Background

Trace Organic Contaminants (TrOCs or TOCs)
- Pharmaceuticals
  - Antidepressants
  - X-ray contrasting agents
  - Antibiotics
  - Steroid estrogens
- Personal Care Products
  - Sunscreen
  - Perfumes
  - Skin care
  - Hair care
  - Soaps
- Micropollutants
- Contaminants of emerging concern (CECs)
- PFAS
  - Steroid estrogens
  - Surfactants
  - PAHs
  - Phthalates
  - PCBs
  - Pesticides
- Nanoparticles
- Heavy Metals
- Microconstituents
- Microplastics
- Antibiotic resistance genes
Background

- WRRFs first line of defense
- WRRFs designed for bulk carbon and pathogen reduction
- More recently, there has been a focus on biological nutrient removal
- > 84% of WRRFs facilities in USA have some form of biological treatment
Background

Extending biological treatment to include bulk carbon, nutrient, pathogen AND TOC reduction/removal can help reduce overall energy requirements for WRRFs of the future

<table>
<thead>
<tr>
<th>Method</th>
<th>Average kWh/MG treated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activated sludge</td>
<td>1000 to 2200&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>Ozone</td>
<td>100 to 500&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>GAC</td>
<td>400 to 600&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>UV-H₂O₂</td>
<td>400 to 600&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
</tbody>
</table>


<sup>2</sup>Adapted from Use of Ozone in Water Reclamation for Contaminant Oxidation, WaterReuse Foundation
Background

EDC removal ranges from 20-100%
Cannot use this information to accurately predict removal
Variability in TOrC removal results can be magnified if consistent test procedures are not followed.

Is this variability due to differences in technology?

OR

Is this variability a reflection of multiple testing conditions?
Goals and Objectives

Developed and employed a method for standardizing analysis of biotransformation potential of various TOrCs
Methodology
# Trace Organic Compounds

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Structure</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>17α-ethinylestradiol (EE2)</td>
<td><img src="image" alt="Structure" /></td>
<td>Synthetic estrogen</td>
</tr>
<tr>
<td>C_{20}H_{24}O_{2}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonylphenol (NP)</td>
<td><img src="image" alt="Structure" /></td>
<td>Surfactant</td>
</tr>
<tr>
<td>C_{15}H_{24}O</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salicylic Acid (SA)</td>
<td><img src="image" alt="Structure" /></td>
<td>Analgesic and Antimicrobial</td>
</tr>
<tr>
<td>C_{7}H_{6}O_{3}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trimethoprim (TMP)</td>
<td><img src="image" alt="Structure" /></td>
<td>Antibiotic</td>
</tr>
<tr>
<td>C_{14}H_{18}N_{4}O_{3}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbamazepine (CBZ)</td>
<td><img src="image" alt="Structure" /></td>
<td>Antiepileptic</td>
</tr>
<tr>
<td>C_{15}H_{12}N_{2}O</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Selected based on prior fate studies and collaborator interest
<table>
<thead>
<tr>
<th>Standardized Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bioreactor redox conditions</td>
</tr>
<tr>
<td>Representative biomass</td>
</tr>
<tr>
<td>No change in cell condition (3-6 hrs)</td>
</tr>
<tr>
<td>Non-toxic initial substrate concentrations</td>
</tr>
<tr>
<td>Fast, direct measure of removal</td>
</tr>
<tr>
<td>Inexpensive sample preparation</td>
</tr>
</tbody>
</table>

Ideal test should incorporate all of the above
Experimental

Standard methodology employed on:

- Lab-Scale Batch Experiments
- Full-Scale Sampling Campaign
- Full-Scale Batch Experiments
Results from Lab-Scale Experiments
Lab-Scale Objectives

Two fundamental questions:

