Field Test of a Pilot-Scale Sequential Reductive/Oxidative Bioelectrochemical Process for CAHs Removal from Contaminated Groundwaters

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International Symposium on Bioremediation and Sustainable Environmental Technologies
May 8 – 11, 2023 | Austin, Texas

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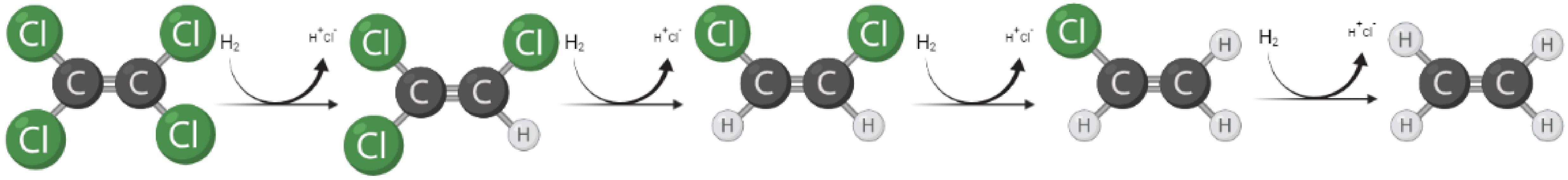
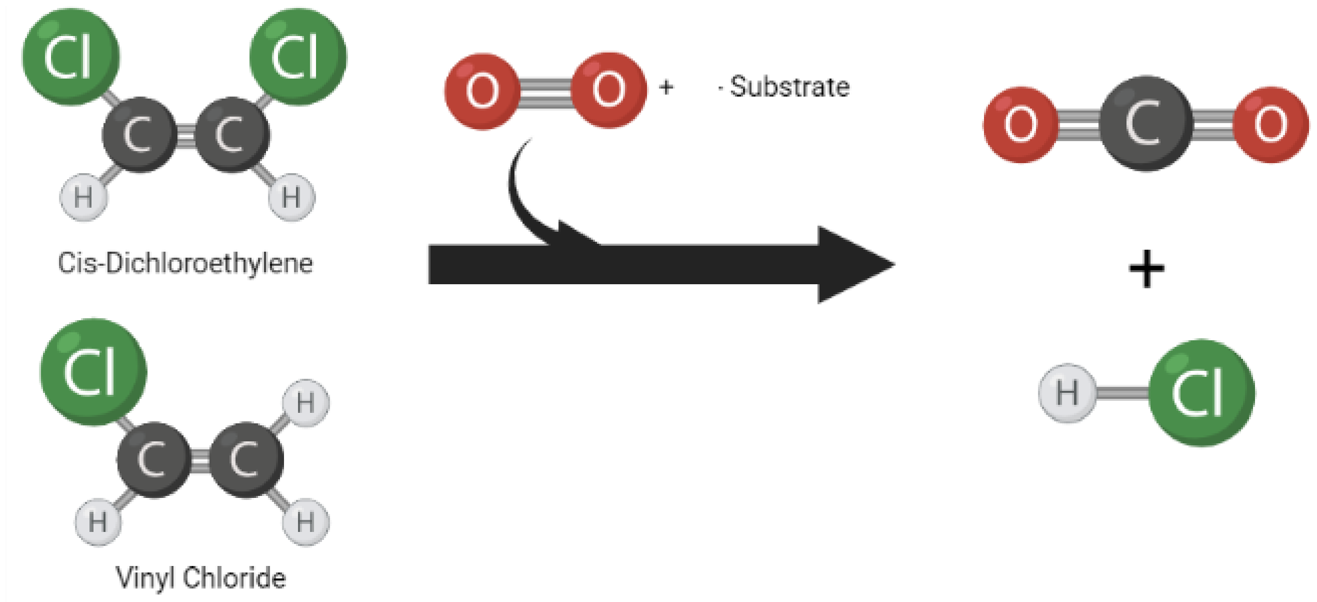
BATTELLE
It can be done

Biological Reductive Dechlorination - BRD



- Chlorinated Aliphatic Hydrocarbons removal can be obtained by BRD
- Fermentable organic matter is usually adopted to enhance BRD in contaminated groundwaters
- Over the past years many types of organic compounds have been investigated for BRD stimulation
- Today low costs and eco friendly approach are gaining the interest of the scientific community

Biological Oxidative Dechlorination

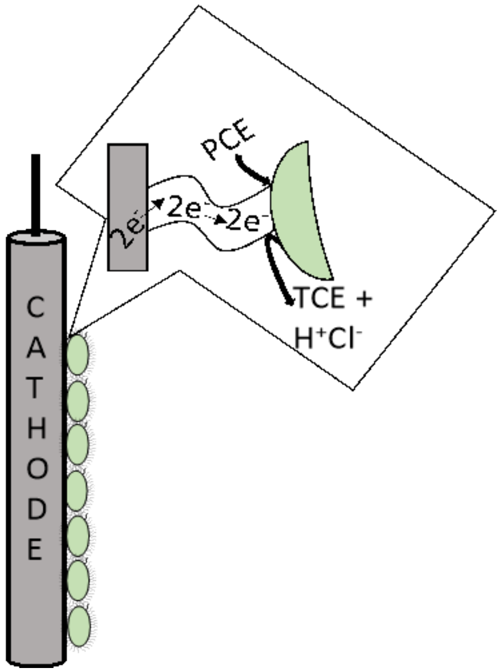


- The BRD reaction usually promotes the accumulation of low chlorinated by-products like vinyl chloride
- To fulfil the removal of CAHs is interesting to couple the BRD with another biological reaction which require aerobic conditions
- The Biological Oxidative dechlorination reaction is a co-metabolic reaction in which peculiar enzymes as oxygenase and monooxygenase degrade low chlorinated CAHs to CO_2

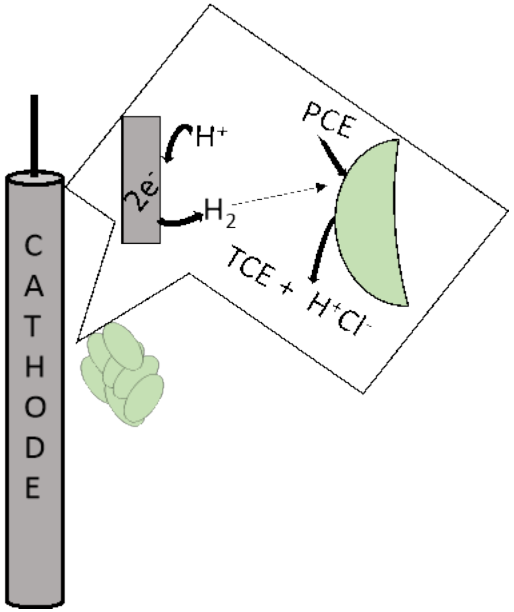
Bio-Electrochemical Systems (BES)

