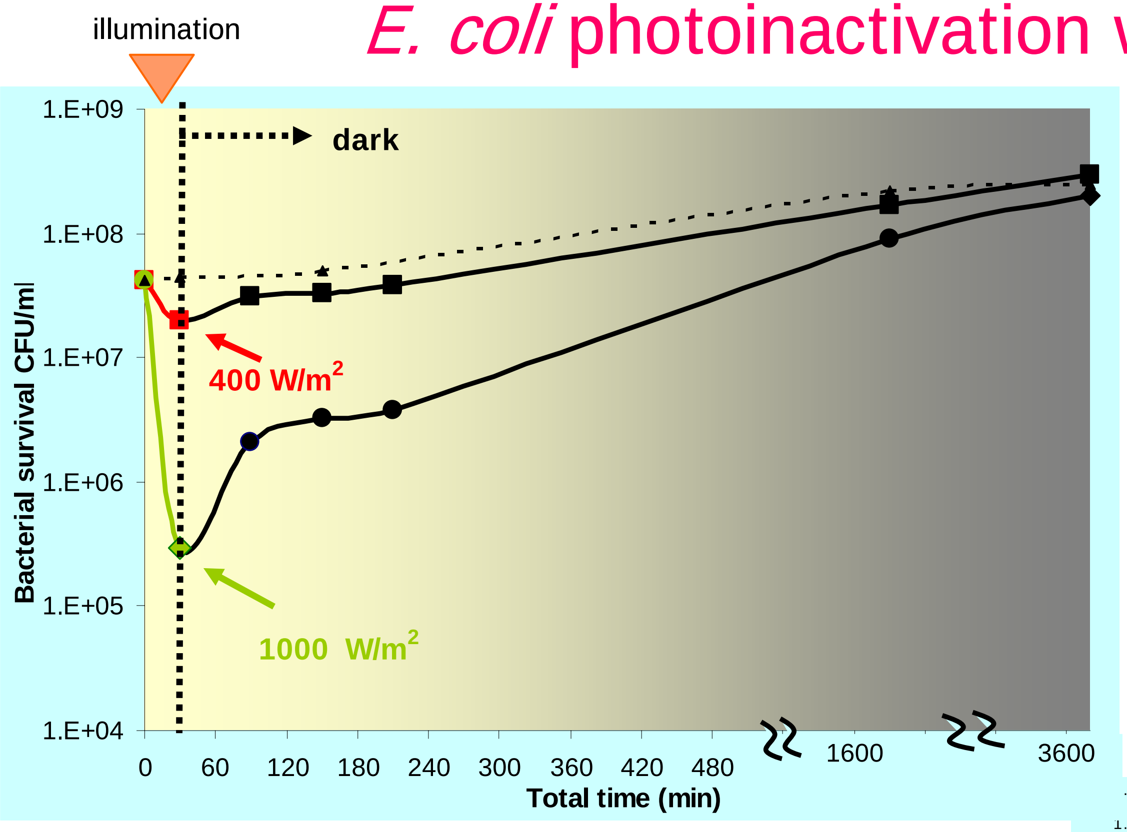
What is the duribility of the photodisinfection ?

