UNIVERSIDAD POLITECNICA DE VALENCIA

CAMPUS DE ALCOY

1ª Jornada Técnica sobre procesos de oxidación avanzada en el ciclo integral del agua

"Proceso foto-Fenton: Estrategias de aplicación en condiciones próximas a la neutralidad"

Catedra FACSA de innovación en el ciclo integral del agua

UNIVERSITAT JAUME•I

Castellón - 15 de enero de 2016

Grupo de Procesos de Oxidación Avanzada
Ana Mª Amat Payá

UNIVERSIDAD POLITECNICA DE VALENCIA
CAMPUS DE ALCOY

APPLICATION OF PHOTO-FENTON PROCESSES AT CIRCUMNEUTRAL pH

- INTRODUCTION PHOTO-FENTON
- FENTON –LIKE PROCESSS:
  - PROCESSES USING OTHER METALS AS PHOTOCATALYSTS
  - PHOTO-FENTON PROCESSES AT CIRCUMNEUTRAL pH
    - Fe^0 ; supported Iron Fe (Films; Zeolites…)
    - Complex Formation (Oxalate, Citrate, EDTA, EDDS, Humic acids, Fulvic acids, SBO)
  - CONCLUSSIONS

FENTON PROCESSES

- 1894: Discovered by J. Fenton
- 1934 : Haber y Weiss the oxidant specie: ·OH

  Barb y cols. Propose mechanism (·OH)
- The 60th : Pollutants oxidation
- The 90th Application in wastewater treatment
- 2000s : Real wastewater at pilot plant
- 2010s : Photo-Fenton at Circumneutral pH

HOMOGENEOUS PHOTOCATALYSIS

FENTON PROCESS:

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH^- + HO\cdot$$

Reduction **Fe (III) to Fe (II).**

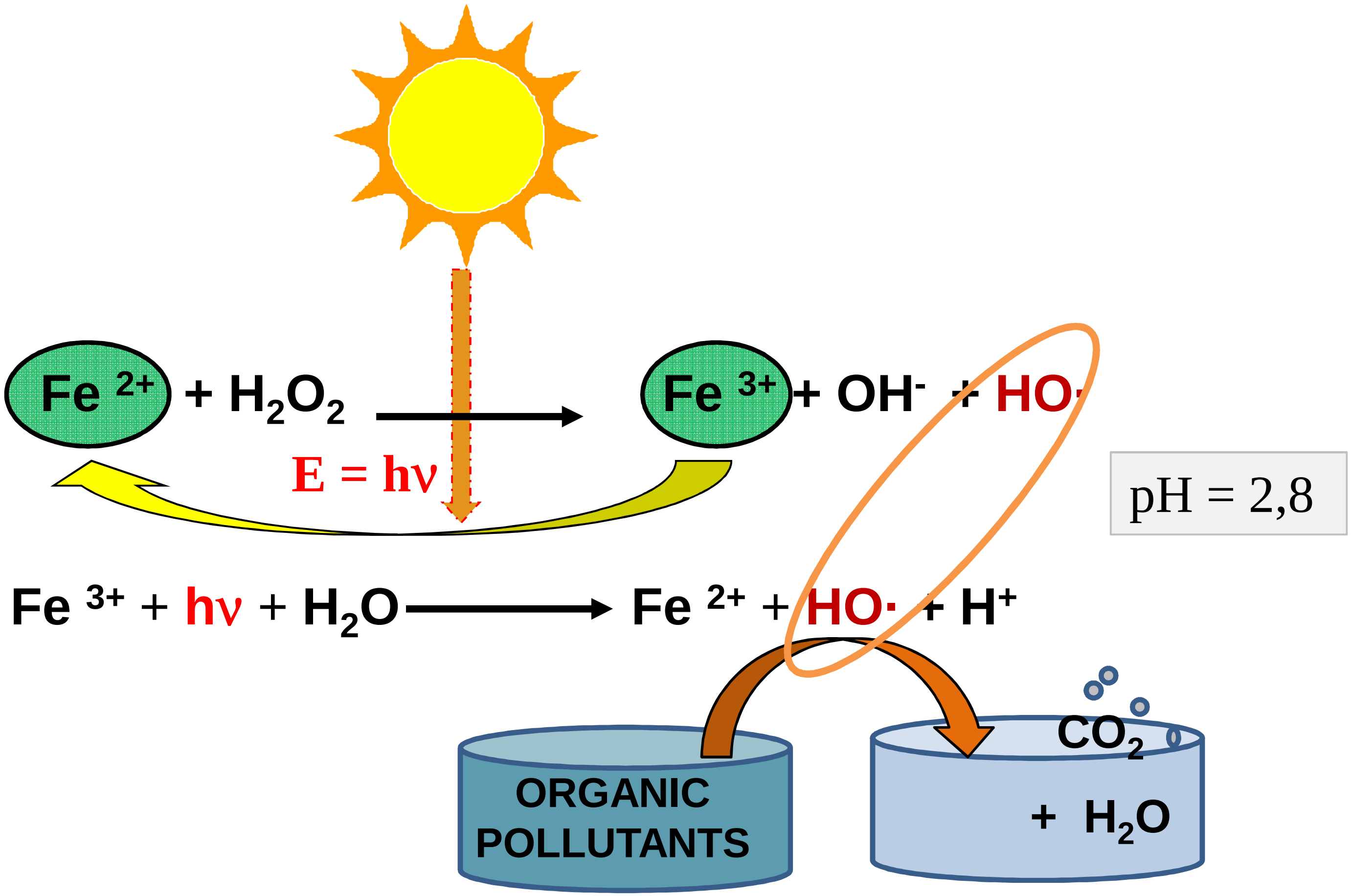
UV Light or **SOLAR Light**

PHOTO-FENTON:

$$Fe^{3+} + h\nu + H_2O \longrightarrow Fe^{2+} + HO\cdot + H^+$$

PHOTOCATALYTIC

SOLAR PHOTO-FENTON



FENTON MECHANISM

- $Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH^- + OH^\bullet$ $\quad k = 70 M^{-1}s^{-1}$

  The required amount of oxidizer to the degradation of the organic pollutants are generated: **($OH^\bullet$)** which is trapped by both Fe^{2+} and H_2O_2

- $Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + H^+ + HO_2^\bullet$ $\quad k = 1\text{-}2 \cdot 10^{-2}\ M^{-1}s^{-1}$

  Very slow reaction: the rate-limiting step in the degradation of the organic pollutants

- $HO^\bullet + H_2O_2 \rightarrow HO_2^\bullet + H_2O$ $\quad k = 1.7\text{-}4.5 \cdot 10^{7}\ M^{-1}s^{-1}$

- $Fe^{2+} + HO^\bullet \rightarrow Fe^{3+} + OH^-$ $\quad k = 3.2 \cdot 10^{8}\ M^{-1}s^{-1}$

$OH^\bullet$ generate Fe^{3+} that as the pH increases precipited as ferric oxyhydroxides

- $Fe^{3+} + HO_2^\bullet \rightarrow Fe^{3+} + O_2 + H^+$ $\quad k = 1.2 \cdot 10^{6}\ M^{-1}s^{-1}$
- $Fe^{2+} + HO_2^\bullet + H^+ \rightarrow Fe^{3+} + H_2O_2$ $\quad k = 1.2 \cdot 10^{6}\ M^{-1}s^{-1}$
- $HO_2^\bullet + HO_2^\bullet \rightarrow H_2O_2 + O_2$

Photo Fenton Reaction

- $Fe(OH)^{2+} + hv \rightarrow Fe^{2+} + {\cdot}OH$

Water Res. 44: 545-554

UNIVERSIDAD POLITECNICA DE VALENCIA
CAMPUS DE ALCOY

FENTON REACTIONS

Reacción	k ($M^{-1}s^{-1}$)	Referencia	
$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH^- + {}^{\bullet}OH$	76	Wailing (1975)	(1.1)
$Fe^{2+} + H_2O_2 \rightarrow Fe^{2+} + H^+ + {}^{\bullet}OOH$	0,01	Wailing (1975)	(1.2)
$Fe^{2+} + {}^{\bullet}OH \rightarrow Fe^{3+} + OH^-$	$3,2 \times 10^8$	Stuglik yZagorski (1981); Buxton *et al.* (1988)	(1.3)
$OH + H_2O_2 \rightarrow {}^{\bullet}OOH + H_2O$	$2,7 \times 10^7$	Buxton *et al.* (1988);Christensen *et al.* (1982)	(1.4)
${}^{\bullet}OOH \rightarrow O_2^{\bullet -} + H^+$	$1,58 \times 10^5\ s^{-1}$	Bielski *et al.* (1985)	(1.5)
$O_2^{\bullet -} + H^+ \rightarrow {}^{\bullet}OOH$	$1,0 \times 10^{10}$	Bielski *et al.* (1985)	(1.6)
$Fe^{2+} + {}^{\bullet}OOH \xrightarrow{+H^+} Fe^{3+} + H_2O_2$	$1,2 \times 10^6$	Jayson *et al.* (1969); Rush y Bielski (1985)	(1.7)
$Fe^{3+} + {}^{\bullet}OOH \rightarrow Fe^{2+} + H^+ + O_2$	$3,1 \times 10^5$	Rush y Bielski (1985)	(1.8)
${}^{\bullet}OH + {}^{\bullet}OOH \rightarrow H_2O + O_2$	$1,0 \times 10^{10}$	Sehested *et al.* (1969)	(1.9)
${}^{\bullet}OH + {}^{\bullet}OH \rightarrow H_2O_2$	$4,29 \times 10^9$	Sehested *et al.* (1969)	(1.10)
${}^{\bullet}OOH + {}^{\bullet}OOH \rightarrow H_2O_2 + O_2$	$8,23 \times 10^5$	Bielski *et al.* (1985)	(1.11)
$Fe^{3+} + O_2^{\bullet -} \rightarrow Fe^{2+} + O_2$	$5,0 \times 10^7$	Rothschild y Allen (1958)	(1.12)
$Fe^{2+} + O_2^{\bullet -} \xrightarrow{+H^+} Fe^{3+} + H_2O_2$	$1,0 \times 10^7$	Rush y Bielski (1985)	(1.13)
${}^{\bullet}OH + O_2^{\bullet -} \rightarrow O_2 + OH^-$	$1,0 \times 10^{10}$	Sehested *et al.* (1969)	(1.14)
${}^{\bullet}OOH + O_2^{\bullet -} \xrightarrow{+H^+} H_2O_2 + O_2$	$9,7 \times 10^7$	Bielski *et al.* (1985)	(1.15)
$RH + {}^{\bullet}OH \rightarrow R^{\bullet} + H_2O$		Beltrán de Heredia *et al.* (2001)	(1.16)
$R^{\bullet} + Fe^{2+} \xrightarrow{H^+} RH + Fe^{3+}$		Beltrán de Heredia *et al.* (2001)	(1.17)
$R^{\bullet} + R^{\bullet} \rightarrow R - R$		Beltrán de Heredia *et al.* (2001)	(1.18)
$R^{\bullet} + Fe^{3+} \rightarrow R^+ + Fe^{2+}$		Beltrán de Heredia *et al.* (2001)	(1.19)

FENTON MECHANISM

REACTION MECHANISM OF OH• WITH ORGANICS COMPOUNDS

A) Hydrogen abstraction C-H, N-H, O-H

- $RH + HO^{\bullet} \rightarrow H_2O + R^{\bullet}$

B) Addition to the double bonds

- $HO^{\bullet} + C{=}C \rightarrow HO\text{-}C\text{-}C^{\bullet}$

C) Electronic transfer

- $HO^{\bullet} + RX \rightarrow OH^{-} + RX^{\bullet -}$

D) Addition to aromatic rings

E) Other….