Bioelectrochemical systems are devices that exploit the ability of “electro-active” microorganisms to exchange electrons with solid electrodes

In a biocathode, the electrons are supplied to the microorganisms by a direct or a hydrogen mediated mechanism, while through a bioanode is possible to supply oxygen to stimulate oxidative dechlorination



Direct Interaction



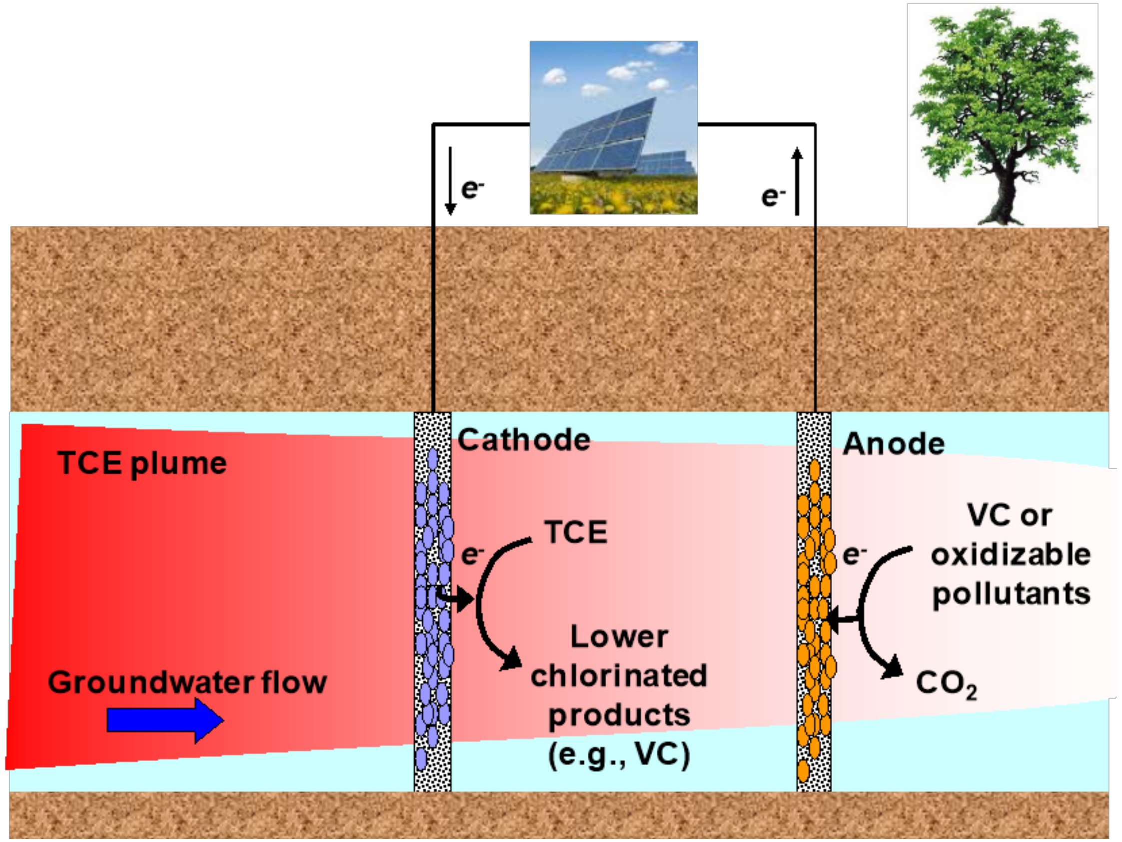
Hydrogenophilic interaction

Bio-Electrochemical Assisted Reductive Dechlorination (BEARD)

Electrodes can be used to **locally manipulate the redox potential**, thereby creating **reducing** or **oxidizing** conditions, favorable to the biodegradation of target contaminants

Possible advantages

- **Clean**: no need to inject chemicals or oxygen
- **Tunable**: greater control over the microbial activity at the electrodes
- **Sustainable**: low energy required, that can be provided by solar panels



Scope of the presentation

The scope of the presentation is the analysis of the pilot performances in a real contaminated site

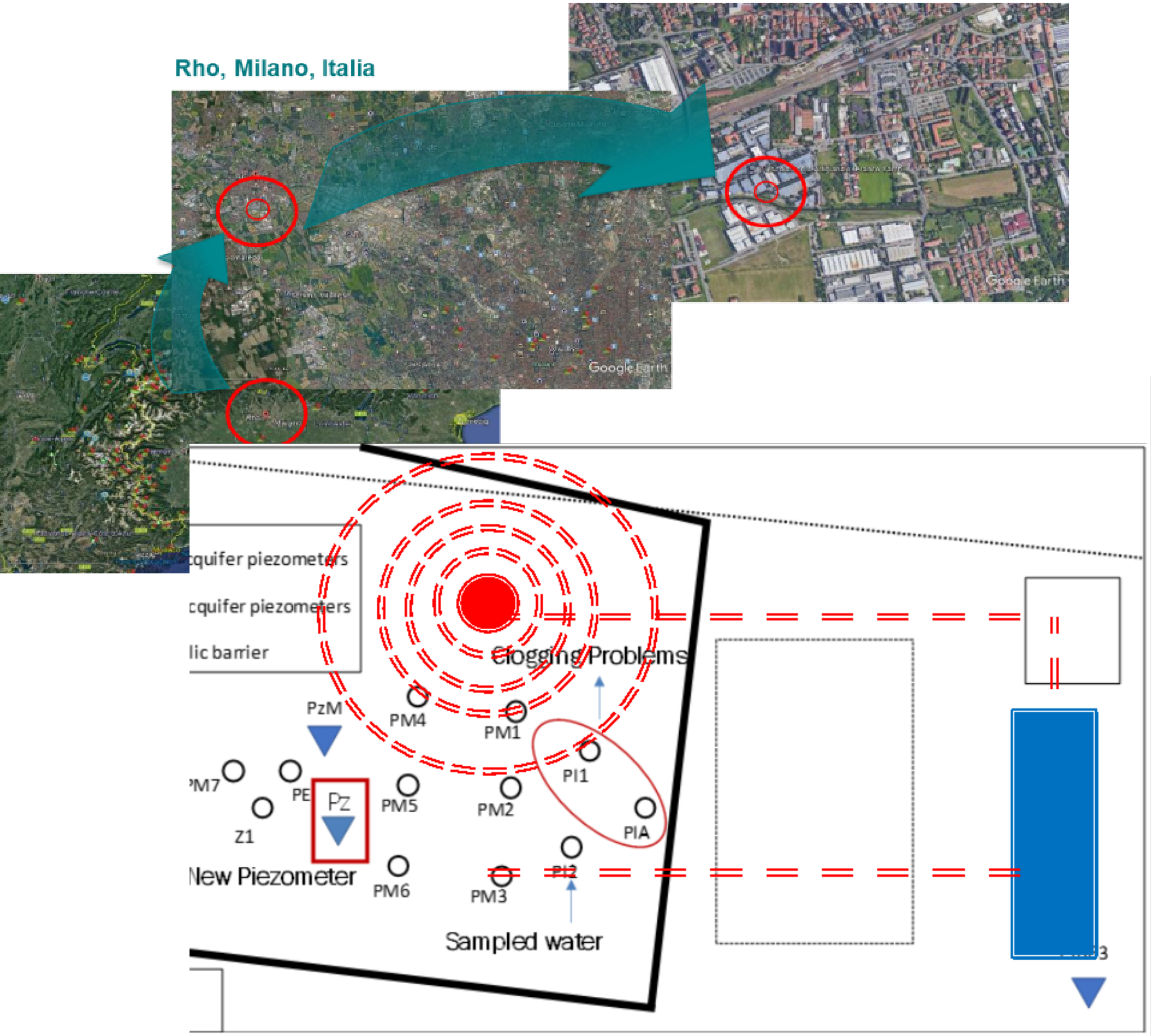
Main investigated parameters:

