Biochar for Stormwater Treatment:
Technology Overview & Case Study Survey

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Biochar Physical Properties

Highly porous; surface area up to 500 m$^2$/g

3 distinct pore types:

1. **External pores**: Dependent on particle size
2. **Macropores**: Dependent on feedstock
   - 10-100 µm range for wood biochars
3. **Micropores**: Dependent on production
   - 1-10 nm range = 10-100 water molecules!
   - Majority of surface area with high potential sorption

Variety of sizes = remove range of sizes of aqueous and particulate contaminants
Biochars are primarily stable Carbon Rings = Graphene Sheets

**Biomass:**
- Lignin
- Cellulose
- Hemi-Cellulose

Carbon content in wood biochars > 80% typical
Also oxygen, hydrogen, and ash compounds: Mg, Ca, Si
Mineral ash content affects reactivity, pH, and salinity
- Nutrient and metal precipitates
Biochar Sorption Properties

Biochars are primarily stable carbon rings = graphene sheets
  • Can provide sorption of hydrophobic contaminants

Surface functional groups add reactivity
  • Mostly oxygen-containing = cation exchange capacity
  • Some anion exchange capacity

Environmental aging increases CEC

<table>
<thead>
<tr>
<th>Biochar Type</th>
<th>CEC @ pH = 7 (meq/100 g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh</td>
<td>~10-20</td>
</tr>
<tr>
<td>Aged</td>
<td>~20-80</td>
</tr>
<tr>
<td>Historical</td>
<td>&gt;100</td>
</tr>
</tbody>
</table>

Sorption capacity of Biochar could increase over time!

Image Source: BEKbiochar; Data Source: Cheng et al. 2006
Biochar Contaminant Removal

<table>
<thead>
<tr>
<th>Contaminants</th>
<th>Removal Effectiveness</th>
<th>Removal Mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy Metals (Cu, Zn, Pb, etc.)</td>
<td>Generally good but capacity may be limited</td>
<td>Cation exchange, surface sorption in nanopores, chemical precipitation</td>
</tr>
<tr>
<td>Nutrients</td>
<td>Variable; Depends on Nutrients and Biochar</td>
<td>Ion exchange, chemical precipitation</td>
</tr>
<tr>
<td>Trace Organics (PAHs, PCBs,</td>
<td>Good but variable, limited data</td>
<td>Surface sorption, other mechanisms possible</td>
</tr>
<tr>
<td>Organics = VOCs</td>
<td>Good but limited data</td>
<td>Surface sorption, other mechanisms possible</td>
</tr>
<tr>
<td>Bacteria</td>
<td>Excellent but limited data</td>
<td>Hydrophobic interactions</td>
</tr>
</tbody>
</table>

Most research has investigated aqueous phases contaminants

**BUT** for stormwater, filtration mechanisms remove particulates with associated pollutants
Stormwater Pollution Overview

Major source of water impairment
- Increased urbanization is root of problem
- Tightening regulations = increased attention
- Highly variable = difficult to treat

Numerous contaminants:
- Sediment/TSS
- Nutrients (N, P)
- Heavy Metals (Cu, Zn)
- Oil compounds
- Other organics
- Bacteria

Particulate-Bound: Contaminants attached to particles (>0.45 µm)
- Common for N, P, Metals

“Dissolved”: Size fraction (<0.45 µm); Can be many forms
Stormwater Treatment Approaches

Media Filters

- High flow systems = small footprint
- Higher cost for high priority sites
- Media to remove contaminants
  - Target both dissolved and particulate
- **Biochar** as filtration media

Biofiltration

- Low flow as Low Impact Development (LID)
- Lower cost but require more space
- Media to remove contaminants and support plant growth
- **Biochar** as component of biofiltration media
  - Removes contaminants
  - Support plant growth
  - Provides water holding
Design: Biochar is not Created Equal

Properties depend on feedstock and production conditions:

- **Physical**: surface area, pore sizes, hardness/friability
- **Chemical**: Reactivity, ash content
- **Design Parameters**: Sorption capacity, particle size, hardness

Material Screening is Critical
Raw biochar contains fine particles = clogging
• May also leach contaminants and reduce removal

Rinsing or sieving for high flow applications

Particle size tradeoff:
• Coarser media = higher flow rate
• Finer media = More effective treatment

Blending can increase flow rate, but results can be mixed
• Process can also create fine particles = hardness matters

Low-flow bioretention: fine pose limited problem for flow rates, but may pose leaching issues
Design: Media Blends

Blended media often better choice:
- Enhance contaminant removal = multiple mechanisms and redundancy
- Adjust water chemistry
- Reduce media costs

Many Secondary Components:
- Inert: Sand, gravel, pumice
- Organic: Coconut coir, peat, compost
- Reactive: Zeolites, activated carbon

Bioretention media: Typically sand + organic + biochar
Media filters: Often include higher cost media
Lab-Based testing to develop media for copper and zinc removal

Collaborative research commercialization project:

1. Select best biochar from available sources
   – Also assess processing requirements

2. Create and assess media blends
   – Using best biochar and secondary components

3. Fully characterize complete filtration blends
   – Contaminant removal, filter lifetime, hydraulics, pH, toxicity, etc.
OSU Media Development Results