Organic radicals generated ($R^{\bullet}$) react with H_2O_2 or O_2 generating hydroxil radicals ($OH^{\bullet}$) or peroxide radicals ($ROO^{\bullet}$)

$R^{\bullet} + H_2O_2 \rightarrow ROH + OH^{\bullet}$

$R^{\bullet} + O_2 \rightarrow ROO^{\bullet}$

These reactions can produce mineralización of organic compounds to CO_2, H_2O and inorganic iones

PHOTO-FENTON TREATMENT

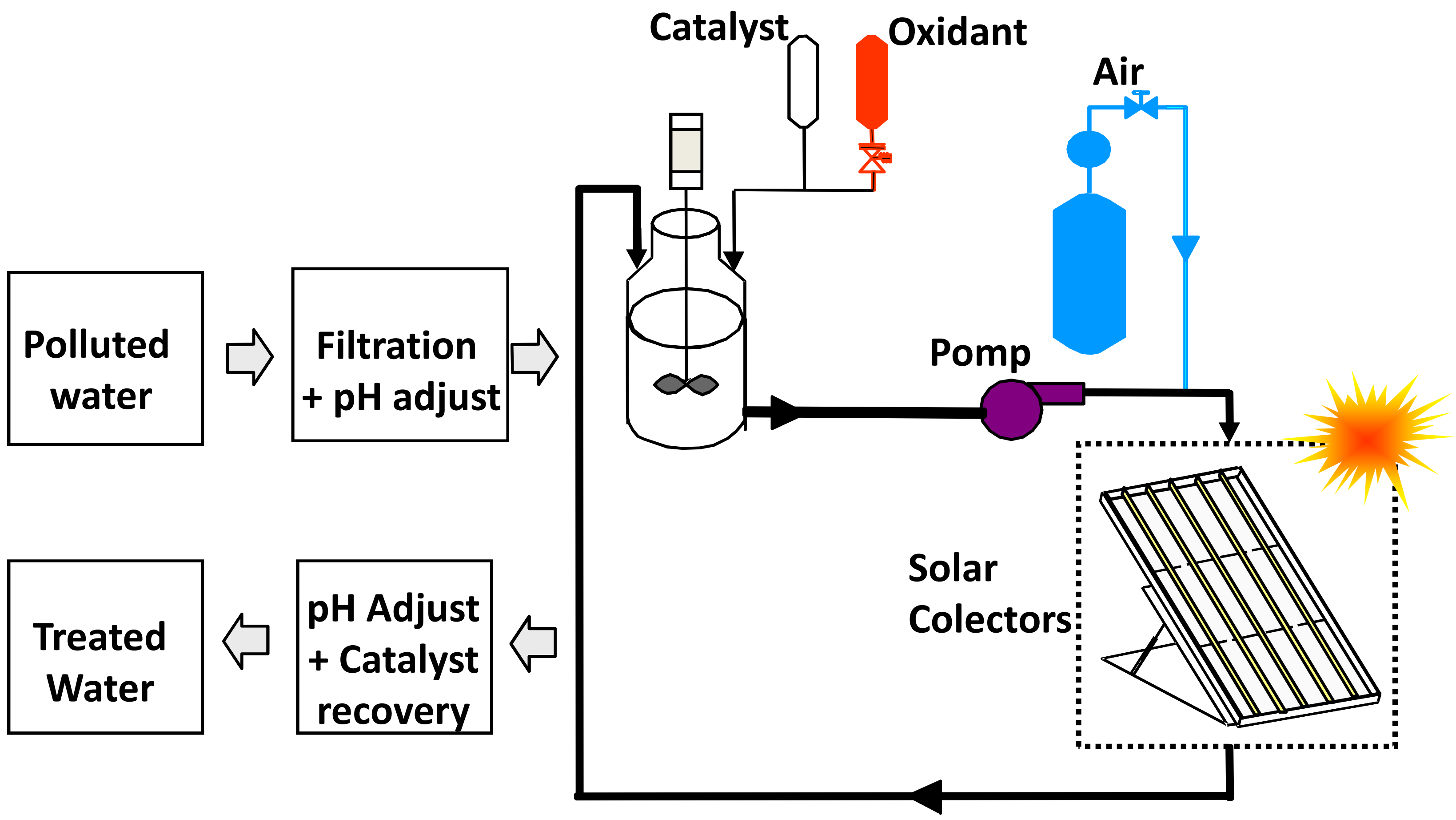
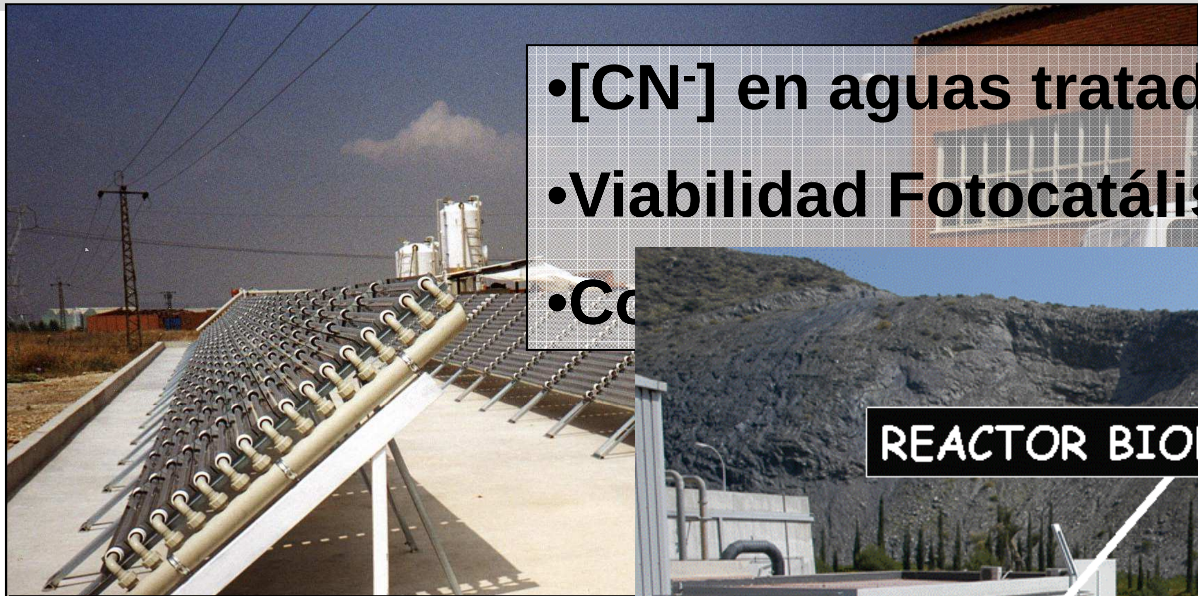


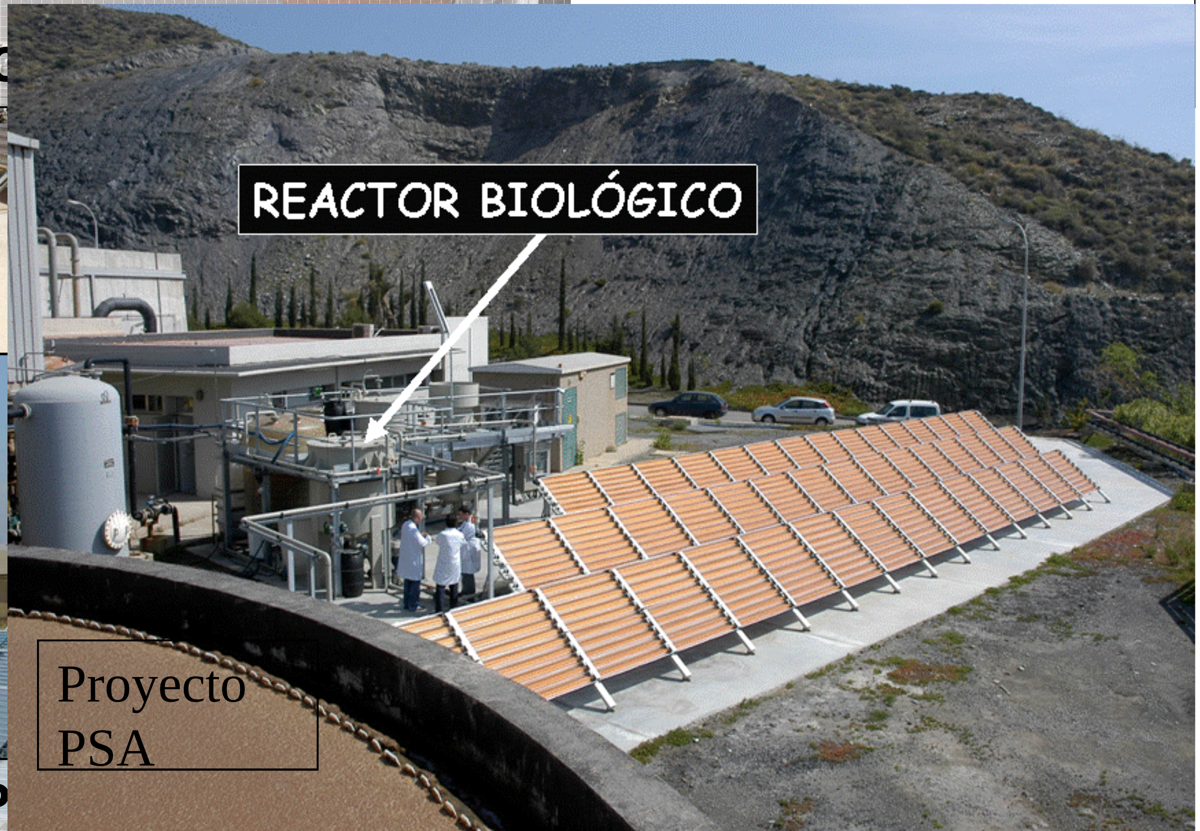
PHOTO-FENTON TREATMENT



•[CN^-] en aguas tratadas = de 0’2 a 20 g/l

•Viabilidad Fotocatálisis: [CN^-] < 8 g/l

•Co



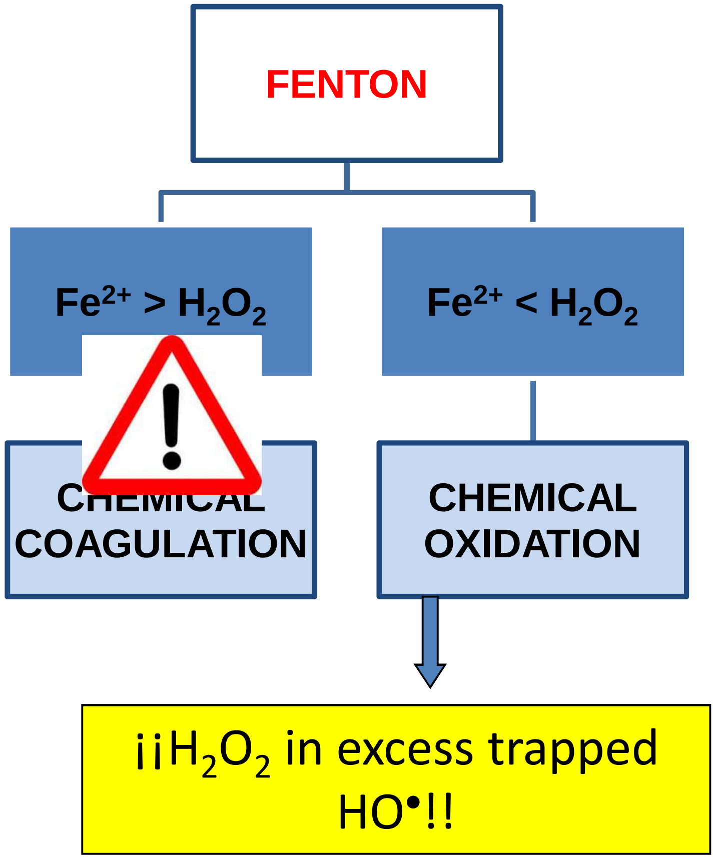
Proyecto PSA

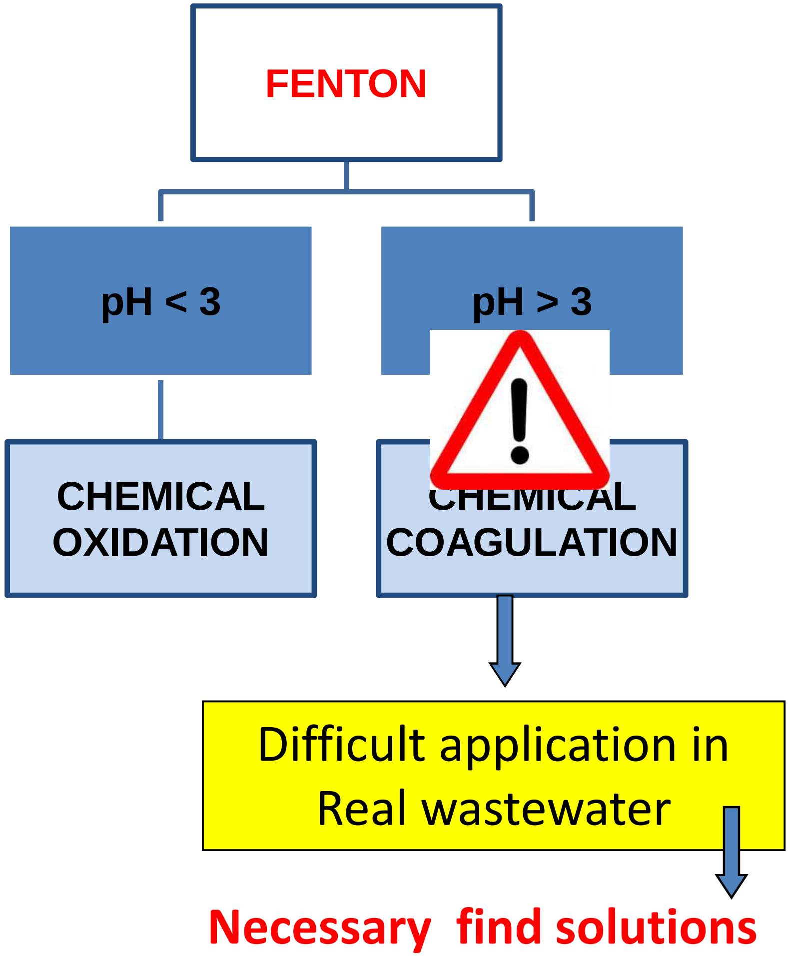
300 m^2 de colectores CP

750.000 envases/año (50% comercializados en Almería)

41.4 kJ/L para mineralizar 108 mg/L de COT.

