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Using Electrocoagulation to Remove Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) From Contaminated Water

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Background

PFAS are a family of manmade chemicals that are used to make commercial products resistant to heat, oil, stains, grease, and water. Common products that use PFAS include nonstick cookware, emulsifiers, and fire-fighting foams (Fig. 1). Unfortunately, the chemical properties that make PFAS useful in the industrial realm, also make them mobile and recalcitrant once they have been released into the environment.

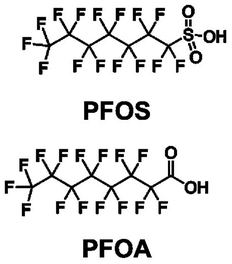

Figure 1. Commercial sources of PFAS and structures of PFOS and PFOA

The two most common PFAS are perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) (Fig. 1). The frequency with which PFAS are currently being discovered in the environment has led the Environmental Protection Agency and the Department of Defense to make identifying PFAS sites and developing methods to remove PFAS from contaminated soil and water one of their highest priorities.

Many treatment technologies have attempted to degrade or absorb PFAS, but very few have had much success. Our objective was to use electrocoagulation to remove PFOA from contaminated water.

Research Questions

Electrocoagulation (EC) is a processes that runs a direct current through a metal anode and cathode. The circulated current causes the metal anode to form a hydroxide flocculent (floc) which can co-absorb/co-precipitate some pollutants. Our research question was to determine the efficacy of using EC to remove PFOA from solution. We also wanted to quantify how treatment variables like pH, PFOA concentration and electrical current affected removal efficiencies.

Methods

Each experiment treated 200 mL of PFOA (1-100 mg/L) in a 400-mL beaker along with 1 mg of NaCl salt. The solution was spiked with 1 mL of ^{14}C-labeled PFOA. ^{14}C-analysis was conducted in a scintillation counter (Fig. 2).

Spiking the samples with ^{14}C-labeled PFOA allowed us to track the carbon in the PFOA structure. This greatly simplified detection and avoided the typical costs associated with triple quadrupole mass spectrometer analysis.

The solution was placed on a stir plate with a magnetic stirrer in the solution spinning at a constant 700 rpm. The anode and cathode were connected to a DC unit which was turned on to generate roughly 11 volts and 0.5 amps. The solution ran under these conditions for 1 hour to generate the floc (Fig. 3), and 1.5 mL samples were taken every 10 minutes in 1.5 mL centrifuge tubes. Before samples were analyzed they were centrifuged for 3 minutes at 100,000 rpm. 1 mL of sample was transferred into a 7 mL scintillation vile containing 6 mL of Ultima Gold scintillation cocktail. The samples were analyzed in a scintillation counter (Fig. 2).

Figure 2. Liquid scintillation counter used to quantify ^{14}C-PFOA.

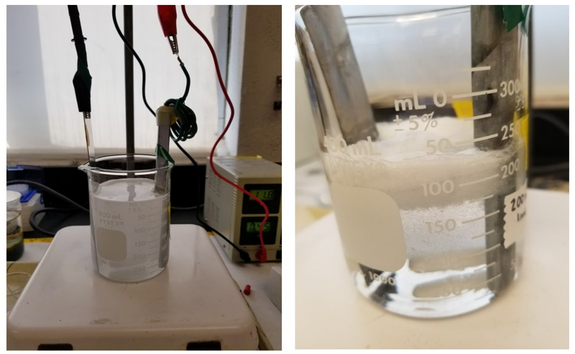

Figure 3. Generation of zinc hydroxide floc during EC experiments

Results

By running a series of experiments, we found that PFOA removal increased by the addition of hydrochloric acid (lower pH). Initial PFOA concentration had only a modest effect on removal efficiencies and increasing the electrical current (amperage) increased removal.

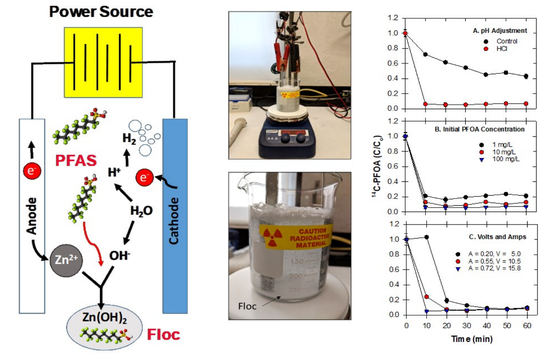

Figure 4. Schematic, photographs and summarized results from UCARE research using electrocoagulation.

Moving Forward

Moving forward with these experiments there are a number of key questions we need to pursue. These include:

1. What is the stability of the PFAS-zinc floc produced from the electrocoagulation (i.e., is it safe for disposal)?

2. Can the PFAS be oxidized when precipitated as a floc?

3. Can we eliminate the floc and oxidize the PFAS directly via electrochemical oxidation using various cathode/anodes?