



UNIVERSITÀ
DEGLI STUDI
DI PALERMO

Dipartimento di Ingegneria Chimica,
Gestionale, Informatica, Meccanica



ELETTRODIALISI INVERSA PER L'ENERGIA E L'AMBIENTE: APPROCCIO SINERGICO ALL'ABBATTIMENTO DI INQUINANTI IN ACQUA ATTRAVERSO L'USO DEL PROCESSO DI ELETTRODIALISI INVERSA

**Prof. Onofrio Scialdone, responsabile dell'unità di ricerca di
Elettrochimica del Progetto ReaPower
Dott.ssa Adriana D'Angelo, PhD student**

L'unità di elettrochimica del progetto REAPower

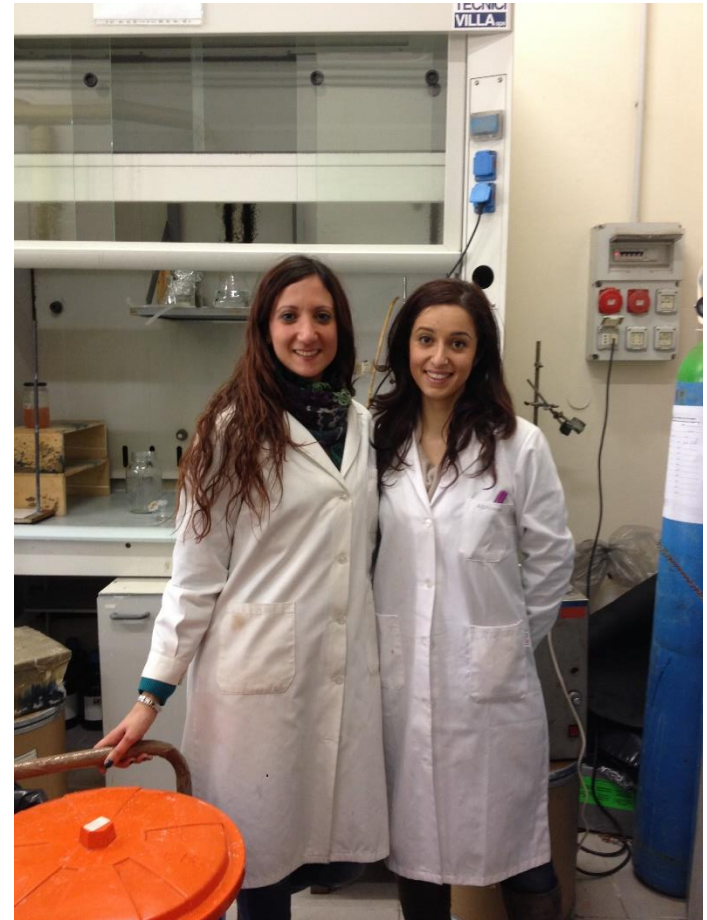
Onofrio Scialdone, Alessandro Galia



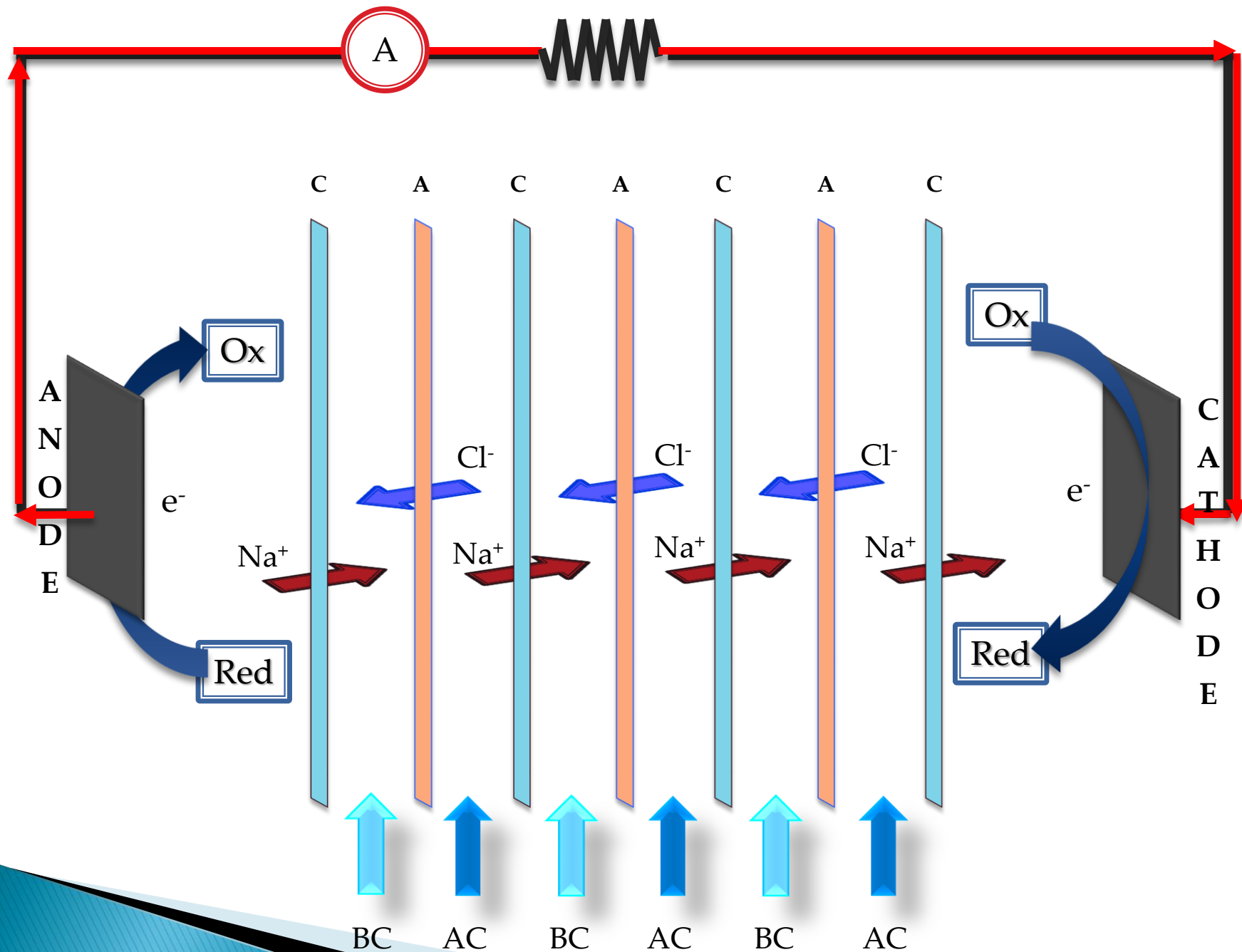
Serena Antonino ***Chiara*** ***Roberta***
Grispo Monaco ***Guarisco*** ***Riccobono***



Giuseppe
Fanale



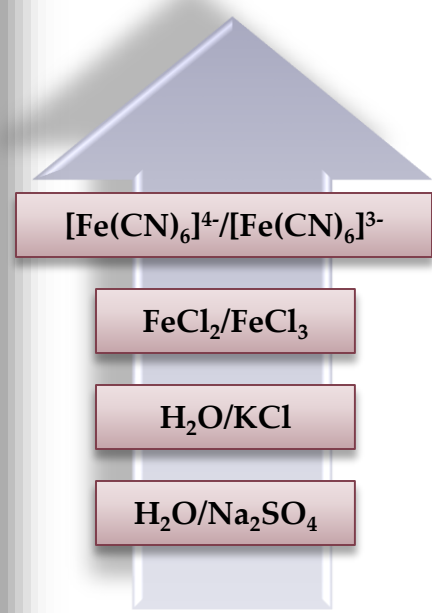
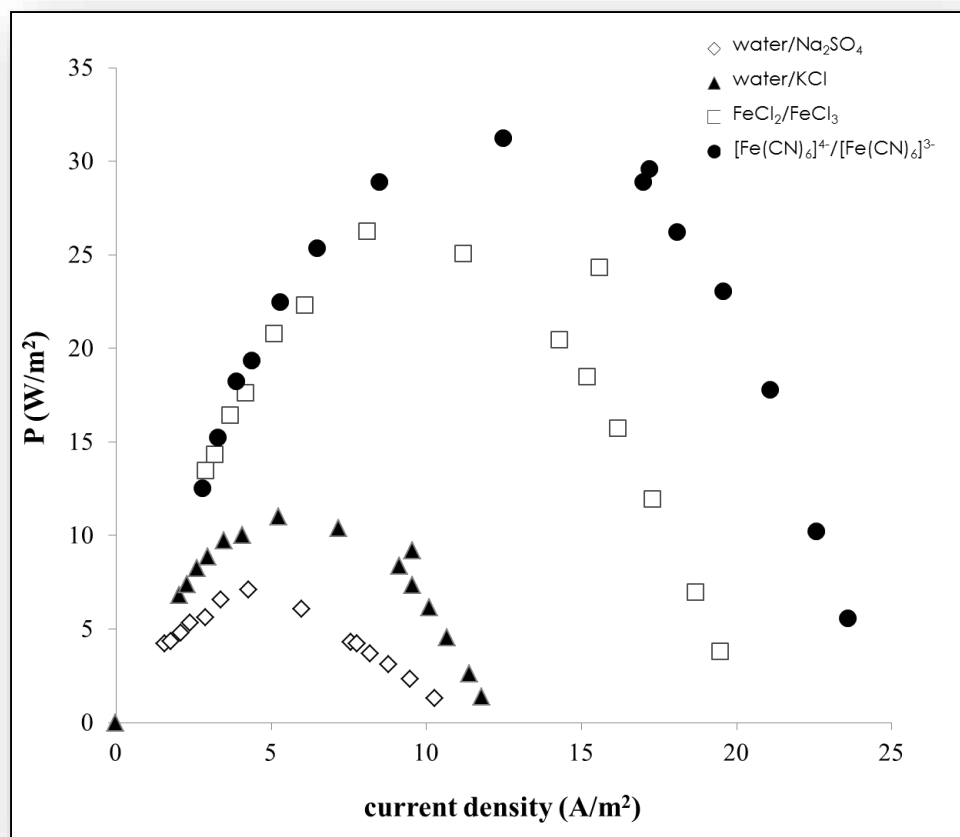
Elisa De ***Adriana***
Lumè ***D'Angelo***



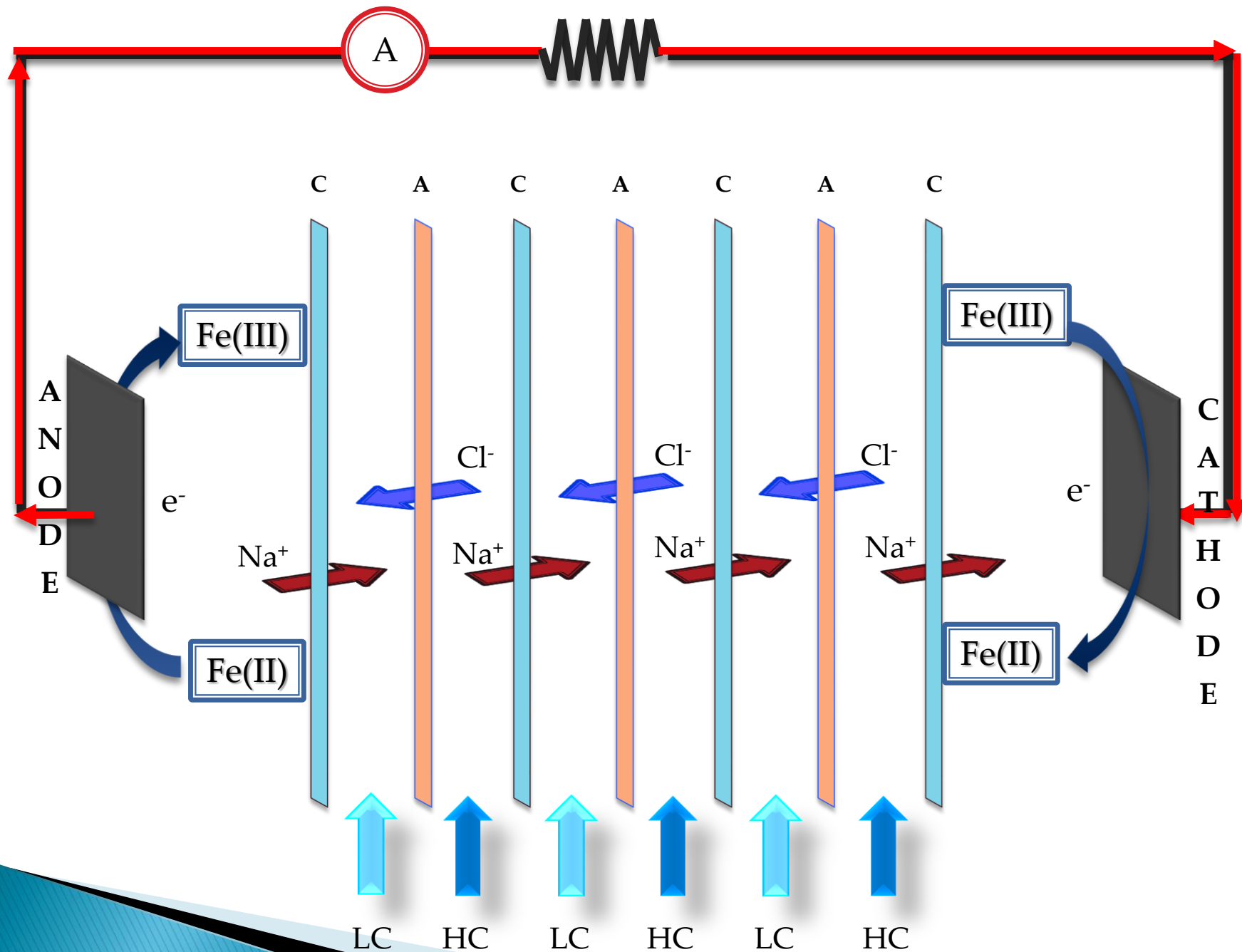
✓ EFFETTO DEI PROCESSI REDOX

GENERAZIONE DI ENERGIA

Plot of power density (computed as the ratio between the power and the total area of cationic membranes) vs. current density recorded in a stack of 40 cells pairs. HC (NaCl 0.5 M) and LC (NaCl 0.01 M) compositions

