Long Term Treatment and Disposal of Landfill Leachate

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Presentation

• Brief introduction – Debra Reinhart
• In Situ Nitrification/Denitrification in Bioreactor Landfills – Nicole Berge
• Combined Chemical and Biological In-situ Treatment of Mature Landfill Leachate – Eyad Batarseh
Project Objectives

- To conduct laboratory experiments aimed at examining the capacity of a bioreactor landfill to provide complete in-situ treatment of landfill leachates so that they may be released to the environment without adverse impact.
Organic Waste Degradation

- Inorganic
- Organic
- Non-Biodegradable
- Biodegradable
- Insoluble
- Soluble

Bar chart showing the breakdown of MSW into various components.
Why Treat Recalcitrant Organics?

• Adverse health and environmental effects
• Source of methane
• Potential metal transport
Ammonia-Nitrogen Concentrations in Leachate

* Taken from Ehrig 1989
Why Remove Ammonia?

- Toxicity
- Oxygen demand
- Impact on post-closure
In-Situ Nitrification and Denitrification in Bioreactor Landfills
Ammonia-Nitrogen

- Currently removed ex-situ
- In-situ nitrification/denitrification would be advantageous
- Lab studies have shown effectiveness of such processes; lack information for field implementation
Research Objectives

• Determination of optimal environmental conditions and kinetics of in-situ nitrification,

• Development of an implementation strategy for in-situ nitrification and denitrification at field-scale, and

• Completion of an economic comparison between in-situ and ex-situ leachate treatment.
Laboratory Studies

• Waste acclimation process
  – Acclimate waste source with nitrifying and denitrifying populations
  – Demonstrate potential for in-situ nitrification and denitrification
Waste Acclimation Process

- Contains aerobically digested MSW
- Recirculate leachate every 2-3 days
- Continuously add air
Laboratory Studies

• Microcosm studies
  – Define kinetics of nitrification process
  – Different environmental conditions expected in field-scale bioreactor landfills
Microcosm Operation

Operation:
• 200g of waste (wet weight) + 20g wood chips
• Moisture content of waste is field capacity (63%, wet weight)
• Spike with NH$_4$-N
• Fill headspace with O$_2$
• Vary Temp, O$_2$, and NH$_4$
Microcosm Studies

- Sample for various liquid and gas phase parameters over time

  **Leachate:**
  - pH
  - Anions: nitrate, nitrite, sulfate
  - COD
  - Ammonia (sorbed + liquid-phase)

  **Gas:**
  - N₂
  - Presence of H₂S
  - N₂O
  - O₂
  - CH₄
  - Gas Volume

- Measure nitrification kinetics

- Complete nitrogen mass balances to determine the fate of nitrogen
Environmental Conditions Evaluated

- Gas-Phase Oxygen (0.7, 4.0, 4.5, 17, 100%)
- Temperature (22, 35, and 45°C)
- Ammonia Concentration (500 and 1000 mg N/L)
- Old waste
Waste Acclimation Process: Important Observations

• Operated for almost 1,000 days
• In-situ nitrification and denitrification are feasible
• Denitrification can occur in older portions of a landfill, even under low biodegradable C:N conditions
Microcosms Tests: Tasks Completed

• Microcosms at 500 and 1000 mg N/L:
  – Temperatures: 22 and 35°C
  – Oxygen levels: 0.7, 4.0, 4.5, 17 and 100%
• Comparison between acclimated and unacclimated wastes
• Abiotic Controls
  – All temperatures
• Biotic Controls
  – All temperatures
Microcosm Studies

• Tasks being discussed today:
  – Different gas-phase oxygen concentrations
    • 0.7, 4.0, 4.5, 17 and 100%
  – Temperatures
    • 22 and 35°C
Impact of Oxygen Concentration on Ammonia Removal

Temperature = 22°C

Ammonia Concentration (mg N/L)

Time (Days)
Nitrous Oxide Production at Different Oxygen Levels

**Mass and Percentage of N\textsubscript{2}O Produced**

- Mass of N\textsubscript{2}O Produced
- % of N Converted to N\textsubscript{2}O

Temperature = 22\textdegree C

* Maximum mass produced in each study
Nitrogen Gas Production at Different Oxygen Levels

