Bench-Scale Digestion Studies

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Presentation Outline

- Background
- Objectives of Study
- Materials & Methods
- Results & Discussion
- Summary & Conclusions
- Future Work
Background

- Sludge treatment and disposal costs represent 35-40% of the total cost of treating wastewater
- Promulgation of Standards for Use or Disposal of Sewage Sludge, Title 40 CFR Part 503 established:
  - Requires Compliance Monitoring
  - Meeting Pathogen Reduction Criteria
  - Meeting Vector Attraction Reduction Criteria
Pathogen Reduction: Class A

- Monitor fecal coliform or *Salmonella* sp. Bacteria
  - Fecal coliform < 1000 MPN per gm of total solids
  - *Salmonella* sp. < 3 MPN per 4 gm of total solids

- Alternative 1: Thermally Treated Sludge, Time-Temperature Requirement.
  - 4-Time-Temperature Regimes with equations

  - Elevated pH > 12, maintain for 72 hr, max. temperature > 52 °C for 12 hours, air dry 50% solids
Pathogen Reduction: Class A Cont’d

- **Alternative 3: Prior Testing for Enteric Viruses and Viable Helminth Ova in Raw Sludge.**
  - If enteric viruses > 1 PFU per 4 gm TS and Viable helminth ova > 1 per 4 gm TS must analyze after sludge treatment.

- **Alternative 4: Sludge Treated in Unknown Process.**
  - Enteric viruses < 1 PFU per 4 gm TS
  - Viable helminth ova < 1 per 4 gm TS
  - Document operating parameters that achieve pathogen reduction criteria.
Pathogen Reduction: Class A Cont’d

- Alternative 5: Use One of 7 PFRP Processes.
  - Composting
  - Heat Drying
  - Heat Treatment
  - Thermophilic Aerobic Digestion
  - Beta Ray Irradiation
  - Gamma Ray Irradiation
  - Pasteurization

Pathogen Reduction: Class B

- **Alternative 1**: geometric mean fecal coliform density of 7 samples < 2 million CFU or MPN per gm of TS.
- **Alternative 2**: Use of one of 5 PSRP Processes.
  - Aerobic Digestion
  - Air Drying
  - Anaerobic Digestion
  - Composting
  - Lime Stabilization
- **Alternative 3**: Use of Process Equivalent to PSRP Process.
Vector Attraction Reduction

- **Option 1**: 38% reduction in VS content by aerobic or anaerobic digestion.
- **Option 2**: 40 days additional anaerobic digestion with < 17% additional VS destruction.
- **Option 3**: 30 days additional aerobic digestion with < 15% additional VS destruction.
- **Option 4**: SOUR for aerobically digested sludge $\leq 1.5$ mg oxygen per hour per gm of total solids.
Option 5: Aerobic processes > 40° C for 14 days or longer and average temp. @ 45 ° C or higher.

Option 6: Addition of alkali to pH of 12 at 25 ° C and maintain for 2 hours, and then maintain at pH of 11.5 for an additional 22 hours.

Option 7: Moisture reduction by achieving ≥ 75% solids content prior to mixing with other materials.
  - Contains no unstabilized solids.
Option 8: Moisture reduction by achieving $\geq 90\%$ solids content prior to mixing with other materials.
- Contains some unstabilized solids.

Option 9: Inject sewage sludge or septage below ground surface.

Option 10: Incorporate sludge or septage into soil within 6 hours after application.

Option 11: Sludge or septage applied must be covered daily with soil or other material.
Aerobic Digestion

- Continuation of the activated sludge process.
- Digesters are operated in the endogenous phase.
- Microorganisms oxidize their own protoplasm into carbon dioxide, water, and ammonia.
- Subsequently, ammonia is removed through nitrification.
To meet pathogen reduction criteria, aerobic digesters must be operated at:
- a detention time of 40 days @ 20°C to 60 days @ 15°C to meet Class B requirements.
- a detention time of 10 days @ 55°C to 60 °C to meet Class A requirements.
Ozonation Destruction Mechanism

- Ozone is a very reactive oxidizing agent.
- Cesbron et al. reports that ozone is used for solubilizing and converting slowly biodegradable particulate organics into low molecular weight, readily biodegradable compounds.
- According to Scheminski et al. ozone attacks and destroys the cell wall releasing intracellular components.
Ozonation

- Scheminski et al. demonstrated that 60% of the solid organic components of digested sludge can be transformed into soluble substances at a specific ozone consumption rate of 0.5 g O$_3$ per gram of organic dry matter (ODM).
- Park et al. achieved 65% removal of Suspended Solids at an ozone dose of 0.5 g O$_3$ consumed per g of dried solids.
- Sakai et al. eliminated excess sludge production by ozonating RAS at an ozone dosage of 34 mg O$_3$ per gram of SS (0.034 kg/kg SS).
Yasui et al. demonstrated sludge reduction or elimination efficiencies ranging from 62.5 % to 100 % for nine different types of wastewaters.

Ozone dosage of 0.05 g of O$_3$ consumed per gram of SS applied was used in the bench-scale, pilot-scale, and full-scale studies.

Nitrogen and phosphorus concentrations in the effluent eventually increased and equaled those of the influent.

