Wastewater regeneration using solar technologies on a demonstration scale

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Joint Centre University of Almería-Plataforma Solar de Almería

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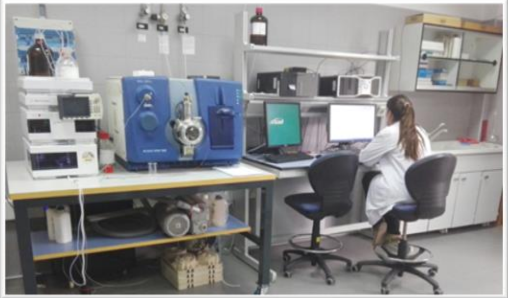

- Physicists
- Chemists
- Biologists
- Industrial engineers
- Chemical engineers

- ✓ **Water treatment (desalination, decontamination, microalgae)**
- ✓ **Control, modelling and optimization of solar processes**
- ✓ **Medium and high temperature solar thermal energy**
- ✓ **Integration of thermal and photovoltaic energy in buildings**

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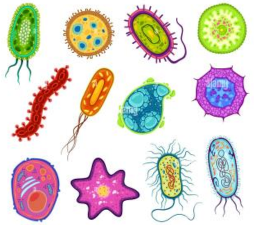
CHALLENGES TOWARDS THE USE OF REGENERATED WATER IN AGRICULTURE

EU Regulation 2020/741

MORE RESTRICTIVE DISINFECTION TARGETS

PERSISTENT INDICATOR MICROORGANISMS



GREATER RESTRICTIONS ON DBO_5, TOTAL SUSPENDED SOLIDS AND TURBIDITY

MICROCONTAMINANTS STIPULATED IN THE RISK MANAGEMENT PLAN

[1]EU 2020/741 of the European Parliament and of the Council of 15 May 2020 on minimum requirements for water reuse (L 177/32).

EU regulation: water reuse (EU 2020/741)

Table 2 – Reclaimed water quality requirements for agricultural irrigation

Reclaimed water quality class	Indicative technology target	Quality requirements				
		E. coli (number/100 ml)	BOD_5* (mg/l)	TSS** (mg/l)	Turbidity (NTU)	Other
A	Secondary treatment, filtration, and disinfection	≤ 10	≤ 10	≤ 10	≤ 5	*Legionella* spp.: < 1 000 cfu/l where there is a risk of aerosolisation Intestinal nematodes (helminth eggs): ≤ 1 egg/l for irrigation of pastures or forage
B	Secondary treatment, and disinfection	≤ 100	In accordance with Directive 91/271/EEC (Annex I, Table 1)	In accordance with Directive 91/271/EEC (Annex I, Table 1)	-	
C	Secondary treatment, and disinfection	≤ 1 000			-	
D	Secondary treatment, and disinfection	≤ 10 000			-	

*BOD_5: Biochemical oxygen demand

**TSS : Total suspended solids

EU regulation: water reuse (EU 2020/741)

- The concept of micro-pollutants is introduced in this legislation, although specific limits have not yet been established.

Risk management plan

«Identify any additional water quality requirements necessary to ensure sufficient protection of the environment and of human and animal health»

New proposal concerning urban wastewater treatment - Directive COM(2022) 541

EUROPEAN COMMISSION

Brussels, 26.10.2022
COM(2022) 541 final

ANNEXES

to the Proposal for a

IRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

concerning urban wastewater treatment (recast)

Energy neutrality

Low energy demanding solutions and technologies, energy recovery, ...

Table 3: Requirements for quaternary treatment of discharges from urban wastewater treatment plants referred to in Article 8(1) and (3).

Indicators	Minimum percentage of removal
Substances that can pollute water even at low concentrations	80%

Note 1: The concentration of the organic substances referre[...] (a) and (b) shall be measured.

(a) Category 1 (substances that can be very easily treated):

(i) Amisulprid (CAS No 71675-85-9),

(ii) Carbamazepine (CAS No 298-46-4),

(iii) Citalopram (CAS No 59729-33-8),

(iv) Clarithromycin (CAS No 81103-11-9),

(v) Diclofenac (CAS No 15307-86-5),

(vi)— Hydrochlorothiazide (CAS No 58-93-5),

(vii) Metoprolol (CAS No 37350-58-6),

(viii)— Venlafaxine (CAS No 93413-69-5);

(b) Category 2 (substances that can be easily disposed of):

(i) Benzotriazole (CAS No 95-14-7),

(ii) Candesartan (CAS No 139481-59-7),

(iii) Irbesartan (CAS No 138402-11-6),

(iv) mixture of 4-Methylbenzotriazole (CAS No 29878-31-7) and 6-methyl-benzotriazole (CAS No 136-85-6).