Temperature = 22°C

* Maximum mass produced in each study
Ammonia Removal Rates: Kinetic Equation

\[ R = \left( \frac{0.68 C_N}{83 + C_N} \right) \frac{\%O_2}{3.43 + \%O_2 + \frac{\%O_2^2}{40}} \]

Where,

- \( R \) = ammonia removal rate (mg N/g dry waste-day)
- \( K_s \) = half-saturation constant (mg/L-N)
- \( C_N \) = total ammonia-nitrogen concentration (mg/L-N)
- \( k \) = specific rate of removal of ammonia (mg N/day-g dry waste)
- \( K_O \) = oxygen half-saturation constant (%O_2)
- \( \%O_2 \) = gas-phase concentration of oxygen (%)
- \( K_I \) = inhibition observed at high oxygen concentrations (%O_2)
Ammonia Removal Rates at Various Oxygen Levels

Temperature = 22°C
Temperature Impact: Ammonia Removal at 5% $O_2$

- Ammonia Concentration (mg N/L)
  - 0  200  400  600  800  1000  1200
- Ammonia Removal Rate (mg N/g dry waste-day)
  - 0.0
  - 0.1
  - 0.2
  - 0.3
  - 0.4
  - 0.5
  - 0.6
  - 0.7

22C Rates
35C Rates
Monod Fit - 22C
Monod Fit - 35C

1.5 times greater
Temperature Impact: Ammonia Removal at 17% O₂

Ammonia Concentration (mg N/L) vs. Ammonia Removal Rate (mg N/g dry waste-day)

- 22°C Rates
- 35°C Rates
- Monod Fit - 22°C
- Monod Fit - 35°C

The graph shows that at 35°C, the removal rates are approximately 1.6 times greater compared to 22°C.
Temperature Impact:
Ammonia Removal at 100% $\Omega_2$

Ammonia Concentration (mg N/L)

Ammonia Removal Rate (mg N/g dry waste-day)

35C Rates
22C Rates
Monod Fit - 35C
Monod Fit - 22C

3.5 times greater
Conclusions

• Ammonia readily and rapidly disappears at all oxygen levels
  – Removal is via nitrification
  – Feasible at the field-scale
• Some denitrification occurs in aerobic environments
• Rates appear to follow Monod kinetics with Andrew’s inhibition term to account for oxygen
Conclusions

• Evaluate impact of pH on nitrification rates
• Additional studies are needed at different temperatures and oxygen levels
• Field-scale verification is needed and is planned
What’s Next…..

- Continue to evaluate ammonia removal at 45°C
- Evaluate pH impact
- Conduct field study
Combined Chemical and Biological In-Situ Treatment of Mature Landfill Leachate
Recalcitrant Organics Removal

- Mature leachate has more non-biodegradable organic compounds when compared to young leachate.
- Biological treatment cannot remove these organics.
- A chemical or physical method is needed.
Recalcitrant Organics in Mature Leachate

• Humic Substances
  – Results from biodegradation
  – The majority of the non-biodegradable DOM
  – High molecular size
  – No universal structural formula (In landfill leachate an example has C=56.2%, H=8.8%, O=26.7%, N =8.3%)

• Xenobiotic Organic Compounds
  – Derived from hazardous materials allowed into the landfill
  – Low concentrations
  – Includes aromatic hydrocarbons, halogenated hydrocarbons, phenols, other compounds
Proposed Treatment

Chemical Oxidation
- Effective for removal of recalcitrant organics
- High cost

Biological Treatment
- Not effective for removal of recalcitrant organics

Combined Chemical and Biological Treatment
- Effective for removal of recalcitrant organics
- Low cost compared to oxidation alone
- Low cost compared to biological treatment alone
Oxidants Used

• Fenton’s Reagent (proven to treat leachate organics)
  – Advanced oxidation technique (OH radicals)
  – Hydrogen peroxide + ferrous (Fe (II))
  – More reactive in acidic conditions

• Ferrate (Fe (VI)) (never been tried on leachate)
  – Powerful
  – Non toxic by-products
  – Active over a wide pH range
Research Objectives