INTRODUCTION PHOTO-FENTON PROCESS





Klamerth et al. (2010) Water Res. 44: 545-554.
Bernabeu et al. (2011) Catal. Today 161: 233-240; (2012) Chem. Eng. J. 198-199: 65–72

SOLUTIONS OF PHOTO-FENTON PROCESS

pH = 3 → Inconvenient for effluents to be discharged in natural systems

FENTON-LIKE PROCESSES

Processes at circumneutral pH

- **Fe^0**
  Fe/ Zeolites
- **Oxalate**
  Citrate
  Chitosane
  EDTA
  EDDS
- **Humic Acids**
  Fúlvic Acids
- **SBO**

processes using other metals as photocatalysts

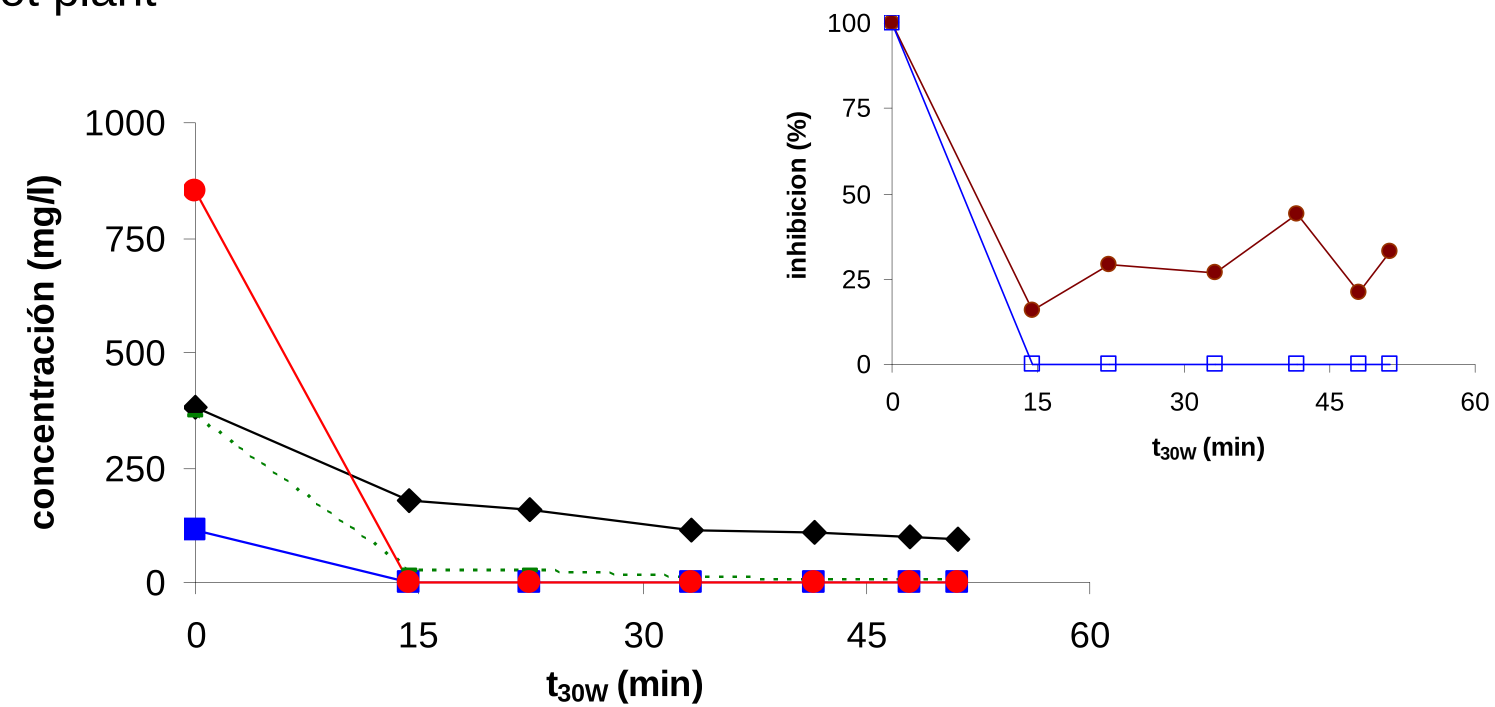
Possible role in the process of other species different to hydroxyl radical, such as superoxide

Vermilyea et al.(2009) Environ. Sci. Technol. 43: 6927-6933.
Applied Catalysis B: Environmental 146 (2014) 192– 200

FENTON-LIKE PROCESSES: processes using other metals as photocatalysts (copper)

Finishing metal Industry wastewater

Toxicity (%) to the activated sludge of industrial wastewater treated by irradiation in pilot plant



Solar treatment with $\mathbf{H_2O_2}$. Cyanide degradation(•), free cyanide (■), Total carbono (◆) Copper degradation (▲). Toxicity (vibrio *fischeri)* (•), Activated sludge toxicity (□).

FENTON-LIKE PROCESSES: processes using other metals as photocatalysts (copper)

Finishing metal Industry wastewater

Toxicity (%) to the activated sludge of industrial wastewater treated by irradiation in pilot plant

t= 0; Toxicty = 75%

t= 3h, Toxicity = 37%

t= 6h, Toxicity = 13%

FENTON-LIKE PROCESSES:
processes a circumneutral pH

Processes at circumneutral pH

- **Fe^0**
  Fe/Zeolite
- **COMPLEX FORMATION**
  - **Oxalate, Citrate, Chitosane, EDTA, EDDS**
  - **Humic acids, Fulvic acids**
  - **SBO**

Advantageous:

- **Stabilization of iron ions** over a wider pH
- High absorption of UV–vis radiation,

$$[RCO_2–Fe]^{2+} + hv \rightarrow [R\cdot] + CO_2 + Fe^{2+}$$

$$Fe^{3+} + H_2O_2 \rightarrow Fe^{3+} + \cdot OH + OH^-$$

Disadvantageous:

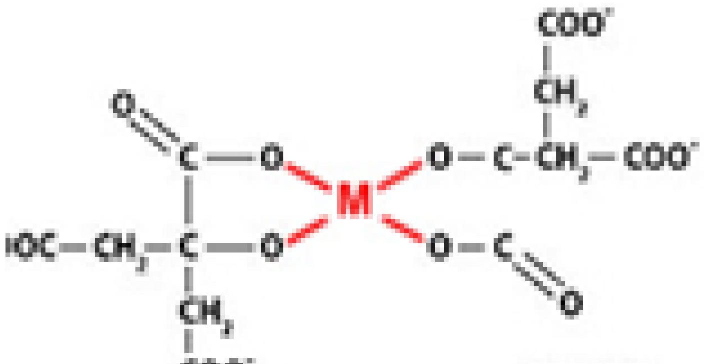
- **Limited stability** of the employed complexing agent
- Formation of very **stable non-photoactive iron complexes** (may hinder the participation of iron in the Fenton reaction)
- **Potential Toxicity** of chemicals auxiliaries

FENTON-LIKE PROCESSES:
processes a circumneutral pH: citric Acid

COMPLEX FORMATION: CITRIC ACID

Iron ligand for application in photo-Fenton processes:

• Availability and the possibility of improving the Fenton reaction at pH values above 2.8 (up to neutrality), with high quantum yields of Fe(II) (Φ_{FeII}) and hydroxyl radical generation .



CITRATE

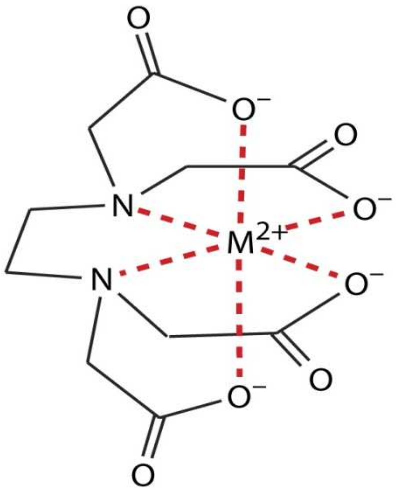
Furthermore, citric acid is biodegradable, and therefore environmentally friendly in contrast to other ligands, such as EDTA, that show poor biodegradability.

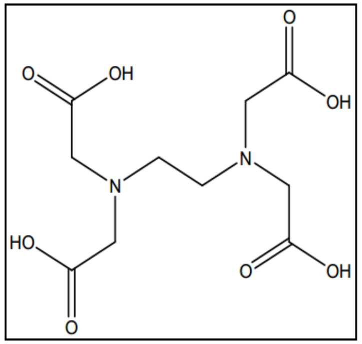
(Sillanpaa and Pirkanniemi, 2001),

(Zepp et al., 1992, Abrahamson et al., 1994, Zhang et al., 2006 and Kwan and Chu, 2007).

FENTON-LIKE PROCESSES:
processes a circumneutral pH: EDTA

COMPLEX FORMATION: EDTA





$$[Fe(II)(EDTA)]^{2-} + H_2O_2 \rightarrow [Fe(III)(EDTA)]^{1-} + OH^{-} + \bullet OH \quad (1)$$

Low biodegradability
Toxicity

C.Y. Kwan, W. Chu / Chemosphere 67 (2007) 1601–1611
DeLuca, Dantas, Esplugas, Water research 61 (2014) 232-242

FENTON-LIKE PROCESSES:
processes a circumneutral pH

COMPLEX FORMATION:

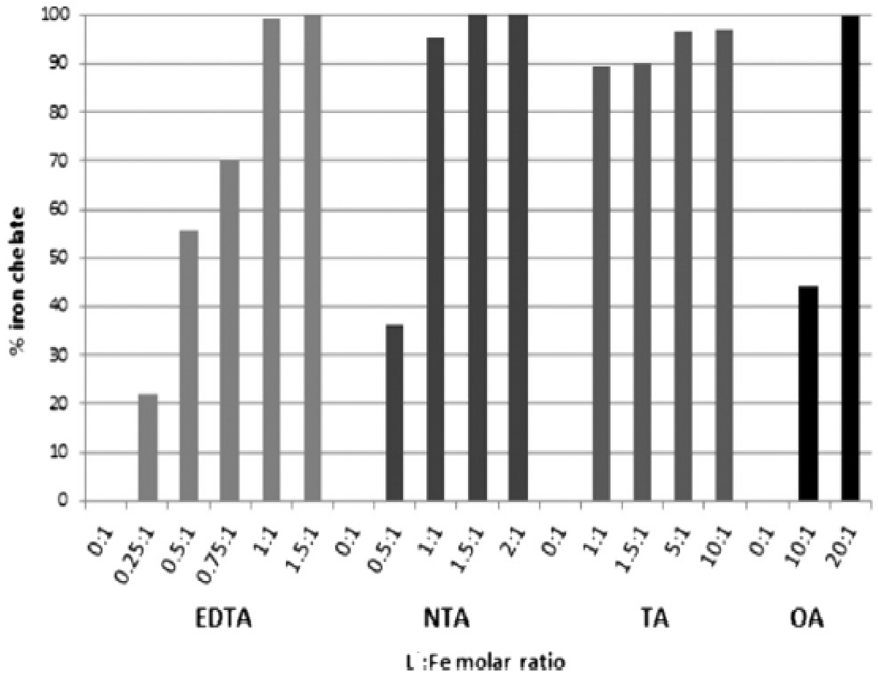


Fig. 1 – Percentage of iron chelates formed with several L:Fe(III)molar ratio tested.

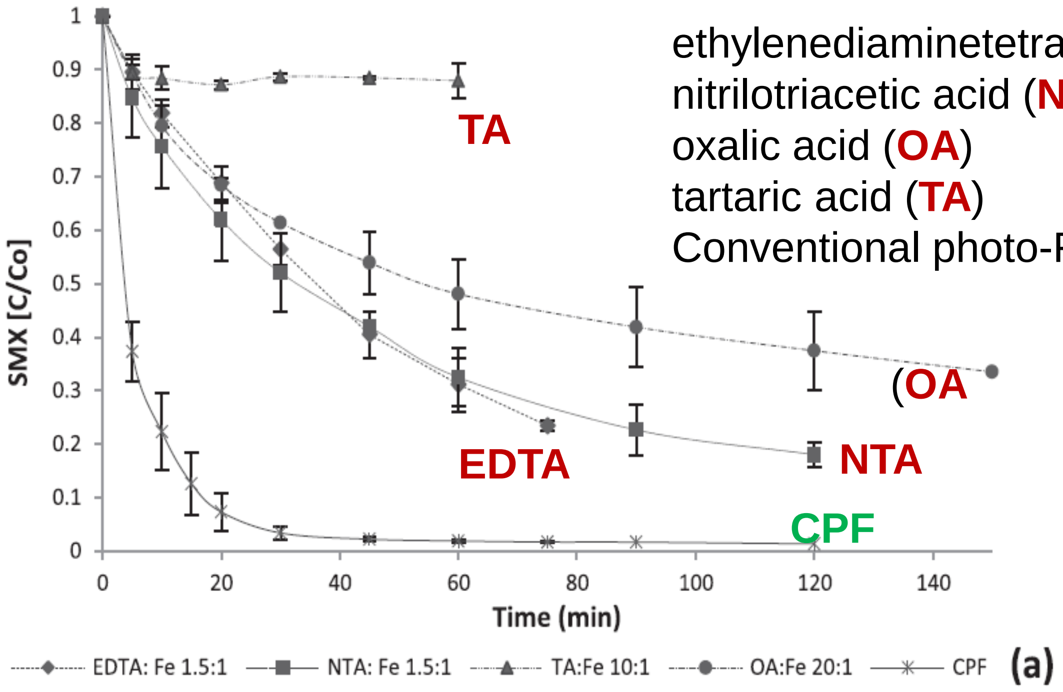
ethylenediaminetetraacetic acid (**EDTA**);
nitrilotriacetic acid (**NTA**);
oxalic acid (**OA**)
tartaric acid (**TA**).