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Advanced oxidation processes (AOPs)

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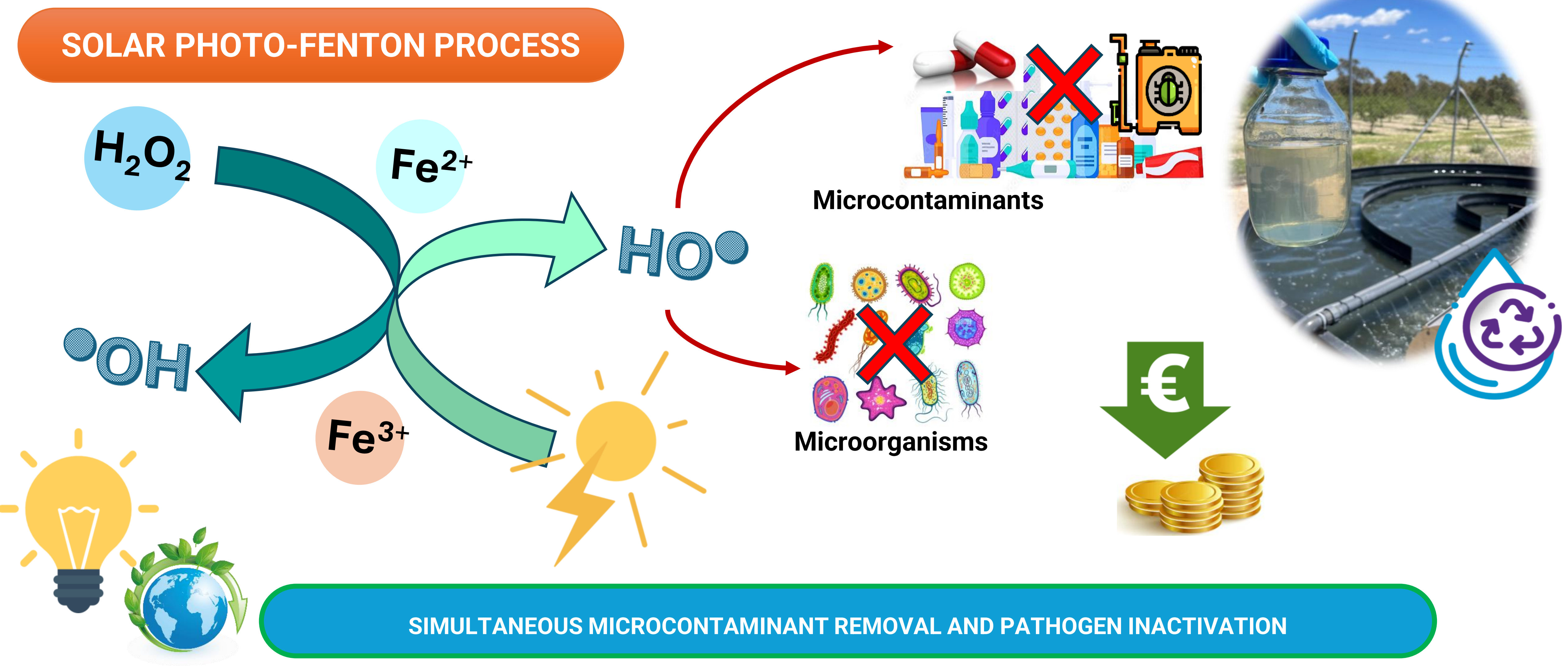

SIMULTANEOUS MICROCONTAMINANT REMOVAL AND PATHOGEN INACTIVATION

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https://ciesol.com/software/

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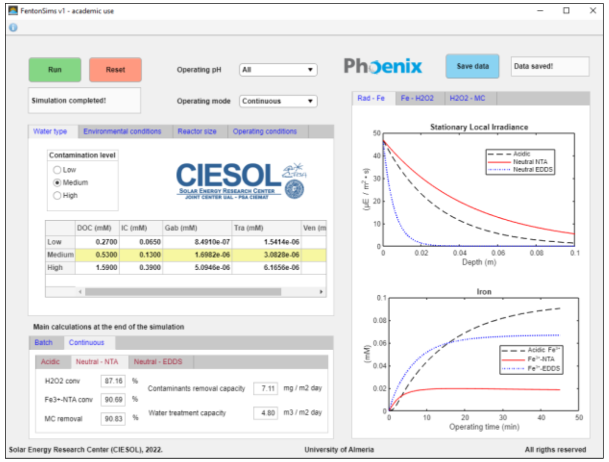