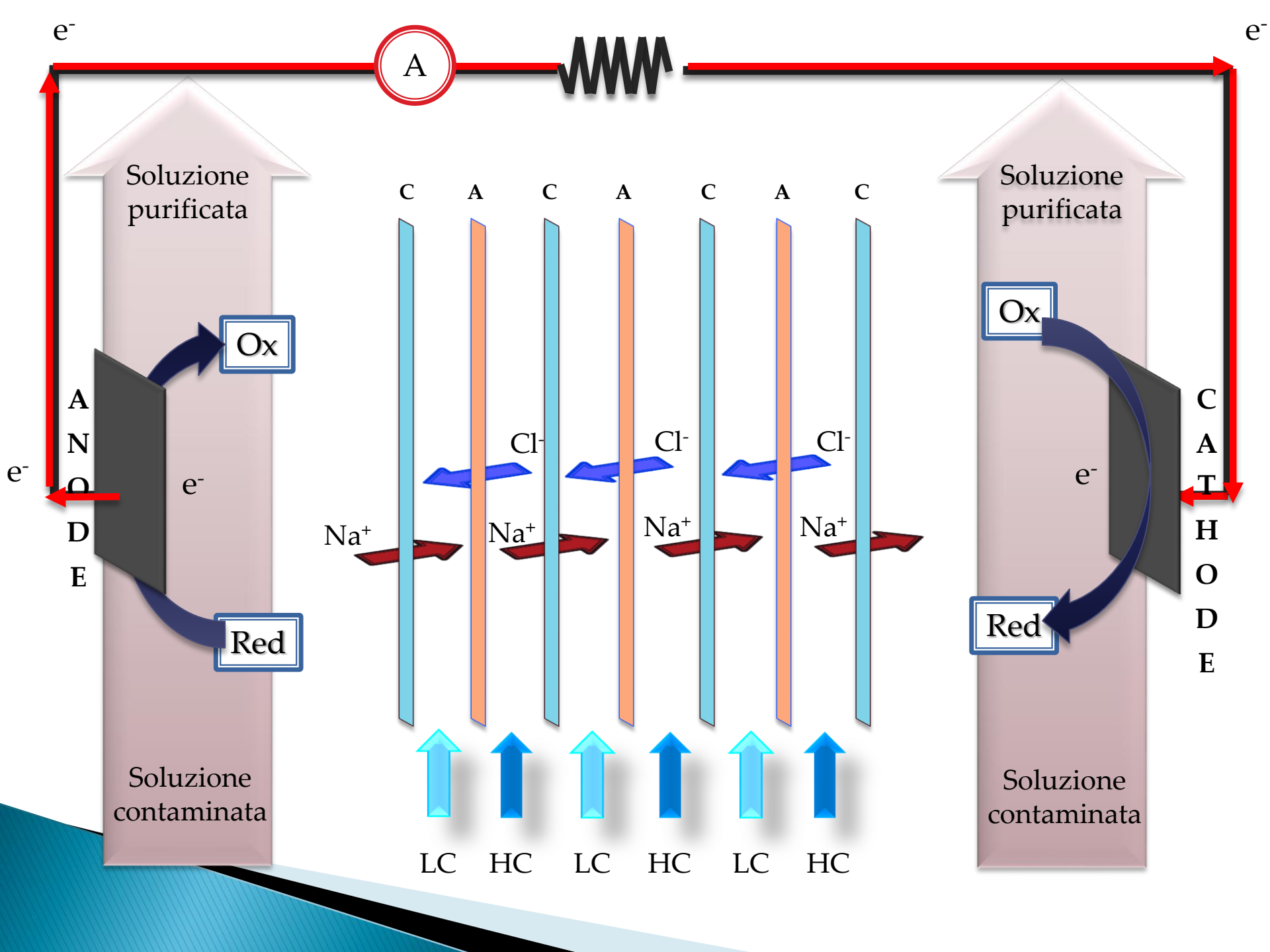


Redox processes	electrode	External membrane	Max power (W)	Max Power density respect to geometric area of cathode (P)	Max power respect to total area of cationic membranes (W/m²)	ΔV	Current Density (A/m²)
H ₂ O → 2H ⁺ + 0.5 O ₂ + 2e ⁻ H ₂ O + e ⁻ → OH ⁻ + 0.5 H ₂	Ti/IrO ₂ Ta ₂ O ₅ anode Pt cathode	Cationic Nafion	0,07	7,1	0,18	1,8	4,1
Cl ⁻ → 0.5 Cl ₂ + e ⁻ H ₂ O + e ⁻ → 0.5 H ₂ + OH ⁻	Ti/RuO ₂ -IrO ₂ anode Pt cathode	Cationic Nafion	0,11	11,03	0,27	2,4	5,3
Fe ³⁺ + e ⁻ = Fe ²⁺	Carbon felt	Anionic Selemion	0,26	26,2	0,66	3,24	8,1
[Fe(CN) ₆] ³⁻ + e ⁻ = [Fe(CN) ₆] ⁴⁻	Carbon Felt cathode Ti/IrO ₂ Ta ₂ O ₅ anode	Cationic Nafion	0,31	31,25	0,78	2,5	12,5



Un nuovo obiettivo

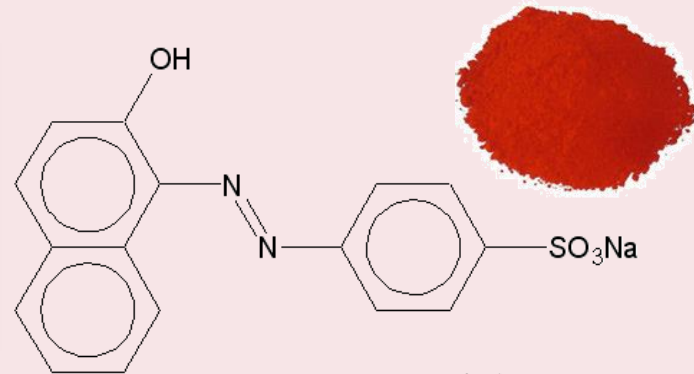
**Utilizzazione dei processi di elettrodialisi inversa
per la generazione di energia elettrica e il
trattamento di acque contaminate da inquinanti
refrattari**



Gli inquinanti modello



Cromo (VI)



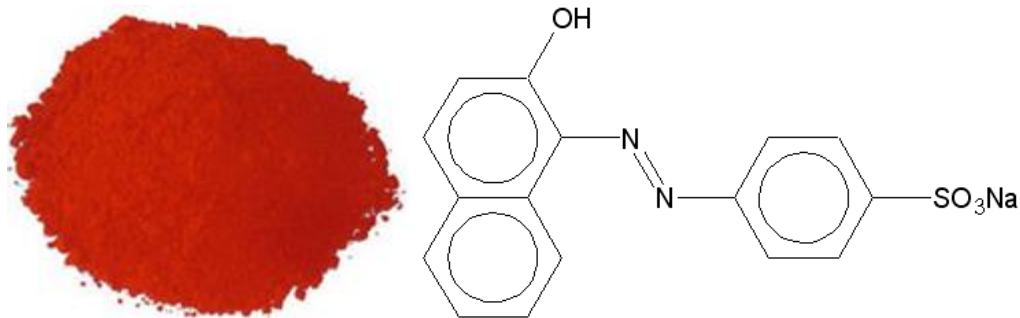
Acid Orange 7

I Coloranti Azoici

Tra i coloranti sintetici presenti sul mercato più del 50% sono caratterizzati dalla presenza del gruppo cromoforo **azoico (N=N)**.

A causa del loro elevato grado di aromaticità, la maggior parte di essi non è biodegradabile in condizioni aerobiche e può essere ridotta in intermedi tossici e pericolosi in condizioni anaerobiche.

L'**Acid Orange 7** (AO7) è il colorante monoazoico acido più prodotto, presenta buona solubilità in acqua, con discreta solidità alla luce e buon potere tintoriale; viene ampiamente utilizzato nelle industrie di cartone, per la colorazione e nella tintura della lana tessile*.



Elementi innovativi

TRATTAMENTO DI
SOLUZIONI
CONTAMINATE



PROCESSI
REDOX

Studio innovativo di un processo di elettrodialisi inversa per la generazione di energia elettrica e il trattamento simultaneo di acque contaminate da inquinanti organici ed inorganici.

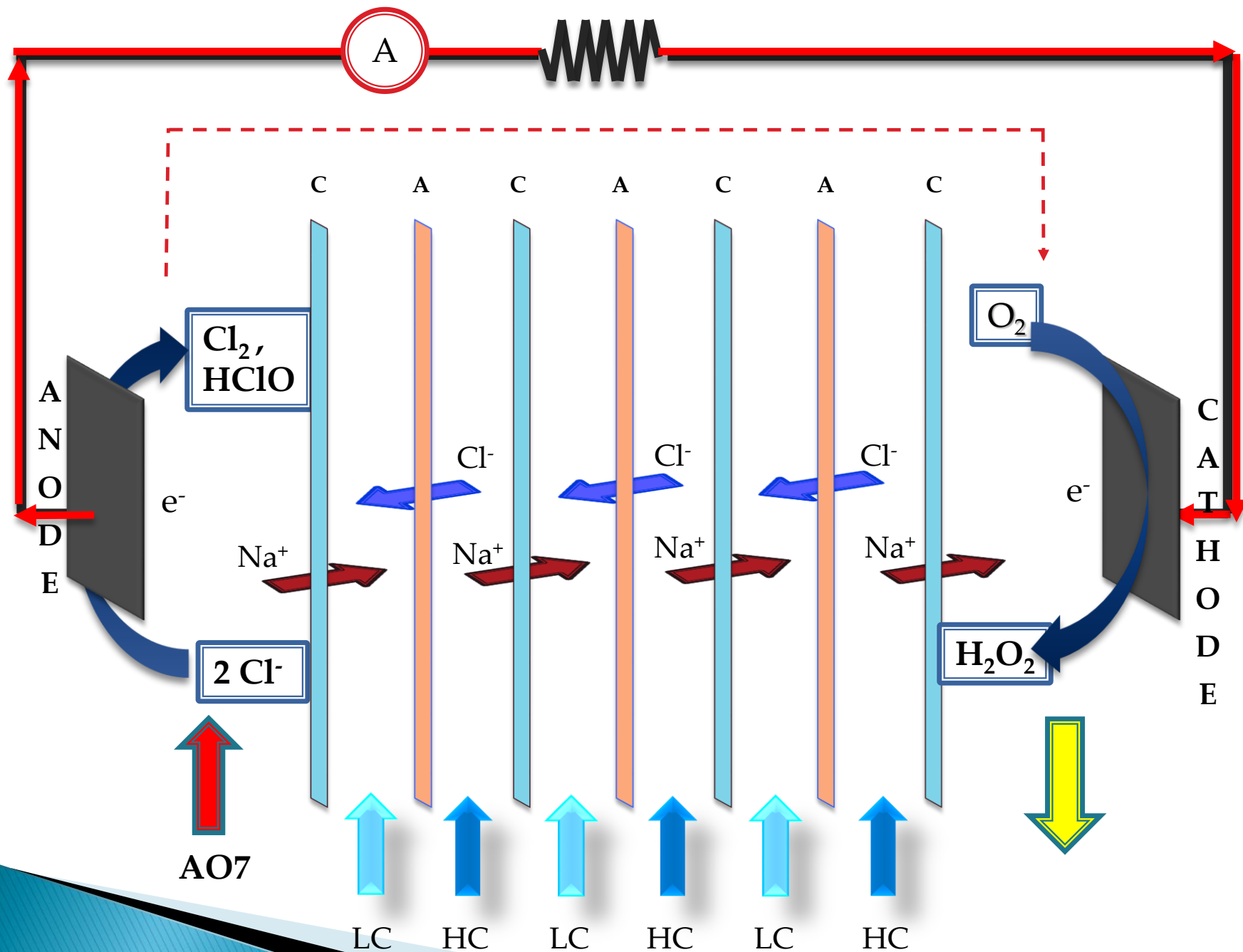
Opportunità di effettuare trattamenti elettrochimici di abbattimento **senza apporto di energia elettrica** dall'esterno.

