Uncovering Electrochemical Removal Mechanisms In The Remediation Of Emerging Organic Contaminants From A Clay Soil

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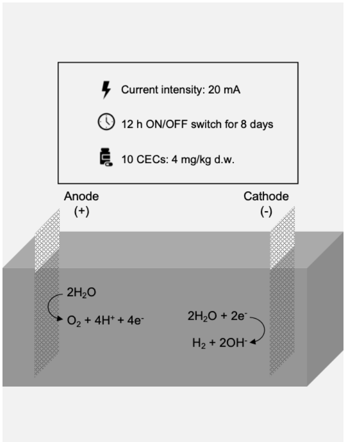

The effectiveness of electrokinetic (EK) remediation in removing a mixture of 10 different contaminants of emerging concern (CECs) from a clay soil was assessed. Initially, the CECs showed natural attenuation between 0% and 90%, but with EK treatment of 20mA for 12 hours ON/OFF, the removal increased to 14% and 100%. For CECs that were more resistant to biodegradation, EK application induced electro-chemical degradation. Daily irrigation improved the rates of electro-oxidation, osmosis, and migration, resulting in higher CECs decay. After 8 days of EK treatment, CECs decay increased, surpassing the decay lag phase of some compounds. However, after 16 days, the CECs showed similar removal rates with and without EK, with only 4 CECs showing a positive impact of approximately 10%. While EK treatment can improve CECs' removal from soil, the study found that the 16-day treatment resulted in pH alterations that decreased the bioremediation efficiency and inhibited electro-degradation near the cathode.

Introduction

Concerns about soil pollution are growing worldwide, and can severely degrade major ecosystem services provided by soils. A new class of compounds, the contaminants of emerging concern (CECs), that comprise a wide variety of chemicals such as pharmaceuticals and personal care products, has emerged as the focus of many scientific publications. These compounds are prone to accumulate in soil, hinder the food chain, and leach to ground and surface waters, carrying unexpected environmental and human health risks. The development of novel electrokinetic (EC) technologies for the remediation of soils contaminated with CECs is a goal and is underway, but its mechanisms of action remain largely ignored. In this study [1], we assessed the short-term effect of EK application on the mobilisation and degradation of CECs mixture under biotic or abiotic conditions, with or without irrigation. The soil's physicochemical properties, including temperature, moisture, pH, and conductivity, were comprehensively analysed. Furthermore, the persistence of CECs and other soil properties were investigated after an extended EK application till day 16, and its effects were measured after eight and sixteen days of treatment.
The motivation is to progress in executing strategies that foster the development of Circular Economy policies, coupled with the target of achieving Zero pollution. This goal is to be realised through reducing soil contamination and enhancing restoration efforts, which are among the key ambitions of the ISLANDR project.

Material and Methods

The soil used (0–15 cm depth, 1 m^2) was collected in an organic tomato plantation located in São Nicolau, Santarém, Portugal (39°12'42.6"N, 8°42'41.5"W). Prior to use, the soil was sieved (2.0 mm) to remove the coarse fractions, and its physiochemical characterisation was undertaken, presenting a clay texture and a high content of minerals and organic colloids. The microcosms set-up was designed in order to: (i) assess EC process potential to enhance CECs removal without the use of a processing fluid, and (ii) disclose EC contribution to CECs decay [1,2]. The soils were spiked with ten CECs – 17β-estradiol (E2; naturally occurring estrogen), sulfamethoxazole (SMX; bacteriostatic antibiotic), bisphenol A (BPA; plasticiser), ibuprofen (IBU; an analgesic, nonsteroidal anti-inflammatory drug), 17α-ethinylestradiol (EE2; semisynthetic estrogen), oxybenzone (OXY; sunscreen agent), diclofenac (DCF; an analgesic, nonsteroidal anti-inflammatory drug, triclosan (TCS; an antimicrobial disinfectant), caffeine (CAF; a central nervous system stimulant) and carbamazepine (CBZ; anticonvulsant) – and their status (i.e. residual amounts and spatial distribution) evaluated on the 4 day fort he short term experiments, and after 8 and 16 days fort he long term experiments. The current used in the EC processes was set to 20 mA (0.27 mA/cm^2) with an ON/OFF switch of 12 h, i.e. a continuous application of identical periods of current and void [1].