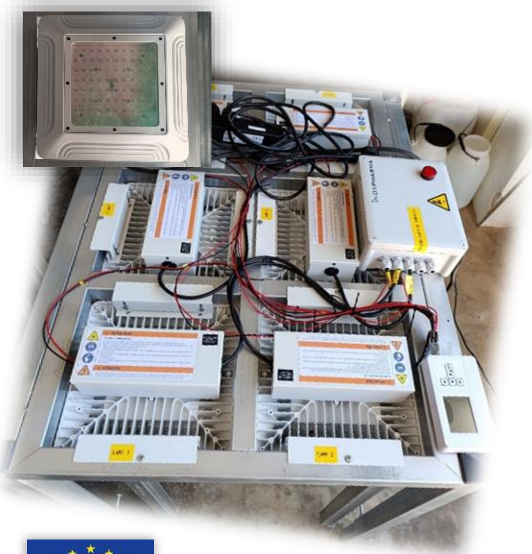

Life Phoenix

The solar photo-Fenton process & raceway pond reactors

State of the art

2014

Carra et al.,

- Excess of photons in tubular reactors

  Sci. Total Environ. 478:123-132

- Proposal for the use of RPR to treat WWTP secondary effluents

  J. Hazard. Mater. 279:322-329

2017

Arzate et al.,

- First continuous flow operation at pilot scale focused on CEC removal

  Chem. Eng. J. 316:1114-1121

2019

De la Obra et al.,

- First continuous flow operation at pilot scale focused on disinfection

  Appl. Catal. B-Environ. 247:115-123

Soriano-Molina et al.,

- Use of mechanistic model for RPR design

  Appl. Catal. B-Environ. 256:117801

2020

Sánchez Pérez et al.,

- Solar photo-Fenton cost estimation at pilot scale

  Sci. Total Environ. 736:139681

DEMONSTRATION SCALE

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Solar photo-Fenton treatment plant

El Bobar WWTP, Almería (Spain)

100-m^2 RPR

Liquid depth: 10 – 18 cm

Life
ulises

LIFE18 ENV/ES/000165)

aqualia
energylab
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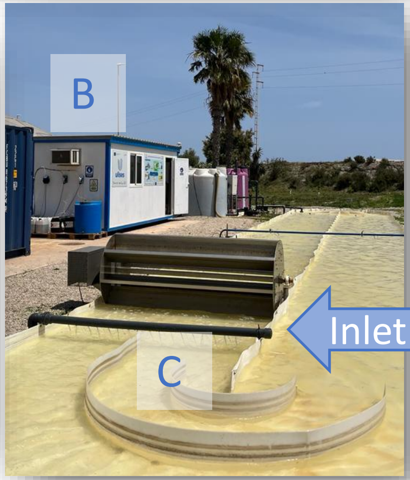
Solar photo-Fenton treatment plant



D Calcium carbonate filter

E Storage tank

A Conditioning tank

B Dosing pump

Gualda-Alonso et al., Applied Catalysis B: Environmental 319: 121795 (2022)

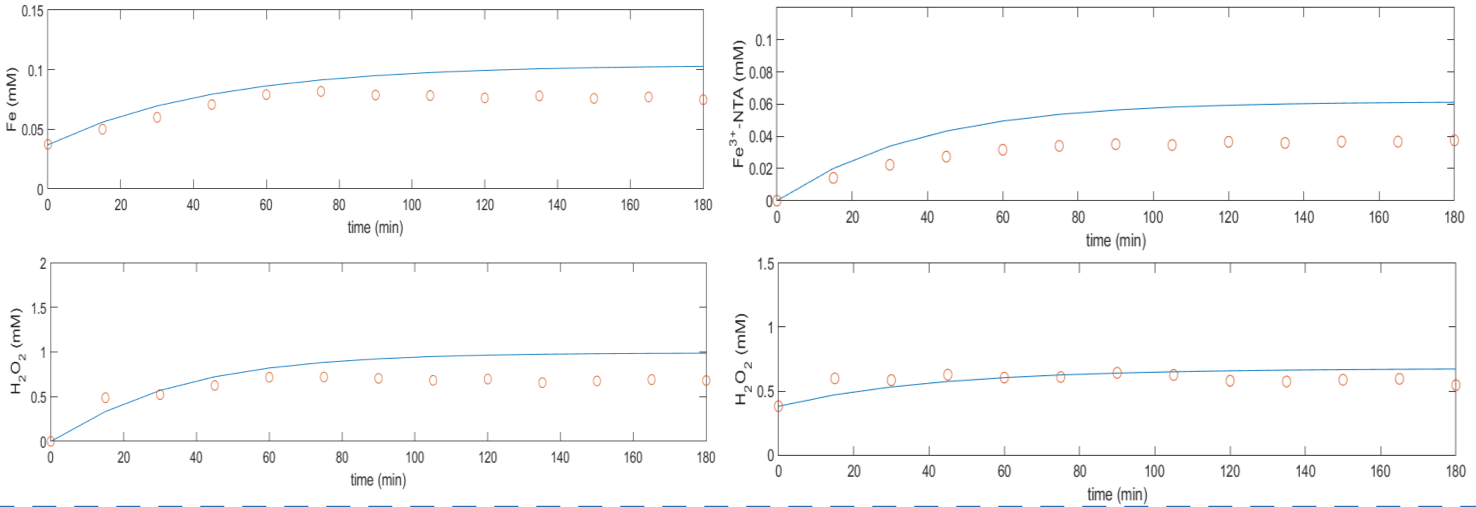
100 m^2-RPR operation in continuous flow mode