- Cathodic potentials
- Hydraulic retention time (HRT)

Anions Reductions was determinate for each utilized condition to evaluate the effect on the RD reaction

Microcosms tests were done to understand the pilot behavior in the different explored conditions

Field Test of the Bioelectrochemical Technology



The BioElectro Reactor is working with a GCW® (Groundwater Circulation Well) provided by IEG Technologies Gmbh

Field Test of the Bioelectrochemical Technology

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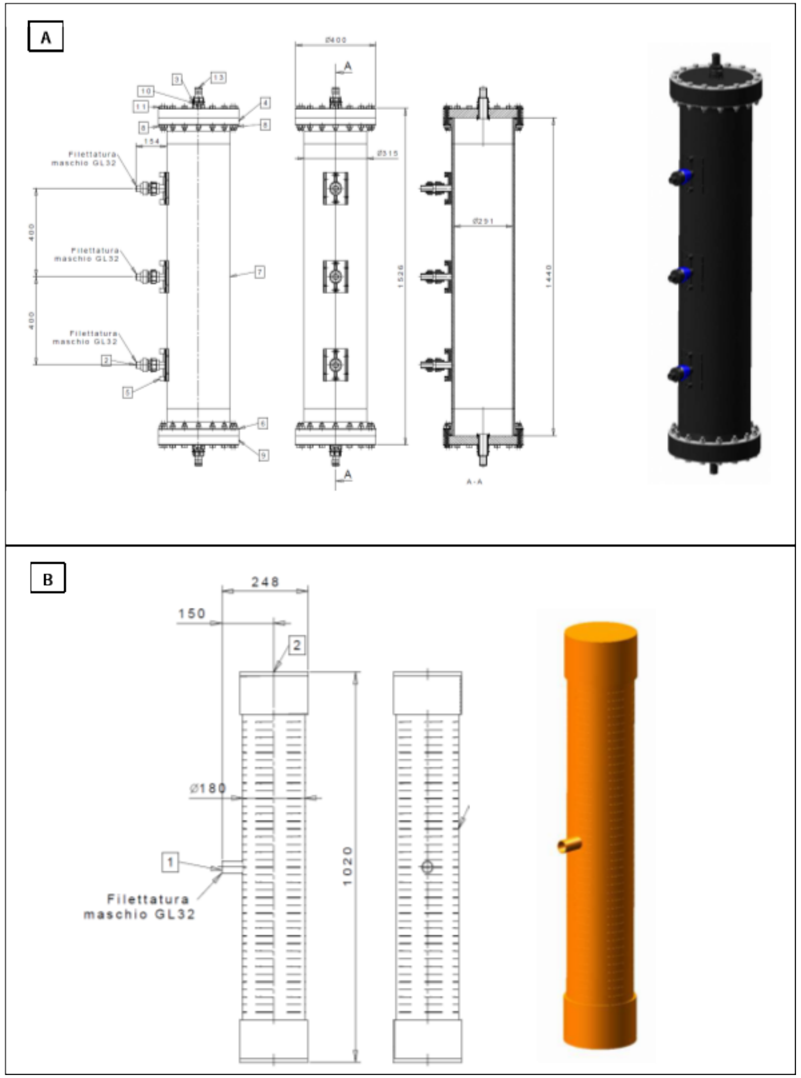
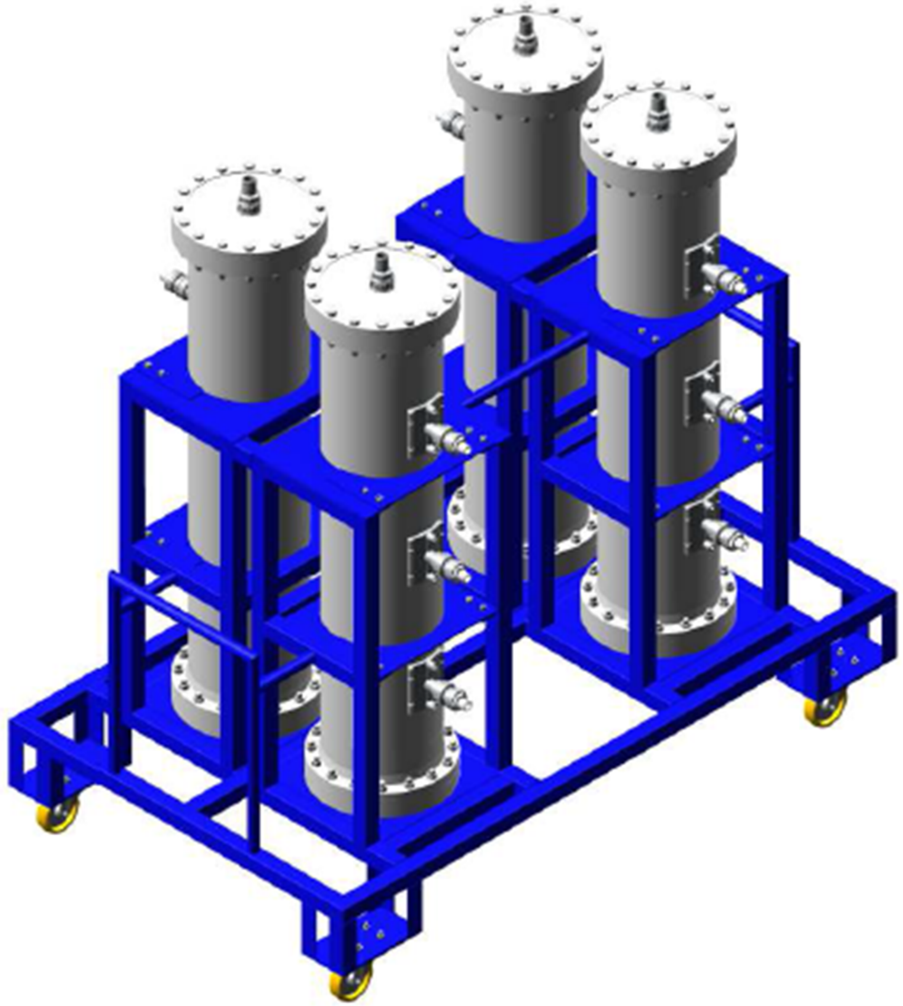