1. Does the initial TOrC concentration to biomass ratio (S0/X0) have an impact on the estimated pseudo-first order kinetic parameters?
2. Does the presence of readily biodegradable substrate (rbCOD) impact the estimated pseudo-first order kinetic parameters?
Lab-Scale TOrC Biotransformation

- SA, EE2 and NP more readily bio-transformed under aerobic conditions
- No statistical difference existed in estimated parameters between tests at 1 mg/L and 0.0005 mg/L
Lab-Scale TOrC Biotransformation

Readily biodegradable substrates can “suppress” rbTOrC biotransformation

Nitrifying lab culture

Denitrifying lab culture

Unique parameters that need to be estimated
Lab-Scale TOrC Biotransformation

Findings from lab-scale results suggest that biotransformation of TOrC is linked to sorption.

<table>
<thead>
<tr>
<th>Sorption Potential</th>
<th>Biodegradability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log $K_D$</td>
<td>$k_{bio}$ (L/g biomass as COD-day)</td>
</tr>
<tr>
<td></td>
<td>&lt; 2.5</td>
</tr>
<tr>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Medium</td>
<td>EE2, NP</td>
</tr>
<tr>
<td>Low</td>
<td>“readily” biotransformable TOrC</td>
</tr>
</tbody>
</table>
Lab-Scale Key Takeaways

• No statistical difference between tests at 1 mg/L and 0.0005 mg/L
• Presence of rbCOD will impact TOrC parameter
• Biotransformation of SA, EE2 and NP under aerobic conditions is more rapid than under anoxic conditions
• Extended process model shows promise for describing C, N, P and TOrC fate
Results from Full-Scale Experiments
Full-Scale Sampling

**Plant 1**

- From preliminary treatment
- Primary clarifier (Sampling location 1 - PE)
- Aeration Basin
- Secondary clarifier (Sampling location 2 - SE)
- Denitrifying filters
- To disinfection
- Primary sludge
- RAS
- WAS

**Plant 2**

- From preliminary treatment
- Primary clarifier (Sampling location 1 - PE)
- Aeration Basin
- Secondary clarifier (Sampling location 5 - SE)
- To disinfection
- Primary sludge
- RAS
- WAS
- ANA 1
- ANA 2
- ANX 1
- ANX 2
- AER 1
- AER 2

**Plant 3**

- From preliminary treatment
- Primary clarifier (Sampling location 1 - PE)
- BOD Aeration
- Secondary clarifier (Sampling location 2 - SE)
- Nitrification
- Denitrification
- Tertiary clarifier
- Effluent filters
- To dechlorination
- Primary sludge
- RAS
- WAS
- RAS
- WAS

**Nitrogen removal**

**Bio-Nitrogen and Bio-phosphorus removal**

**Bio-Nitrogen and chemical P removal**
Key Takeaways from Full-Scale Experiments

- SA and EE2 were biotransformed most rapidly under carbon limited aerobic conditions followed by anoxic and then anaerobic conditions.
- TMP biotransformation rates were variable and showed no preference for anaerobic, anoxic or aerobic conditions.
- NP biotransformation was more rapid in the anaerobic zone than the anoxic or aerobic zones.
- Strategies that aim to enhance attenuation of rbCOD should focus on maximizing the reaction time under carbon limited conditions ($HRT_{carbon\ limit}$).
- Process models can accurately predict TOrC fate. The impact of sorption and desorption is significant and needs to be accurately quantified.
Conclusions
Key Conclusions

• TOrC removal in biological reactors can be effectively described using short-term batch experiments
• Batch tests should be performed in the presence and at the incident concentration of the in-situ rbCOD to gauge accurate TOrC removal kinetics
• Strategies that aim to enhance attenuation of SA, EE2, and NP should focus on maximizing the reaction time under carbon limited conditions \( (HRT_{\text{Carbonlimit}}) \)
• Process models can accurately predict TOrC fate. The impact of sorption and desorption is significant and needs to be accurately quantified.
Questions and Contact Information

WERF U3R10

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