Landfill Biocell: Cost-effective Technology to Achieve Sustainability of Landfill Operations

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Key message(s)

• Waste landfill cells could be operated in a “sustainable” manner (but need a paradigm shift in philosophy, design and operation) – third “generation” of waste cell operation

• Some work is needed for system optimization and to convince operators and regulators
Background – first generation landfills

• Conversion of Open Dumps to “Sanitary Landfills”
  • First Generation Landfill – operate a cell as a “Dry-tomb waste cell” to control groundwater contamination
    • Keep water away from waste
    • Leachate management

“Dry-tomb waste cell” is a large Anaerobic Bioreactor in which waste degrades very, very slowly
Background: second generation landfill

• Second Generation – Landfill Bioreactor operation
  • Recirculation of leachate
  • Increased amounts of water and recirculation of nutrients and microbes result in rapid waste degradation rates
• Landfill gas recovery for production of energy becomes a viable option; both economically and environmentally

Possible to operate Landfill Bioreactors in both Anaerobic and Aerobic modes
Third Generation – Sustainable Landfills or Biocells

- Rapid degradation and stabilization
- Energy recovery
- Recovery of Resources and Space

These goals are achieved with a combination of Anaerobic and Aerobic Bioreactor Operation and cell Mining
Biocell concept

- Cell operate under **Anaerobic** conditions for few years, when Energy recovery is economically viable
- Then the cell is operated under **Aerobic** conditions for shorter duration to allow faster stabilization
- The Cell is then **Mined** to recover space and materials.
- The Cell converted to an in-ground “waste processing facility” instead of a “perpetual storage facility”.
Some barriers to Biocell implementation

- **Technical:** Some of the organic materials are not biodegradable (later stages of waste degradation)
  - Presence of Lignin
    - Long-chain organic polymers
    - Increases the difficulty of organic waste degradation
- **Regulatory:** Lack of accurate method to quantify landfill methane potential (common BMP method may not represent landfill scenario)
Lignin degradation in Biocells

• In nature, white-rot and brown-rot fungi produce enzymes that breakdown lignin

• In Biocells, recirculate leachate could be enhanced with enzymes to degrade lignin that would allow access to entrapped nutrients

  • True lignin degraders
    • Lignin Peroxidase (LiP)
    • Manganese Peroxidase (MnP)
Comparison of enzyme types - Batch Experiments

- Factors and Levels
  - Enzyme type
  - Enzyme dose - 3 doses
  - Hydrogen Peroxide (enzyme activator) - 3 doses

- Two enzyme types: LiP and MnP
- Partially degraded waste used in 1 L glass bottle reactors
- Response variable: methane and carbon dioxide gas production
Results - Anaerobic

<table>
<thead>
<tr>
<th>Factors</th>
<th>Treatment Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enzyme Dose (mg/gDS)</td>
<td>-1   0   1</td>
</tr>
<tr>
<td>H₂O₂ Dose (mL/gDS)</td>
<td>0   0.01 0.02</td>
</tr>
</tbody>
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MnP showed better results
Results – Aerobic

MnP showed better results
Flow-through column experiments

Anaerobic bioreactor simulation
Column experimental results - Anaerobic

- Addition of MnP increased dissolved organic carbon (DOC) levels and daily methane gas production rates
Lysimeter experiments – Aerobic

- Lysimeter experiments (in scaled down version of a waste cell)
Lysimeter experimental results - Aerobic

• Enzyme addition:
  • Increased biodegradability and CO₂ Production
  • Increased rate of hydrolysis
Problems with conventional BMP method

• Bio-methane potential (BMP) method is used as a measure of landfill methane generation potential (ultimate gas generation potential, Lo) because the use of theoretical calculations overestimate the Lo.
• BMP method uses a batch experimental protocol; results vary due to different experimental conditions; nutrients, inoculum.
• The conventional BMP assay originally developed for anaerobic degradation of wastewater sludge; slurry-phase.
• Not considered: heterogeneous nature of solid waste, non-ideal (low moisture) conditions in a landfill environment.
BMP method development – early results

- Batch experiments conducted to study the effects of:
  - Inoculate to substrate ratio
  - Moisture content
BMP method development – early results

• The theoretical ultimate methane potential ($L_{0_{th}}$) was estimated as 466 m$^3$ per tonne of waste volatile solids (WVS), if all the WVS are biodegradable.
• The maximum observed ultimate methane potential ($L_{0_{exp}}$) from BMP assay was 113 m$^3$ per tonne of the WVS.
• Overall, the experimental methane yields were substantially lower than the theoretical values.
Conclusions

• Addition of manganese peroxidase increases waste degradation rates; both under anaerobic and aerobic modes of operation.
  • Increases methane production rates
  • Accelerates waste stabilization during aerobic landfill bioreactor operation
• Theatrical calculations and conventional BMP method overestimate the methane generation potential. Further work required to develop a BMP method applicable in landfill situations.
Overall effect of enzyme enhancement

- Biocell without enhancement

- Biocell with anaerobic enhancement

- Biocell with aerobic enhancement

- Biocell with anaerobic and aerobic enhancement
THANK YOU!