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# Integrated Electrokinetic and Microbial Fuel Cell Technologies for Remediation of Hexavalent Chromium in Groundwater

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## BACKGROUND:

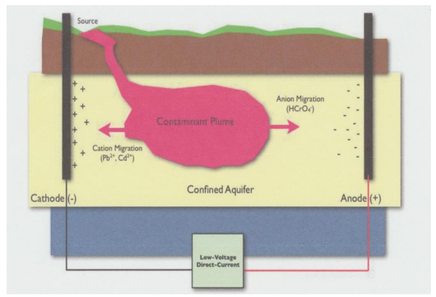
- Hexavalent Chromium ($Cr^{VI}$) is an EPA priority groundwater pollutant due to its high toxicity and prevalence in natural waters.
- Exposure to $Cr^{VI}$ can cause lung cancer, kidney and liver damage, respiratory problems, ulcers, and skin irritation.
- A 2011 study by the Environmental Working Group found $Cr^{VI}$ present in 31 of 35 major cities in the United States.
- Traditional ex-situ remediation (pump and treat) of aquifers contaminated with $Cr^{VI}$ is energy intensive, slow, and highly invasive.
- This research proposes a sustainable and green remediation approach utilizing the integration of electrokinetic and microbial fuel cell (MFC) technologies in low permeability aquifers.

A map showing $Cr^{VI}$ contaminated groundwater across the United States

Skin Irritation Caused by $Cr^{VI}$

## ELECTROKINETIC TECHNOLOGY

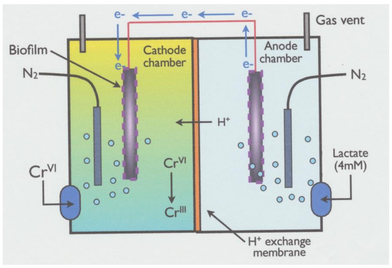
- Heavy metals (such as chromium) are one of the main contaminants that can be removed by electrokinetic processes in groundwater.
- One of the advantages of electrokinetic transport is to mobilize contaminants in low permeability zones of aquifers, such as clayey sand.
- Electrokinetic system is comprised of the following components:
  i. External direct current source
  ii. A positively charged electrode (anode)
  iii. A negatively charged electrode (cathode)




Electrokinetic contaminant transport

## MICROBIAL FUEL CELL TECHNOLOGY

- Microbial Fuel Cells exploit bacteria's natural ability to break down organic matter in order to generate energy. *Shewanella Oneidensis* strain MR-1 was used in these experiments.
- Carbon dioxide, electrons, and protons are generated in the anode.
- The electrons generated in the MFC redox reaction can be used to reduce heavy metals found in groundwater.
- Electrons and protons are used in the cathode to reduce $Cr^{VI}$ to $Cr^{III}$.
- A Proton Exchange Membrane (PEM) allows for the passage of protons across compartments.
- Anaerobic conditions are required in anode and cathode compartments.

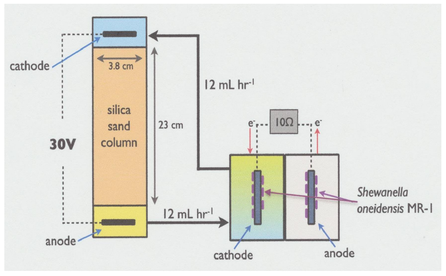



Electron Donor: Lactate
Electron Acceptor: $Cr^{VI}$

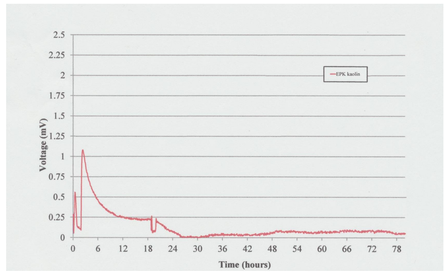
Anode Reaction: $C_3H_6O_3 + 3H_2O \rightarrow 3CO_2 + 12e^- + 12H^+$
Cathode Reaction: $HCrO_4^- + 7H^+ + 3e^- \rightarrow Cr^{3+} + 4H_2O$

RESEARCH OBJECTIVE: To investigate the remediation potential of the integrated electrokinetic and microbial fuel cell technologies in the reduction of $Cr^{VI}$ present in groundwater sources.

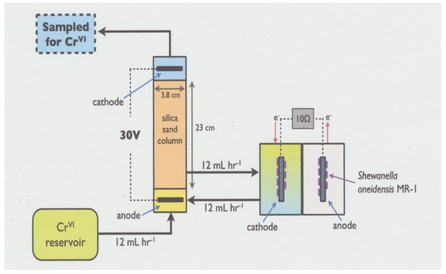
## RESEARCH RESULTS:



