The Status of Bioreactors

Debra R. Reinhart, PhD, PE
University of Central Florida
“……a sanitary landfill operated for the purpose of transforming and stabilizing the readily and moderately decomposable organic waste constituents within five to ten years following closure by purposeful control to enhance microbiological processes. The bioreactor landfill significantly increases the extent of waste decomposition, conversion rates and process effectiveness over what would otherwise occur within the landfill.”
Why Operate a Landfill as a Bioreactor?

- to increase potential for waste to energy conversion,
- to store and/or treat leachate,
- to recover air space, and
- to ensure sustainability
Status

- 1993 - less than 20 landfills recirculating leachate
- 1997 - ~ 130 landfills recirculating leachate
- My estimate - ~ 5% of landfills
Regulatory Status

- EPA permits recirculation of indigenous liquids into landfills with Subtitle D liners
- Some states more stringent
- EPA is considering nonindigenous liquid addition
EPA Concerns

- long-term fate of metals,
- the lack of data that demonstrate the reduction of environmental risk and liability, and
- increased operational requirements
- landfill gas capture,
- leachate treatment and storage,
EPA Concerns - Cont’d

• landfill space and capacity reuse,
• greenhouse gas abatement,
• bioreactor design,
• solid waste density considerations,
• settlement,
• waste pretreatment,
• cover,
• management of amendments.
Europe

The European Union Council Directive on Landfilling of Waste has identified the need to optimize final waste disposal methods and ensure uniform high standards of landfill operation and regulation throughout the European Union (EU).
Essential Needs for a Bioreactor

- Composite liner
- Appropriate density of MSW
- Appropriate daily cover
- Leachate recirculation system
- Active gas collection system
- Appropriate final cover system
- Competent landfill operator
Leachate Recirculation
Leachate Quantity

![Graph showing the relationship between waste receipt and liquid required for different percentages (10%, 15%, 20%, 25%). The x-axis represents waste receipt in tonnes per day, ranging from 0 to 6000. The y-axis represents liquid required in m³ per day, ranging from 0 to 2000. Each line represents a different percentage, with 10% being the steepest and 25% the shallowest.](image-url)
Storage
Leachate Storage Impact on Off-site Treatment
Leachate Collection System Performance
Clogging Potential
Performance Monitoring
Maintenance
Bioreactor Design - Horizontal Device Placement

![Graph showing lateral movement vs. application rate and permeability](image)
Bioreactor Design - Vertical Well Placement

![Graph showing the relationship between lateral movement, application rate, and permeability. The graph plots lateral movement in meters on the y-axis and application rate in cubic meters per day on the x-axis. The permeability is indicated by different line styles: blue triangles for 1.0E-3, black dots for 1.0E-4, and red squares for 1.0E-5.]
Gas Collection
LFG Generation Curves

- Half-Life = 1.35 yr
- Half-Life = 3.68 yr
- Half-Life = 20 yr

Cubic meters LFG

Year
LFG Collection From Operating Landfills

Horizontal Collectors

Sub-Cap Collector

Leachate Collection System - LFG Collector Network
Odor Potential
Cover Issues
Alternative Daily Cover
Impact on landfill Operations
Impact on landfill Operations

• Construction (sequencing)
• Location of roads/access
• Monitoring
  – Settlement
  – Side Seeps
  – Odors
Research Needs
Long Term Sustainability

- Fate of metals
- Fate of other inorganics/recalcitrants
- Flushing bioreactor?
Waste Compaction
Vertical Permeability $= 10^{-4} \text{ cm/s}$

$K_V = K_H$

$K_V < K_H$

$K_V > K_H$
Settlement

- The Keele Valley Landfill - settlement rates of 10-12 cm/month in wet areas, 5-7 cm/month in dry areas.
- Yolo County, CA test cells - wet cell settlement rates > three times parallel control cell (17 mos)
- lower settlement enhancement (~ 5%) was reported at aerobic cells in Columbia Co
- The Trail Road Landfill in Ontario, Canada reported a 40% recovery of airspace (8 yrs)
Nonindigenous Liquids

• Supplement nutrients and moisture,
• Dispose of liquid waste products,
• Compensate for insufficient leachate volumes, and/or
• Avoid concentration of inorganic contaminants in leachate
Ponding Water

Waste

Heterogeneity

Impermeable Cover

Ponding Water

Preferential Channels

Gas Flow
Leachate Applied Intermittently at an average rate of $2 \text{ m}^3/\text{m/day}$

Waste Permeability $= 10^{-3} \text{ cm/s}$
Daily Cover Permeability $= 10^{-5} \text{ cm/s}$
Landfill Stability
Leachate Quality

Chemical Oxygen Demand, mg/L Thousands

Year

Closure
Impact of Waste Processing
Recovery of Composted Materials
Aerobic Bioreactor

- Rapid stabilization of waste
- Enhanced settlement
- Evaporation of moisture
- Degradation of organics which are recalcitrant under anaerobic conditions
- Reduction of methane emissions
Research Issues - Aerobic Bioreactor

- How much air is needed?
- How can air be delivered?
- What is the impact on the water balance?
- How are landfill fires prevented?
- What are the economic implications?
Anaerobic Decomposition

\[ C_6H_{10}O_5 + H_2O \rightarrow 3CH_4 + 3CO_2 \]
Aerobic Decomposition

\[ C_6H_{10}O_5 + 6O_2 \rightarrow 6CO_2 + 5H_2O \]
Aerobic Landfill
Flammability of Landfill Gas

Explosive Range of Methane in Air

5% to 14/15%
Effect of Diluent Gases on Flammability Limits

Methane in Mixed Atmosphere (%)

Fraction of Diluent in Atmosphere
We Can Construct a Flammability Chart
Mixtures that can not be formed

Explosive Range

Capable of forming flammable mixtures with air (contains too much methane to be in explosive range)

Not capable of forming flammable mixtures with air
Example: 
Anaerobic Landfill Gas

CH\(_4\) = 55%
CO\(_2\) = 45%
O\(_2\) = 0%
N\(_2\) = 0%
Example:
Arid Region Anaerobic Landfills with Gas Collection Systems
Example:

Aerobic Landfill Gas

\[ \text{CH}_4 = 37.5\% \]
\[ \text{CO}_2 = 49.5\% \]
\[ \text{O}_2 = 0\% \]
\[ \text{N}_2 = 13\% \]
Example:
Aerobic Landfill Gas
Economic Impacts

Benefits
- Enhanced gas production
- Recovered space
- Reduced env. impact
- Reduced post-closure care

Costs
- Capital costs
- Operating costs