Results and Discussion

The decay of the CECs was observed in sterile soil over four days. Under abiotic conditions, the decay rate was below 7%. However, under biotic conditions, the decay rate increased to 20%. The level of decay varied for individual compounds, with E2 showing the highest decay rate at 90%, while recalcitrant CECs showed a much lower decay rate at 13% [1].

The application of the EC treatment for four days resulted in a significant increase in decay levels under both biotic and abiotic conditions. The increase was around 17% for biotic conditions and 6-28% for abiotic conditions. Interestingly, the EK treatment was most effective for the recalcitrant compounds (OXY, DCF, TCS, CAF, and CBZ), regardless of the presence of soil microbiota [1].

Daily irrigation during the four-day EK treatment resulted in the highest decay values for all CECs except SMX. This was due to higher electrochemical oxidation rates and the mobilisation of compounds by electroosmosis and electromigration [1].

Longer experiments challenged the conclusions from the short-term treatments. The longer experiments supported the use of EC to accelerate the removal of CECs in the first 8 days. However, after 8 days, the longer application of EC (20 mA, ON/OFF periods of 12 h) negatively impacted the removal of most CECs, except for the compounds classified as type III (decay ≤ 50%, t½ ≥ 16 days), where EK positively increased their decay levels even after 16 days of treatment [1].

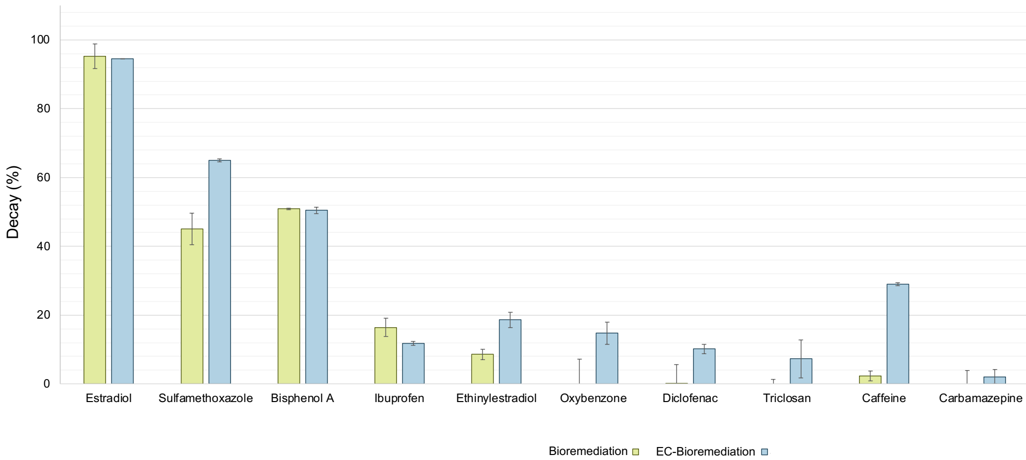

Figure 1. Decay percentages and standard deviations (mean ± SD) of all contaminants of emergent concern for the Bioremediation and Electrochemical-Bioremediation treatment after 4 days at room temperature, 19 ± 0.5 ºC (adapted from [1]).

Conclusions

Based on the testing conditions, we have concluded that the EC remediation method should only be applied for short periods. The design of this method should also be guided by the irrigation regime used, as the water content has an effect on the electro-degradation of certain CECs (Contaminants of Emerging Concerns). For the selection of EC conditions, the focus should be on the most stubborn compounds, while also ensuring that the pace of the bioremediation processes is not negatively affected.

Acknowledgments

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