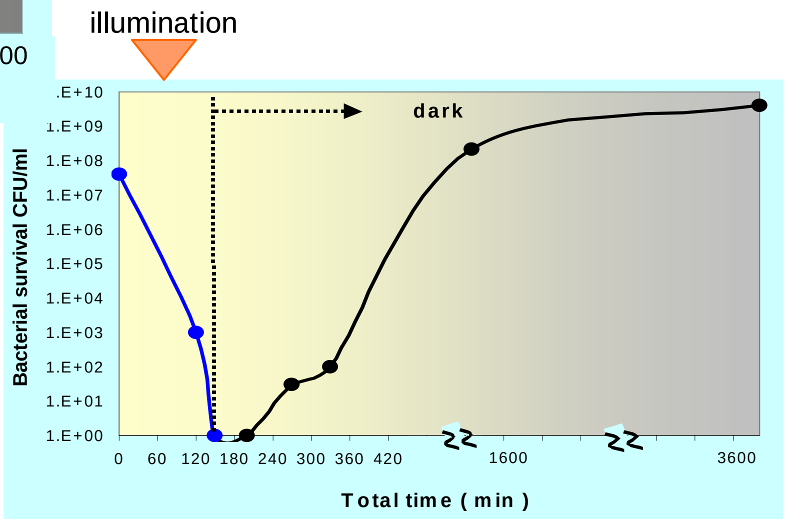


After 24 h in the dark, no bacteria were detected for photocatalytic system but not for the system without illumination

- What does it happens after stopping illumination before total lost of bacterial culturability?.

E. coli photoinactivation without TiO_2





✓ At 30 min of irradiation, the bacteria are not completely destroyed when illumination is stopped. Bacterial concentration increase in the dark.

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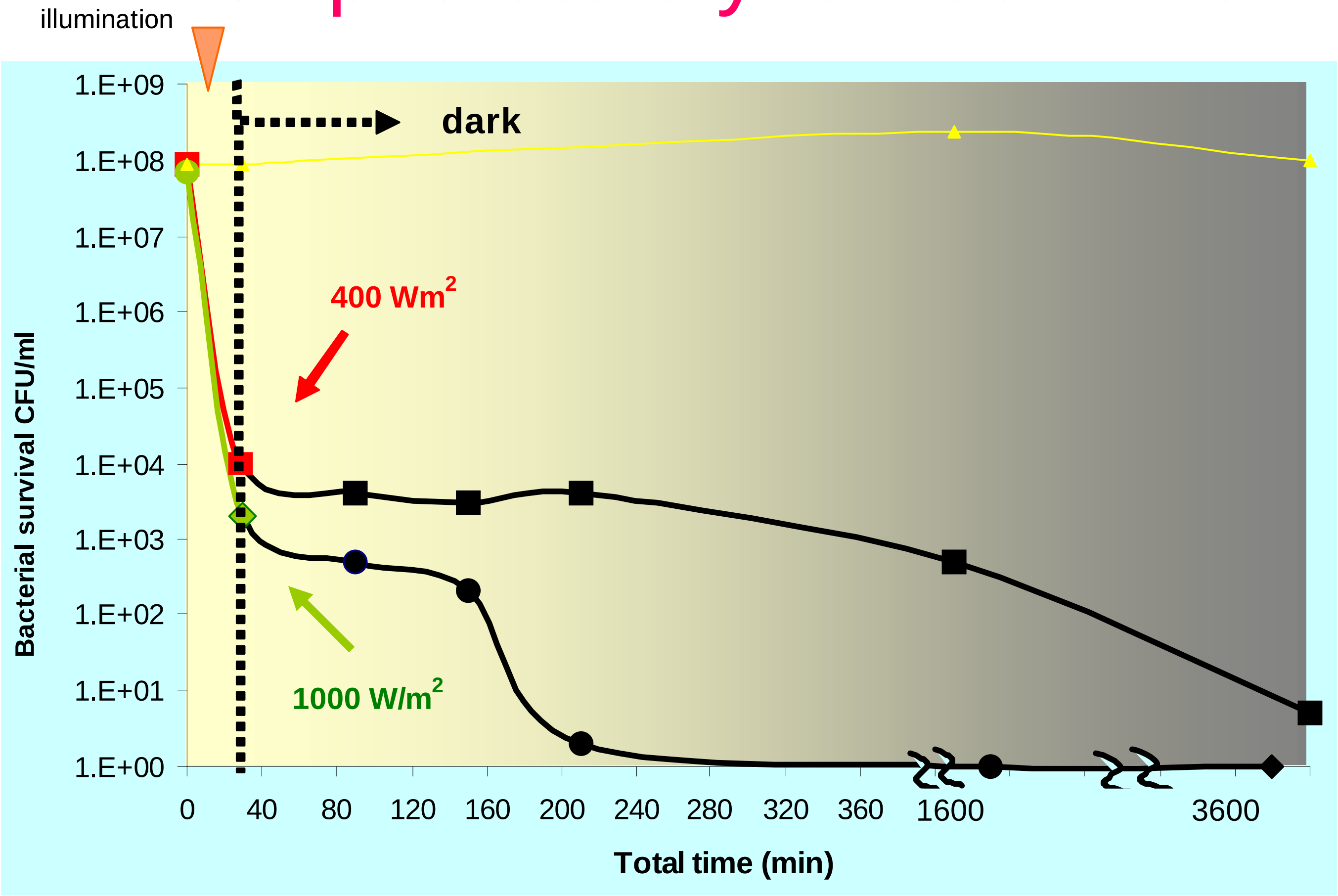
E. coli photocatalytic inactivation