GENERAZIONE DI ENERGIA ELETTRICA E SIMULTANEO ABBATTIMENTO DI INQUINANTI REFRATTARI AI TRATTAMENTI BIOLOGICI

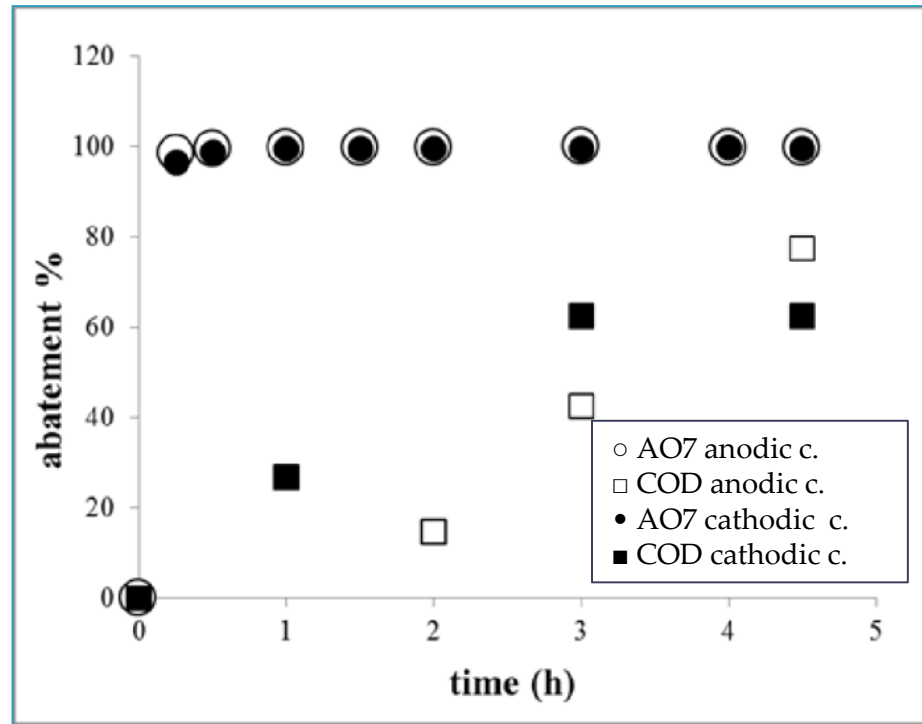
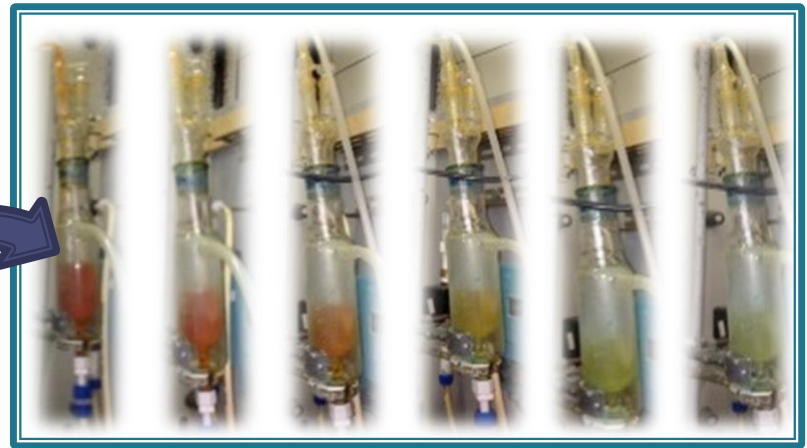
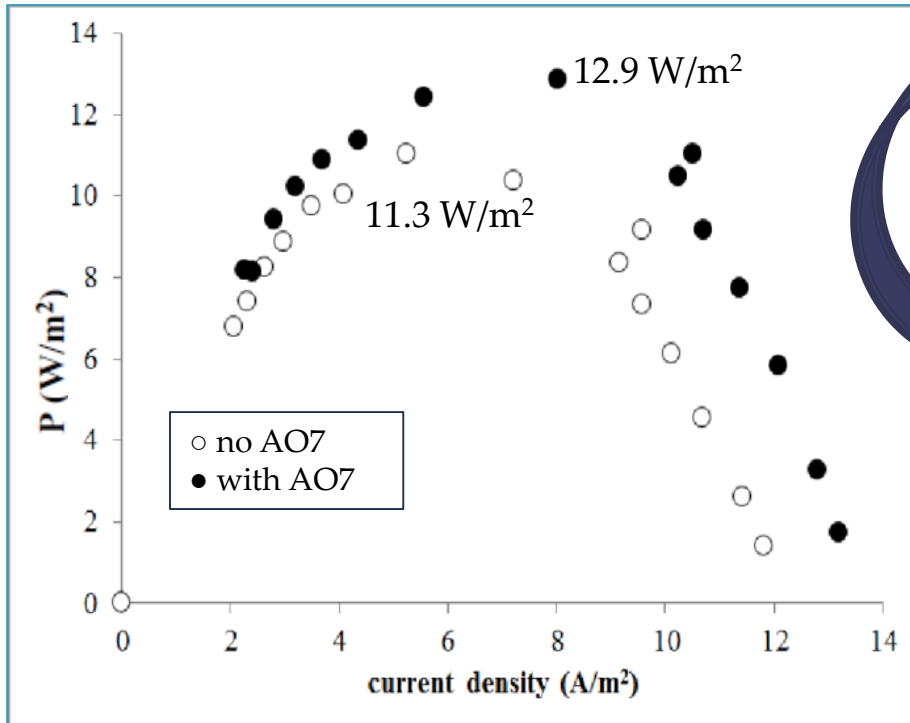
ABBATTIMENTO ELETTROCHIMICO DI AO 7*



*E. Brillas, I. Sirès, M. A. Oturan, *Chem. Rev.* 109 (2009) 6570
O. Scialdone, A. Galia, S. Sabatino, *J. Appl. Catal. B*, 2014



ABBATTIMENTO AO7



Gli equilibri delle reazioni elettrodiche sono spostati verso la formazione dei prodotti (perossido di idrogeno e cloro attivo) guidati dalla reazione con il colorante

Experiments conducted in a stack equipped with 40 cell pairs fed with HC (5 M NaCl) and LC solutions (0.5 M NaCl). Two separated cathodic (0.085 M Na_2SO_4 and 0.5 mM $FeSO_4$ at a pH of 2 (H_2SO_4)) and anodic solutions (0.085 M NaCl at a pH of 2 (HCl)). Anode: Ti/RuO_2-IrO_2 . Cathode: Carbon felt.

Il problema del trattamento del Cr(VI)

LE PRINCIPALI FONTI DI CONTAMINAZIONE

- concia delle pelli
- industria tessile
- industria delle vernici
- industria galvanica
- produzione di refrattari

TOSSICITÀ DEL Cr(VI)

- ✓ Mutageno
- ✓ Cancerogeno
- ✓ Tossico per i microrganismi

REFRATTARIO AI
CONVENZIONALI
I METODI DI
TRATTAMENTO

PROCESSI
ELETTROCHIMICI

Inquinanti Inorganici

i metalli pesanti se presenti nei reflui, sotto forma ionizzata, in concentrazioni elevate esplicano un'attività tossica ed inibitrice dei processi di depurazione biologica dei liquami.

Le percentuali di abbattimento dei metalli pesanti da parte dei processi depurativi primari e secondari sono abbastanza elevate

diretta conseguenza del trattamento è una rilevante concentrazione di metalli nei fanghi, con inconvenienti nelle successive fasi di stabilizzazione biologica e di smaltimento finale, soprattutto se per usi agricoli

Cromo (VI)



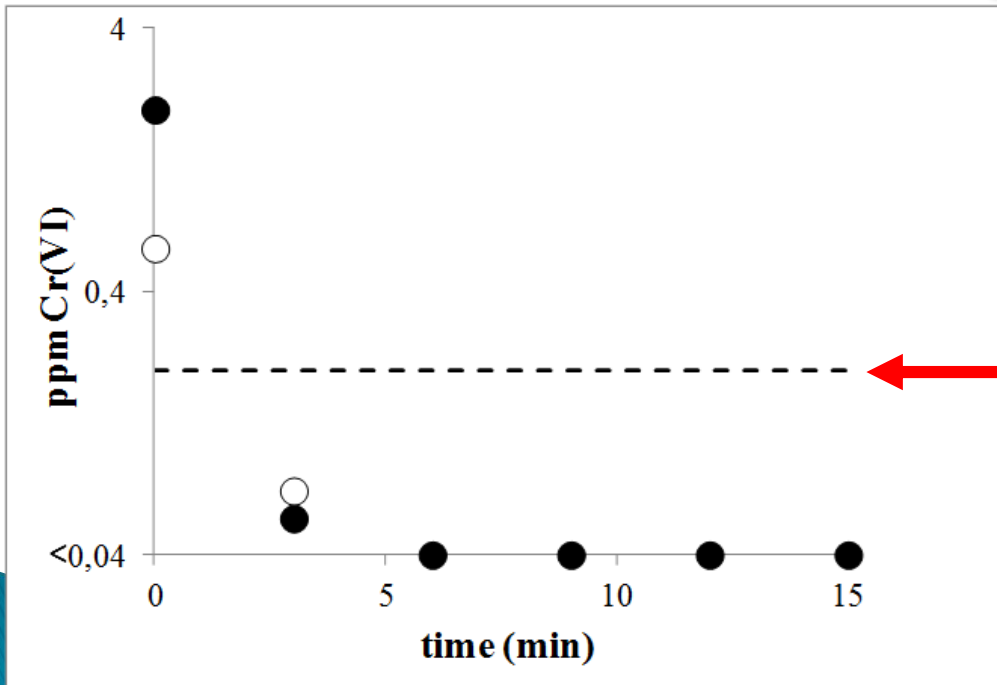
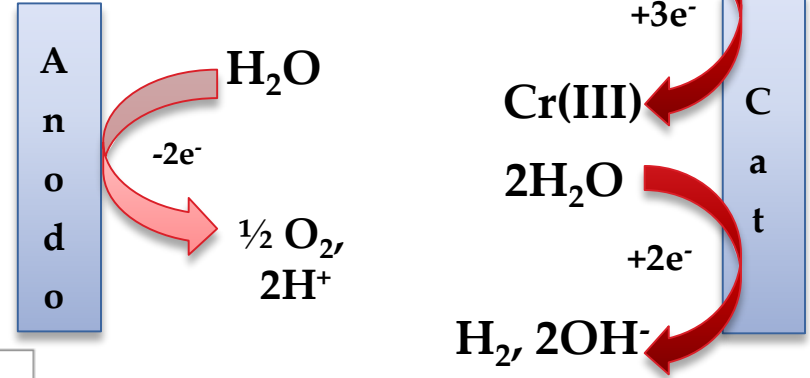
<<BRESCIA – Il problema del cromo esavalente nell'acqua...sentenza di condanna per un'azienda galvanica responsabile dell'inquinamento della falda bresciana attraverso cromo esavalente... Trentotto i pozzi che la Procura ha ordinato di chiudere...>>

Bergamo Sera, martedì 11 Marzo 2014

GENERAZIONE DI ENERGIA ELETTRICA E SIMULTANEO ABBATTIMENTO DI INQUINANTI REFRATTARI AI TRATTAMENTI BIOLOGICI

RIDUZIONE DEL Cr(VI)

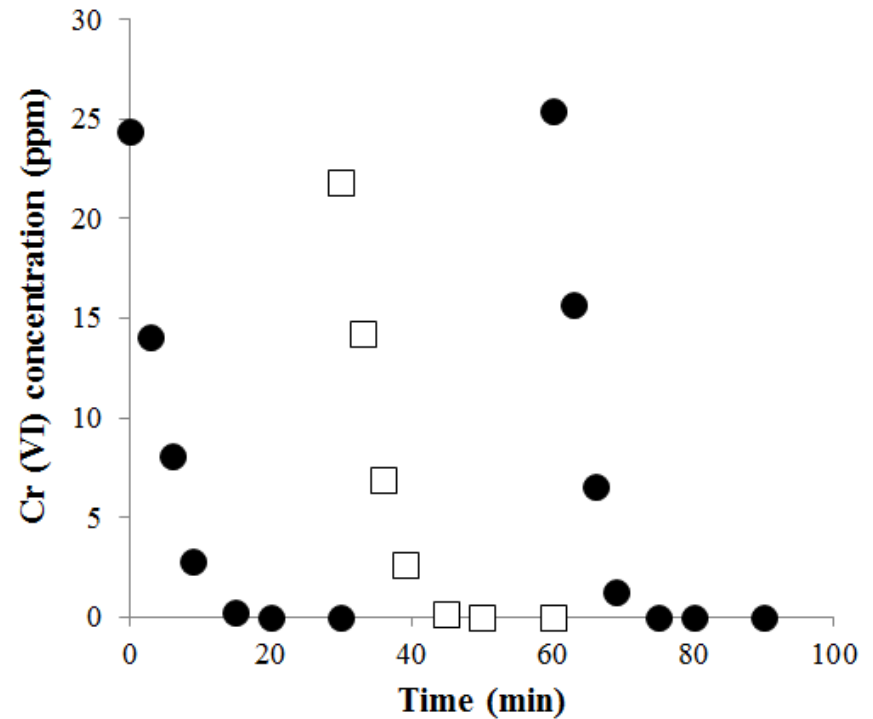
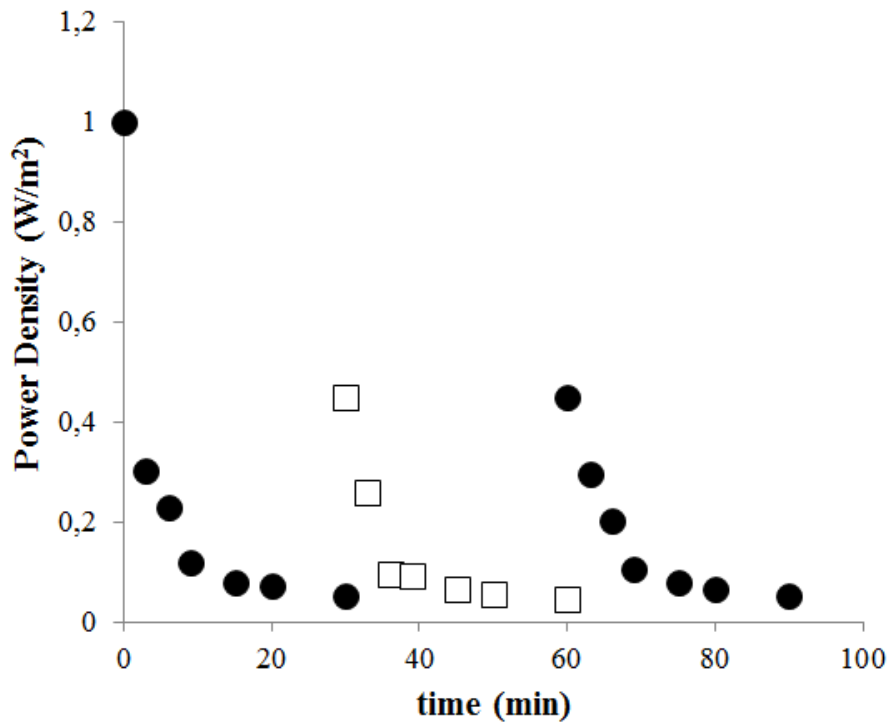
- Riduzione elettrochimica del Cr(VI) a Cr(III) usando una soluzione iniziale contenente $K_2Cr_2O_7$ e Na_2SO_4 e adoperando come catodo carbon felt
- Ossidazione dell'acqua su anodo DSA



Limite
normativo

Experiments performed in a stack equipped with 40 cell pairs fed with HC and LC solutions (5 M and 0.5 M NaCl, respectively) and with two different electrodes: carbon felt as cathode and IrO_2/Ta_2O_5 as anode.

