Effectiveness of GAC and Biofiltration for Removal of Trace Organic Compounds

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- east coast, just west of Washington DC
- 54 mgd AWT facility for Potable Reuse
- a Surface Water Augmentation Project
- supplements the Occoquan Reservoir
- a major raw water supply source for Northern Virginians

Photo Credit: Roger W. Snyder
Why UOSA Considered a Change to Ozone with Biological Activated Carbon (BAC)

Potential Economic Benefits:
- 20 year life cycle cost of status quo is 10% – 40% higher than the O3/BAC alternative depending on regeneration frequency assumed
  - Savings of $2.5M - $13M over the life of the project
- Potential to avoid another $22.4M in future capital costs to expand GAC process

Results from Preliminary Paper Study
Why UOSA Considered a Change to Ozone with Biological Activated Carbon (BAC)

- Potential environmental and social benefits reported from use of O$_3$/BAC:
  - Improved disinfection
  - Oxidation of some inorganics (iron/manganese)
  - Odor & color removal
  - 90 - 99% removal of specific recalcitrant pharmaceuticals and other trace organics
  - Up to 60% removal of bulk dissolved organics
  - Lower Greenhouse Gas Emissions

Measured Full Scale Removals from Prior Research at UOSA
Existing Physical Advanced Treatment System
O$_3$/BAC Process Considered at UOSA
Historical Results of Testing Full Scale for Drinking Water Parameters (for period of 2006 to 2014)

- Trace Organic Compounds, Metals, Radionuclides, Microbials and Disinfection Byproducts met Federal Primary Drinking Water Standards
- All Inorganics except seasonal Nitrate-N and dry weather Total Dissolved Solids (TDS) met Federal Primary and Secondary Drinking Water Standards
- Nitrate-N concentration is intentionally elevated in warm weather to delay onset of anaerobic conditions in the reservoir hypolimnion. The majority of the Nitrate-N is naturally denitrified in the reservoir before reaching the drinking water intakes to below 5 mg/L. Operating protocol is to increase denitrification at plant if nitrate at water plant intake ever reaches 5 mg/L (1/2 the limit)
- TDS is diluted to well below the 500 mg/L Secondary Standard before reaching the drinking water intakes
Examples of UCMR and Other Drinking Water Related Analytes Monitored during UOSA’s O₃/BAC Pilot Testing

<table>
<thead>
<tr>
<th>Parameter</th>
<th>UCMR No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perchlorate</td>
<td>1</td>
</tr>
<tr>
<td>N-nitroso-dimethylamine (NDMA)</td>
<td>2</td>
</tr>
<tr>
<td>1,4-dioxane</td>
<td>3</td>
</tr>
<tr>
<td>PFOA/PFOS</td>
<td>N/A</td>
</tr>
<tr>
<td>TCEP/TCPP</td>
<td>N/A</td>
</tr>
<tr>
<td>Pharmaceuticals &amp; Personal Care Products (PPCPs- Negative DW L221 &amp; Positive DW L220)</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Site Specific Bench Testing for Fatal Flaws

- Laboratory Batch Tests on UOSA Water
- Ozone demand
- Ozone residual decay rate
- Ozonation byproducts at varying ozone doses/residuals
  - Bromate
  - NDMA & other Nitrosamines
  - PFOA/PFOS & other Perfluorinated Compounds
  - Perchlorate

![Graph showing ozone concentration over time for a dose of 4.8 mg/L at 10°C.]
Perchlorate Concentrations in Ozonated Multimedia Filter Effluent during UOSA Bench Testing

EPA Drinking Water Health Advisory for Perchlorate is 15 ug/L
Perfluorinated Compound Concentrations in Ozonated Multimedia Filter Effluent during UOSA Bench Testing

EPA Drinking Water Health Advisory for sum of PFOA + PFOS is 70 ng/L
Bromate Concentrations in Ozonated Multimedia Filter Effluent during UOSA Bench Testing

![Graph showing bromate concentrations in relation to mg O3/mg DOC ratio. The graph indicates that drinking water MCL is 10 ug/L and suggests operating the process with an O3/DOC ratio at 0.75 or lower.]

Need to operate process with an O3/DOC ratio at 0.75 or lower
UOSA O3/BAC Pilot

**Level 1**
Channel Feed Pumps
Constant Head Tank
Ozone Generator
Ozone Destruct

**Level 2**
Ozone Gas Transfer
Ozone Contact

**Level 3**
Biologically Activated Carbon Filters
Average COD Concentrations (colored bars) and 95% UCLs (error bars) for the period 12/7/15 to 5/9/17
COD Removed with and without O3, EBCT = 23.5 minutes

- Highest O₃ dosed spent GAC removed twice as much COD as the non-ozonated, spent GAC
Pilot Test Results - TOC

After 5 Months, Effluent TOC in Spent GAC with 4.5 mg/L Ozone (blue triangles) Matches Regenerated GAC Without Ozone (purple squares). For 0.65 O₃/DOC ratio dose - **25% reduction TOC, 42% reduction COD, 60% reduction UV254**
Pilot Test Results – Trace Organics

- 60 – 100 analytes evaluated
- about 30 were detectable in the influent
TTHM and HAA5 Formations for Spent & Regenerated GAC with and without Pre-Ozonation
NDMA Levels for Influent, Spent GAC, and Regenerated or Spent GAC with Pre-Ozonation