Started with lab testing of 7 Biochars

- Good copper removal by most biochars
- Zinc removal more variable

Most effective biochars used for further testing

Subsequent column testing to select best media blends
- Testing with real stormwater
- Intended for high flow media filters
Rapid Small Scale Column Tests (RSSCTs) to determine breakthrough

100% Biochar (#1) vs. 75% biochar / 25% pelletized peat

Pelletized peat dramatically improved zinc effectiveness

- How effective is biochar for high flow media?
- Different Biochar? Include as minor component?
Comprehensive Biochar Feasibility Study

Biochar from nearby Port Townsend Paper Company Mill
• Rinsed, screened, and blended

Treatability testing for copper and zinc removal:
• Final mixture: ~80% rinsed biochar / 20% pelletized peat
  – Flow rate of 5-10 inches/minute = high flow media
  – Mean copper removal = 99.3%
  – Mean zinc removal = 99.5%
PoPT Pilot Testing

Pilot testing of upflow filter design
• Passive downspout filter using PT biochar media
• Design flow rate = 15 gpm
• Installed April 2014; 4 sampling events
• Estimated volume treated = ~10,000 gallons
• Device constructed by John Miedema

<table>
<thead>
<tr>
<th></th>
<th>Mean Influent</th>
<th>Mean Effluent</th>
<th>Benchmark</th>
<th>Mean Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ug/L</td>
<td>ug/L</td>
<td>ug/L</td>
<td>%</td>
</tr>
<tr>
<td>Total Copper</td>
<td>46.5</td>
<td>2.52</td>
<td>17</td>
<td>93.5%</td>
</tr>
<tr>
<td>Total Zinc</td>
<td>4925</td>
<td>7.46</td>
<td>120</td>
<td>99.8%</td>
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</tbody>
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Below site discharge benchmarks
PoPT Full Installation

Full installation in December 2014
• 18 downspout treatment devices
• 2 custom-built in-ground filters
• Monitoring 2014-2015 rainy season
• Implementation by Jofran Enterprises

Downspout Filters Removal:

<table>
<thead>
<tr>
<th></th>
<th>Mean Influent ug/L</th>
<th>Mean Effluent ug/L</th>
<th>Mean Removal %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Copper</td>
<td>54.2</td>
<td>7.88</td>
<td>71.1%</td>
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<tr>
<td>Total Zinc</td>
<td>1018</td>
<td>39.0</td>
<td>92.6%</td>
</tr>
</tbody>
</table>

In-Ground Filters Removal:

<table>
<thead>
<tr>
<th></th>
<th>Mean Influent ug/L</th>
<th>Mean Effluent ug/L</th>
<th>Mean Removal %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Copper</td>
<td>2419</td>
<td>1336</td>
<td>52.6%</td>
</tr>
<tr>
<td>Total Zinc</td>
<td>1078</td>
<td>366</td>
<td>52.9%</td>
</tr>
</tbody>
</table>

Overall, Results Indicated:
• Excellent removal with downspout filters
• Variable removal with in-ground filters
• **Media rinsing is critical** to improve flow rates and contaminant removal and to prevent leaching of fine particles
• Port Townsend biochar can cause a short-term nutrient pulse, especially un-rinsed
Multiple studies to investigate updates to state bioretention mixture

- In Response to P and Cu Leaching from Sand / Compost Mixture
- Two studies included biochar: Kitsap County and City of Redmond Projects

Kitsap County Bioretention Testing

1. Leaching of multiple bioretention components
   - Tested for N, P, and Cu to eliminate poor components
2. Leaching of media blends
3. Contaminant removal of blends
   - Tested for multiple stormwater pollutants

3 Component classes: Bulk aggregate, bulk organic, organic additive

2 biochars included as organic additives
- Unrinsed “Biochar” Leached high P
- Rinsed “High Carbon Fly Ash”
Kitsap County Bioretention Results

2 Biochar blends: 70% sand, 20% coconut coir, 10% fly ash (biochar)
- Different sand varieties
- Fly ash (biochar) among top performers
Conclusions

Biochar is a promising stormwater treatment approach
   But MANY questions remain

Results for high flow media are promising but inconclusive

May be more effective as component of bioretention soil mixtures:
   • Can provide long-term replacement for compost mixtures
   • Contaminant removal may increase with ageing as CEC increases
   • Provides plant growth and water holding benefits

Successful projects should consider:
   • Biochar is not created equal = treatability testing and material screening
   • Rinsing/Sieving to remove fines = higher flow rate and contaminant removal
   • Media blends to improve performance
   • Testing after implementation
Research Needs and Directions

Laboratory research

• Contaminant removal mechanisms
• Filter longevity
• Stormwater / Biochar compatibility
• Emerging contaminants

Monitored Field Trials, Especially Biofiltration:

• Removal mechanisms including particulate removal
• Focus should be on long-term effectiveness vs. standard designs:
  – Does effectiveness of biochar media improve over time?
  – Do biochar-based mixtures (without compost) support plant growth?
  – Can inclusion of biochar increase system lifetime compared to compost
Questions?

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