acidic pH VS neutral pH

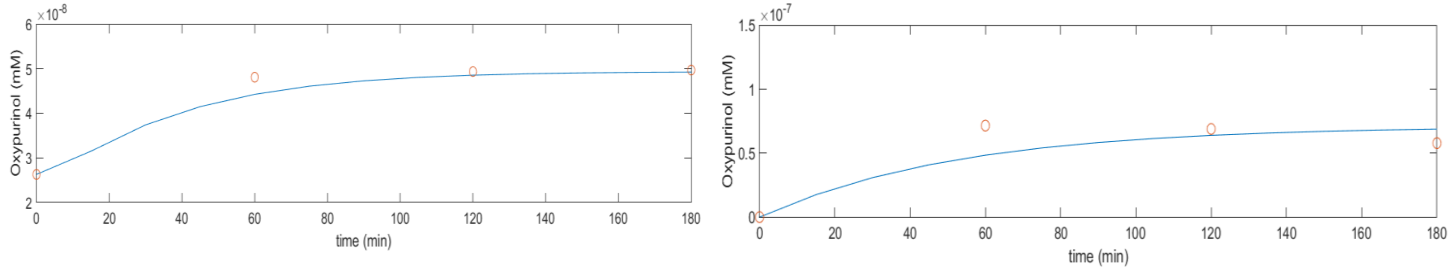
24 m^3/h — 18 cm liquid depth, 45 min HRT

10 cm liquid depth, 60 min HRT — 10 m^3/h

Reagent consumption



CEC removal



Gualda-Alonso et al., Journal of Hazardous Materials 132101 (2023)

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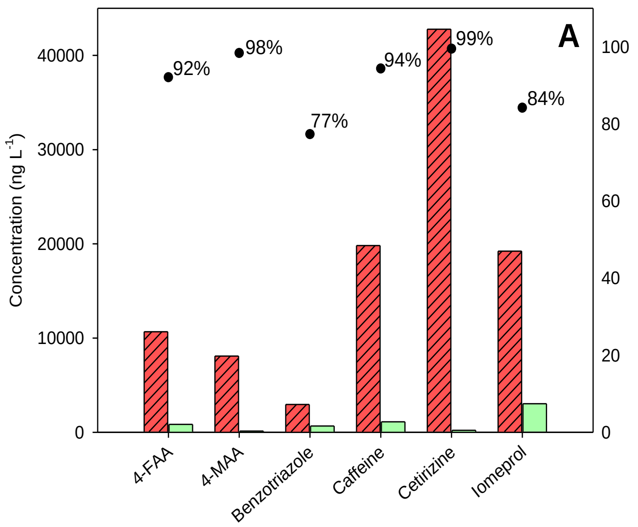
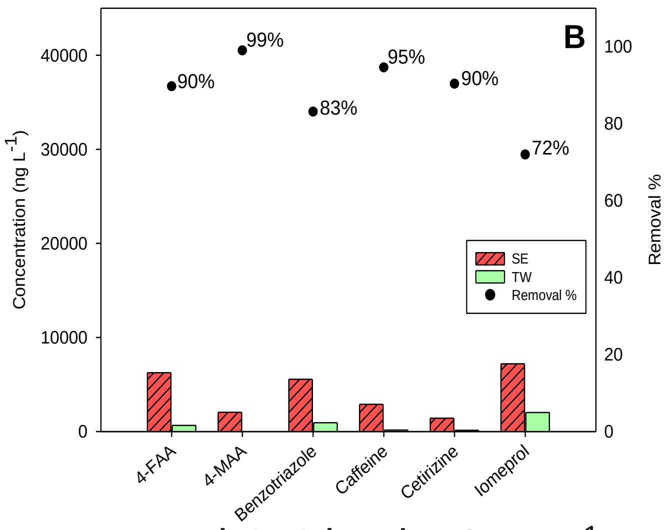
Continuous flow operation

10 cm (Winter)



Total CEC load: 183 µg L^{-1}

18 cm (Summer)