Chelates of EDTA and NTA presented more stability than OA and TA,

DeLuca, Dantas, Esplugas, Water research 61 (2014) 232-242

FENTON-LIKE PROCESSES:
processes a circumneutral pH: EDTA

COMPLEX FORMATION: EDTA



ethylenediaminetetraacetic acid (**EDTA**);
nitrilotriacetic acid (**NTA**);
oxalic acid (**OA**)
tartaric acid (**TA**)
Conventional photo-Fenton (pH =2,8) **(CPF)**.

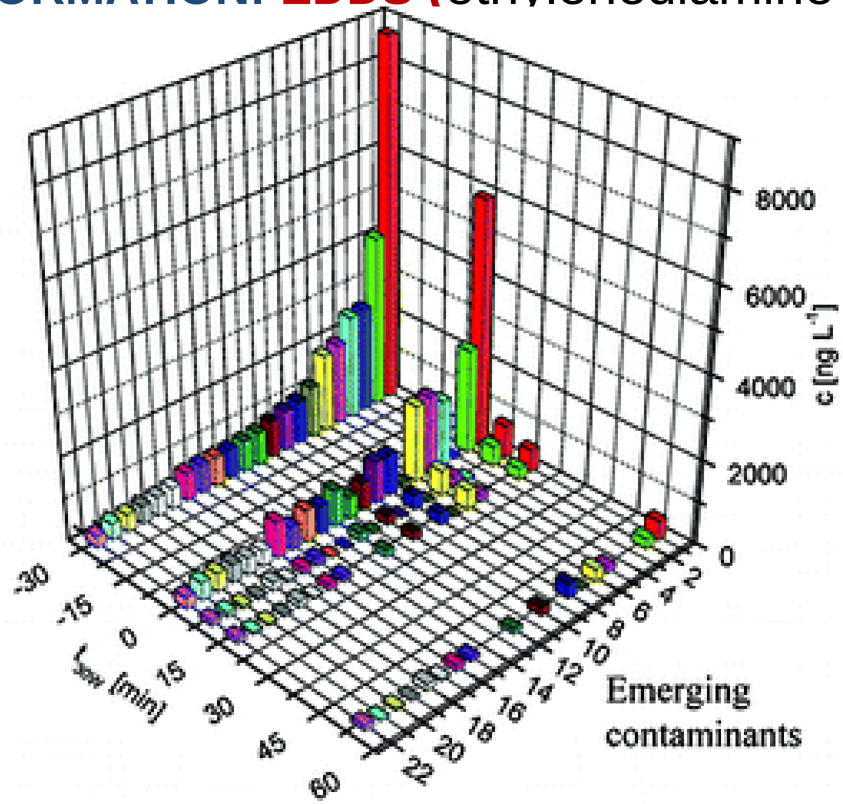
Fig. SMX removal by photo-Fenton like at neutral pH with Fe(III)-L chelates and trend of pH values over time reaction.
(pH = 7.0), ([SMX]0=0.079 mM; $[Fe^{2+}]_0$ = 0.089 mM; $[H_2O_2]_0$ = 0.294 mM;

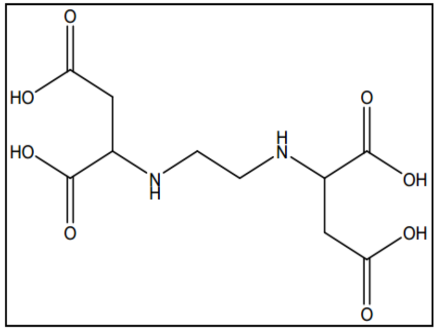
DeLuca, Dantas, Esplugas, Water research 61 (2014) 232-242

FENTON-LIKE PROCESSES:
processes a circumneutral pH: EDDS

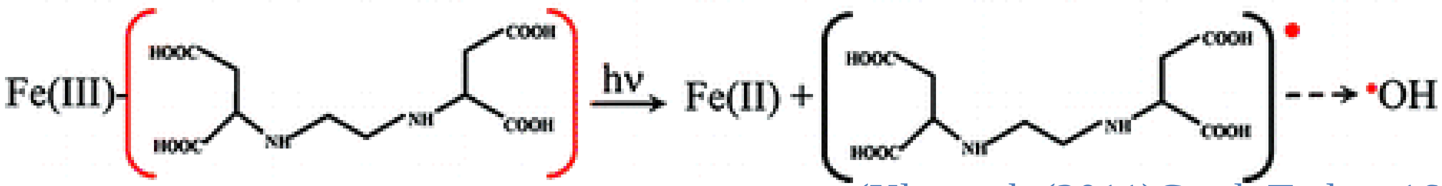
COMPLEX FORMATION: EDDS (ethylenediamine-N,N′-disuccinic acid)

- Neutral pH
- CPC
- Degradation of 22 Eps In MWTP





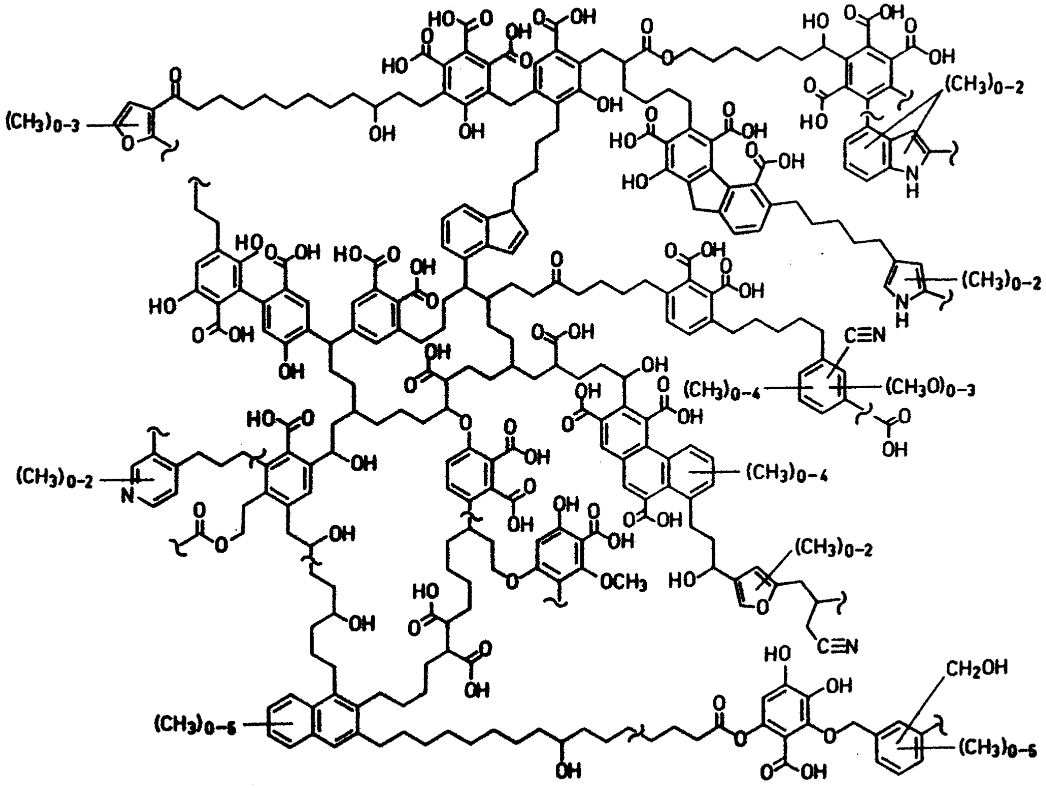
degradation rate 95.5% in t_{30W} = 63 min,
Lower peroxide consumption:
(61 mg L^{-1} pH =6,3
80 mg L^{-1} at pH 3).

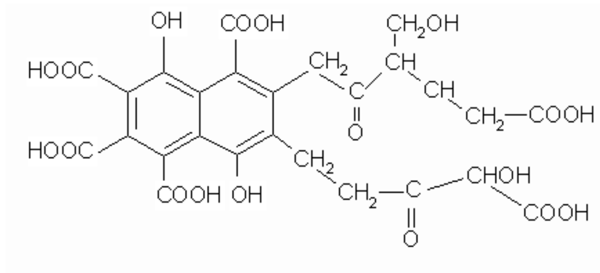


(Klamerth (2011)Catal. Today, 161: 241-246.

FENTON-LIKE PROCESSES:
processes a circumneutral pH: Humic Acids

COMPLEX FORMATION: HUMIC and FULVIC ACIDS





These substances contain functional groups that are able to complex iron

Mikutta et al (2011) Environ. Sci. Technol., 45: 9550–9557
Lipczynska-Kochany et al. (2008) Chemosphere 73: 745-750.
Georgi et al.(2007) Appl. Catal. B: Environ. 72: 26-36.
Fan et al. (2011) Chemosphere 82: 229-236.

FENTON-LIKE PROCESSES:
processes a circumneutral pH: Humic acids

COMPLEX FORMATION: HUMIC and FULVIC ACIDS

Dreissena polymorpha (zebra mussel) is an invasive freshwater bivalve mollusc that causes important technical and environmental problems

Neutral photo-Fenton could be a promising alternative as ca.90% damaged larvae were detected in only 3 hours irradiation in the presence of H_2O_2 (10 mg/l).

This process was clearly more effective than sunlight irradiation, H_2O_2, or dark Fenton.

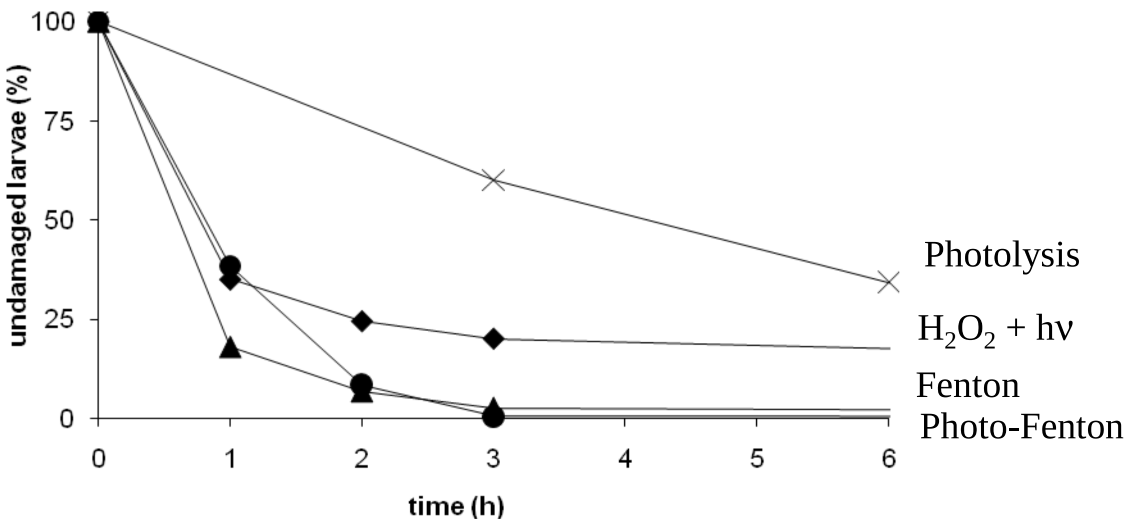
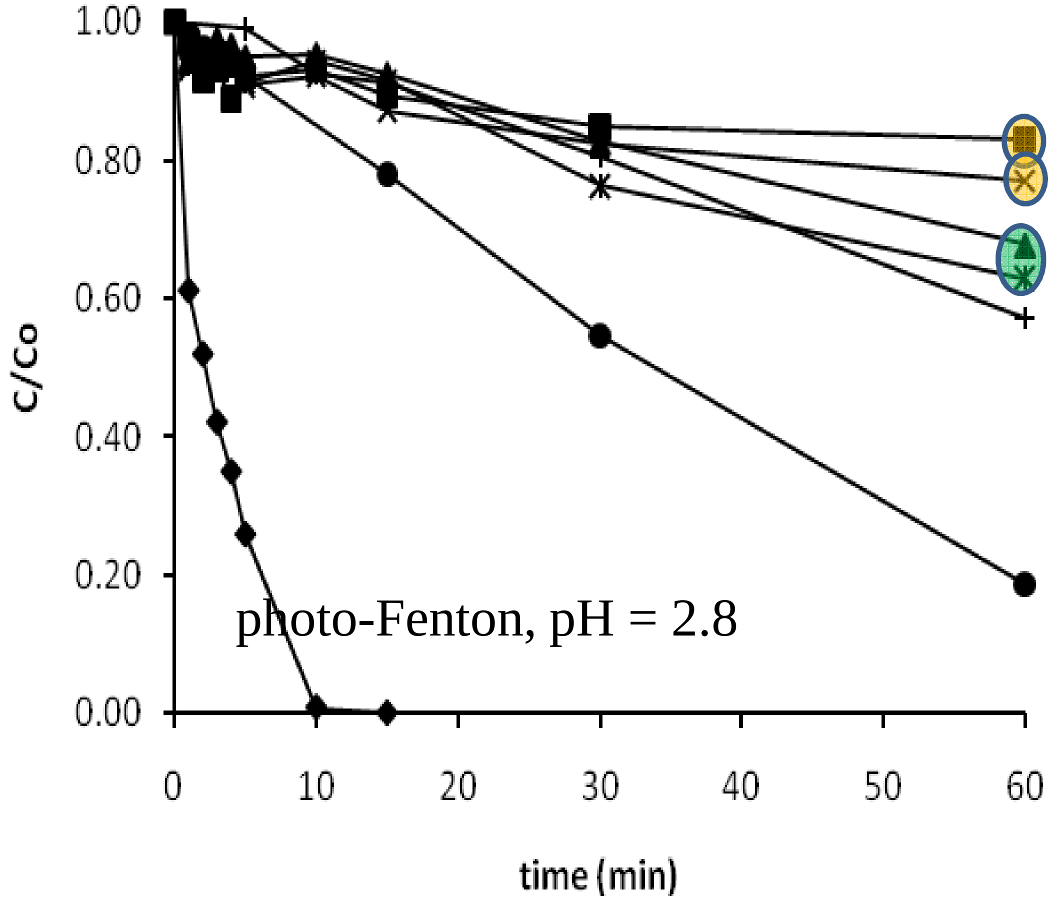


Photo-Fenton (5 mg/l of iron and 10 mg/l of H_2O_2, sunlight) (▲), Fenton (5 mg/l of iron and 10 mg/l of H_2O_2) (●), 10 mg/l of H_2O_2 (♦) and control experiment (×).

