EVALUATING BIOCHAR IN SUSTAINABLE STORMWATER TREATMENT OF HEAVY METALS

US BIOCHAR INITIATIVE 2016

#USBI2016
8/22/2016
SARAH BURCH
PRESENTATION GOALS

• HIGHLIGHT BIOCHAR SYSTEM BENEFITS
• STATE RESEARCH GOALS IN WATER TREATMENT
• DISCUSS METHODS TO ACHIEVE GOALS
• PRESENT PRELIMINARY RESULTS
• CONCLUDING EMPHASIS ON SUSTAINABILITY IN WATER-ENERGY-CARBON NEXUS
WHY HAS BIOCHAR RESEARCH INCREASED IN LAST 10 YEARS?
BIOCHAR IS NOT ALL THE SAME

Lehmann (2007)

(Mohan et al. 2014)

<table>
<thead>
<tr>
<th>Product Distribution (wt%)</th>
<th>35*</th>
<th>30</th>
<th>35</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid Fraction</td>
<td>10</td>
<td>70*</td>
<td>20</td>
</tr>
<tr>
<td>Liquid (bio-oil)</td>
<td>10</td>
<td>5</td>
<td>85*</td>
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RESEARCH OBJECTIVES

- EVALUATE EFFICACY OF BIOCHAR AS A SUSTAINABLE ADSORBENT MEDIA
  - COMPARE REMOVAL WITH GRANULAR ACTIVATED CARBON (GAC)
- DETERMINE EFFECTS OF FEEDSTOCK AND PYROLYTIC CONDITIONS ON METALS REMOVAL
  - DOUGLAS FIR CHIPS AND HAZELNUT SHELLS
  - 300, 500, AND 700 °C
- ELUCIDATE MECHANISM FOR METALS REMOVAL BY BIOCHAR
  - CHARACTERIZATION OF BIOCHARS
    - FTIR SPECTROSCOPY, TGA-MS, SEM IMAGING, XRD
    - pH, PROXIMATE CARBON ANALYSIS, BET SURFACE AREA
  - BATCH AND COLUMN ADSORPTION EXPERIMENTS
  - ADSORPTION MODELING

Images by Kurt Spokas, 2013 (http://istc.illinois.edu/research/biochar/index.cfm)
MOTIVATION: COPPER REMEDIATION

• COPPER PRESENT IN STORMWATER RUNOFF
  • BRAKE PAD WEAR
  • PIPES, FUNGICIDE, ALGAECIDE

• LOW CONCENTRATION OF COPPER TOXIC TO SOME AQUATIC ORGANISMS

• CONCENTRATIONS AS LOW AS 2 PARTS PER BILLION (PPB) INHIBIT OLFACTORY SYSTEM IN JUVENILE COHO SALMON

• CURRENT BMPS REDUCE COPPER TO AS LOW AS 5 PPB
EXPERIMENTAL PROCEDURE BATCH EXPERIMENTS

• SYNTHETIC STORMWATER
  • 1 MM NAACL
  • 0.185 MM NAHCO₃
  • 100-1500 PPB CU
  • PH 6

• SORBENT
  • 40 – 50 MESH SIZE SIEVED BIOCHAR

• TUMBLE/EQUILIBRATE FOR 48 HOURS

• ANALYZE
  • DISSOLVED COPPER WITH ICP-OES
  • PH

Prepare Media and Synthetic Stormwater

Add 80 mL stormwater and sorbent to HDPE Bottles

Tumble Mixtures

Filter and Analyze Samples

48hr
SELECTING BIOMASS FEEDSTOCK AND PRODUCTION TEMPERATURE: BATCH RESULTS

- **Hazelnut**
  - H300
  - H500
  - H700

- **Douglas Fir**
  - D300
  - D500
  - D700

\[ q_e (\text{mg/g}) \]

\[ C_e (\text{mg/L}) \]
COMPARISON TO GRANULAR ACTIVATED CARBON (GAC)

H700 Biochar and GAC Langmuir Isotherms

\[ q_e = \frac{C_e \cdot K \cdot q_{\text{max}}}{1 + K \cdot C_e} \]

- **H700 Biochar**: 
  - \( K = 6.42 \)
  - \( q_{\text{max}} = 4.50 \)

- **GAC**: 
  - \( K = 6.63 \)
  - \( q_{\text{max}} = 1.88 \)
COLUMN EXPERIMENTAL SETUP
EVALUATING TRANSPORT PROCESSES

Hand, et. al. 1983

http://web.deu.edu.tr/atiksu/ana07/arith4.html
Influent Concentration

- H700
- GAC

**Influent Concentration**

- **1.26 mg/g**
- **1.35 mg/g**

**Elapsed Time (days)**

- **2 ppb**
POTENTIAL FOR RELEASE OF ADSORBED COPPER?