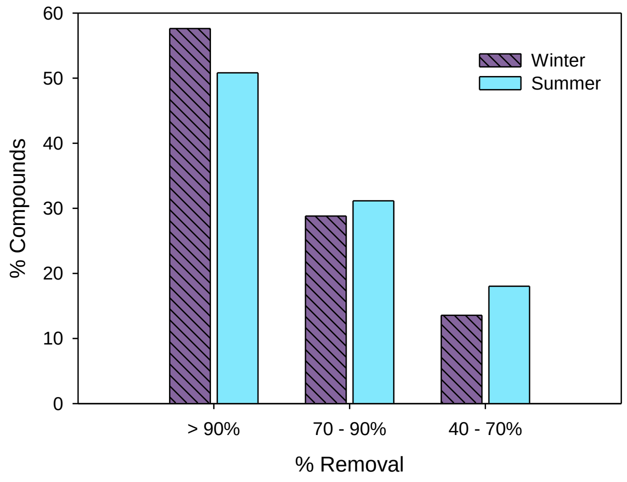
Total CEC load: 58 µg L^{-1}

88%

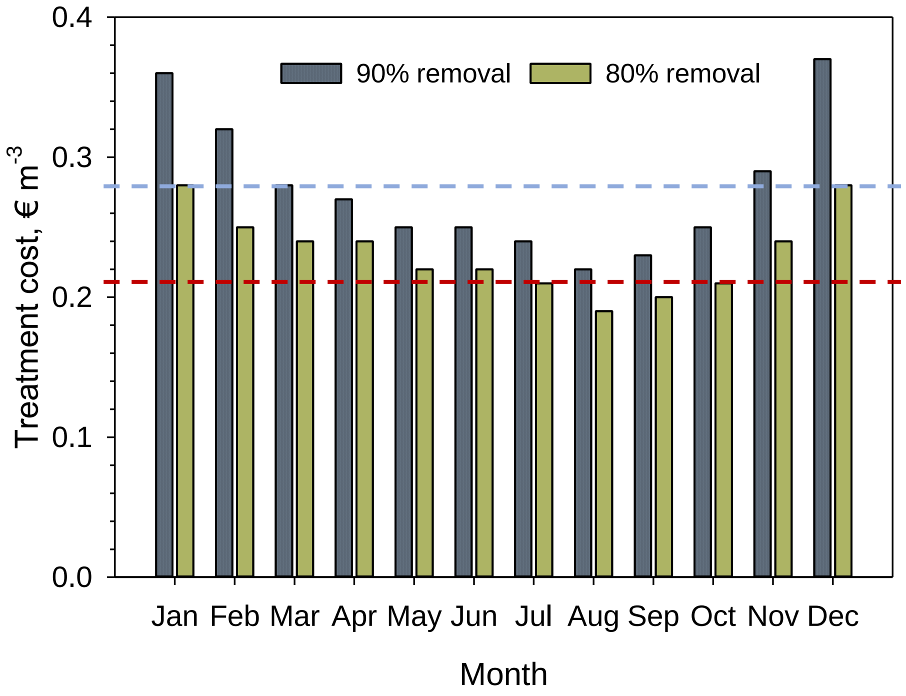
85%

Removal rate of the total CEC load

Up to 69 compounds out of the 115 investigated **were detected** in the raw secondary effluents, with some differences depending on the sampling period



Economic assessment



1 m^2 of RPR surface area can reclaim water to supply the daily-water requirements of 1,000 m^2 of greenhouse-grown vegetables.

The average annual treatment cost estimated at 0.23 € m^{-3} for 80% CEC removal and 0.28 € m^{-3} for a 90%.

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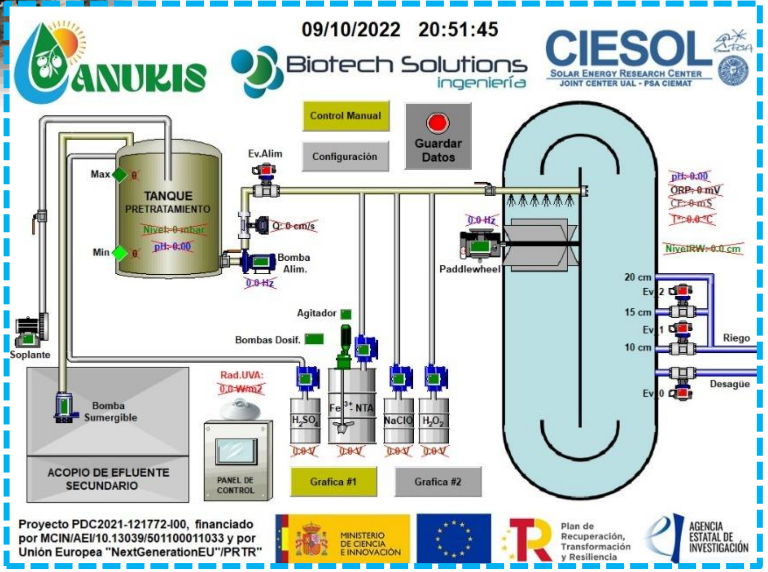
Solar photo-Fenton reactor in a rural area