FENTON-LIKE PROCESSES:
processes a circumneutral pH: Humic acids

COMPLEX FORMATION: HUMIC ACIDS

Relative concentration of **caffeine** (50 mg/l) vs. irradiation time

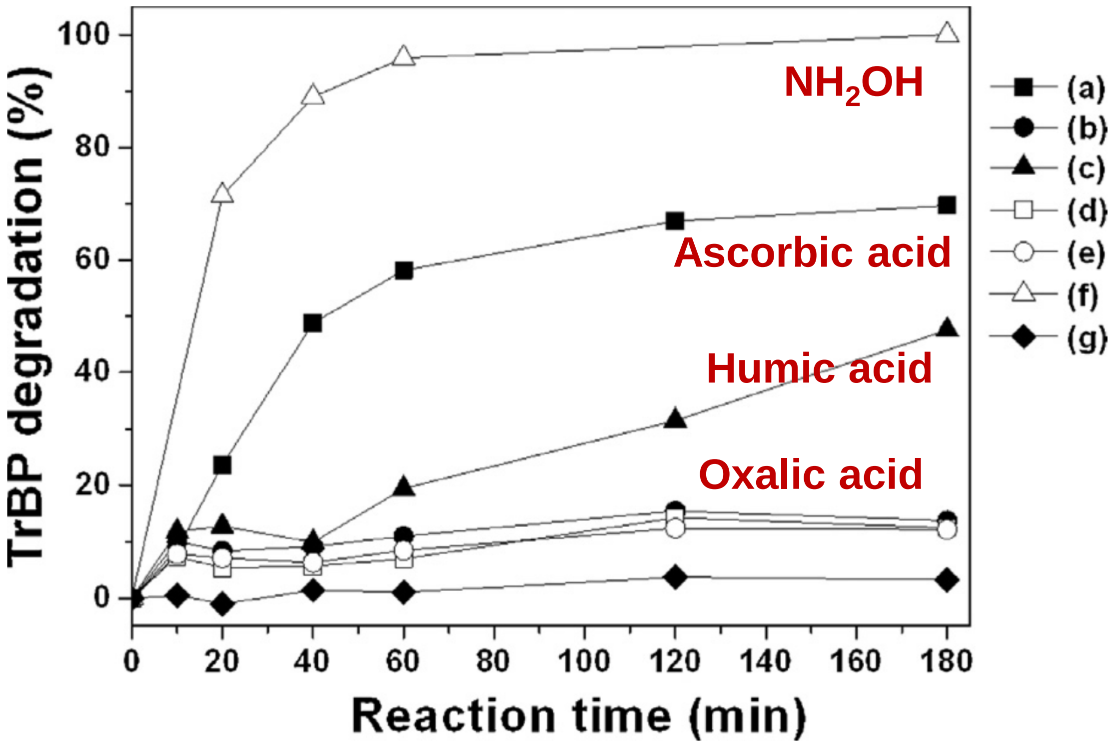


(■) photo-Fenton, pH = 7, distilled water;
(×) photo-Fenton, pH = 7, tap water
(▲) photo-Fenton, pH = 7, **humic acids**, distilled water;
(✳) photo-Fenton, pH = 7, **humic acids**, tap water

UNIVERSIDAD POLITECNICA DE VALENCIA
CAMPUS DE ALCOY

FENTON-LIKE PROCESSES:
processes a circumneutral pH: humic acids

COMPLEX FORMATION:



Effects of reducing agents on the kinetics of **TriBromoPhenol degradation**.

(a) Ascorbic Acid
(b) oxalic acid,
(c) p-hydroquinone,
(d) humic acid,
(e) gallic acid,
(f) NH_2OH,
(g) Without Reducing Agents,

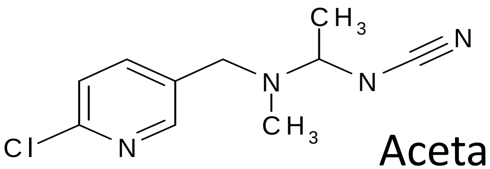
$[TrBP]_0$100 M, $[H_2O_2]$ 20 mM, Fe-Z 109 mg L^{-1}(30 M),

Applied Catalysis B: Environmental 147 (2014) 411– 419

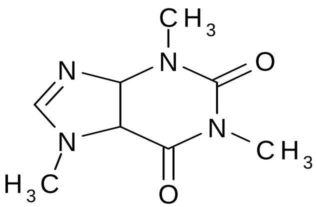
FENTON-LIKE PROCESSES:
processes a circumneutral pH: Humic acids

COMPLEX FORMATION: HUMIC and FULVIC ACIDS

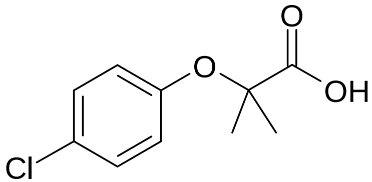
In WTP



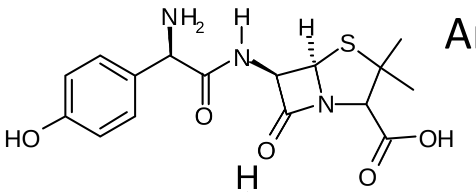
Acetamiprid



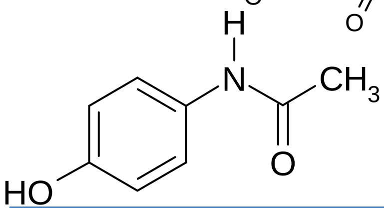
Caffeine



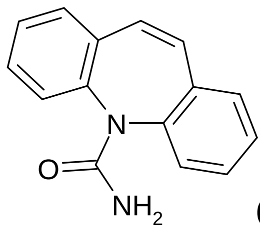
Clofibric Acid



Amoxiciline



Acetaminophen



Carbamazepine

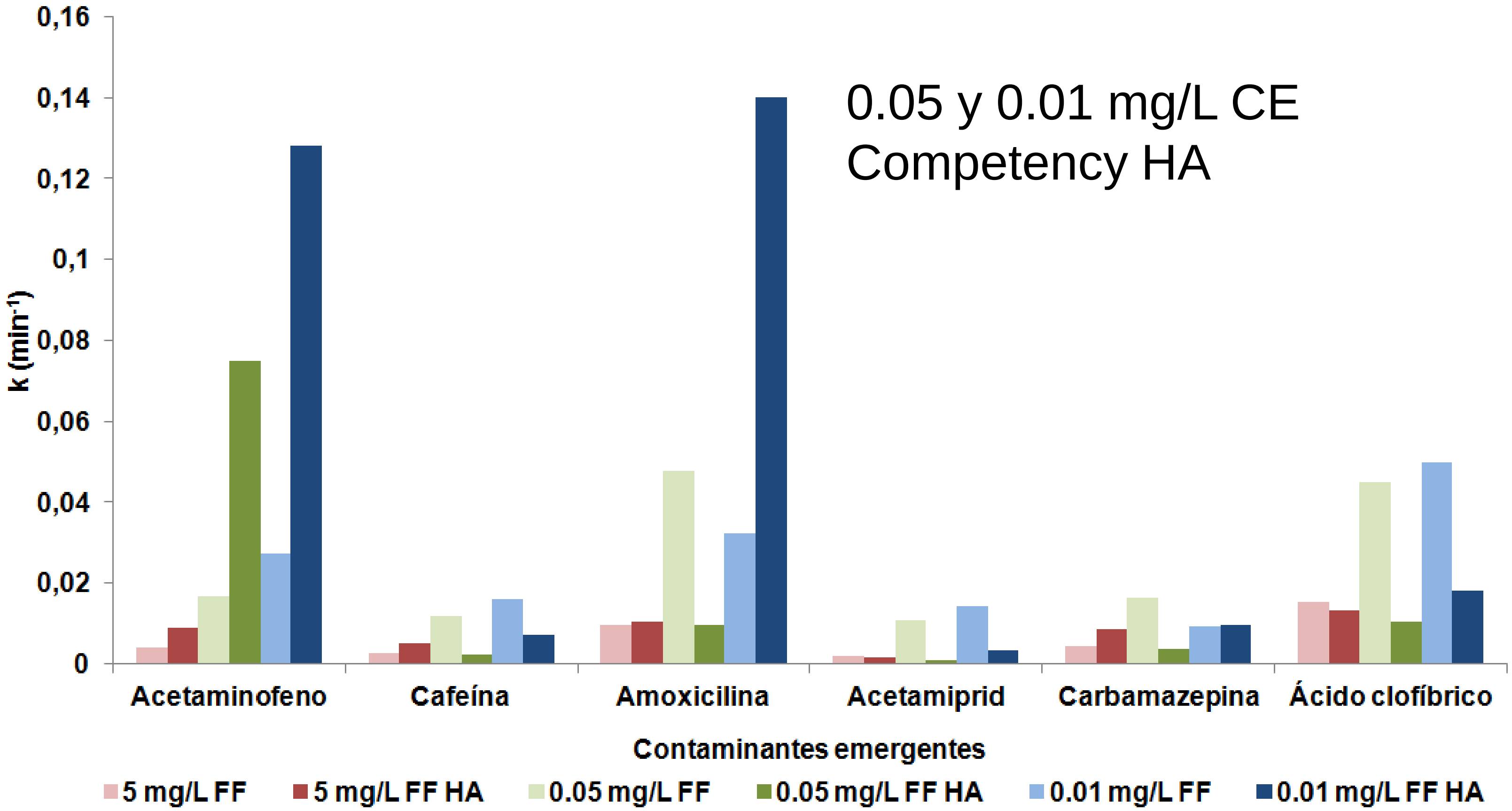
UNIVERSIDAD POLITECNICA DE VALENCIA
CAMPUS DE ALCOY

FENTON-LIKE PROCESSES:
processes a circumneutral pH: Humic acids

COMPLEX FORMATION: HUMIC and FULVIC ACIDS

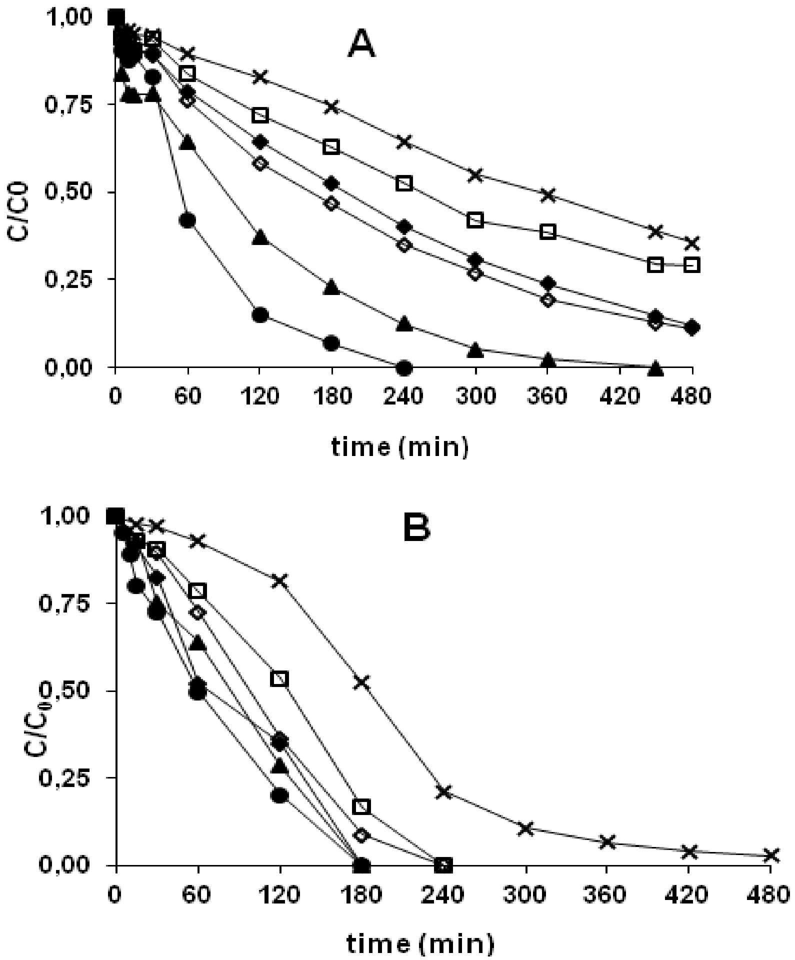
In WTP

0.05 y 0.01 mg/L CE
Competency HA



UNIVERSIDAD POLITECNICA DE VALENCIA
CAMPUS DE ALCOY

FENTON-LIKE PROCESSES:
processes a circumneutral pH: Humic acids



neutral photo-Fenton in distilled water (A)

amoxycillin (▲),
acetaminophen (♦),
acetemiprid (×),
caffeine (□),
clofibric acid (●)
carbamazepine (◊).