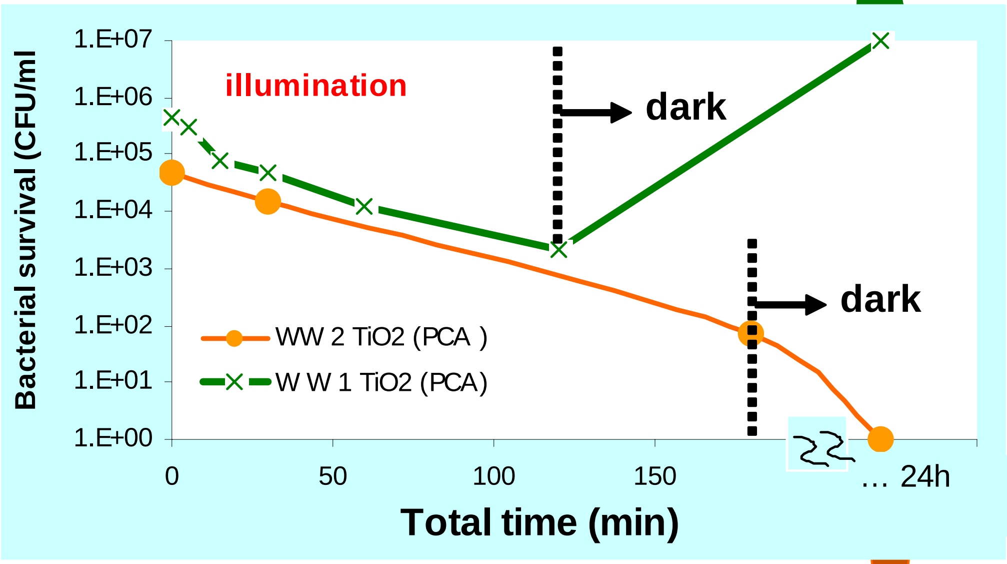


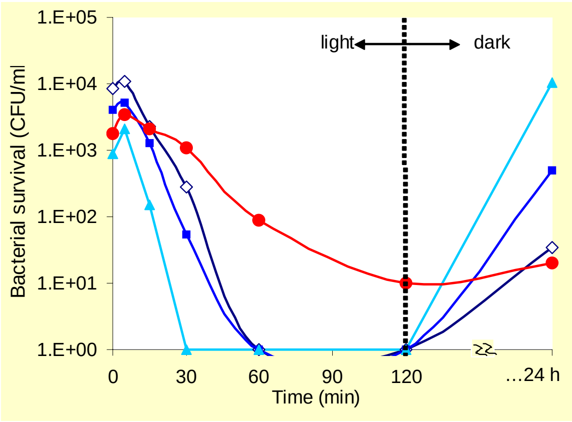
- After the irradiation in the presence of TiO_2, bacterial survival keeps decreasing
- A « residual disinfection effect » was observed in the dark
- An increase in light intensity, increases also the post irradiation effect in the dark