Effetto dell'aggiunta di Cr(VI) nel comparto catodico



Plot of power density (A) and concentration of Cr(VI) (B) vs. time achieved in a stack equipped with 10 cell pairs and carbon felt as cathode (100 cm²) and Ti/IrO₂-Ta₂O₅ as anode.



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Conclusioni

- Studio e messa a punto dei processi redox per elettrodialisi inversa
- Sviluppo di un processo di elettrodialisi inversa per la generazione di energia elettrica e l'abbattimento di inquinanti refrattari



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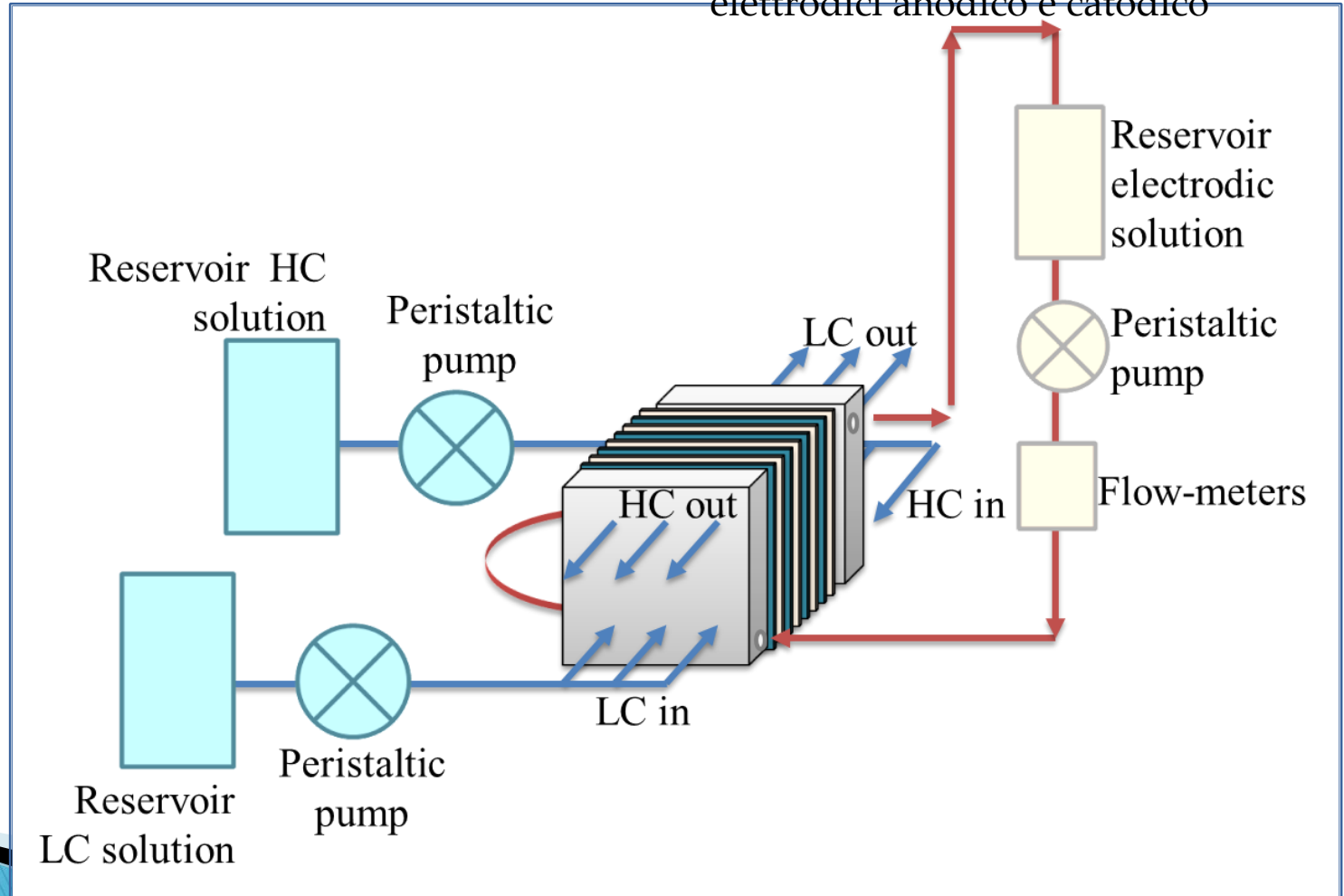


Grazie per la
cortese attenzione

Apparato Sperimentale

SISTEMA A SINGOLO RICIRCOLO

La soluzione elettrodica è continuamente fatta ricircolare fra i due comparti elettrolici anodico e catodico



I Coloranti

Tra i possibili inquinanti presenti nei corpi idrici, i coloranti rappresentano una classe di composti organici largamente utilizzata in molti campi industriali, in particolare in campo tessile.

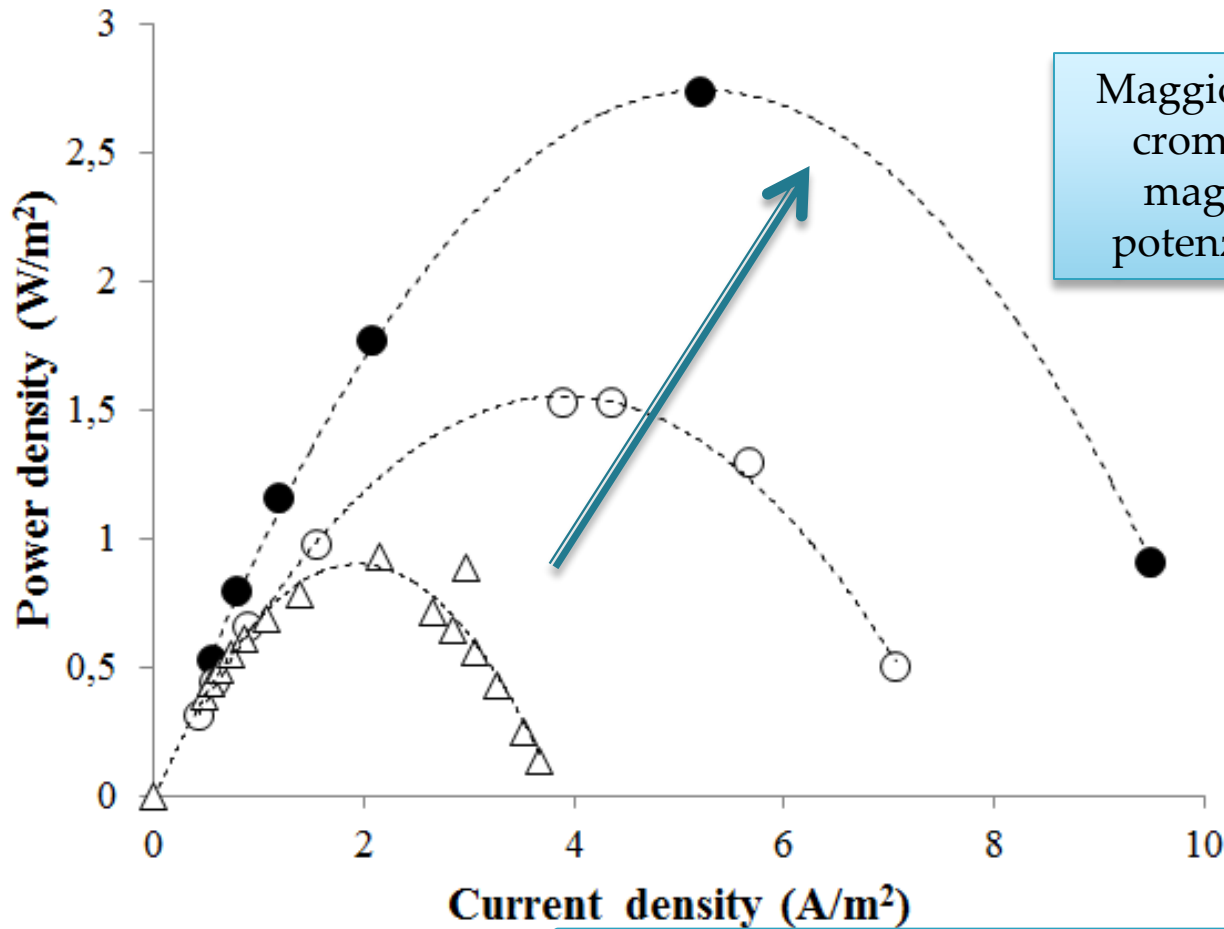


Sono più di 100.000 le tipologie di coloranti organici in commercio in continua crescita nel mercato mondiale con una produzione di oltre $7 \cdot 10^5$ tonnellate/anno*

La loro intensa applicazione può provocare gravi fattori di rischio sia per l'ambiente che per l'uomo.

* E. Brillas et al, "Decontamination of wastewaters containing synthetic organic dyes by electrochemical methods", Applied Catalysis B:Environmental 87(2009) 105-145.

Effetto della concentrazione del Cr(VI)



Maggiore è la concentrazione di cromo presente in soluzione maggiore sarà la densità di potenza msurabile dal sistema

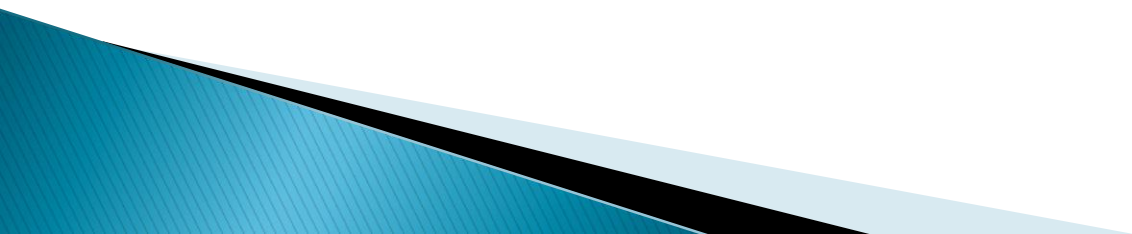
Elisa De Lumè

reports power densities (normalized to the cathode geometric area of 100 cm²) vs. current densities recorded changing the external resistance between 160 and 1 ohm in the **absence** (△) and in the presence of 25 (○) and 50 (●) ppm of Cr (VI) in the cathodic solutions.

THANKS FOR YOUR KIND ATTENTION

Publications and Communications (2013):

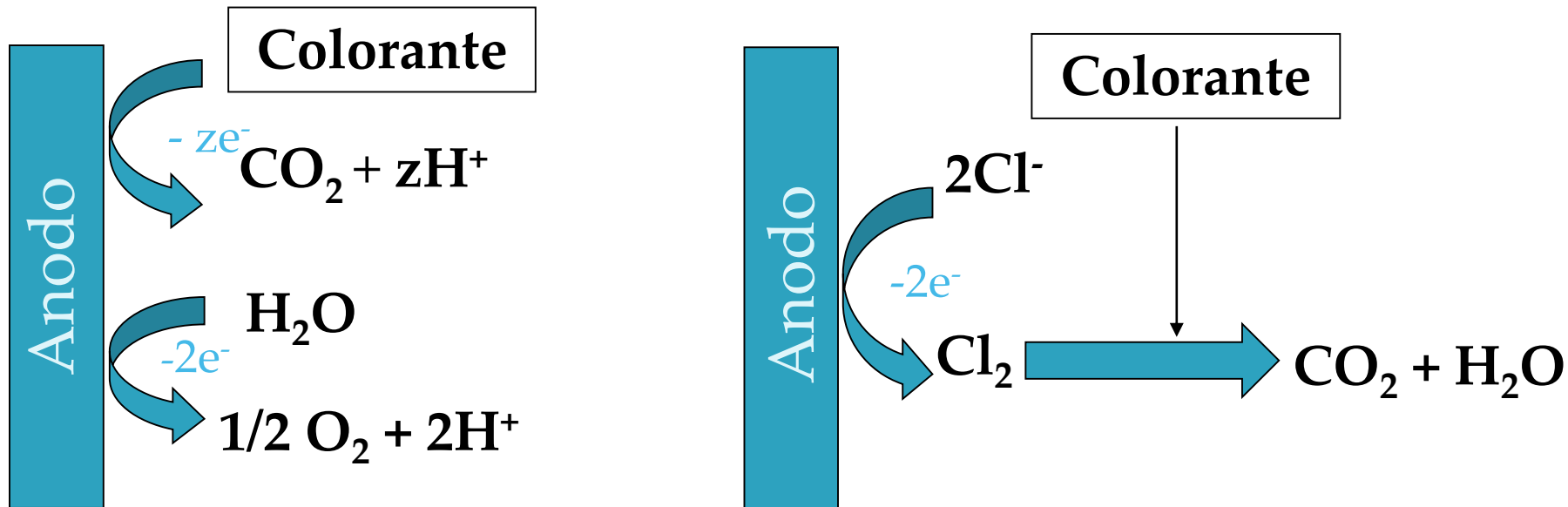
- O. SCIALDONE, A. D'ANGELO, A. ALBANESE, A. GALIA, C. GUARISCO, "Investigation of electrode material - redox couple systems for reverse electro dialysis processes. Part II: experiments in a stack with 10-50 cell pair", Journal of Electroanalytical Chemistry 704 (2013) 1-9
- O. SCIALDONE, A. GALIA, A. D'ANGELO, "Energy capture and abatement of recalcitrant pollutants in reverse-electrodialysis cells using salinity gradients" submitted to "Journal of Electrochemistry Communication", 2013.
- A. D'ANGELO, A. GALIA, R. RICCOBONO, E. DE LUME', O. SCIALDONE "Abatement of recalcitrant pollutants in aqueous solutions by reverse electro dialysis processes", Submitted;



Ossidazione elettrochimica diretta:

La specie inquinante si ossida a CO_2 sulla superficie dell'elettrodo.