Reactor Internal Body



Volume 400 L → HRT 1-2 days

Bioelectrochemical upscaled units set up

4 BIOELECTROCHEMICAL REACTORS

REDUCTIVE UNITS → RED 1 - RED2

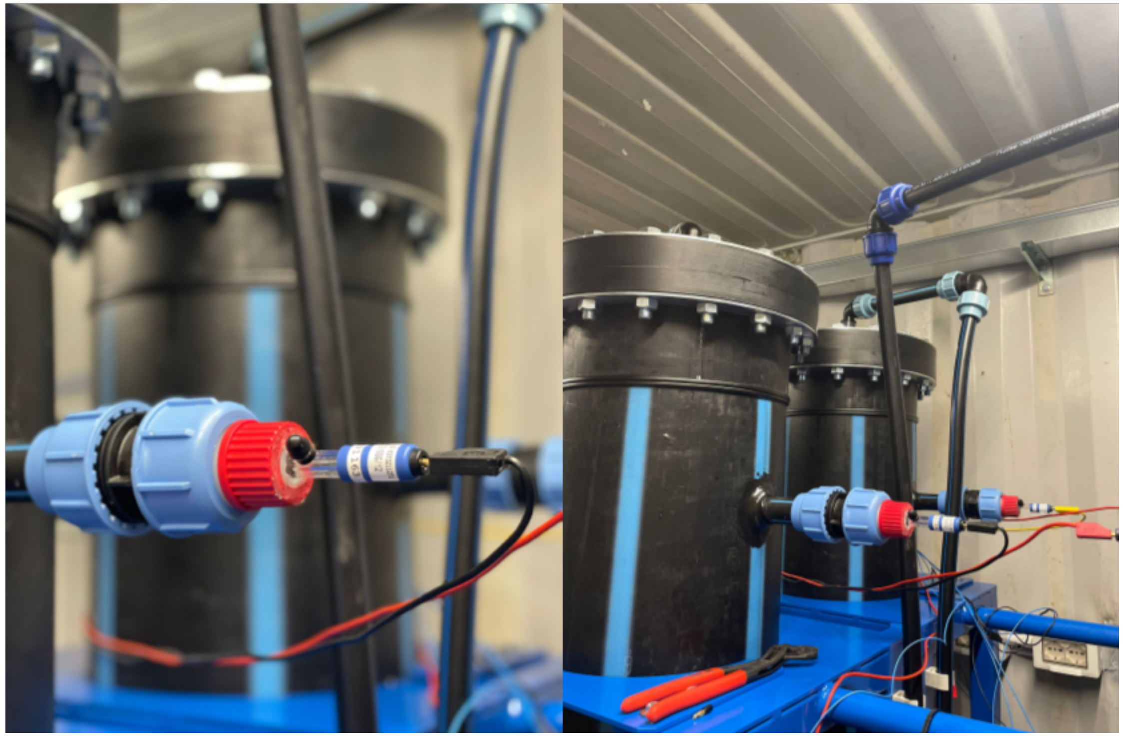
WORKING ELECTRODE → GRAPHITE GRANULES

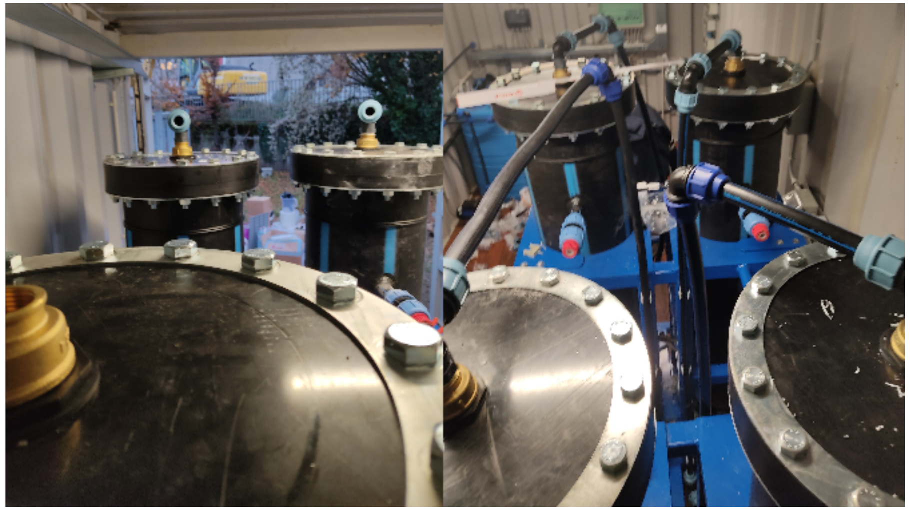
COUNTER ELECTRODE → GRAPHITE GRANULES

OXIDATIVE UNITS → OXI 1 - OXI2