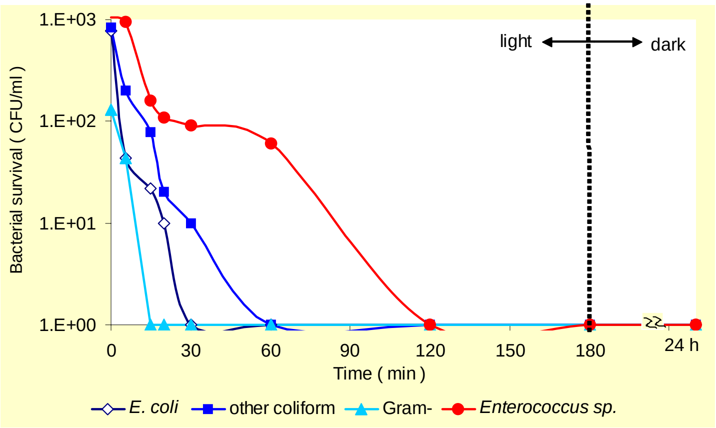
Rincón, A.G and Pulgarin C. *Appl. Catal. B: Environ.* 49 (2004), 99

Effect of the photocatalytic process on a real wastewater containing microbial community

Vidy, Lausanne Switzerland







1 g/l TiO_2, 2 and 3 h of irradiation 1000 W/m^2

- ✓ 3 h of illumination was the time required to rise a bactericide effect
- ✓ No bacterial recovery was observed.
- ✓ EDT24: efficient disinfection time

Rincón, A.G and Pulgarin C. *Appl. Catal. B: Environ.* 49 (2004), 99

What is the sensitivity of different type of bacteria to the photocatalytic treatment?

- Reactor: Suntest
- Illumination time: 3h
- TiO_2 concentration: 1g/l
- Initial concentration of bacteria and total inactivation time for each groupe of bacteria
  - *E. coli*: $9X10^2$ CFU/ml, 30 min
  - Colifoms: $4X10^3$ CFU/ml, 1h
  - *Enteroccosus*: $2X10^3$ CFU/ml, 2h

Wastewater-Switzerland

- Reactor: Suntest
- Illumination time: 3h
- TiO_2 concentration: 0.5 g/l
- Initial concentration of bacteria and total inactivation time for each groupe of bacteria
  - *E. coli*: $8X10^2$ CFU/ml, 2h
  - *Shiguella*: $4X10^2$ CFU/ml, 1.5h
  - *Salmonella*: $6X10^1$ CFU/ml, 1h

Wastewater-Colombia

Biological aspects

- ✓ A "Residual disinfecting effect" is observed after stopping of illumination
- ✓ The sensitivity of different groups of bacteria to the photocatalytic treatment depends on the type of bacteria.
- ✓ *E.coli*, is the more sensitive to the photocatalytic process in all the studied conditions.

- Scaling up is possible?

Field scale experiments for drinking water production

Water from the Leman Lake contaminated with *E. coli* K 12 was exposed to sunlight in different seasons.

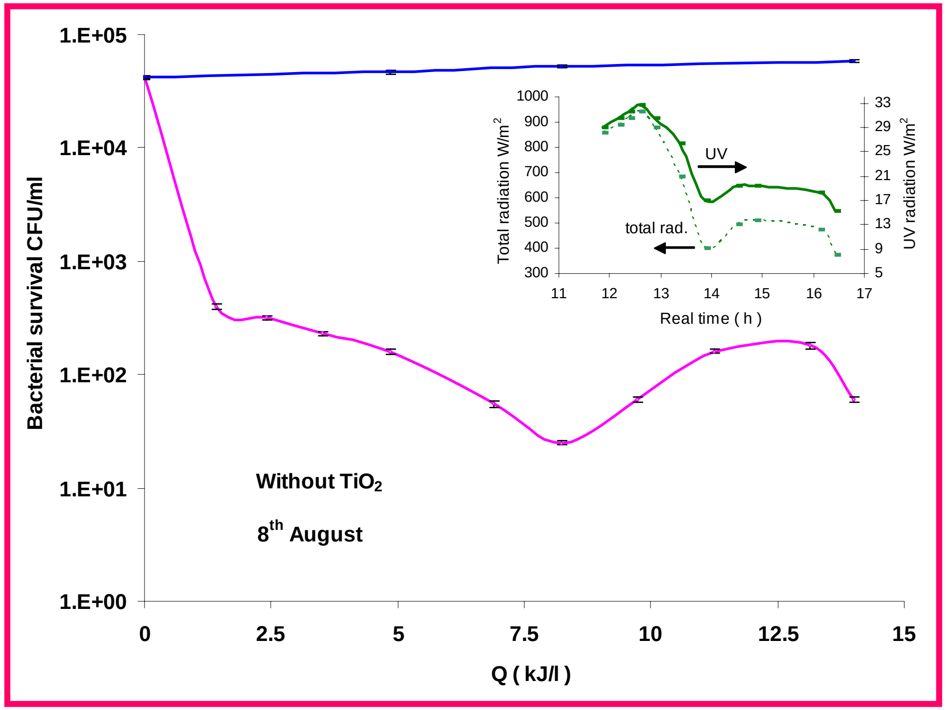
- Effect of the volume of phototreated water
- Water disinfection in the presence and absence of TiO_2
- Post irradiation events
- Cost estimation of the water disinfection by photocatalysis