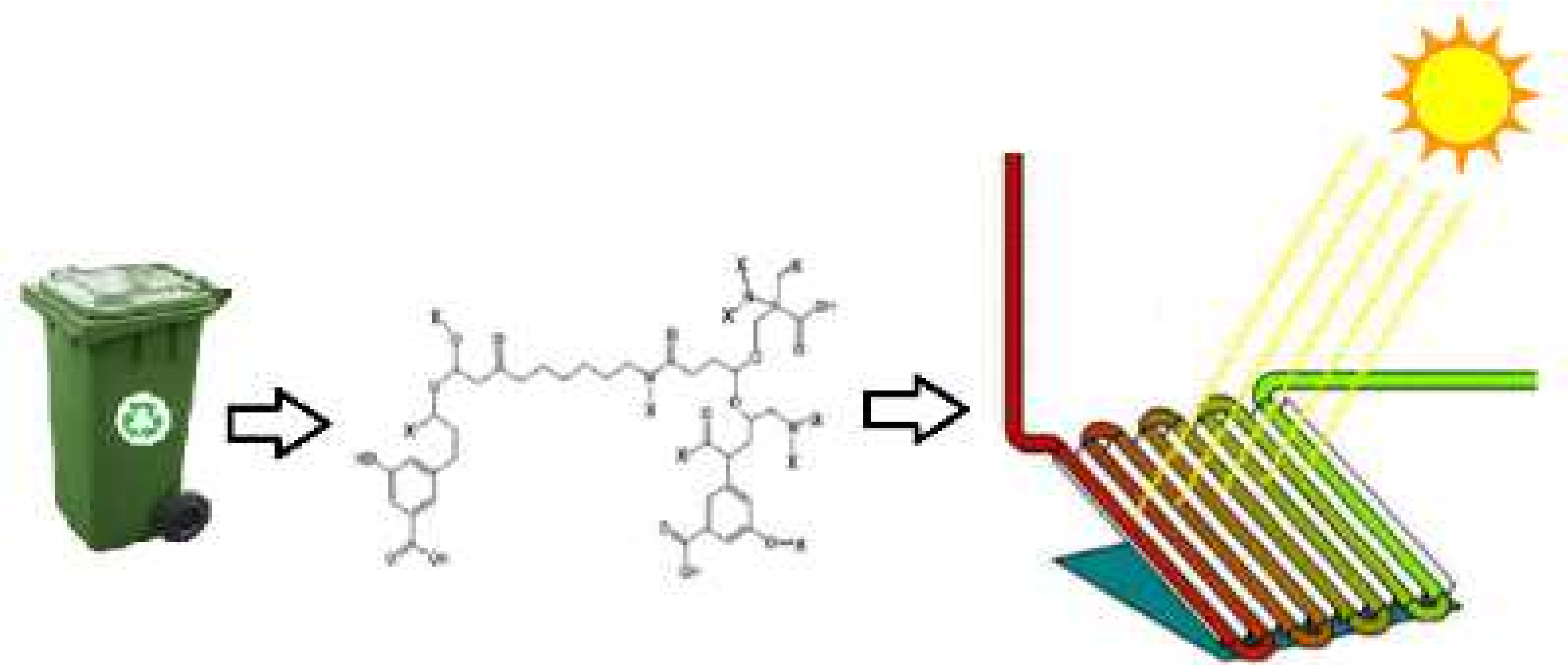
neutral photo-Fenton in distilled water and **humic acids** (10mg/L)(B)

UNIVERSIDAD POLITECNICA DE VALENCIA
CAMPUS DE ALCOY

FENTON-LIKE PROCESSES:
processes a circumneutral pH

COMPLEX FORMATION: SBO

Constituted by macromolecules (67 to 463 kg mol^{-1}) with similar characteristics as humic substances



FENTON-LIKE PROCESSES:
processes a circumneutral pH

COMPLEX FORMATION: SBO

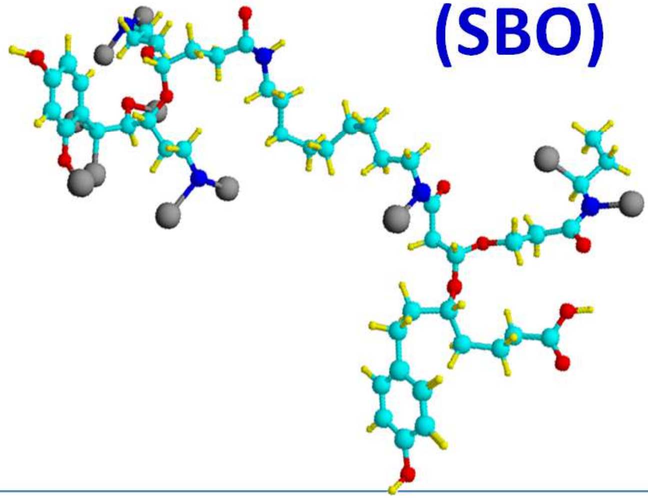
Urban wastes

Organic fraction

-Pre-treatments
-Anaerobic digestion
-Aerobic biodegradation

Biomass

Soluble Bio-Organics (SBO)



Digestion at basic conditions

Centrifugation to remove the non-soluble fraction

Ultrafiltration of supernatant

Drying of the retentate

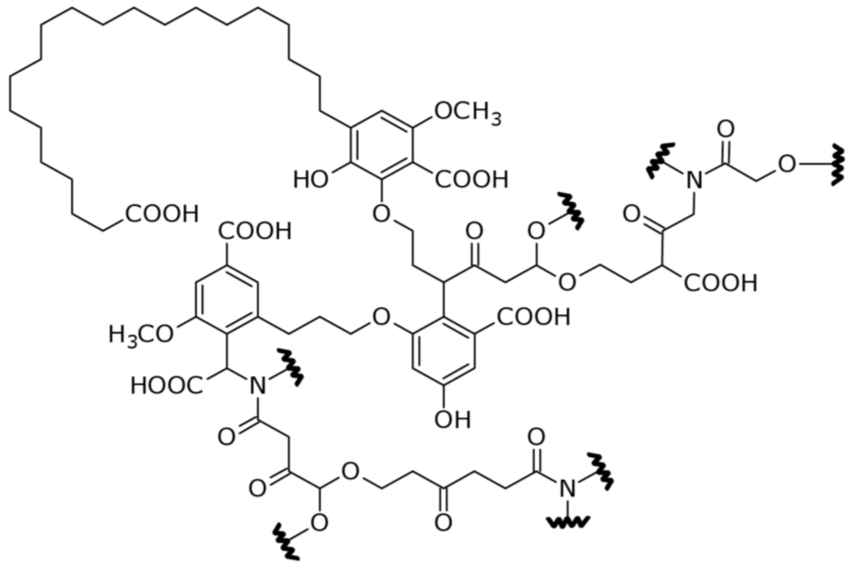
FENTON-LIKE PROCESSES:
processes a circumneutral pH

COMPLEX FORMATION: SBO

A (FORSUD): urban waste organic humid fraction mixed with the digestate from an anaerobic reactor.

B (CVDFT110): mixture of FORSUD, gardening residues and urban sewage sludge

C (CVT230): home gardening and park trimming residues (GR) aerated for 230 days



Functional groups present in SBO (e.g carboxylic or amide) indicate that these substances are able to act as chelating agents for iron, what might be useful to apply photo-Fenton at neutral conditions

Gomis et al.(2013) Catalysis Today. 209: 176-180.

Gomis et al. (2014) Chem. Eng. J. 235: 236-243.

FENTON-LIKE PROCESSES:
processes a circumneutral pH

COMPLEX FORMATION: SBO

	A (FORSUD)	B (CVDFT110)	C (CVT230)
Volatile solids (%, w/w)	84.6	72.7	72.1
Carbon (%, w/w)	45.1	35.5	38.2
Nitrogen (%, w/w)	7.8	4.3	4.0
Si (%, w/w)	0.36	0.92	2.55
Fe (%, w/w)	0.16	0.53	0.77
Al (%, w/w)	0.78	0.44	0.49
Mg (%, w/w)	0.18	0.49	1.13
Ca (%, w/w)	1.32	2.59	6.07
K (%, w/w)	9.2	5.4	3.6
Na (%, w/w)	0.39	0.15	0.16
Cu (mg/l)	100	216	202
Ni (mg/l)	27	71	92
Zn (mg/l)	185	353	256
Cr (mg/l)	11	30	19
Pb (mg/l)	44	75	85
Hg (mg/l)	0.2	0.4	0.2

FENTON-LIKE PROCESSES:
processes a circumneutral pH

COMPLEX FORMATION: SBO

	A (FORSUD)	B (CVDFT110)	C (CVT230)
Aliphatic carbon	43	31	37
Amine	10	8	7
Methoxy	4	-	-
Alkoxy	10	20	14
Anomeric carbon	3	7	4
Aromatic	10	16	13
Phenolic carbon	2	6	5
Phenoxy	1	2	2
Carboxylic	7	9	12
Amide	9	1	1
Carbonilic	1	-	5
Lipophilic/hydrophilic ratio	9.3	5.3	3.6
Aliphatic/aromatic ratio	3.3	1.3	1.8
E_2/E_3 ratio	3.83	2.31	2.38