Universidad de Almería

Uleila del Campo WWTP (Almería)

600 inhabitants



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AGENCIA ESTATAL DE INVESTIGACIÓN

Project PDC2021-121772-I00, funded by MCIN/AEI/10.13039/501100011033 and European Union “NextGenerationEU”/PRTR

Belachquer-El Attar et al., Journal of Hazardous Materials 132354 (2023)

Solar photo-Fenton reactor in a rural area

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Uleila del Campo WWTP
(Almería)

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PRETREATMENT TANK

CONTROL PANEL, REAGENT AND EFFLUENT PUMPS

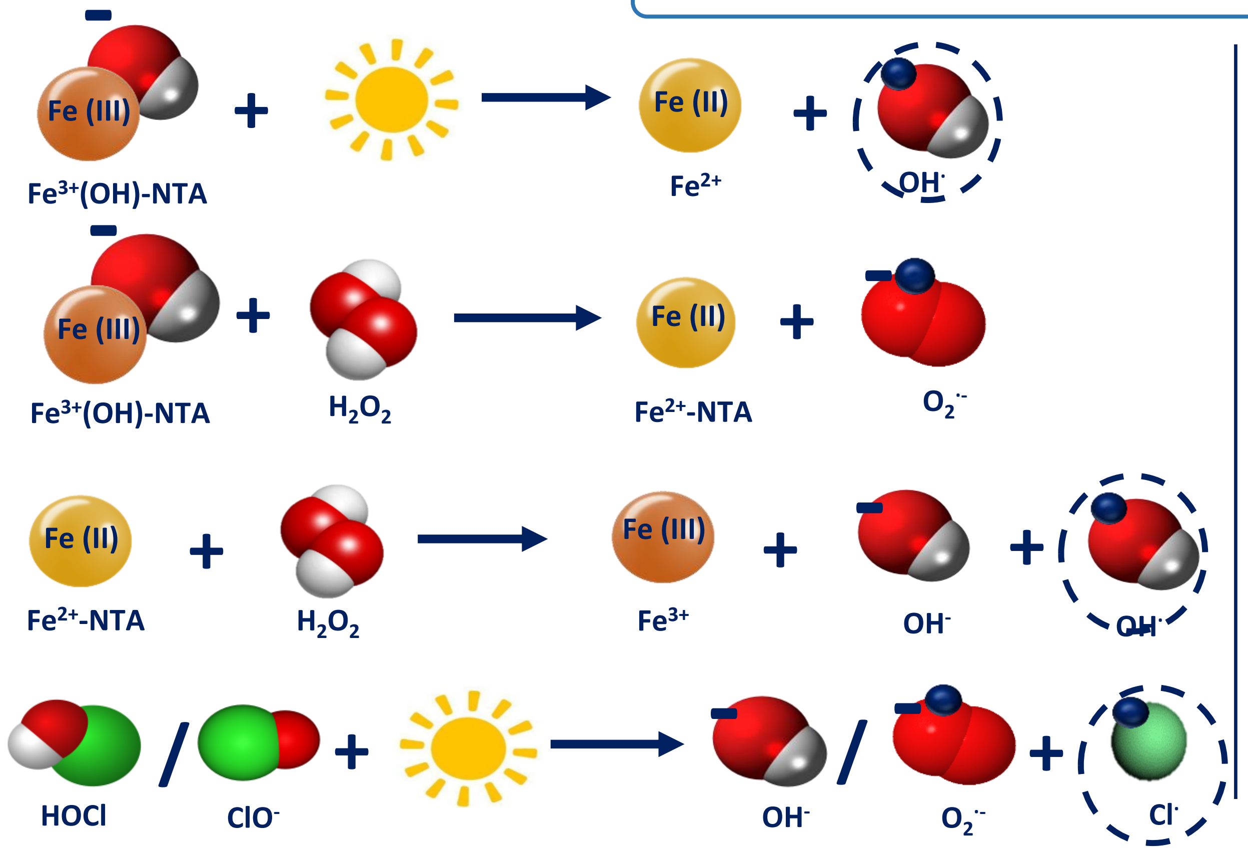
RACEWAY *REACTOR OF* 37 m^2 (Maximum volume: 7400 L)