È fondamentale la scelta del materiale anodico e delle condizioni operative ottimali.

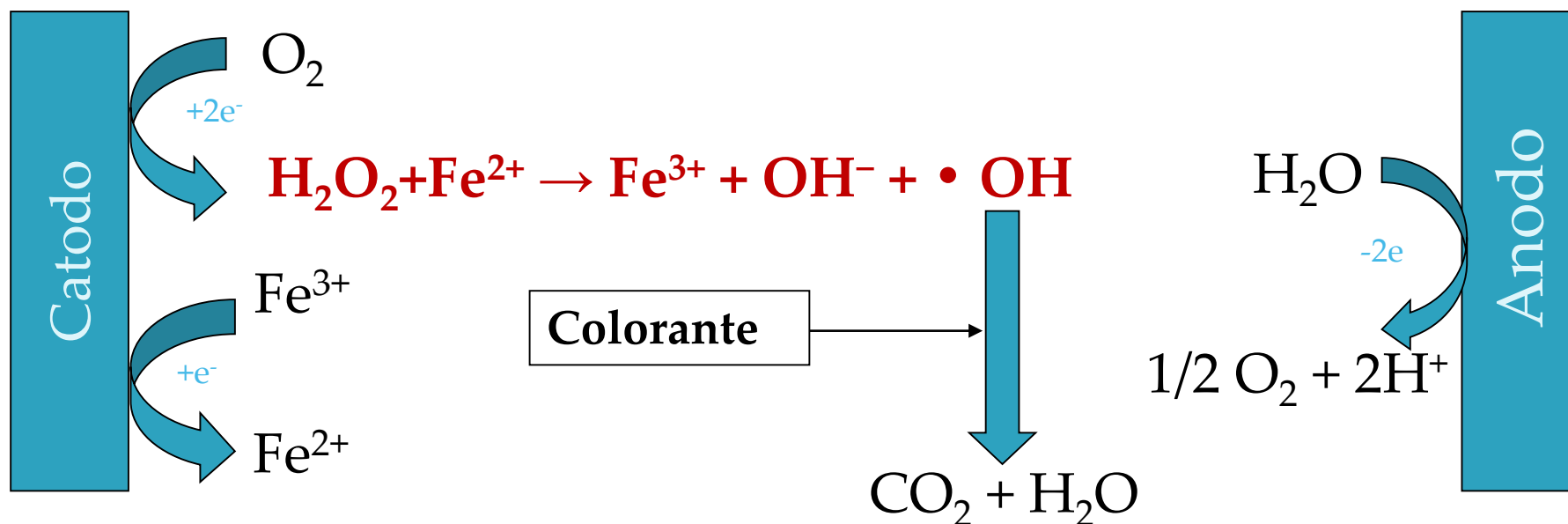


Ossidazione elettrochimica indiretta con cloruri:

L'ossidazione dello ione cloruro, presente nell'effluente acquoso, porta alla formazione di cloro attivo, specie in grado di ossidare gli inquinanti organici complessivamente fino alla mineralizzazione.

Elettro-Fenton:

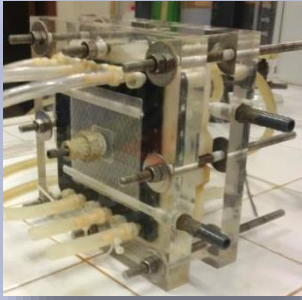
L'elettro-Fenton rientra tra i processi elettrochimici indiretti. L'abbattimento del colorante avviene tramite il perossido di idrogeno generato elettrochimicamente al catodo per riduzione dell'ossigeno. Esso presenta un potere ossidante basso, viene infatti attivato in **effluenti acidi** con ioni **Fe²⁺** come catalizzatore (processo Fenton) per produrre **radicali ossidrilici •OH** caratterizzati da un forte potere ossidante* .



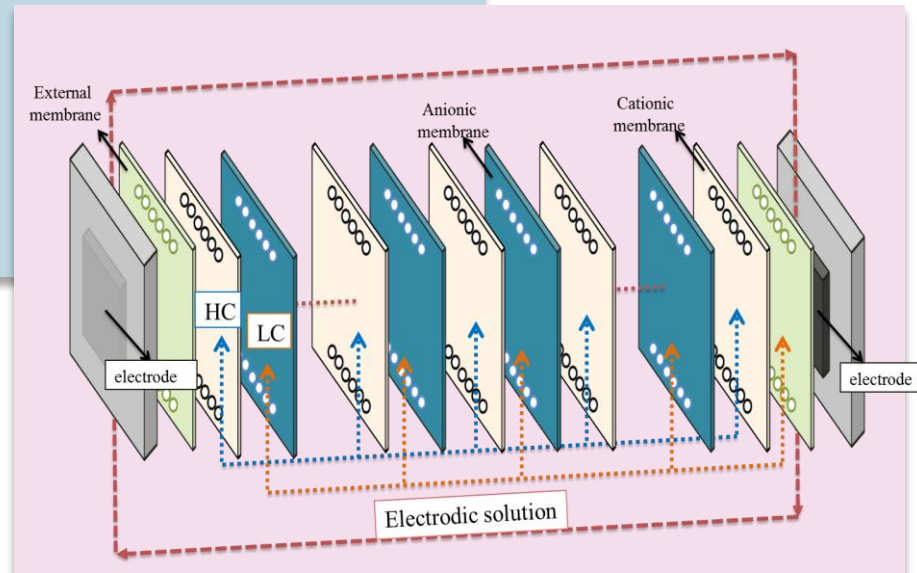
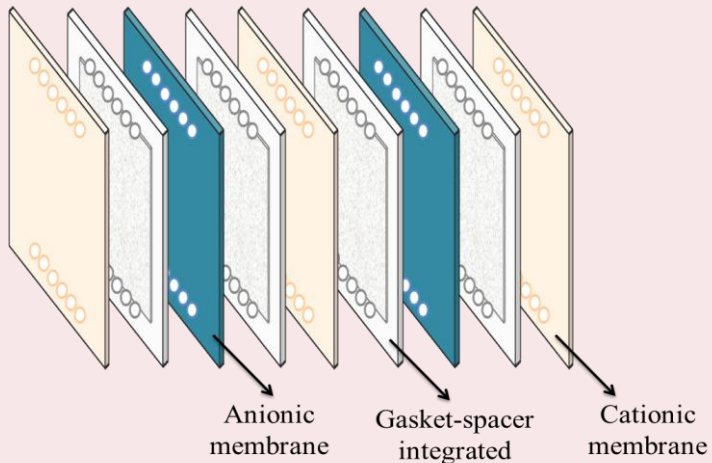
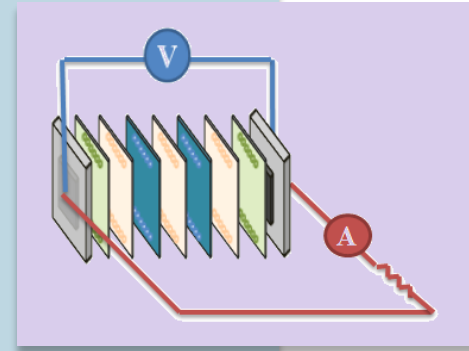
*.Mehmet A. et al., "Removal of Acid Orange 7 from water by electrochemically generated Fenton's reagent", Journal of Hazardous Materials 163 (2009) 1213–1220.

Vantaggi	Svantaggi
<i>Utilizzo dell'elettrone come reagente</i>	<i>Costi di investimento</i>
<i>Selettività</i>	<i>Energia elettrica</i>
<i>Velocità di reazione</i>	<i>Basse efficienze di corrente (CE) ad elevati abbattimenti</i>
<i>Condizioni operative blande</i>	
<i>Costi di gestione</i>	<i>Elettrolita di supporto</i>

L'applicabilità su scala industriale dei processi elettrochimici in campo ambientale risulta limitata dalla presenza di diversi svantaggi.



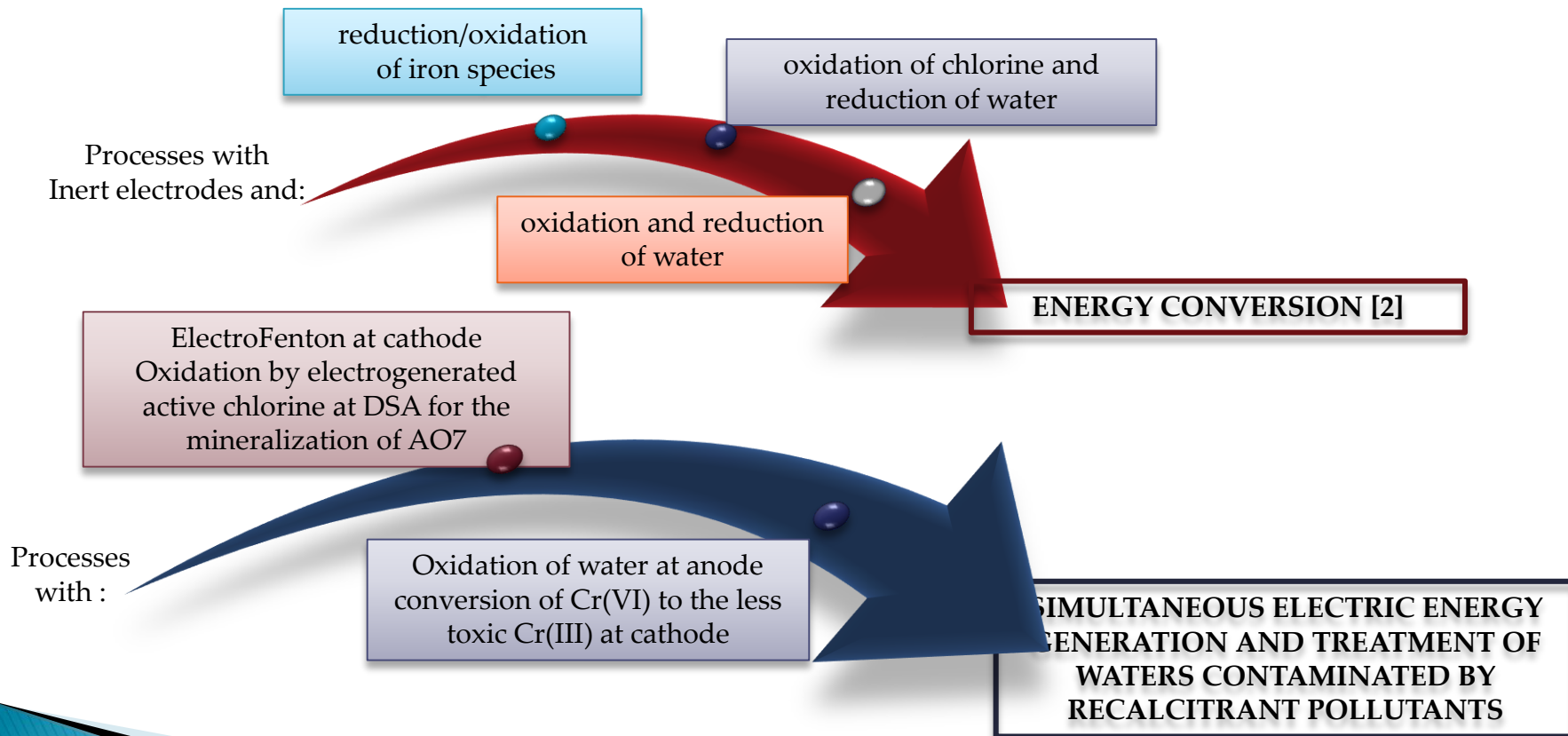
Apparato Sperimentale



Aim of this study:

To investigate the behavior of electrode systems under operative conditions of interest for RED applications

✓ Selection of redox processes and electrode materials [1]

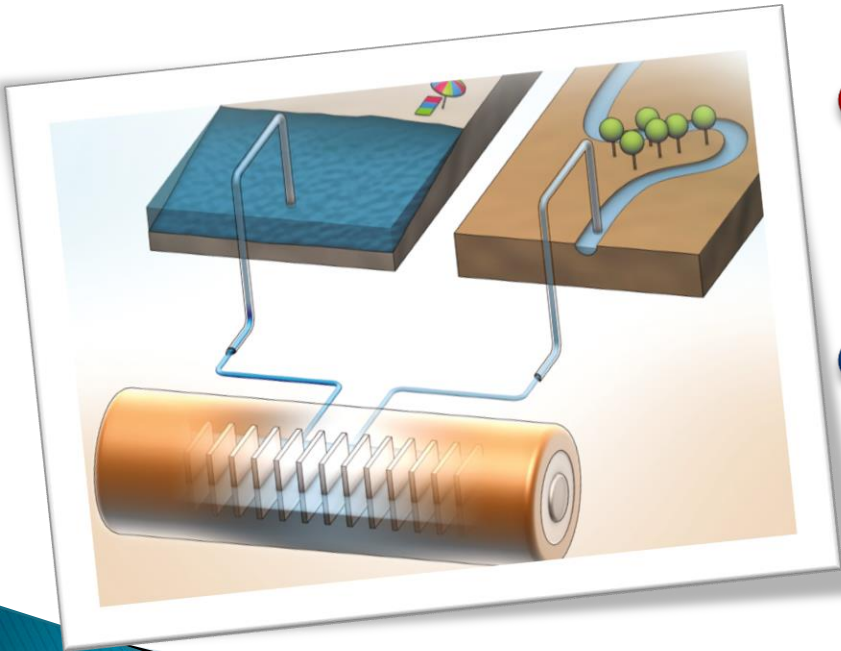


1. O. Scialdone, A. D'Angelo, C. Guarisco, S. Grispo, A. Galia / *Journal of Electroanalytical Chemistry* 681 (2012) 66–75
2. O. Scialdone, A. D'Angelo, A. Albanese, A. Galia, C. Guarisco / *Journal of Electroanalytical Chemistry* 704 (2013) 1–9

Introduction

Energy can be generated from the reversible mixing of salt solutions with different concentrations and is called **salinity gradient power (SGP)**.