Photocatalytic treatment as a final treatment for drinking water production

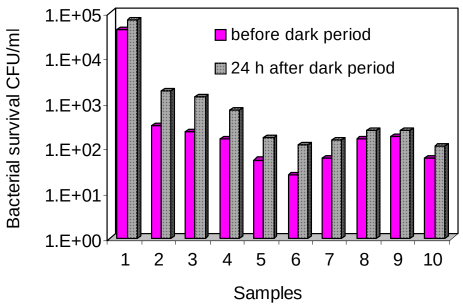
Compound parabolic collector (CPC) placed at the EPFL.

- Photocatalytic disinfection via TiO_2
- Water from Leman Lake contaminated with *E. coli* was exposed to sunlight

Water disinfection in the absence of TiO_2 - post irradiation effects



❖ Bacterial concentration slightly re-increases:
- some bacteria recover their culturability;
- decrease of UV intensity and modification of the visible spectral composition of sunlight
- there is possibly a replication of the remaining culturable cells.



❖ Total disinfection was not reached during illumination and bacterial recovery was observed even before the illumination stopped as well as in the post irradiation period EDT_{24} was not reached.

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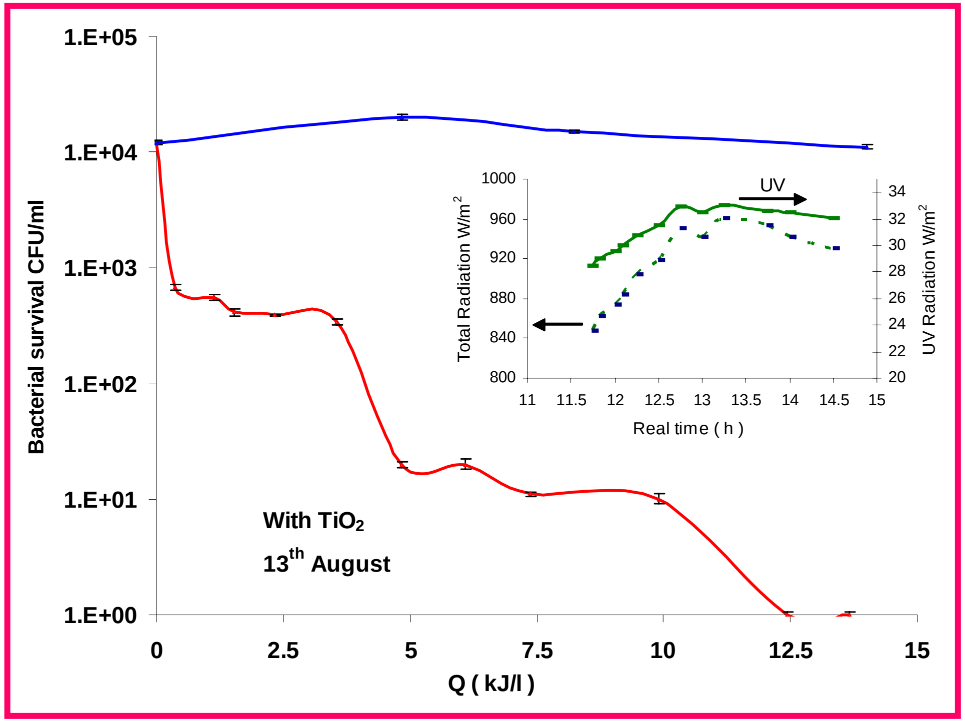
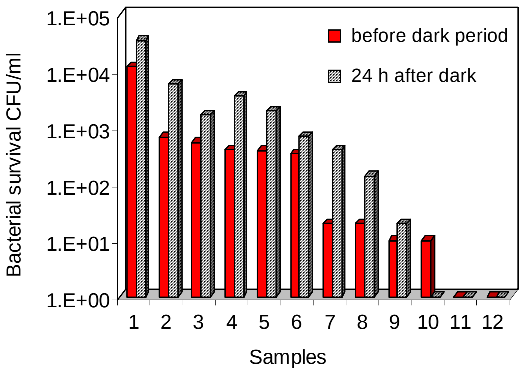
Photocatalytic treatment as a final treatment for drinking water production