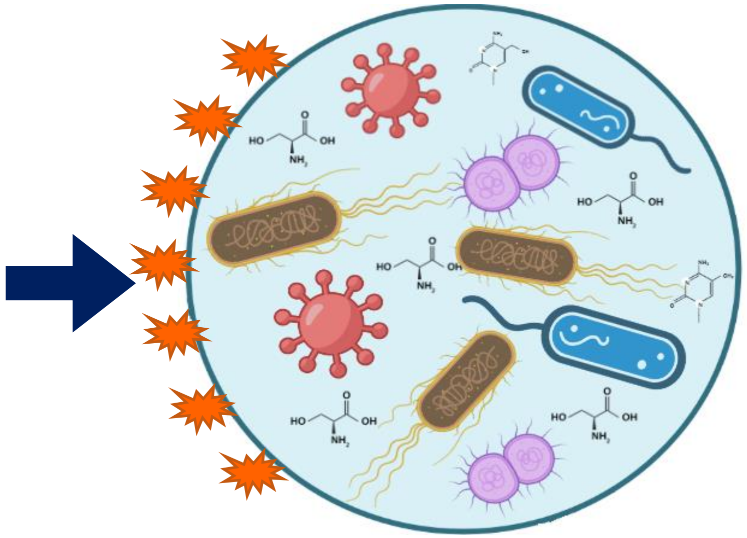
Liquid depth: 10 – 20 cm

ALTERNATIVE LOW-COST SUSTAINABLE TREATMENT

SOLAR CLOR-PHOTO-FENTON

Solar photo-Fenton + NaOCl





Belachqer-El Attar et al., Sci. Total Environ. 834: 155273 (2022)

SOLAR CLOR-PHOTO-FENTON

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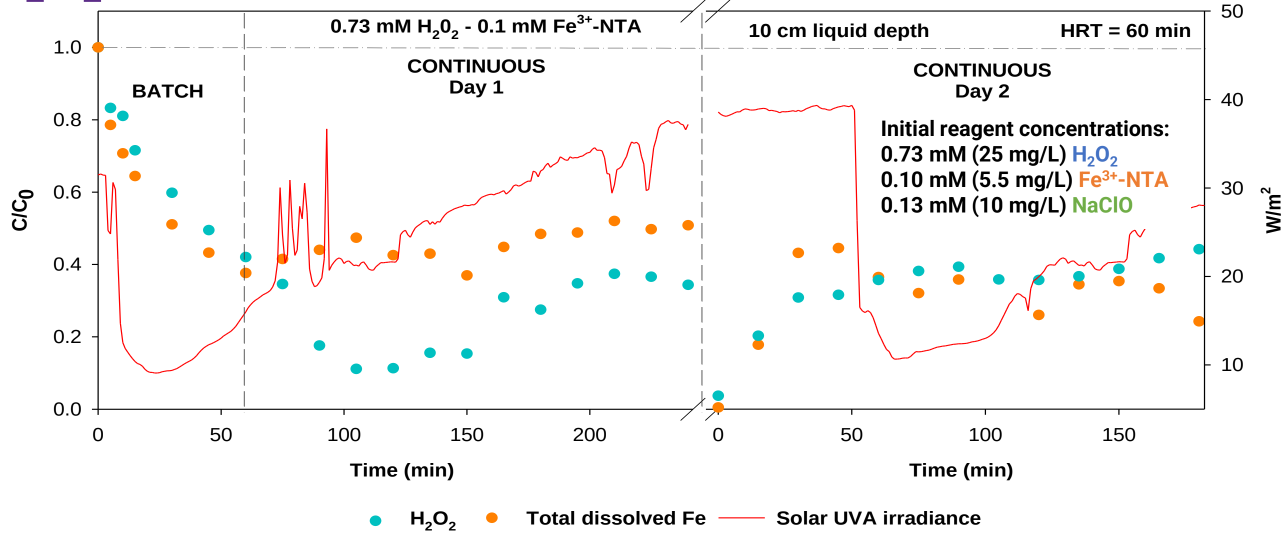
H_2O_2 consumption, total dissolved Fe and solar UVA irradiance