- The energy that theoretically can be generated per m^3 of river water is 1.7 MJ when mixed with the identical sea water volume or even 2.5 MJ when mixed with a large surplus of sea water [3].



- It is possible to convert this potential energy into useful electricity with an 85% efficiency [4].

- The salinity power available is potentially 2.6 TW [5], which should be sufficient to satisfy either the global electricity demand (2 TW) or 16% of the total present energy consumption [6].

3. Veerman J, Metz SJ, Saakes M, Harmsen GJ (2009) J Membr Sci 327:136

4. Post JW, Hamelers HVM, Buisman CJN (2008) Environ Sci Technol 42:5785

5. Wick GL, Schmitt WR (1977) Mar Technol Soc J 11:16

6. Energy information administration; www.eia.doe.gov

OPPORTUNITIES FOR THE APPLICATION

CHALLENGES:

- ✓ low cost membrane development
- ✓ pretreatment of the solutions to feed the stack
- ✓ cost and toxicity of redox couple, cost of electrodes
- ✓ cost of the stack



ECONOMICS

HEALTH

SAFETY

ENVIRONMENT

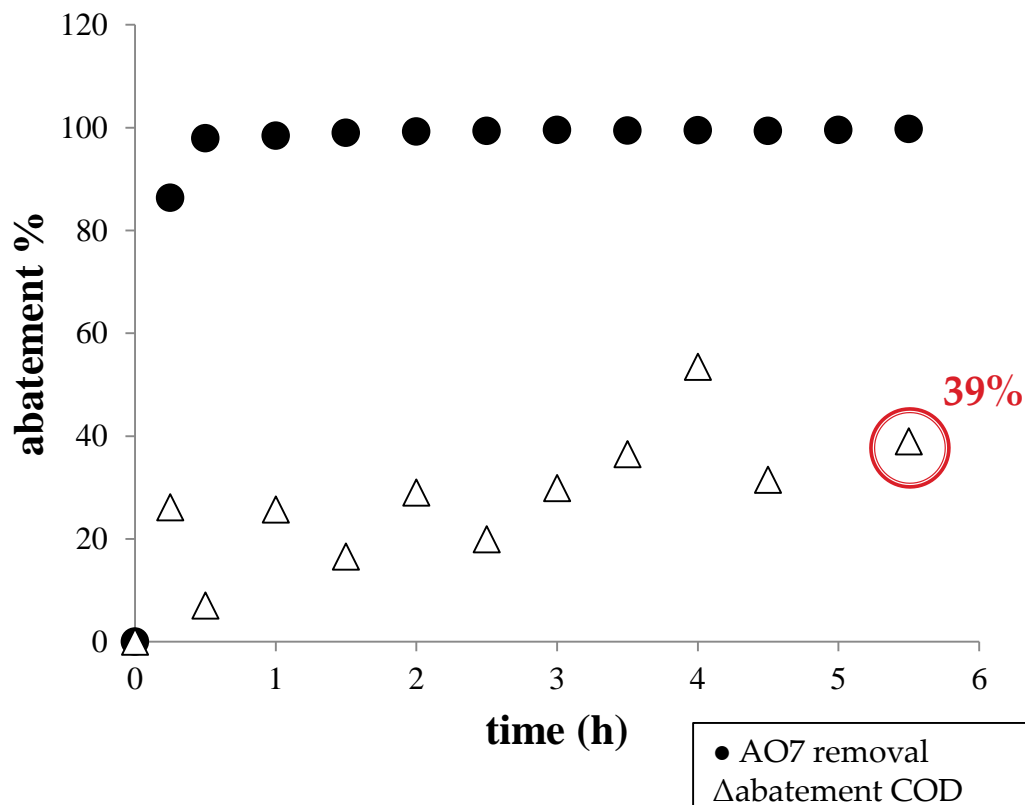
IMPROVEMENTS:

- ✓ **Membranes:**
 - increase in availability ($> \text{Km}^2/\text{year}$)
 - reduction of the cost ($< 2\text{€}/\text{m}^2$)
- ✓ filtration of brine and sea solutions through a rotating filter drum
- ✓ **redox system:** high stability, low redox voltages, couple redox and electrode low cost, high performing external membranes
- ✓ graphite and DSA **electrodes** are used \rightarrow relatively inexpensive
- ✓ **RED** is a clean and sustainable technology

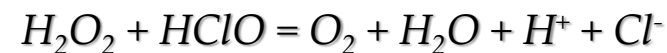


✓ SINGOLO CIRCUITO IDRAULICO

ABBATTIMENTO
AO7



Si registra un più lento abbattimento del COD inseguito all'innescarsi della reazione fra H_2O_2 con $HClO$



Reazione che provoca una riduzione della concentrazione delle due specie ossidanti

I prodotti di degradazione del AO7 sono stati identificati mediante HPLC

sono acidi carbossilici (ossalico, maleico, malonico and acido lattico)

Experiments performed in a 40 cell pair stack fed with HC (5 M NaCl) and LC solutions (0.5 M NaCl). AO7 (150 mg/L) was added to a solution containing NaCl (0.085 M) and 0.5 mM $FeSO_4 \cdot 7H_2O$. pH was adjusted to 2 by H_2SO_4 addition. Anode: Ti/RuO₂-IrO₂. Cathode: Carbon felt.

Experimental set-up

Experimental apparatuses

Anion exchange membrane FUJI

Gasket + spacer integrated

Cation exchange membrane FUJI

frame of PMMA + carbon felt electrode

frame of PMMA + DSA electrode

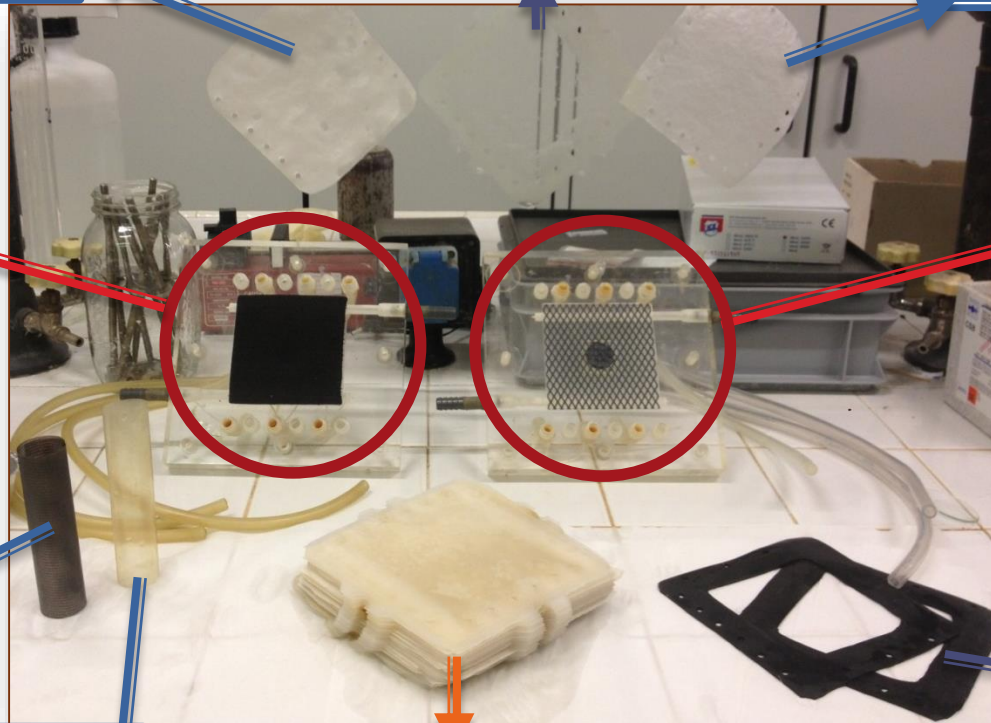
Cation exchange membrane NAFION

Anion exchange membrane SELEMION

membrane stack with alternating 40 CEM and 40 AEM

gasket

Stack supplied by REDSTACK



Experiments in stack:

1 GENERATION OF ELECTRIC ENERGY

ELECTRODIC SOLUTION

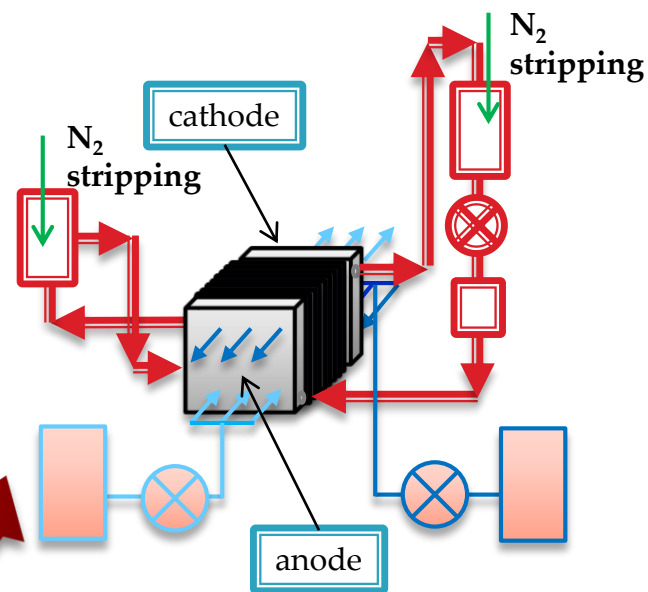
- Na_2SO_4 (0.04 M) (Sigma Aldrich) for water/ Na_2SO_4 system;

- NaCl or KCl (Sigma Aldrich) for water/ NaCl system;

- FeCl_2 and FeCl_3 (0.3 M) from Sigma Aldrich or $\text{K}_3[\text{Fe}(\text{CN})_6]$ and $\text{K}_4[\text{Fe}(\text{CN})_6]$ (0.3M) from Labochem were used as received for iron redox couple systems.

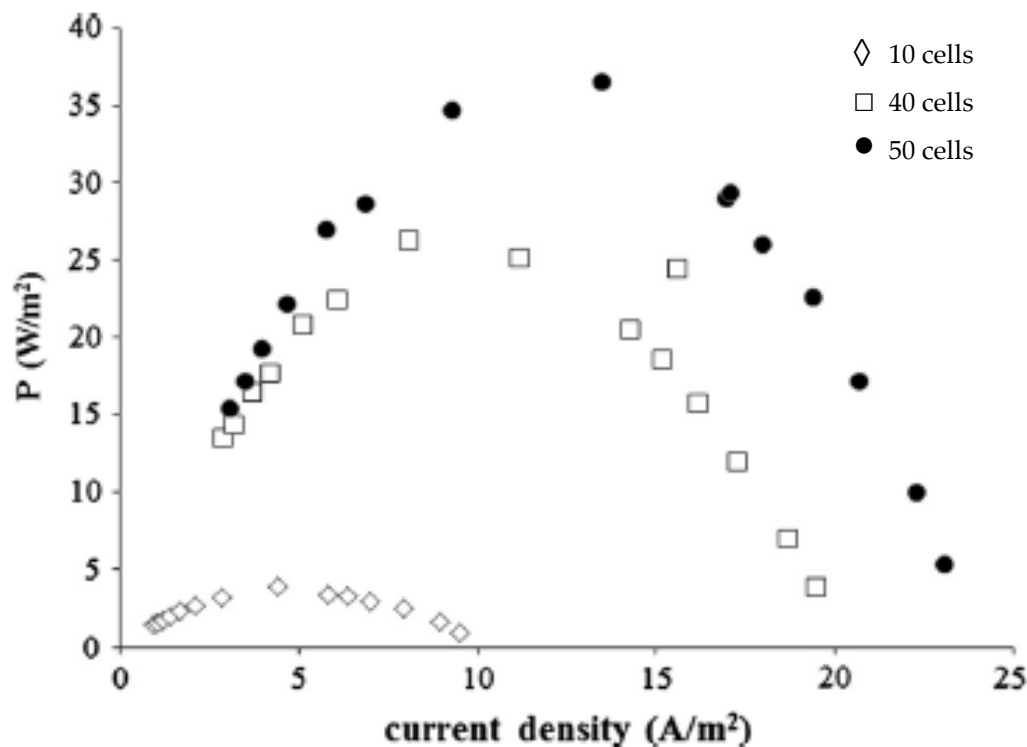
WATER SOLUTION

Solutions used in HC and LC compartments were prepared by dissolving NaCl (5 M or 0.5 M in HC and 0.5 M or 0.01 M in LC solutions)