H700 Adsorption plus Desorption

1.35 mg/g

0.18 mg/g

13.5% Released
SURFACE COMPLEXATION MODELING

- INCORPORATES BOTH CHEMICAL BONDING (SURFACE) AND ELECTROSTATIC INTERACTIONS (SOLUTION)

\[ \Delta G_{\text{adsorption}} = \Delta G_{\text{intrinsic}} + \Delta G_{\text{coulombic}} \]

\[ K_{\text{ads}} = K_{\text{int}} \times K_{\text{coul}} \]

- DIFFERING PH, IONIC STRENGTH, METAL LOADINGS, AND COMPETITION WITH OTHER IONS

- USED TO ACCURATELY PREDICT HEAVY METALS SORPTION FOR VARYING CONDITIONS ONTO:
  - HYDROUS FERRIC OXIDE, CALCITE
  - ALUMINUM OXIDE, MANGANESE DIOXIDE
  - GRANULAR ACTIVATED
  - NATURAL ORGANIC MATTER

- APPLICABLE TO BIOCHAR BASED ON IMPORTANCE OF SURFACE FUNCTIONAL GROUPS IN METALS REMOVAL

Figure: Schematic Representation of EDL Structure according to Gouy-Chapman [Dzombak and Morel, 1987]
ELECTROPHORETIC MOBILITY (EPM) TITRATION

Mobility (um/s)/(V/cm) vs pH

- H700 Titration 1
- H700 Titration 2
WORKING HYPOTHESIS

- AROMATIC C-C RINGS ARE MOST EFFECTIVE IN REMOVING DISSOLVED COPPER FROM AQUEOUS SOLUTION
- THROUGH SURFACE COMPLEXATION MECHANISM OCCURRING IN DISTRIBUTED PI-BONDED ELECTRONEGATIVE FIELDS.

Kleber et al, 2014
FUTURE WORK

- ADDITIONAL FTIR TESTING – BETTER DEFINITION OF FUNCTIONAL GROUPS
- X-RAY DIFFRACTION (XRD) – INVESTIGATE STRUCTURE
- C-13 NMR SPECTROSCOPY – ESTIMATE AROMATIC DOMAIN
- NEAR-EDGE X-RAY ADSORPTION FINE STRUCTURE (NEXAFS) – AROMATIC DOMAIN
- CHNO ANALYSIS – DEFINE ELEMENTAL COMPETITION, ESTIMATE AROMATICITY
- COLLECTED STORMWATER COLUMN STUDIES – INVESTIGATE ENVIRONMENTAL APPLICATION

Kleber et al, 2014
CONCLUSIONS

BIOCHAR EXCEEDS PERFORMANCE IN COPPER REMOVAL OF INDUSTRY STANDARD, GAC, IN BATCH AND FIXED-BED COLUMN EXPERIMENTS.

• MECHANISM FOR REMOVAL NEEDS TO BE EVALUATED TO OPTIMIZE PRODUCTION CONDITIONS.

• BIOCHAR HAS POTENTIAL TO ADVANCE SUSTAINABILITY THROUGH MULTIPLE SYSTEM BENEFITS.
ACKNOWLEDGEMENTS

• Jeff Nason, Oregon State University- PhD Advisor
• Markus Kleber, Todd Jarvis, Meghna Babbar-Sebens, David Myrold – PhD committee
• Mark Johnson, EPA- Biochar Production and Characterization assistance
• Joy-Marie Gerould, Oregon State University – Undergraduate Researcher, Batch experiments and preliminary characterization
• Nason Lab Group – shared laboratory equipment, skills, and knowledge

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