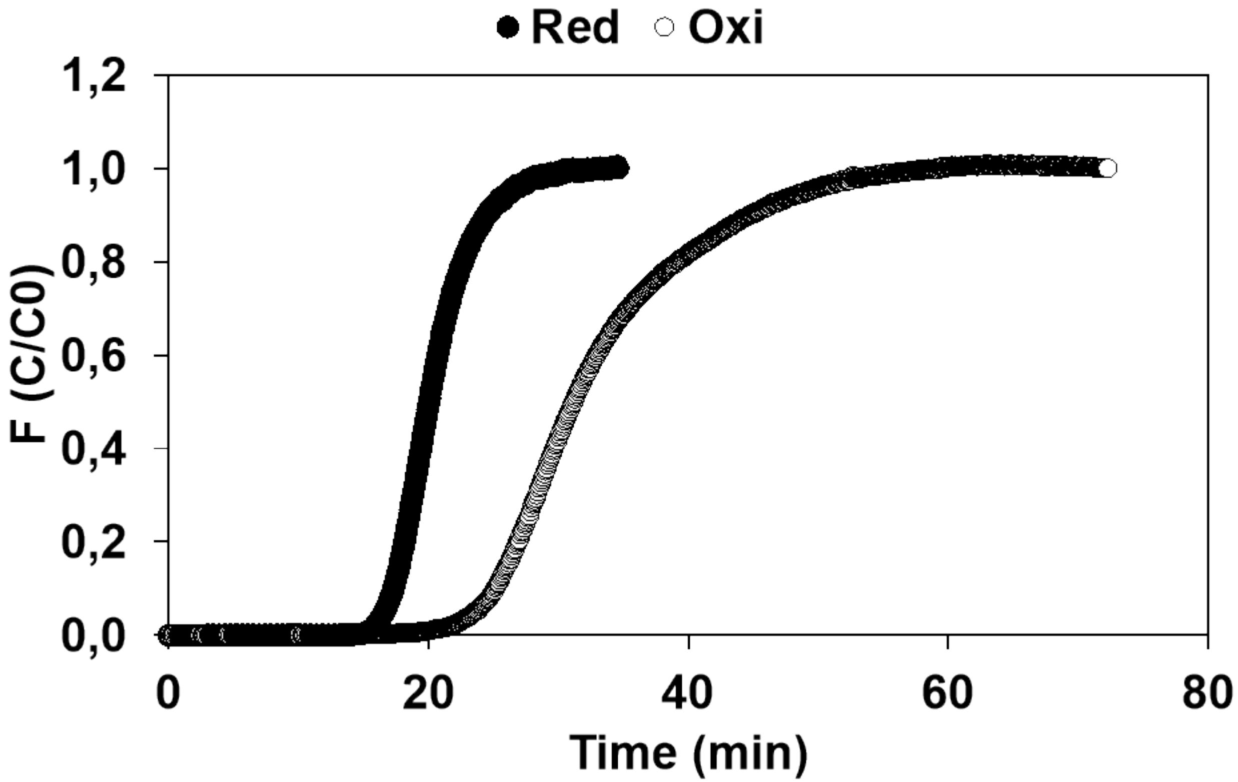
WORKING ELECTRODE → MMO ELECTRODE

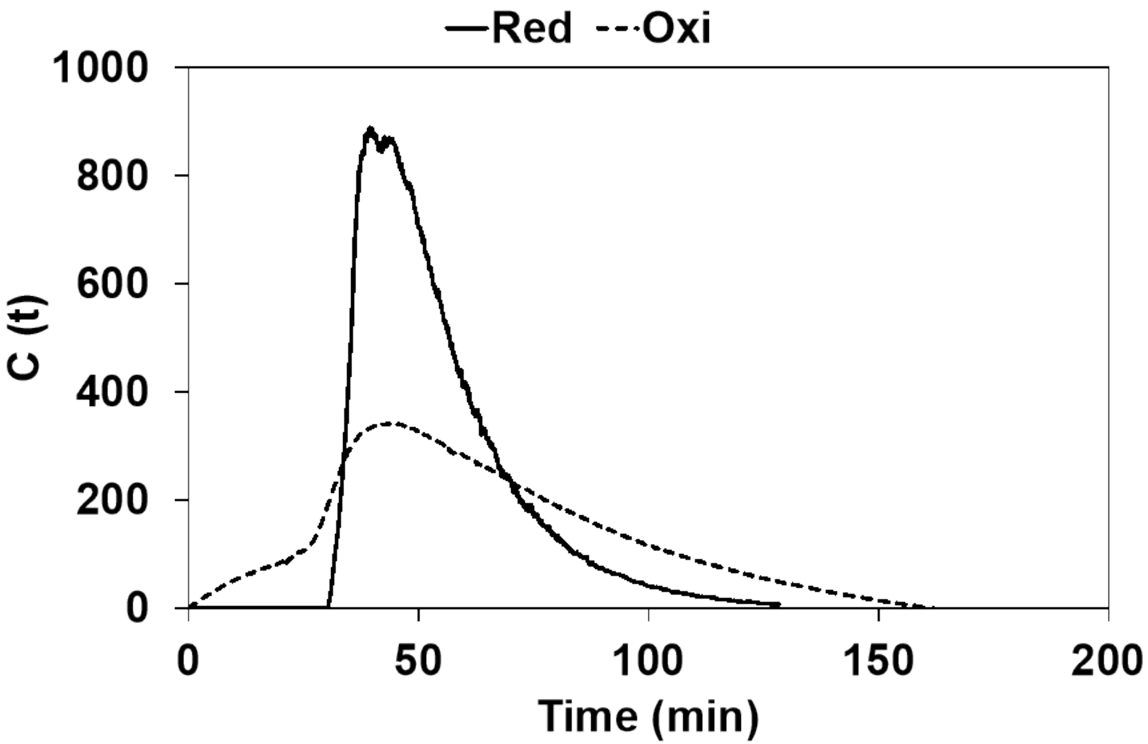
COUNTER ELECTRODE → GRAPHITE GRANULES





Preliminary tests of the Bioelectrochemical Technology: Tracer test





	F - TEST	C - TEST	GEOMETRIC	POROSITY
Reductive unit volume (L)	37	41	105	35
Oxidative unit volume (L)	45	64	105	46