Expect concentration reductions through the environmental buffer:
- Periodic complete washout as a result of significant storm flow,
- 8 or 10:1 dilution factor is expected based on annual flows,
- UV photolytic destruction in stream flow and upper layers of reservoir, and further biodegradation in natural environment
NDMA SDS Levels for Influent, Spent GAC, and Regenerated or Spent GAC with Pre-Ozonation

- Suggests significant improvement in finished water quality at the WTP by removing precursor compounds that may contribute to nitrosamine formation at the downstream WTP or in its distribution system

- Although not displayed here significant reductions in NDMA formation were observed simply by ozonating the influent

- **Excellent** reductions in NDMA formation were observed in preozonated BAC biofilters as well as regenerated GAC biofilter w/o ozone

- CDPH Notification Level & NWRI DPR Standard = 10 ng/L

![Graph of NDMA Formation in System Distribution Simulation](image)
1,4 Dioxane Levels for Influent, Spent GAC, and GAC with Pre-Ozonation

- All biofilter effluent 1,4 Dioxane concentrations were less than the 1 ug/L CDPH Notification Level and criteria identified by the WRRF 11-02 NWRI Expert Panel for a deminimus risk for DPR.
1,4 Dioxane Levels for Spent GAC with Advanced Oxidation Process (Ozone and Peroxide)
Most Large Water Supplies in NC have Upstream Major NPDES Wastewater Discharges (blue dots below). Each Colored Area is a River Basin.
Cost of Alternative Treatment Trains for a 10 mgd facility

<table>
<thead>
<tr>
<th>Process</th>
<th>Capital Cost Range</th>
<th>O&amp;M Cost Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>MF/RO/AOP*</td>
<td>$5-10/gpd</td>
<td>$1-2.5/thou gal</td>
</tr>
<tr>
<td>Ozone/BAC</td>
<td>$1.5-4/gpd</td>
<td>$0.3-1.2/thou gal</td>
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</tbody>
</table>

*Assumes ocean outfall available for RO
Conclusions

- UOSA already consistently meets permit limits and provides water fit for the purpose of the surface water augmentation type potable reuse in the Occoquian Basin.
- Adding ozone for O₃/BAC will improve water quality and minimize life cycle costs.
- Ozone did not increase perchlorate or perfluorinated compound concentrations and concentrations are well below drinking water advisory levels.
- High doses of ozone increased bromate, but bromate formation can be limited by controlling ozone dose to operate at O₃/DOC ratios less than 0.75.
Conclusions

- Ozone did form some NDMA, but after acclimation NDMA was acceptably removed and NDMA precursor removal was dramatic.
- Ozone-BAC provided some removal of trace organics/CECs. Ozone-enhanced BAC provided removals comparable to relatively fresh regenerated GAC. A couple of compounds, such as PFOS/PFOA are better removed by fresh GAC and a couple of compounds, such as 1,4 Dioxane are better removed by ozonation/BAC.
- Ozone also provides a strong disinfectant barrier which is very important in potable reuse.
- RO plus AOP as required in CA provides an excellent barrier at higher cost.
Conclusions

- NC has a large amount of unplanned (de facto) potable reuse
- Planned IPR can provide water supply quality and quantity benefits and is increasing across the US
- Be proactive in assessing the trace organics in your system. Testing then compare to EPA and other guidance levels. Assess best removal techniques for any contaminants where more removal is desired. Best treatment depends on the contaminant – e.g. AOP for 1,4-Dioxane
## Present Worth Cost Comparison for Current GAC Biofiltration Vs. Ozone-enhanced GAC Biofiltration

<table>
<thead>
<tr>
<th>Based on Current COD Level (Pilot Tested)</th>
<th>OBF @ 1.3 mg/L Ozone Dose</th>
<th>GAC Adsorption @ 124 lb/MG Design GAC Usage Rate</th>
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</thead>
<tbody>
<tr>
<td>GAC Regeneration Frequency (years)</td>
<td>15</td>
<td>2.5</td>
</tr>
<tr>
<td>Capital Cost ($ million)</td>
<td>$25.0</td>
<td>$18.4</td>
</tr>
<tr>
<td>Present Worth of O&amp;M Cost ($ million)</td>
<td>$5.0</td>
<td>$14.1</td>
</tr>
<tr>
<td>Total Present Worth Cost ($ million)</td>
<td>$30.1</td>
<td>$32.5</td>
</tr>
<tr>
<td>Total Present Worth Cost Including Uprating Savings ($million)</td>
<td>$7.3</td>
<td>$32.5</td>
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</table>
Present Worth Cost Comparison for Current GAC Biofiltration Vs. Ozone-enhanced GAC Biofiltration

<table>
<thead>
<tr>
<th>Based on Historic Higher COD Level</th>
<th>OBF @ 2.6 mg/L Ozone Dose</th>
<th>GAC Adsorption @ 220 lb/MG Design GAC Usage Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAC Regeneration Frequency (years)</td>
<td>15</td>
<td>1.4</td>
</tr>
<tr>
<td>Capital Cost</td>
<td>$26.2</td>
<td>$18.4</td>
</tr>
<tr>
<td>Present Worth of O&amp;M Cost ($ million)</td>
<td>$7.7</td>
<td>$25.1</td>
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<tr>
<td>Total Present Worth Cost ($ million)</td>
<td>$33.9</td>
<td>$43.5</td>
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<tr>
<td>Total Present Worth Cost Including Uprating Savings ($million)</td>
<td>$11.2</td>
<td>$20.9</td>
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