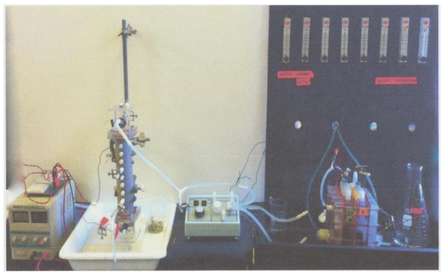

Experimental set-up for the semi-batch EK-MFC System



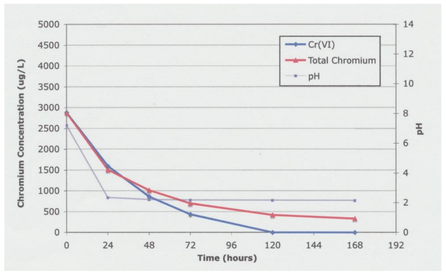

Voltage produced during the EK-MFC semi-batch experiment



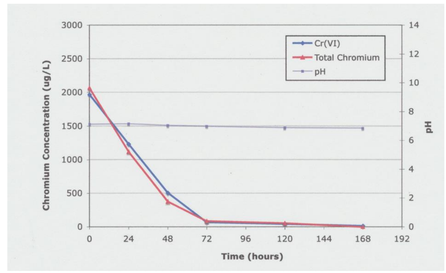

Experimental set-up for the continuous flow EK-MFC System



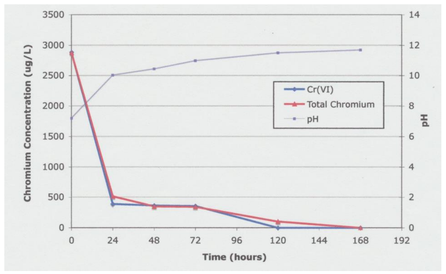
Continuous Flow EK-MFC System



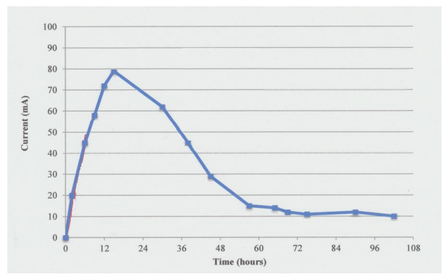

$Cr^{VI}$ and total chromium concentrations in the anode reservoir during electric potential application for aquifer soil



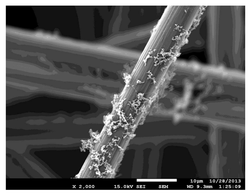

$Cr^{VI}$ and total chromium concentration in the center of the clay column during electric potential application for aquifer soil

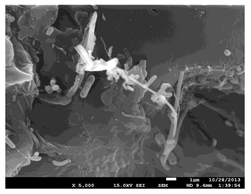



$Cr^{VI}$ and total chromium concentrations in the cathode reservoir during electric potential application for aquifer soil

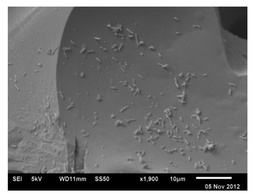


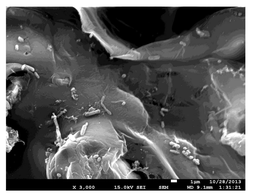

Current measured within the electrokinetic cell for aquifer soil





Scanning electron micrographs of a Proton Exchange Membrane with MR-1 Biomass





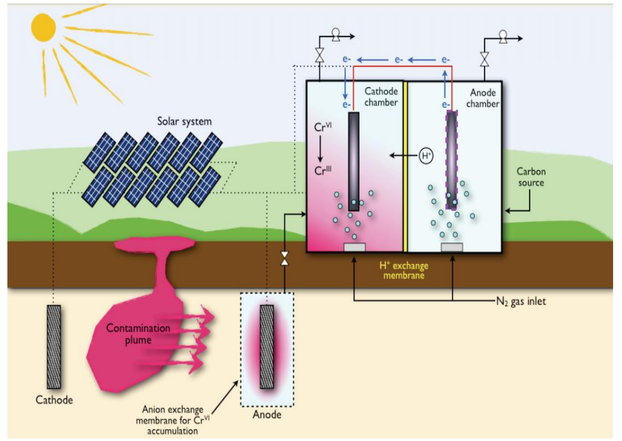
Scanning electron micrographs of the anode electrode with MR-1 Biomass

## SUMMARY AND DISCUSSION:

- $Cr^{VI}$ concentration was significantly decreased in the MFC system using *Shewanella oneidensis* strain MR-1.
- Significant reductions of $Cr^{VI}$ and total chromium occurred in the continuous flow EK-MFC system.
- pH decreased in the anode and increased in the cathode during the continuous flow experiment.
- MFCs can be successfully used to remediate polluted groundwater in a cost-effective manner.
- Electrokinetic technology was demonstrated to be effective in mobilizing $Cr^{VI}$ in bench-scale column simulating aquifer.
- The remediation process discussed in this study has low carbon footprint.

## FUTURE RESEARCH:

- Design and implementation of a pilot-scale process according to the following conceptual rendering:




- Investigate the limitation of electrokinetic transport and MFC technologies for $Cr^{VI}$ reduction.
- Investigate the effectiveness of electrokinectic and MFC technologies for the reduction of other toxic metals (i.e. $U^{VI}$).

## RESEARCHERS IN THE LABORATORY:

## ACKNOWLEDGEMENTS:

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