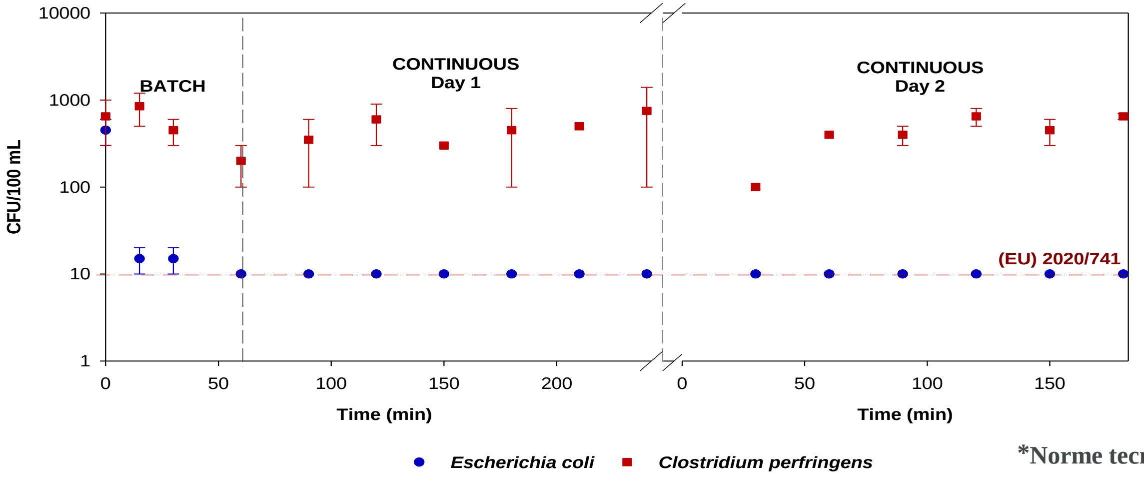


50-60% total microcontaminant removal

Trihalomethanes < 2 µg/L < Regulated limit (30 µg/L)*

Haloacetic acids < 8 µg/L < Regulated limit (60 µg/L)**

Disinfection



***Clostridium perfringens* ⟶ 3 LRV**

***Escherichia coli* ⟶ 6 LRV**

EU 2020/741 Class A (10 CFU/100mL)

*Norme tecniche per il riutilizzo delle acque reflue, 99, 1, 3 aprile 2006, n. 152.

**epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations#Byproducts

Shadow prices and environmental benefit

Shadow prices reflect the monetary value of environmental damage that would occur if effluents were discharged into the environment without removing microcontaminants

Table 1. Shadow prices values for various criteria (€/mg).

Criteria	Scenario	Iomeprol	Oxypurinole1	Gabapentin	Tramadol	Venlafaxine
Min D(x,u)	16	0.0032	0.0064	0.4933	0.0608	0.0010
Med D(x,u)*	8	0.0205	0.0410	6.8306	0.8153	0.0068
Max D(x,u)	3	0.0420	0.0840	13.7053	1.6369	0.0140

Note: Prices calculated based on values from the D function (x,u), with a market price assumed for reclaimed water (desired output) of 0.593€/ m^3.
(*) Scenario 8 is the closest to the mean values of the shadow prices obtained.

Shadow prices and environmental benefit

Table 2. Evaluation of economic and technical-environmental benefits of wastewater treatment.

Scenario	Production capacity (m^3/year)	Total income	Total costs	Economic benefit	Technical-environmental benefit	Overall benefits
		(€/year)				
1	21312	12638.02	10021.60	2616.41	265337.68	267954.10
2	31968	18957.02	15304.17	3652.86	452711.59	456364.45
3	42624	25276.03	22628.11	2647.92	659924.95	662572.86

Utilizing the regenerated water for irrigation generates a total economic benefit of €2,616.41/year, in addition to an environmental benefit based on the monetization of positive externalities, valued at €265,337.68/year.

Environmental Benefits

>>

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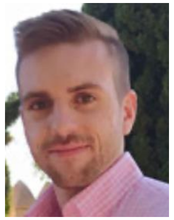
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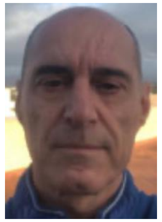
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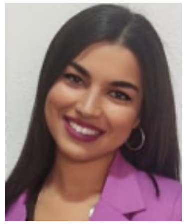
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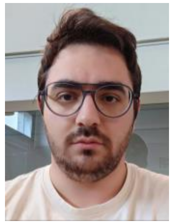
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ulises

Upgrading Wastewater Treatment Plants by Low Cost Innovative Technologies for Energy Self-Sufficiency and Full Recycling. (LIFE ULISES)

Phoenix

Innovative Cost-effective Multibarrier Treatments for Reusing Water for Agricultural Irrigation (LIFE PHOENIX)

SFERA

Solar Facilities for the European Research Area

SFERA III Solar Facilities for the European Research Area

NAVIA

Regeneración de Agua Residual Urbana Mediante Nuevos Materiales y Tecnologías Solares Avanzadas Operadas en Continuo: análisis de nuevos indicadores de calidad del tratamiento (NAVIA)

ANUKIS

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Demostración de Reactores Continuos para Foto-Fenton Solar Destinados a la Regeneración de Efluentes Secundarios de EDAR (ANUKIS)

Regeneración de Aguas para Riego Mediante Energía Solar en Reactores de Bajo Coste Operados en Modo Continuo (AQUELOO)

Thank you!

Solar Energy Research Center (CIESOL)

Joint Center Universidad de Almería-Plataforma Solar de Almería
SPAIN

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