$\varepsilon_{graphite} = 0.336$

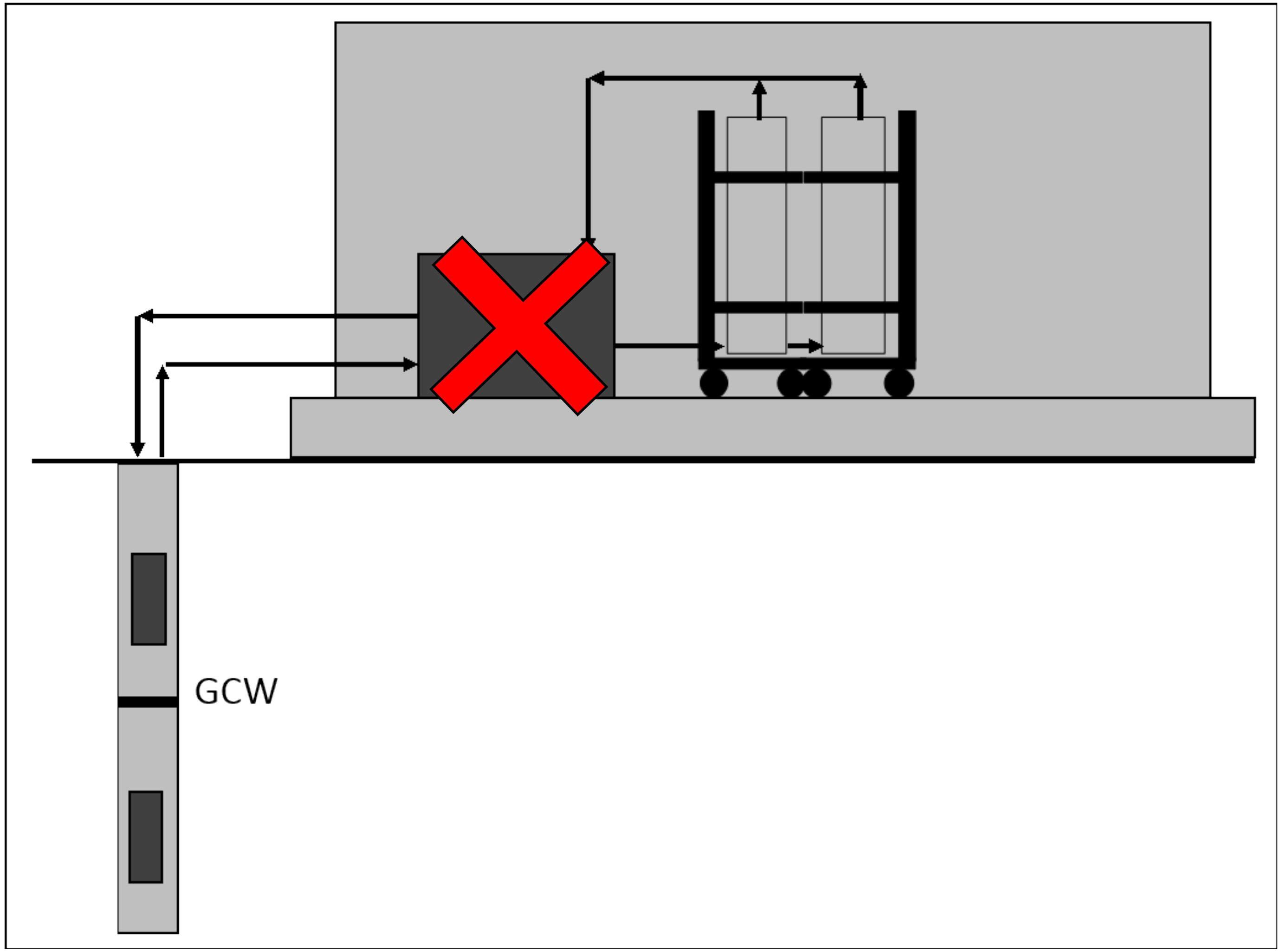
$\varepsilon_{gravel} = 0.472$

Integration of GCW® with the pilot scale bioelectrochemical process

The first configuration of the pilot plant presented an equalization tank for the GW recirculation through GCW.

Due to the presence of residual organic carbon, the equalization tank promotes the aeration of the GW with the consequent biomass growth and related fouling issues.

GCW was directly connected to the pilot bioelectrochemical reactors avoiding the aeration of the GW.



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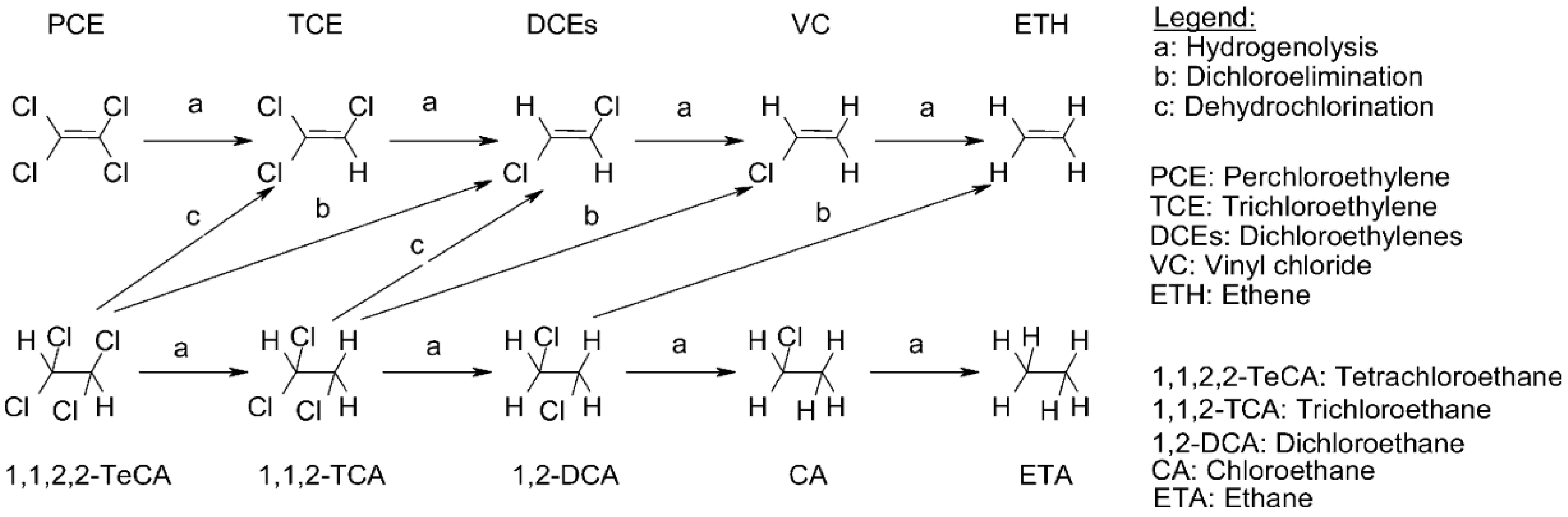
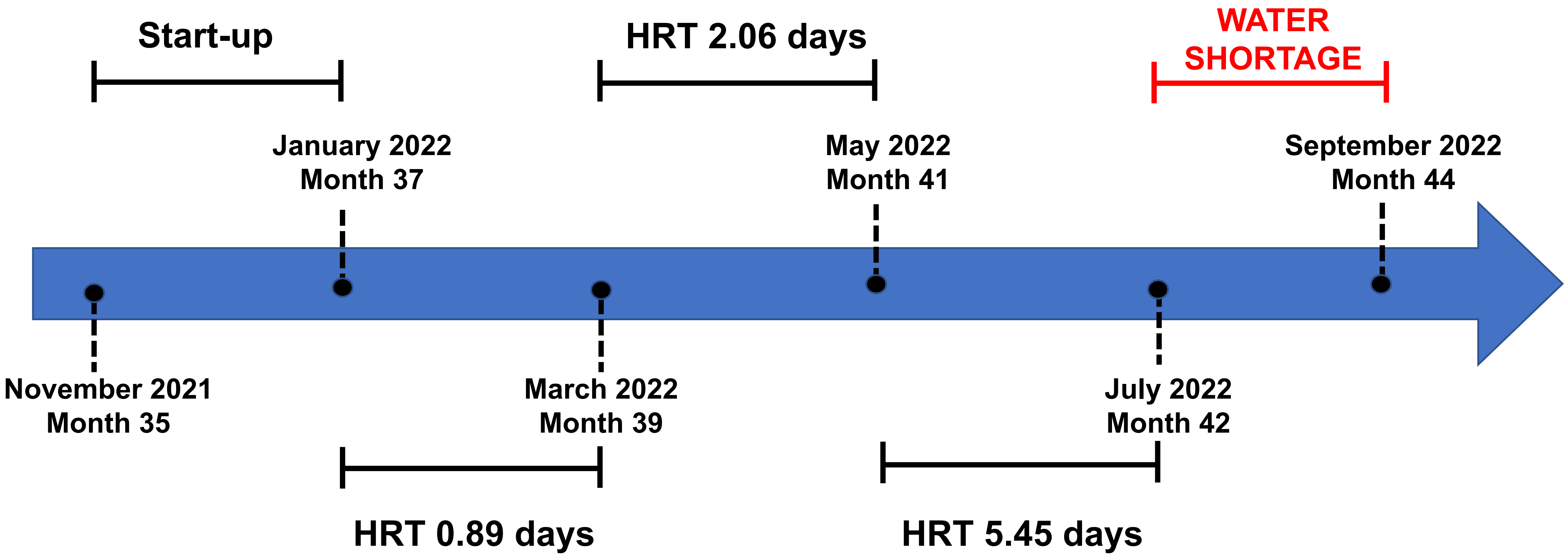