• Determine optimal oxidation conditions (time, dose, pH) for removal of organic compounds using Fenton’s reagent and ferrate
• Determine effect of oxidation on leachate biodegradability using Fenton’s reagent
  • Aerobic (BOD)
  • Anaerobic (BMP)
• Evaluate the efficiency of this treatment in a solid waste matrix
• Conduct an economic analysis of this treatment method
Experimental Work

• Phase I: Oxidation Efficiency (Fenton and ferrate)
  – Completed and discussed in previous meetings

• Phase II: Effect of Oxidation on Leachate Biodegradability (Fenton)
  – Completed and will be discussed here

• Phase III: Overall Scheme (Combined Biological-Chemical Treatment Simulation) (Fenton)
Phase II: Biodegradability After Oxidation

Methodology

Samples collection


Fenton Oxidation

Optimum dose ½ Optimum dose

Biological Tests

Aerobic (BOD) Anaerobic (BMP)
BMPs

BMP: Biochemical Methane Potential

- Samples are placed in media bottles with anaerobic seeded media
- Samples are incubated at 35 °C
- Gas readings are taken weekly (concentration of methane and volume of gas)
# Leachate Characteristics

<table>
<thead>
<tr>
<th>Sample</th>
<th>Cl- (mg/l)</th>
<th>NH3 (mgN/l)</th>
<th>DOC (mg/l)</th>
<th>BOD5 (mg/l)</th>
<th>COD (mg/l)</th>
<th>BOD/COD</th>
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<td>1988</td>
<td>2629.5</td>
<td>1240.2</td>
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<td>1999</td>
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<td>667.1</td>
<td>668.6</td>
<td>33.5</td>
<td>1645.9</td>
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Preliminary Results
DOC Removal Efficiencies

![Bar chart showing DOC removal efficiencies for years 1988, 1995, and 1999 at different H2O2:COD molar ratios. The chart indicates that 1.0 is the optimum dose.](image-url)
Oxidized Leachate
Preliminary Results

BOD$_5$/DOC

Optimum dose

[Bar chart showing the BOD$_5$/DOC values for different doses and years, with the optimum dose indicated.]
Preliminary Results

$\text{BOD}_5/\text{BOD}_{28}$

<table>
<thead>
<tr>
<th>Year</th>
<th>Pretreatment</th>
<th>Dose = 0.5</th>
<th>Dose = 1</th>
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<tbody>
<tr>
<td>1988</td>
<td>0.2</td>
<td>0.6</td>
<td>0.7</td>
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<tr>
<td>1995</td>
<td>0.3</td>
<td>0.6</td>
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<tr>
<td>1999</td>
<td>0.5</td>
<td>0.6</td>
<td>0.7</td>
</tr>
</tbody>
</table>
Preliminary Results
BMPs (1988)

Graph showing CH₄ produced (ml) over time (day) for different categories:
- 1988
- 1988 D1
- 1988 D1/2

The graph illustrates the change in CH₄ production over time for each category.
Preliminary Results
BMPs (1995)
Preliminary Results
BMPs (1999)
Preliminary Results

BMPs
Preliminary Results
BMPs

Methane produced / 6 mg DOC

-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00

Dose = 1
Dose = 0.5
Pretreatment

Benzoic acid

1988
1995
1999
Phase II
Conclusions

-Fenton oxidation improved the aerobic biodegradability of landfill leachate significantly. However, did not improve the anaerobic biodegradability to a great extent.

- Using BOD to determine the biodegradability of leachate in a landfill may be misleading.

- Oxidation increased the rate and extent of aerobic biodegradation.
Phase III: In Progress.....

• Utilize aerobic microcosms to evaluate the effect of oxidation on leachate biodegradability in solid waste
• Optimize and evaluate oxidation of leachate inside a landfill
• Conduct an economical analysis for the treatment method
PLEASE NOTE:

• The results presented are preliminary. All conclusions based on these results are subject to change.
Questions

1. Do you see a future in aerating small sections of a landfill?
2. From your experiences, do you see value in treating leachate in-situ rather than ex-situ?
3. Is there anything not covered that you feel is important to discuss?