✓ EFFECT OF THE NUMBER CELLS PAIR

SIMULTANEOUS GENERATION OF ELECTRIC ENERGY AND ABATEMENT OF RECALCITRANT POLLUTANTS



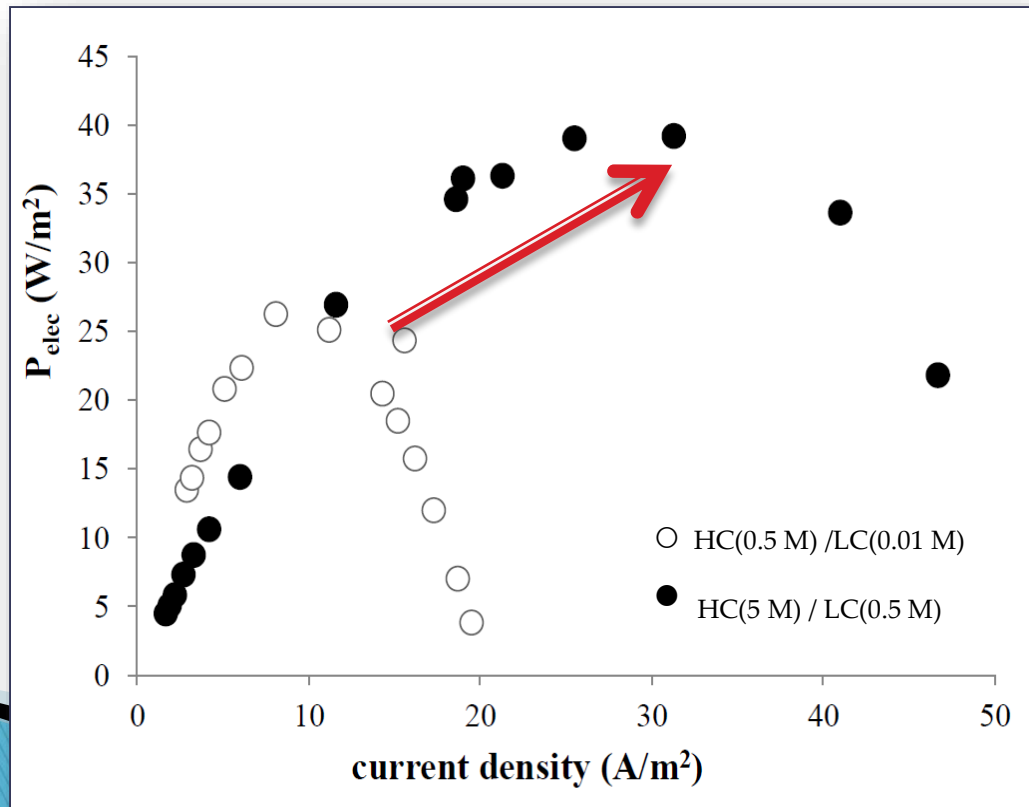
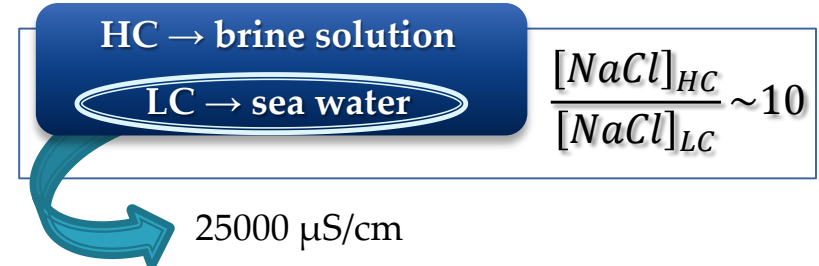
Plot of power densities vs. current density recorded in a stack for $FeCl_2/FeCl_3$ with carbon felt electrodes with an external resistance varied between 1 and 160 ohm with fixed HC (NaCl 0.5 M) and LC (NaCl 0.01 M) compositions.

result of the lower impact of the energetic loss due to the redox processes compared with the overall power generation.

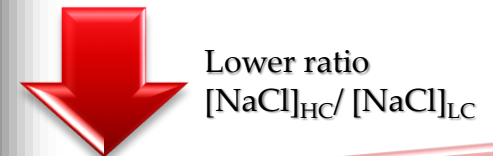
Number of cell	Max power (W)	Max Power density respect to geometric area of chatode (P)	Max power respect to total area of cationic membranes (W/m^2)	ΔV	Current density (A/m^2)
10	0,039	3,9	0,39	0,97	4,4
40	0,25	25,1	0,625	2,44	11,2
50	0,36	36,4	0,73	2,45	13,5

✓ EFFECT OF THE SALINITY GRADIENT

SIMULTANEOUS GENERATION OF ELECTRIC ENERGY AND ABATEMENT OF RECALCITRANT POLLUTANTS



BRINE SOLUTION
SEA WATER



Higher conductivity of LC solution



Experiments in stack:

2

SIMULTANEOUS GENERATION OF ELECTRIC ENERGY AND ABATEMENT OF RECALCITRANT POLLUTANTS

ELECTRODIC SOLUTION

□ TWO HYDRAULIC CIRCUITS :

- **anodic solution** AO7 (150 mg/L), NaCl (0.085 M) and HCl (pH = 2)

- **cathodic solution** AO7 (150 mg/L), Na₂SO₄ (0.085 M), 0.5 mM FeSO₄*7H₂O and H₂SO₄ (pH = 2).

□ ONE HYDRAULIC CIRCUIT:

the electrolytic solution contained AO7 (150 mg/L), NaCl (0.085 M), 0.5 mM FeSO₄*7H₂O, and H₂SO₄ (pH = 2).

ELECTRODIC SOLUTION

□ TWO HYDRAULIC CIRCUITS:

- **anodic solution** Na₂SO₄ (0.1 M) pH=2 (H₂SO₄)

- **cathodic solution** Cr(VI) with an initial concentration of either 0.5 or 2 mg/L,

Na₂SO₄ (0.1 M) as supporting electrolyte at a pH = 2 (H₂SO₄).

ELECTRODES

Anode: DSA-Cl₂,

Cathode: carbon felt

ELECTRODES

Anode: DSA-O₂,

Cathode: carbon felt

WATER SOLUTION

Solutions used in HC and LC compartments were prepared by dissolving

NaCl (5 M or 0.5 M in HC and 0.5 M or 0.01 M in LC solutions)

Conclusions


- All tested redox processes can be used for reverse electro dialysis applications with proper external membranes and electrodes
- Power density was shown to depend also on concentration of **redox species** and on the **number of cell pairs**.
- The utilization of NaCl concentrations for concentrated (HC) and dilute (LC) compartments similar to that of **salt pond** and **seawater** solutions allowed to achieve a drastic **increase of the power output**
- RED can be efficiently used for both the generation of electric energy and the abatement of recalcitrant pollutants or the water disinfection by using widely available salinity gradients

Conclusions

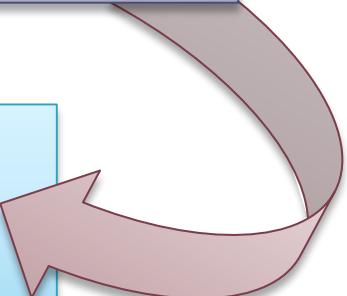
- Experiments were carried out using both two separated and only one hydraulic circuit:
 - When both cathodic and anodic compartments were hydraulically connected, slower abatements of COD occurred.
 - A very fast abatement of color AO7 was achieved in both compartments coupled with a progressive reduction of COD and with the generation of electric energy.
- A very fast removal of Cr(VI) was achieved coupled with the generation of electric energy.
- Power and current densities decreased with treatment time as a result of the consumption of Cr(VI)
- The abatement of pollutants by reverse electro dialysis processes could increase the interest in the use of this technology for water disinfection.

Next step:

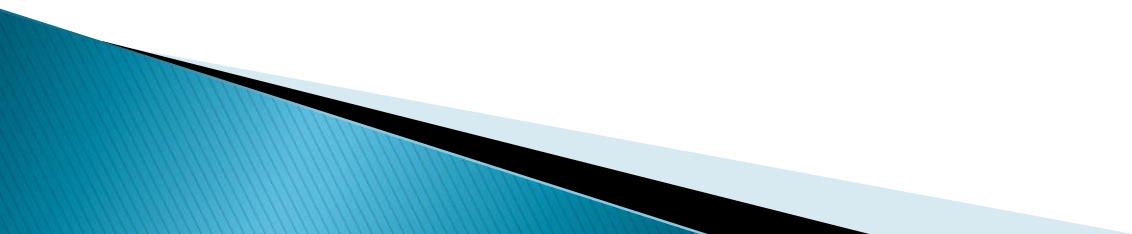
RED-MFC



Utilization of microbial electrodes to increase the generation of electric energy



Possible utilization of redox processes to increase the value of the process and to generate energy and abatement of pollutant simultaneously



ION EXCHANGED MEMBRANES

CATION-EXCHANGE-MEMBRANES (CEM)

ANION-EXCHANGE-MEMBRANES (AEM)

Name	Code	Company	Type	Polymer matrix
FUMASEP	FKS	Fumatech (Germany)	CEM	PET
	FAD	Fumatech (Germany)	AEM	PA PEEK
SELEMION	CMV	Asahi Glass	CEM	POLY(STYRENE-CO-DIVINYBRNZENE)
	AMV	Asahi Glass	AEM	
FUJI	C	FujiFilm	CEM	POLYETHYLENE
	A	FujiFilm	AEM	
NAFION	324	Du Pont	CEM	PERFLUORINATED BILAYER

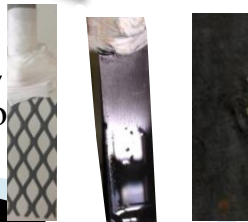
MAIN CHARACTERISTICS:

- ~ Low electrical resistance
- ~ High selectivity of permeation
- ~ Good mechanical and chemical stability

ELECTRODES:

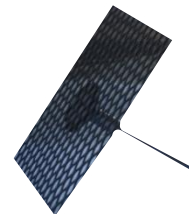
FOR UNDIVIDED AND DIVIDED CELLS

- A) Pt and DSA, in mesh, provided by Magneto
 B) Graphite compact;
 C) Graphit Felt.



A) B) C)

FOR STACK



A)

B)

- A) DSA-Cl₂, in mesh, provided by Magneto
 B) Graphite fet

Size: 10 x 10 cm

Thickness: 2mm

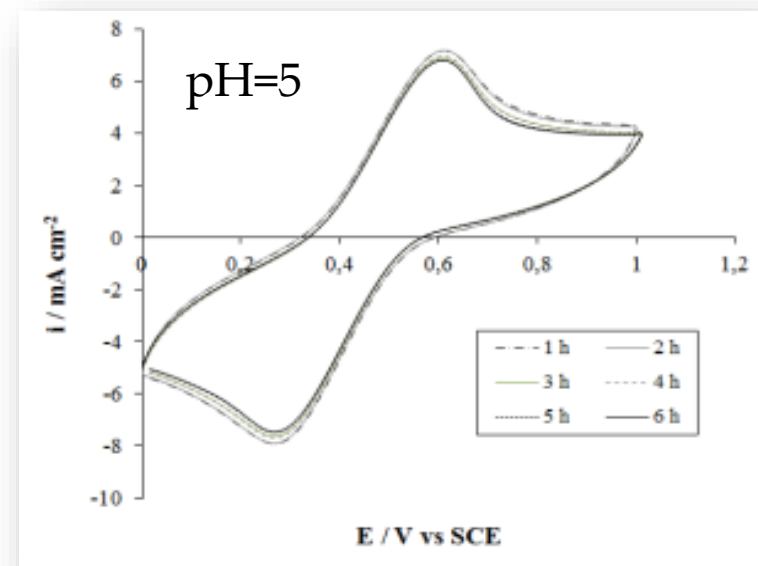
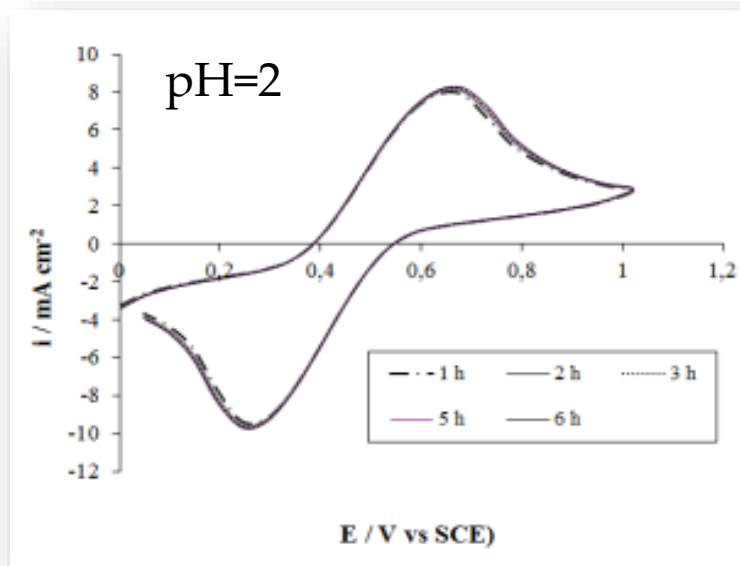
❖ Result and discussion

STABILITY OF THE REDOX COUPLE IN THE TIME

EXPERIMENTAL CONDICTION:

SYSTEM: undivided cell
The electroanalytical behavior of the couple $\text{FeCl}_3/\text{FeCl}_2$ 20 mM in water solutions of Na_2SO_4 0.035 M under nitrogen atmosphere.
 $T = 25\text{ }^\circ\text{C}$. $V = 50\text{ ml}$.