The installation and operation of the GCW promoted the remobilization of TeCA in the aquifer, which resulted the main contaminant.

TeCA presence introduced additional reductive mechanisms which can be performed by dechlorinating microorganisms.

It is also know that TeCA can inhibit dechlorinating activity on chlorinated ethenes.

Pilot plant operational periods timeline



First operating period → HRT 0.89 days

Average flow rate → 471 L/d

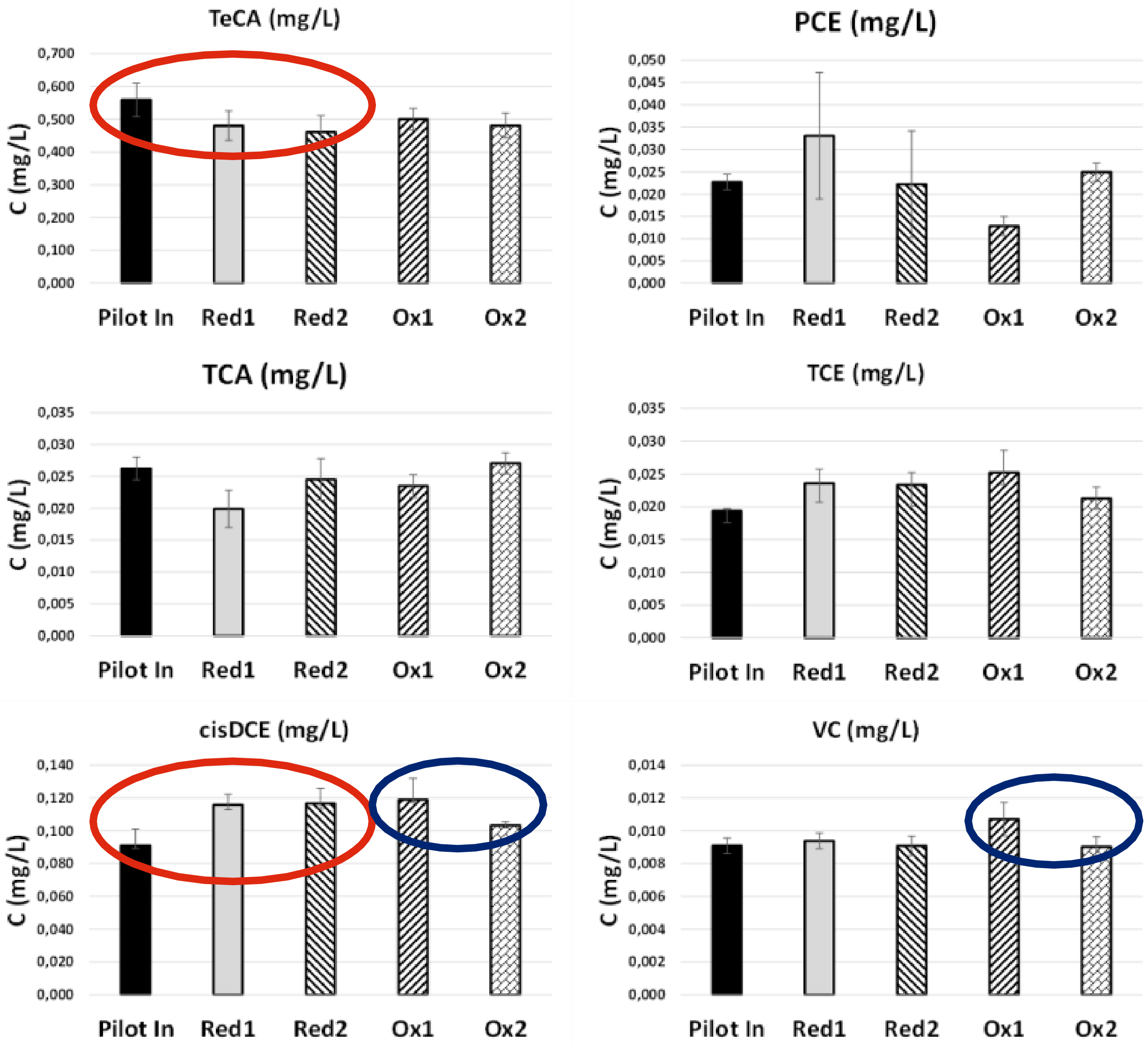
Reductive units polarization potentiostatic @ -450 mV vs SHE

Oxidative polarization galvanostatic +30 mA

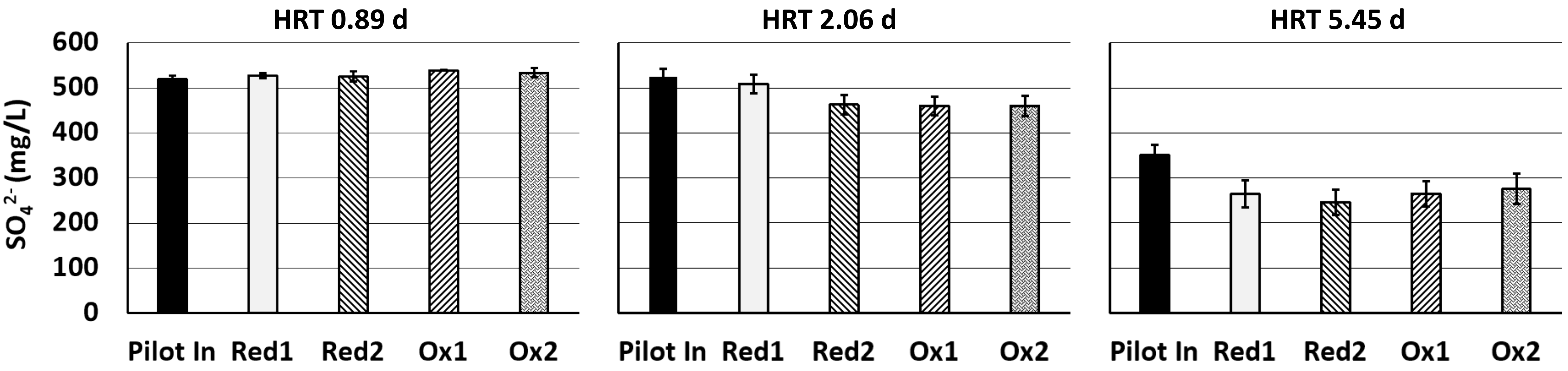
TeCA was probably removed through the dichloroelimination mechanisms due to the increase in cisDCE concentration after the reductive steps