- Active *E. coli* concentration decreases as the accumulated energy increases and arrives to non-detectable level (<1 CFU/ml) when 12.5 kJ/l are applied

- No bacterial recovery was observed after 24 h after stopping of treatment, while regrowth was observed if stopped in middle of exposure EDT_{24} was reached.

Solar UV dose

dose = I X t_r

I: average intensity, W/m^2
t_r: residence time, h

Exp.3 began in the late afternoon when visible light has different spectral characteristics. Solar UV intensity was lower (18.9 W/m^2) than that of the exp. 5 (37.2 W/m^2).

Experiment. Date	TiO_2 (g/l)	V_{TOT} (l)	Bacterial load (CFU/ml)	UV average (W/m^2)	% bacterial inactivation	UV dose (Wh/m^2)	Period of treatment (h:min)
1. January 17, 2003[a]	0.1	70	1200000	7.20	99.99167	9.87	12:00-16:00
2. January 20, 2003[a]	0.1	70	807000	4.92	99.99876	6.75	12:30-16:30
3. August 19, 2003[a]	0.1	70	295000	18.98	**99.8986**	19.52	15:30-18:30
4. September 4, 2003	0.1	70	514000	33.83	99.9961	23.20	13:05-15:05
5. August 21, 2003	0.1	70	414000	37.28	**99.9976**	17.04	12:20-13:40
6. August 15, 2002[a]	--	70	220000	36.24	99.9909	37.28	11:30-14:30
7. May 16, 2002[a]	--	70	400000	36.77	99.9405	37.82	12:20-15:20
8. September 20, 2003[a]	--	70	365000	23.92	99.4247	43.74	10:50-16:10

dose necessary to inactivate approximately 99.9900 % of *E. coli* using a CPC reactor in Lausanne Switzerland.

[a] undetectable value (< 1 CFU/ml) was not reached during irradiation

The UV solar dose necessary to reach a target disinfection level is not a good indicator to predict the impact of the solar photocatalytic process on bacteria.

Rincón, A.G and Pulgarin C. .*Solar Energy*, 77 (2004), 635-648

General conclusions

❖ A systematic study on the effect of physicochemical, biological and chemical parameters on photocatalytic disinfection.

❖ An intensive work with a solar reactor (70 l) demonstrated the feasibility, of the scaling up of the system.

❖ The definition of efficient disinfection time (EDT_x) as a parameter of control for photocatalytic disinfection. The EDT_x depends on the mentioned photochemical and biological aspects. EDT_x should be determined for each specific condition, Thereafter the obtained EDT value can be raised of a certain percentage in order to introduce a range of security.

Thanks for your attention