Soluble effluent TOC concentrations were higher resulting in overall TOC removal efficiencies that were 1 to 7% lower than the control activated sludge process.
Objectives of Study

- Determine and compare the total solids reduction in aerobic digesters versus ozonated digesters.
- Determine and compare the kinetics of volatile suspended solids reduction in the aerobic versus ozonated digesters.
- Estimate the quantity of oxygen required or utilized per mg of total volatile solids destroyed.
- Determine the quantity of ozone required per mg of total solids destroyed.
Bench-Scale Digestion Systems

Ozonated Digesters

Aerobic Digesters
Materials and Methods

- Four, 1-L bench-scale digesters were operated in parallel for 25 days.
- Aerobic digesters #1 and #2 were supplied with air at 1.44 L/min and 1.47 L/min, respectively.
- The applied oxygen loading rate was 432 mg O₂/min and 442 mg O₂/min for aerobic digesters #1 and #2, respectively.
- Ozonated digesters #1 and #2 were supplied air laden with ozone at a rate of 2.78L/min and 2.87L/min, respectively.
Materials and Methods cont’d

- Applied ozone loading rate was 0.36 mg O\textsubscript{3}/min and 0.39 mg O\textsubscript{3}/min for ozonated digester #1 and #2, respectively.
- Operating temperature was 19° C.
- Ozone transfer rate measured by sparging O\textsubscript{3} into potassium iodide solution.
- Ozone was measured by titration with 0.005N sodium thiosulfate (*Standard Methods*).
- COD was measured colorimetrically by HACH method 8000.
- Solids analyses were conducted in accordance with *Standard Methods*. 
# Results and Discussion

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<tr>
<th></th>
<th>Aerobic Digesters</th>
<th>Ozonated Digesters</th>
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</thead>
<tbody>
<tr>
<td>Average TSS</td>
<td>37%</td>
<td>64%</td>
</tr>
<tr>
<td>Removals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average VSS</td>
<td>39%</td>
<td>70%</td>
</tr>
<tr>
<td>Removals</td>
<td></td>
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</tr>
</tbody>
</table>
Solids Degradation Rate AD

\[ y = -0.0141x + 8.4629 \]
\[ R^2 = 0.8199 \]

\[ K_d = 0.014 \text{ days}^{-1} \]

\[ y = -0.0166x + 8.4405 \]
\[ R^2 = 0.8918 \]

\[ K_d = 0.017 \text{ days}^{-1} \]
Solids Degradation Rate OD

\[ y = -0.0386x + 8.4007 \]
\[ R^2 = 0.942 \]

\[ y = -0.0435x + 8.4235 \]
\[ R^2 = 0.8969 \]

\[ K_d = 0.039 \text{ days}^{-1} \]

\[ K_d = 0.044 \text{ days}^{-1} \]
Oxygen Utilized per TVS Destroyed

\[
\frac{O_2 \text{ Utilized}}{TVS_{\text{Destroyed}}} = \frac{(TCOD_0 - TCOD_t)V}{(TVS_0 - TVS_t)V}
\]

\(TCOD_0 \ & \ TCOD_t = \text{Total COD @ start and end of digestion, mg / L}\)

\(TVS_0 \ & \ TVS_t = \text{Total Volatile Solids @ start and end of digestion, mg / L}\)

\(V = \text{Volume of digester, L}\)
<table>
<thead>
<tr>
<th></th>
<th>Oxygen Utilized per Total Volatile Solids Destroyed</th>
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</thead>
<tbody>
<tr>
<td>Aerobic</td>
<td>1.85</td>
</tr>
<tr>
<td>Ozonated</td>
<td>1.82</td>
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</tbody>
</table>

EPA Manual 1.74 – 2.07 lb oxygen per lb of cell mass oxidized.
### Ozone Utilized per TS Destroyed

<table>
<thead>
<tr>
<th>Digester</th>
<th>Ozone Applied per Total Solids Destroyed</th>
<th>Ozone Utilized$^1$ per Total Solids Destroyed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ozonated Digester -1</td>
<td>2.6 mg/mg</td>
<td>0.71 mg/mg</td>
</tr>
<tr>
<td>Ozonated Digester -2</td>
<td>2.8 mg/mg</td>
<td>0.77 mg/mg</td>
</tr>
</tbody>
</table>

27.4% Ozone Utilization$^1$
COD Concentration

37% TCOD Removal Aerobic Digesters

64% TCOD Removal Ozonated Digesters
Soluble COD Concentration

- AD-1: 358 mg/L
- AD-2: 229 mg/L
- OD-1: 22 mg/L
- OD-2: 9 mg/L
Summary

- Four, 1-L bench-scale digesters were operated in parallel for 25 days.
- Two, sparged with air and two with ozone.
- Higher solids and total COD removals were achieved in the ozonated digesters and occurred at a faster rate.
- Soluble COD concentrations increased during the digestion period for both the aerobic and ozonated digesters.
Conclusions: 1

- Average overall TSS removals were 37% and 64%, respectively for the aerated and ozonated digesters.
- Average overall VSS removals were 39% and 70%, respectively for the aerated and ozonated digesters.
- Average oxygen required per mg of TVS destroyed was 1.82 for all four digesters.
- Average ozone dosages were 0.71 and 0.77 mg ozone consumed per mg of TS destroyed in OD-1 and OD-2, respectively.
Conclusions: 2

- Average overall TCOD removals were 37% and 64% for the aerated versus ozonated digesters.

- Average SCOD concentrations increased from 0 to 15 mg/L in the aerobic versus 0 to 294 mg/L in the ozonated digesters.

- Solids degradation constants ($K_D$) of 0.015 d$^{-1}$ and 0.041 d$^{-1}$ were determined for the aerobic and ozonated digesters, respectively.
Future Work

- Biodegradability of supernatant, BOD analyses
- Fecal coliform reduction
- Change air flow rate to aerobic digesters
- Change ozone concentration
- Investigate different initial solids concentrations
Questions?
Settling Characteristics

Sludge After 25 days of Digestion

Air  O₃

Sludge After Settling 30 minutes

Air  O₃