The average TeCA removal rate resulted in 1.23 mg/Ld with an overall coulombic efficiency of 0.83 %

The oxidation capacity resulted significant only for cisDCE and VC, with a removal rate of 0.017 mg/Ld



Competitive reactions for reducing power

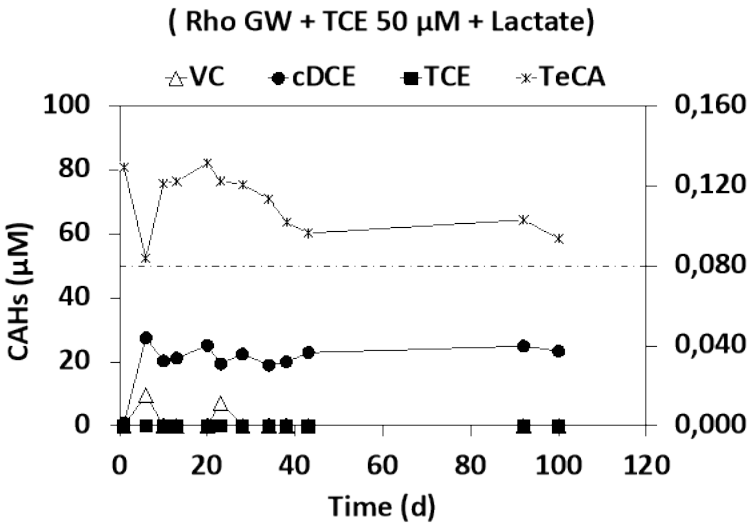


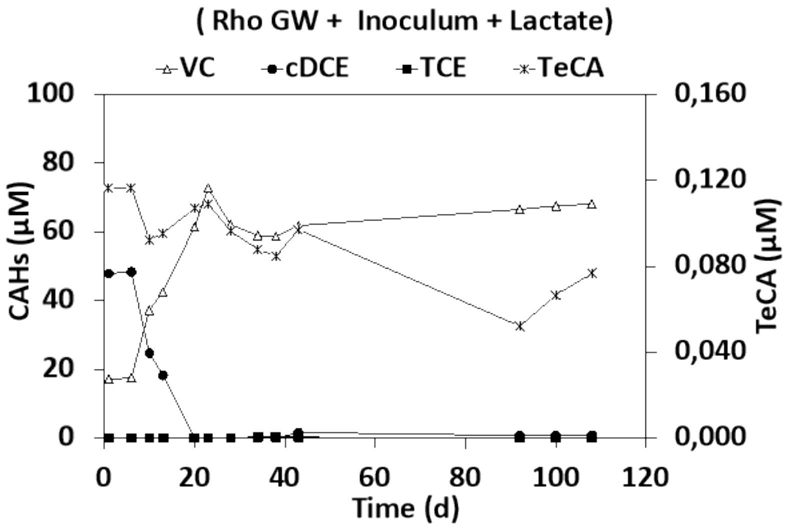
Sulphate reduction was negligible during the first operational period at 0.89 d

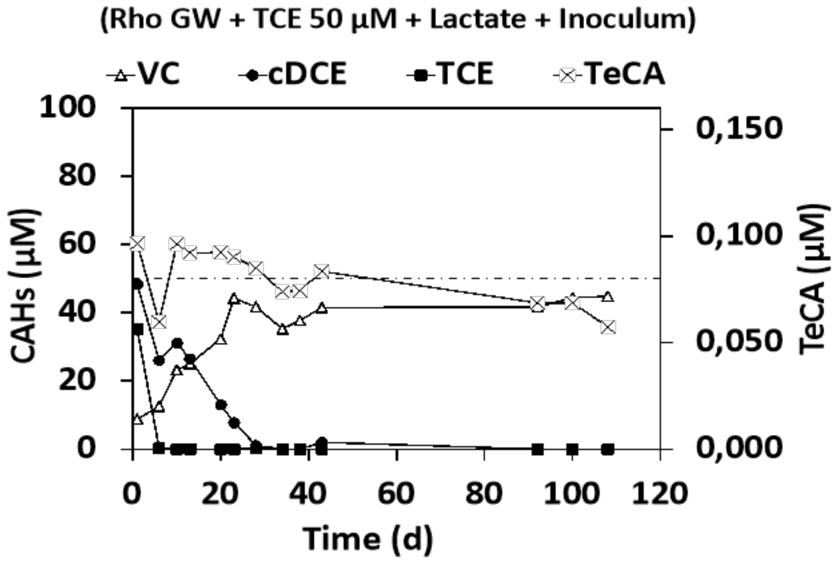
Sulphate reduction at 2.06 and 5.45 d accounted for 61±4 and 36±6 mg/Ld, which corresponded to 1.15 and 0.75 A

Due to the high value of coulombic efficiency (i.e. 751 and 286 %), most of the sulphate reduction can be attributed to the heterotrophic sulphate reduction which can be explained by the presence of organic carbon

Microcosms tests







TeCA resulted recalcitrant to the reductive dechlorinating activity indeed it was not removed in all microcosms.

The indigenous dechlorinating activity was capable only to reduce TCE to cisDCE, while in presence of the specialized inoculum, TCE was completely converted into VC.

TeCA caused a significative inhibitory effect on the dechlorinating biomass on the dechlorinating activity on chlorinated ethenes, indeed the complete reduction of TCE into VC occurred after 30 days instead of 10 days previously observed.

Conclusions

The pilot scale bioelectrochemical process was successfully set up and operated on the Rho site in combination with the GCW® technology;

Despite the good removal performances of the bioelectrochemical process under lab scale condition, the pilot scale removal performances resulted considerably lower, indeed, the groundwater present all the CAHs by-products, including VC;

The scaled-up sequential reductive/oxidative system represents the largest pilot, in terms of volume, regarding Bioelectrochemical systems for CAHs removal.

Future Developments

Future Developments will be focused on the inoculum of a commercial specialized microbial consortium for both TCE and TeCA removal.

More Operating conditions should be investigated to prove the capability of BES for recalcitrant compounds removal in field conditions.

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Thank You for your attention

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 826244-ELECTRA.