UNIVERSIDAD POLITECNICA DE VALENCIA
CAMPUS DE ALCOY

FENTON-LIKE PROCESSES:
processes a circumneutral pH: SBO

APPLICATION EXAMPLE

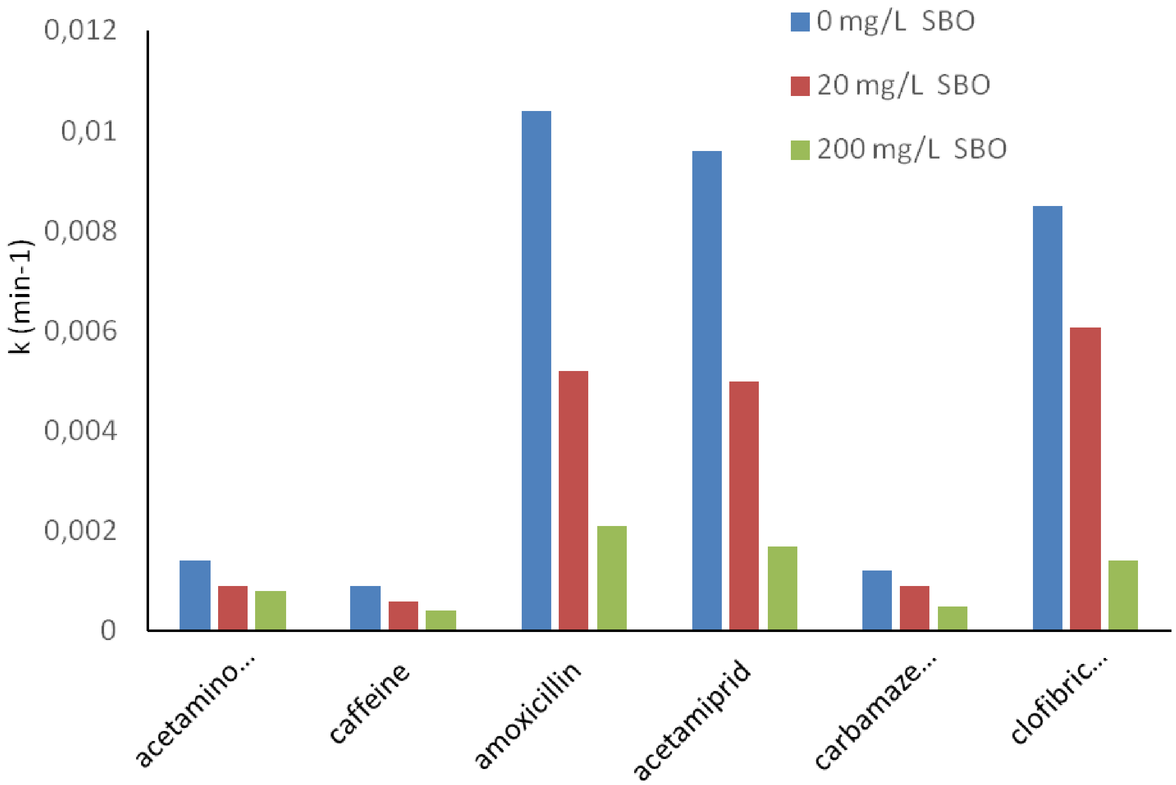
sensitizing effect photolysis

EP(5 mg·L^{-1}) + BOS

Results

Higher SBO concentration resulted in lower k values

The screen effect due to the brown color of SBOs might explain this fact

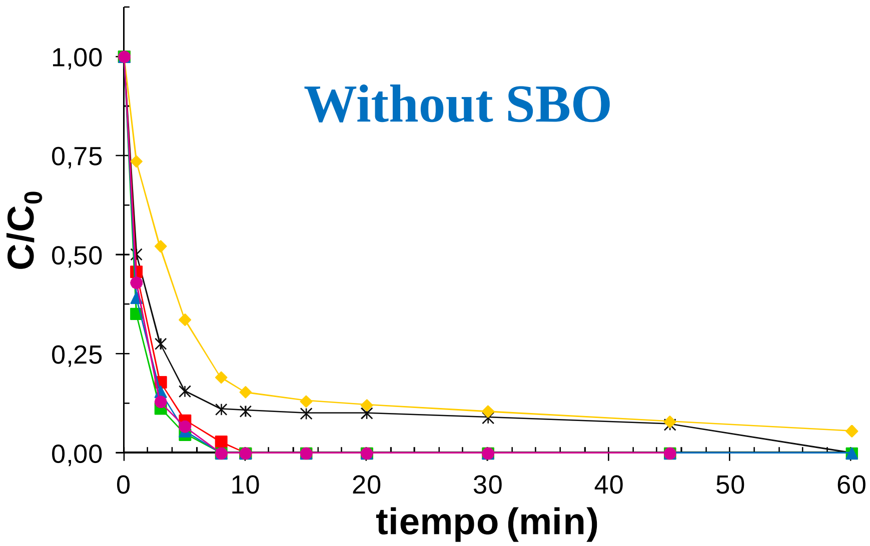


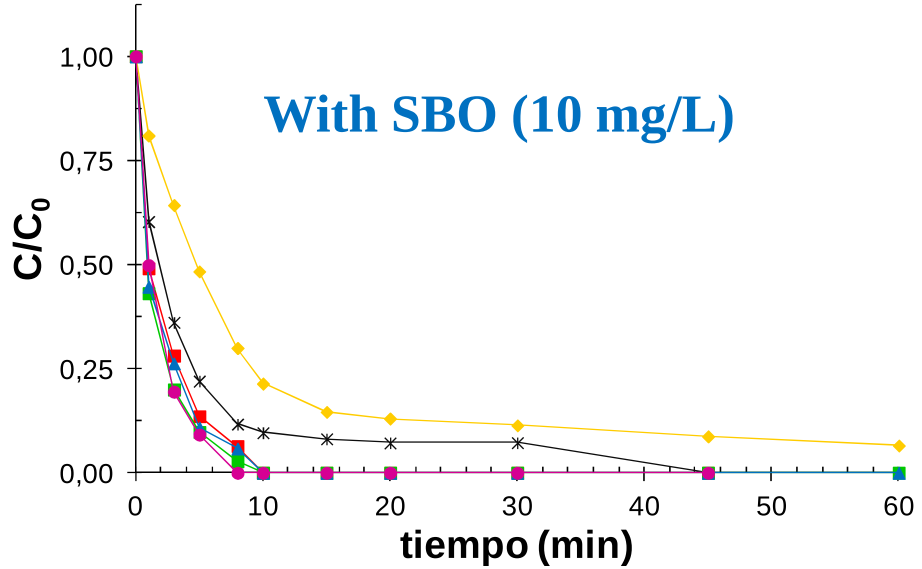
FENTON-LIKE PROCESSES:

processes a circumneutral pH: SBO

APPLICATION EXAMPLE : photo-Fenton pH 2,8

EP (5 mg·L^{-1}) + Fe II (5 mg·L^{-1}) + H_2O_2 (75 mg·L^{-1})

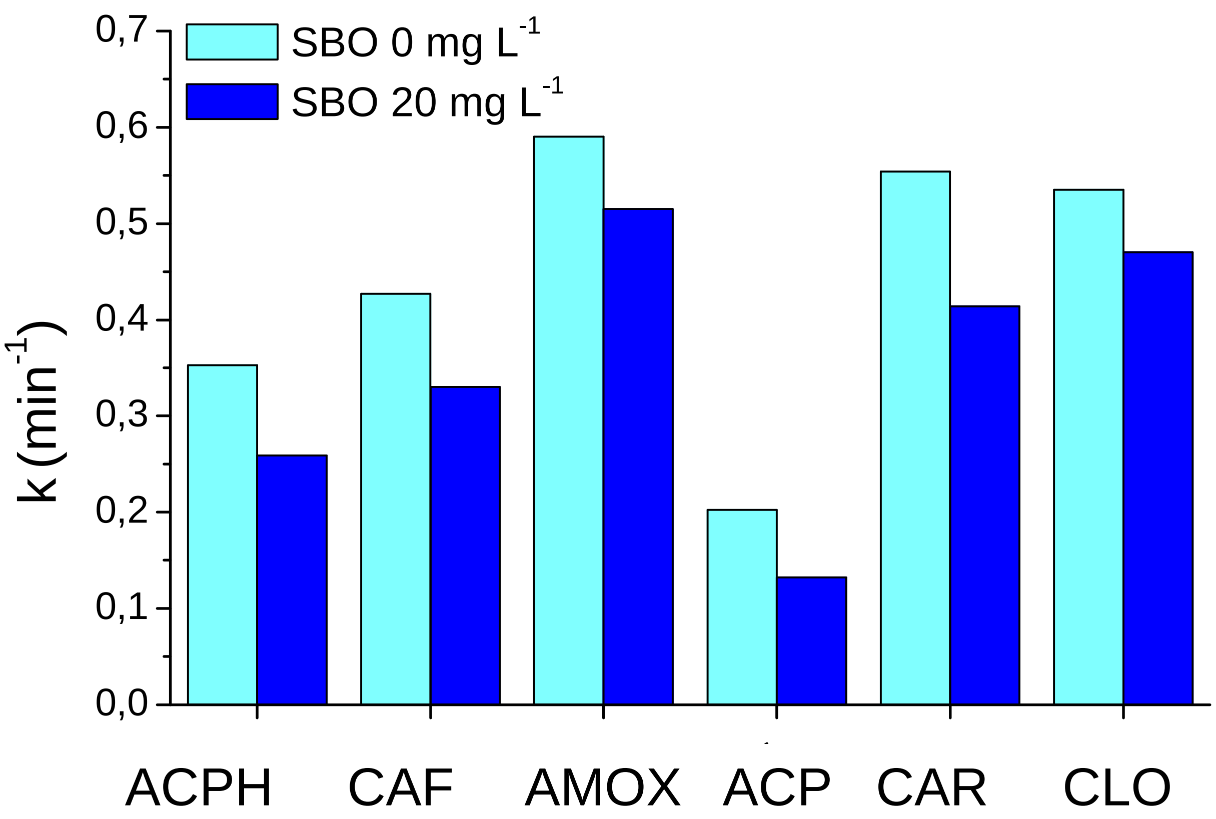




UNIVERSIDAD POLITECNICA DE VALENCIA
CAMPUS DE ALCOY

FENTON-LIKE PROCESSES:
processes a circumneutral pH: SBO

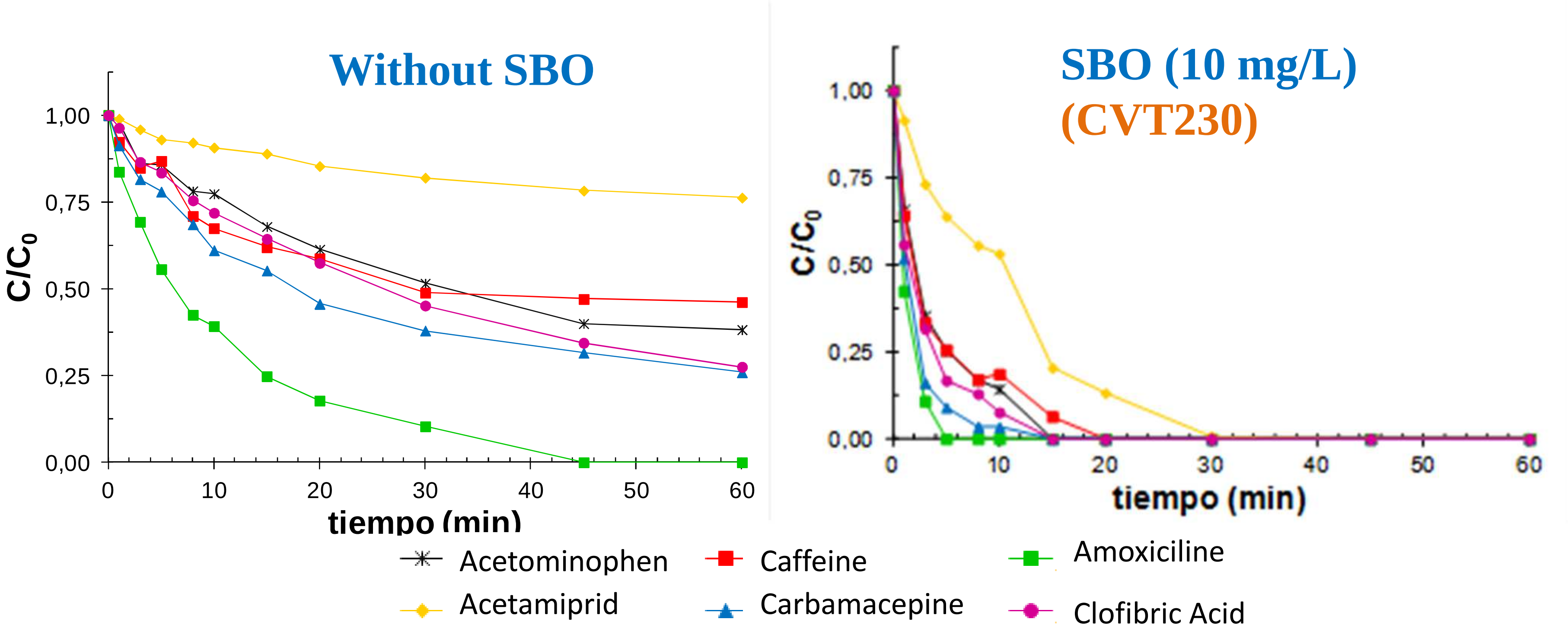
photo-Fenton **pH 2,8**



FENTON-LIKE PROCESSES:
processes a circumneutral pH: SBO

APPLICATION EXAMPLE photo-Fenton pH 5,3

EP (5 mg·L^{-1}) + Fe II (5 mg·L^{-1}) + H_2O_2 (75 mg·L^{-1})

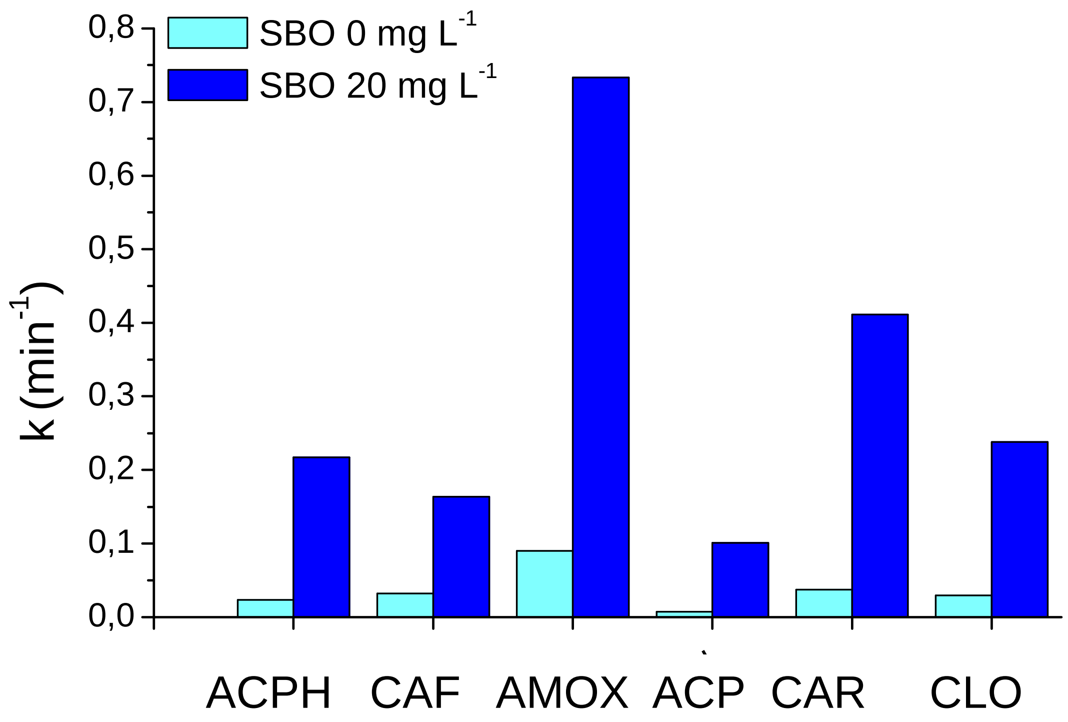


UNIVERSIDAD POLITECNICA DE VALENCIA
CAMPUS DE ALCOY

FENTON-LIKE PROCESSES:
processes a circumneutral pH: SBO

APPLICATION EXAMPLE photo-Fenton pH 5,3

EP (5 mg·L^{-1}) + Fe II (5 mg·L^{-1}) + H_2O_2 (75 mg·L^{-1})



