ESTCP Project ER-201637 Low Energy Chemical Treatment for Graywater Reuse: Mitigating Disinfection Byproducts and Recovering Cathodically Generated Hydrogen for Energy

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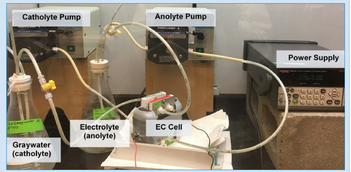
Abstract

Objectives:
The goal of this project is to demonstrate the sustainable use of stable electrocatalytic anode materials to treat graywater for reuse in showers or laundry.

- Verification of effective destruction of chemical oxidation demand (COD)
- Assessment of disinfection by-products (DBP) formation relative to disinfection by-products rule (DBPR2)
- Assessment of net energy requirements with respect to overall sustainability and costs
- Cathodically generated hydrogen will be measured to evaluate its potential for offsetting the energy requirements from the cell
- Successful demonstration of these objectives will inform the design of a pilot-scale system providing the Department of Defense (DoD) with a technically and economically feasible approach for graywater reuse.

Approach:
Optimize EC Configuration

- COD Removal
- DBP Formation
- Energy Consumption



Undivided cells were evaluated first at different current densities and by employing different cathodes.

Divided EC cells were evaluated at one current density, but employing various cathode materials.

Experimental

Bench-Scale Studies Evaluating EC Cell Configuration

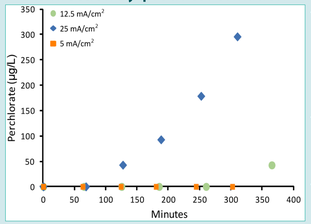
Undivided EC Cell Configuration	
Anode/Cathode Combination	Current Densities Tested (mA/cm²)
Ti/IrO_2-RuO_2 / Stainless Steel	0, 0.3, 5, 12.5, 25
SnO_2 / Stainless Steel	12.5

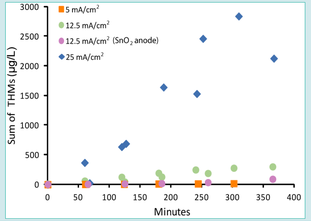
Divided EC Cell Configuration (Sequential Anodic Cathodic)	
Anode/Cathode Combination	Current Densities Tested (mA/cm²)
Ti/IrO_2-RuO_2 / Stainless Steel	12.5
Ti/IrO_2-RuO_2 / Stainless Steel-Sparged	12.5
Ti/IrO_2-RuO_2 / Graphite	12.5
Ti/IrO_2-RuO_2 /Boron Doped Diamond	12.5

Graywater Amendments

Analyses	Filtered & Amended
Chloride (mg/L)	500
Sulfate (mg/L)	150
Bromide (mg/L)	<1.0
Nitrate (mg/L)	<1.0
Perchlorate (µg/L)	<3.0
Chemical Oxygen Demand (mg/L)	200
Total Organic Carbon (mg/L)	30
Conductivity (µS/cm)	1270
pH (standard units)	7

Disinfection By-product Formation

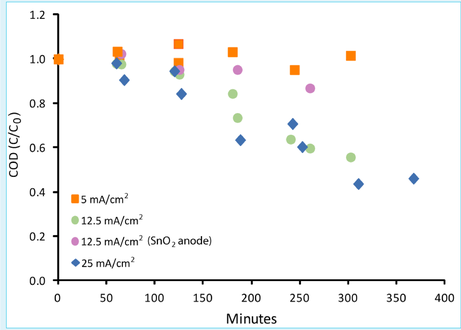


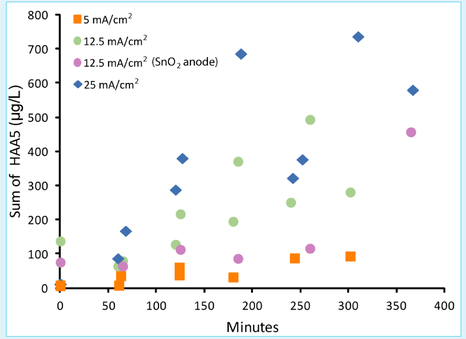


- COD removal is a function of current density at lower current densities.
- 17 W-h L^{-1} energy required for 50% COD removal
- Assuming 4 electrons/mole of COD columbic efficiency for COD removal is 12%

Undivided EC Cell Results

COD Removal

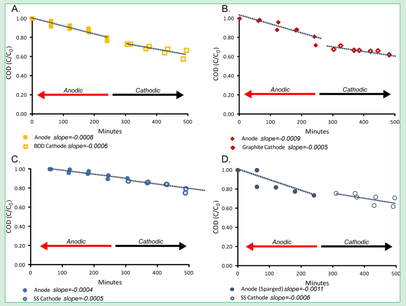




- Free chlorine in excess of 200 mg/L
- Undivided EC cells produced prohibitively high levels of DBPs at higher current densities
- THM formation → current density & specific charge
- HAA5 formation → current density

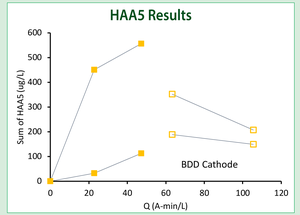
Divided EC Cell Results

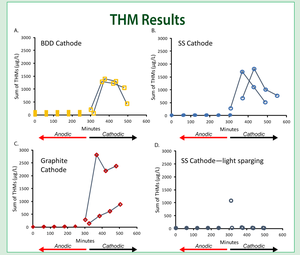
COD Removal



- Divided experiments executed at 12.5mA/cm²
- 50% COD removal BDD & graphite → 13 Wh L^{-1}
- 50% COD removal SS → 20 Wh L^{-1}
- Higher rates of removal on the anode side

Disinfection By-product Formation





- HAA5 removal on BDD cathode
- No THM generation on anode (low pH)
- Gentle sparging → no THM accumulation

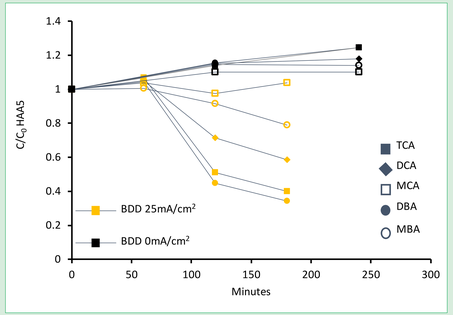
Chloride Trends

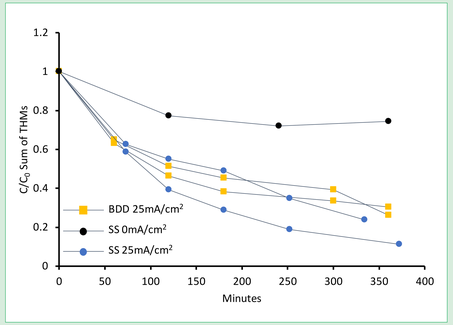
Chloride consumed in the formation of DBPs and released in their removal

	BDD	Graphite	SS
T0	1.00	1.00	1.00
Anodic	0.78	0.88	0.88
	0.77	0.76	0.78
	0.62	0.65	0.63
	0.48	0.53	0.53
Cathodic	0.64	0.69	0.49
	0.64	0.67	0.50
	0.62	0.65	0.48
	0.60	0.62	0.46

- Cathodic THM removal was similar for BDD and SS cathodes (25 mA/cm²)
- No MCA or MBA accumulation or removal observed
- TCA, DCA, and DBA removal observed

Confirmation of Cathodic DBP Removal





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