ELECTRODES: graphite

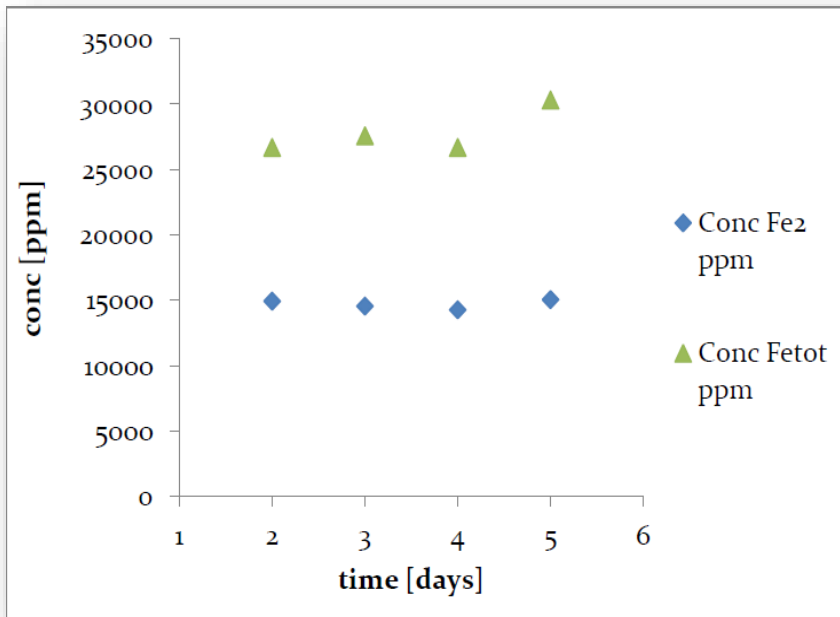


Cyclic voltammogram snapshots of $\text{FeCl}_3/\text{FeCl}_2$ performed at graphite in a water solution of Na_2SO_4 taken at 1 h intervals during potential cycling with a scan rate of 0.1 V s^{-1} in the range 0 - 1V

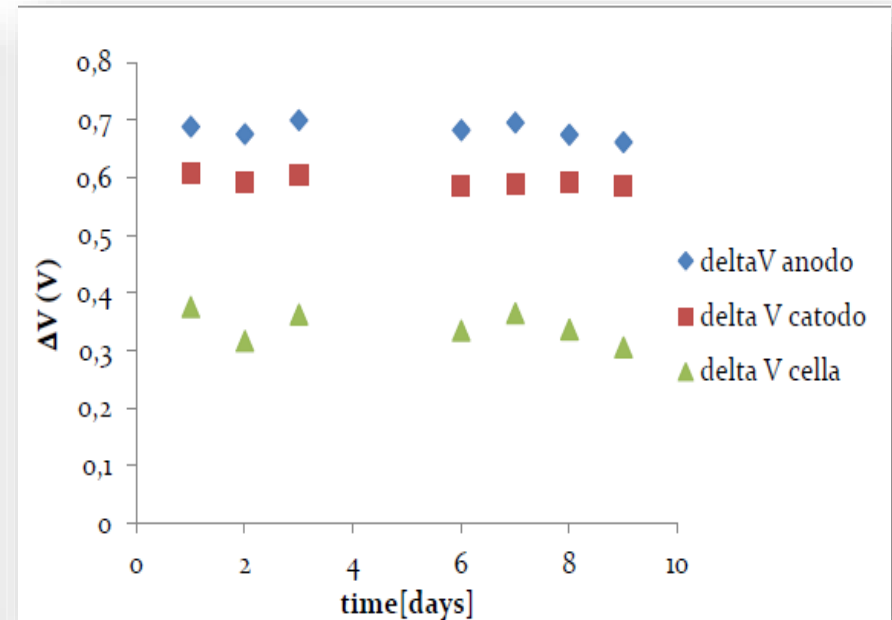
at a pH of 3 (Fig. a) and 5 (Fig. b) under nitrogen atmosphere. $T = 25\text{ }^\circ\text{C}$. $V = 50\text{ ml}$.

STABILITY OF OF THE REDOX COUPLE IN THE LONG-TIME

Initial concentrations of the couple $\text{FeCl}_3/\text{FeCl}_2$ of about 300 mM and an initial pH of 2 at compact **graphite electrodes** in undivided cell with water solution of $\text{NaCl } 0.1 \text{ mol dm}^{-3}$ under amperostatic alimntation with a current density of 10 mA/cm^2 under nitrogen atmosphere. Current in 52mA.



Concentration profiles of Fe(II) and Fe(III) vs. time passed for long-time electrolysis



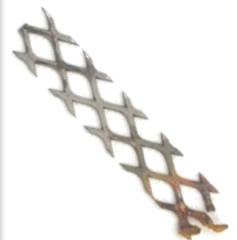
potential profiles of system vs. time

THE SAME ANALYSIS ARE CARRIED WITH CARBON FELT, DSA AND Pt ELECTRODES



RESULTS:

- GOOD STABILITY ON GRAPHITE ELECTRODES (compact or felt)
- DEPOSITION OF IRON OF Pt ELECTRODES



GENERAZIONE DI ENERGIA ELETTRICA E SIMULTANEO ABBATTIMENTO DI INQUINANTI REFRATTARI AI TRATTAMENTI BIOLOGICI

ABBATTIMENTO ELETTROCHIMICO DI AO 7*

- Processi Catodici

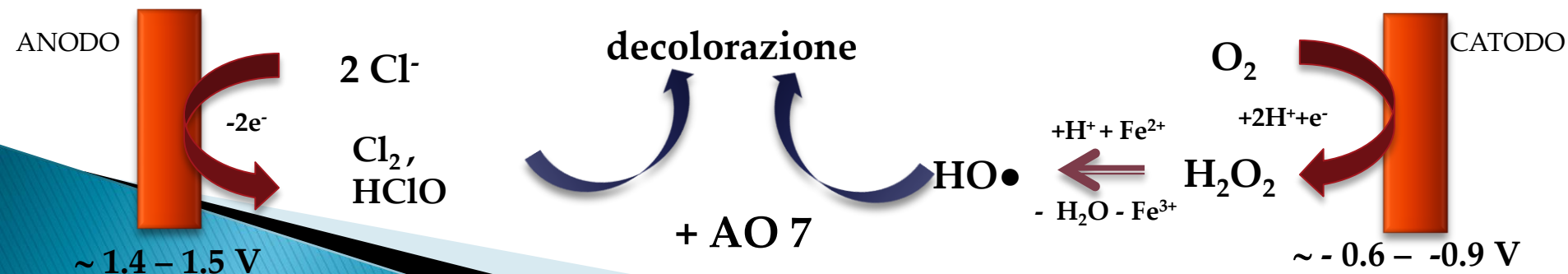
- Riduzione diretta: abbattimenti molto bassi

-Processi scelti

- processi combinati:

- ElectroFenton al catodo
- Ossidazione indiretta con elettrogenazione di cloro attivo su anodi DSA

- Ossidazione indiretta con elettrogenazione di cloro attivo su anodi DSA: abbattimenti elevati e bassi potenziali anodici (>1.3 – 1.5 V vs. SCE)



PASSAGE OF SPECIE BETWEEN ELECTRODE AND SIDE COMPARTMENT

EXPERIMENTAL CONDICTION:

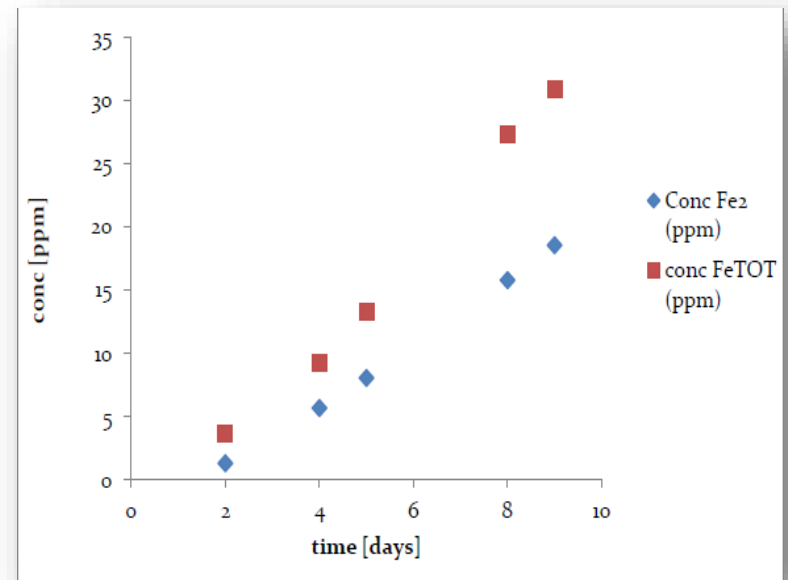
Electrolyses performed with graphite electrodes with the redox couple $\text{FeCl}_3/\text{FeCl}_2$ in A THREE COMPARTMENT CELL in the presence of Fumasep, Selemion, and Fuji anionic membranes with the following configuration under nitrogen atmosphere

Lateral compartment:
water solution of the redox couple (0.3 mol dm^{-3}), NaCl and HCl (pH = 2)

Central compartment: water solution of 0.5 mol dm^{-3} NaCl



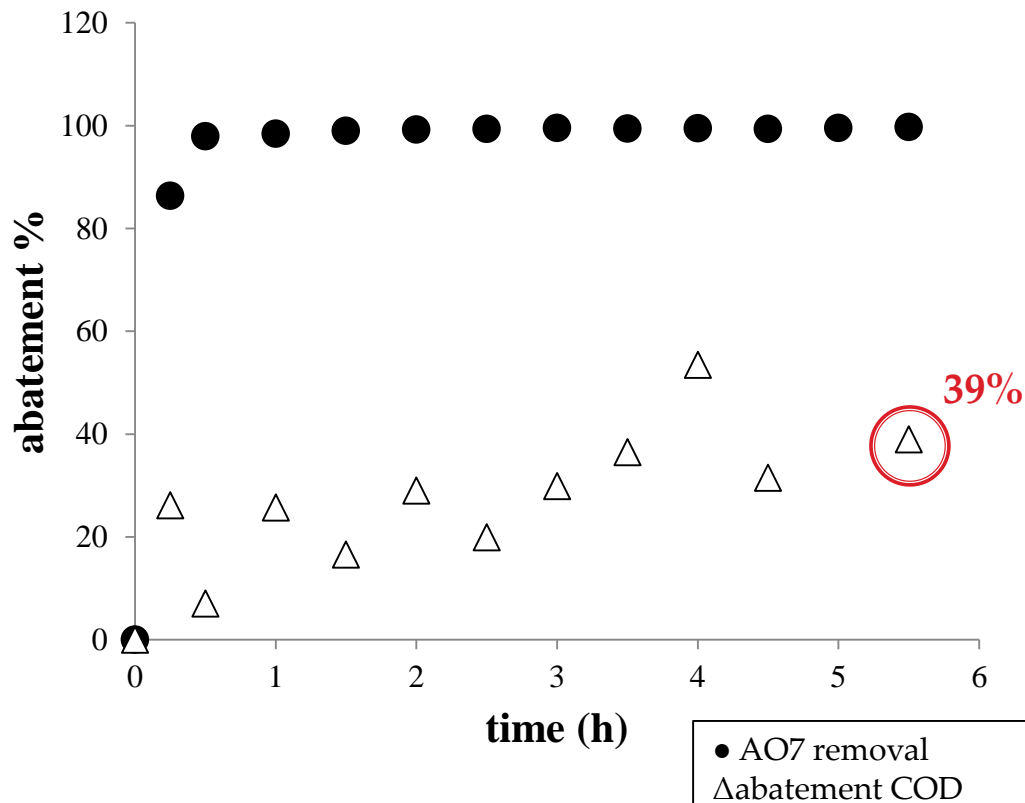
Fig. A) report the concentrations of Fe(tot) vs. time detected in the central compartment



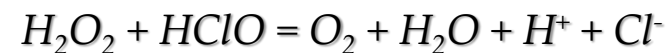
a compartment:
electrode solution $\text{FeCl}_3/\text{FeCl}_2$ (0.3 mol dm^{-3}), NaCl and HCl (pH = 2)
a compartment:
water solution of 0.1 mol dm^{-3} NaCl

✓ SINGOLO CIRCUITO IDRAULICO

ABBATTIMENTO
AO7



Si registra un più lento abbattimento del COD inseguito all'innescarsi della reazione fra H_2O_2 con $HClO$



Reazione che provoca una riduzione della concentrazione delle due specie ossidanti

I prodotti di degradazione del AO7 sono stati identificati mediante HPLC

sono acidi carbossilici (ossalico, maleico, malonico and acido lattico)

Experiments performed in a 40 cell pair stack fed with HC (5 M NaCl) and LC solutions (0.5 M NaCl). AO7 (150 mg/L) was added to a solution containing NaCl (0.085 M) and 0.5 mM $FeSO_4 \cdot 7H_2O$. pH was adjusted to 2 by H_2SO_4 addition. Anode: Ti/RuO₂-IrO₂. Cathode: Carbon felt.