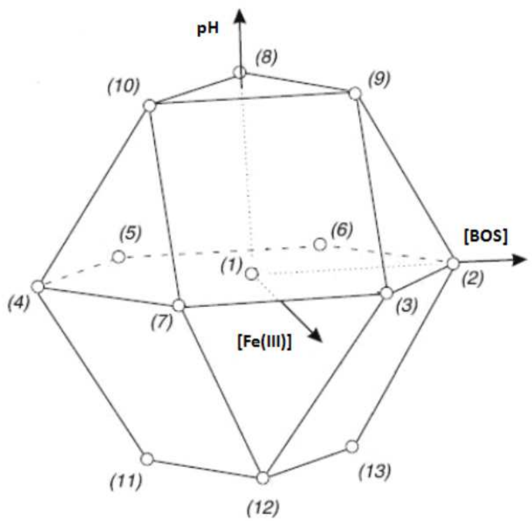
UNIVERSIDAD POLITECNICA DE VALENCIA
CAMPUS DE ALCOY

FENTON-LIKE PROCESSES:
processes a circumneutral pH: SBO

DOEHLERT

3 Factores	Niveles	MIN	MAX	Incremento
[SBO] mg/L	7	15	25	1,7
$[Fe^{3+}]$ mg/L	5	2	6	1
pH	3	3	7	2

Exp.	[Fe (III)]	[SBO]	pH
1	4	20	5
1'	4	20	5
1''	4	20	5
2	6	20	5
3	5	25	5
4	2	20	5
5	3	15	5
6	5	15	5
7	3	25	5
8	5	21,7	7
9	3	21,7	7
10	4	16,7	7
11	3	18,3	3
12	5	18,3	3
13	4	23,3	3

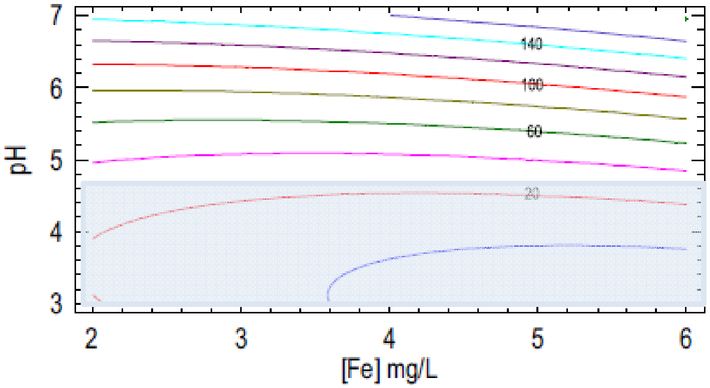


FENTON-LIKE PROCESSES:
processes a circumneutral pH: SBO

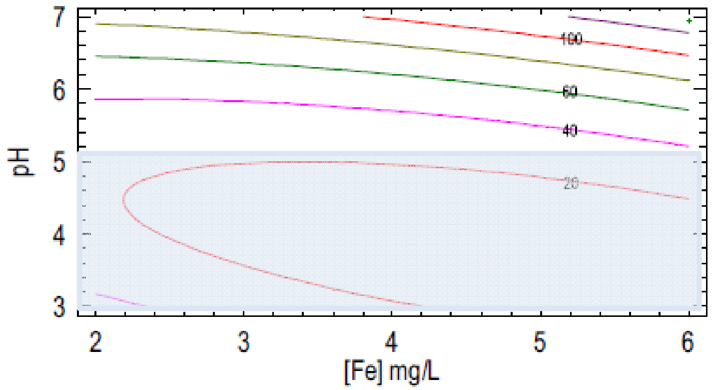
EXPERIMENTAL DESIGN DOEHLERT PHOTO-FENTON BOS
Time to remove 50% with BOS (CVT230)

The photo-Fenton reaction can be extended to pH values close to 5, without too remarkable loss of efficiency

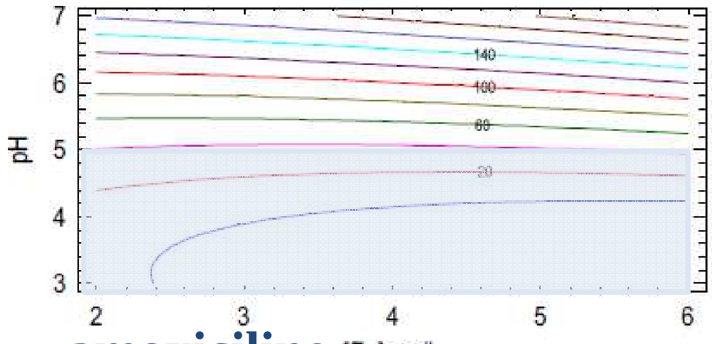
[SBO] = 15 mg L^{-1}

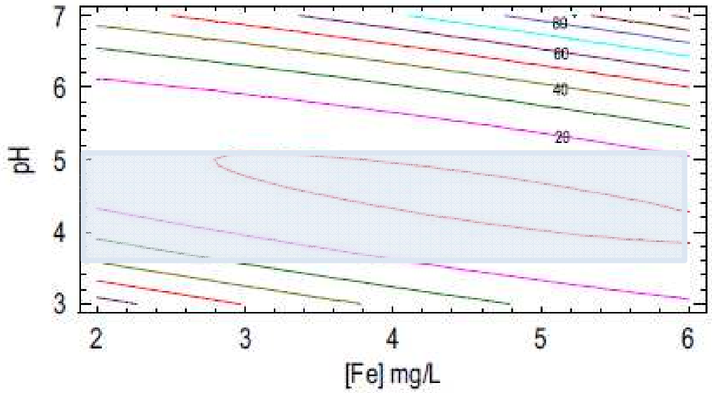


[SBO] = 25 mg L^{-1}



carbamazepine



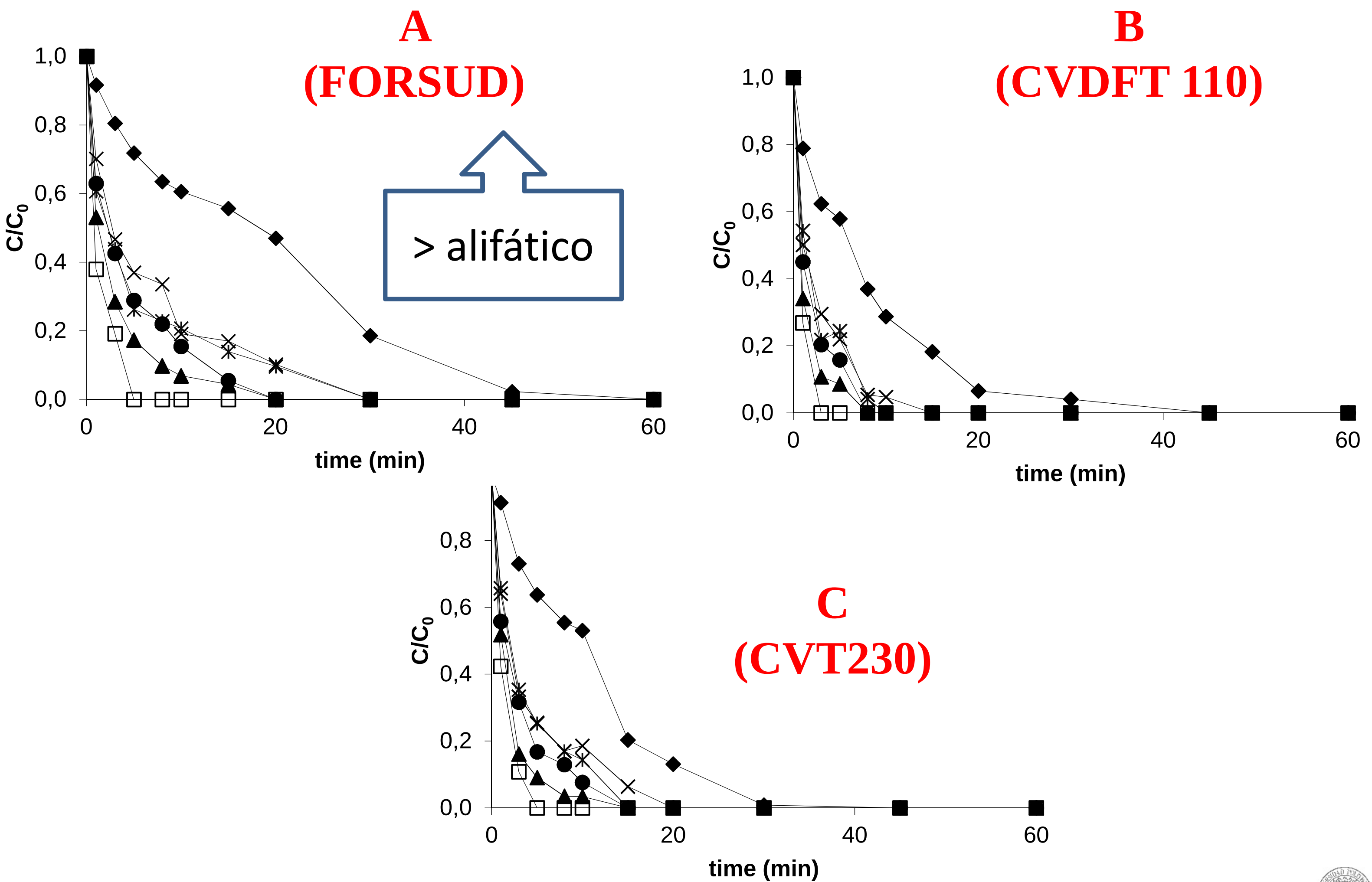


amoxiciline

FENTON-LIKE PROCESSES:
processes a circumneutral pH: SBO

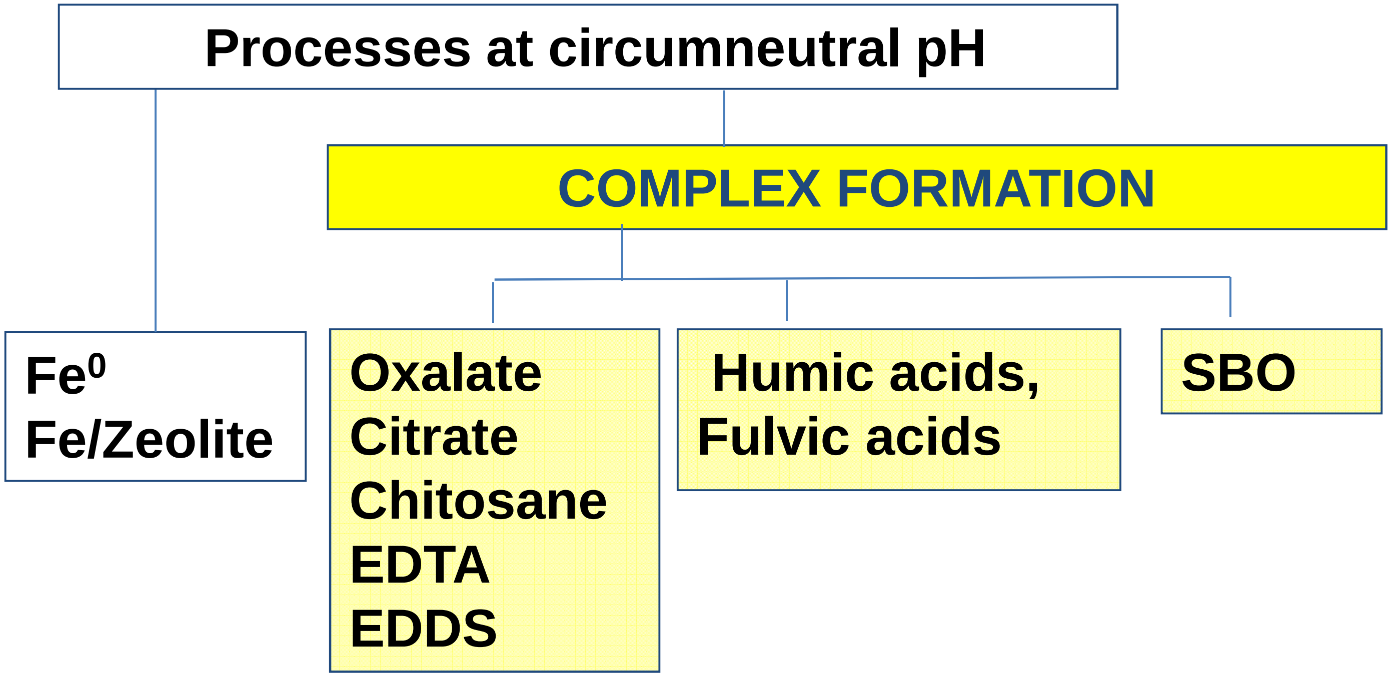
15 de enero de 2016 - Castellón

EFFECT OF DIFFERENT SBO



CONCLUSSIONS:
processes a circumneutral pH

- Existen numerosos estudios que demuestran que es posible aplicar procesos tipo foto-Fenton en condiciones próximas a la neutralidad con buenos porcentajes de degradación de contaminantes y de detoxificación de efluentes.



UNIVERSIDAD POLITECNICA DE VALENCIA
CAMPUS DE ALCOY

1ª Jornada Técnica sobre procesos de oxidación avanzada en el ciclo integral del agua

Grupo de Procesos de Oxidación Avanzada
Ana Mª Amat Payá (aamat@txp.upv.es)