

**Aerobic vs Anaerobic Bioreactor Landfill Case Study – The New River Regional Landfill**

Dr. Debra R. Reinhart, University of Central Florida  
Dr. Timothy Townsend, University of Florida

## **Abstract**

The New River Regional Landfill (NRRL) in north Florida is hosting a Florida Bioreactor demonstration project. The primary goal of the landfill bioreactor demonstration project is to design, construct, operate, and monitor a full-scale landfill bioreactor in Florida in a manner that permits a complete and fair evaluation of this technology as a method of solid waste management in Florida, with appropriate consideration of science, engineering, environmental and economic issues.

The demonstration will include recirculation of leachate, injection of air into portions of the landfill, and the ability to monitor gaseous emissions from the bioreactor. The landfill bioreactor will be instrumented for the purpose of collecting *in-situ* measurements of such parameters as leachate head on the liner, and moisture content and temperature of the waste. The landfill bioreactor at the NRRL is designed to allow operation and testing of both aerobic and anaerobic waste treatment regimes. Construction of bioreactor components is expected to begin in fall 2000 with operation commencing in early 2001. This paper will contrast design/control aspects of operating the landfill in an aerobic vs. anaerobic regime.

## **Introduction**

The bioreactor landfill is an emerging technology for the on-site management of leachate. The benefits of bioreactor landfills have been well documented by a variety of researchers and include enhanced and accelerated waste stabilization, improved leachate quality, and rapid landfill settlement. The most effective (but not the only) element of bioreactor operation is moisture control through leachate recirculation. Leachate is commonly recirculated using tankers at the working face, surface ponds, spray or drip irrigation, horizontal trenches, and/or vertical wells.

The State of Florida has identified the need to demonstrate bioreactor technology at full scale. The New River Regional Landfill (NRRL) in north Florida has volunteered to host the Florida Bioreactor demonstration project. The demonstration will include recirculation of leachate, injection of air into the landfill, and the ability to collect all gaseous emissions from the test cell. The landfill bioreactor will be instrumented for the purpose of collecting *in-situ* measurements of such parameters as leachate head on the liner and moisture content and temperature of the waste. Construction of bioreactor components is expected to begin in fall 2000 with operation commencing in early 2001. Updated information about this project can be found at <http://www.bioreactor.org>.

The traditional method of landfill bioreactor operation involves enhancing waste stabilization by anaerobic microorganisms. Recently, increased interest has been focused on the introduction of oxygen to the landfill to create an aerobic bioreactor. Air is typically injected into the landfill with the same devices as used to extract gas or inject leachate (vertical and horizontal wells). Aerobic bioreactors have been promoted as a method to accelerate waste stabilization and to reduce methane content in landfill gas (Johnson and Baker, 1999; Hudgins and March, 1998). Concerns that remain which prevent widespread use of this technology include the issue of landfill fires and added power costs. The NRRL demonstration project will employ aerobic and

anaerobic bioreactor practices providing an opportunity to compare and contrast technical and economical aspects, as described in this paper.

## **Project Objectives**

The primary goal of the landfill bioreactor demonstration project is to:

*Design, construct, operate, and monitor a full-scale landfill bioreactor in Florida in a manner that permits a complete and fair evaluation of this technology as a method of solid waste management in Florida, with appropriate consideration of science, engineering, environmental and economic issues.*

The specific objectives of the landfill bioreactor demonstration are to:

- ◆ Design and operate the bioreactor using innovative techniques and concepts.
- ◆ Design and operate the bioreactor in a manner to control and measure the major inputs and outputs, e.g. landfill gas production and leachate recirculation rates.
- ◆ Evaluate the use of aerobic bioreactor landfill technology and compare the aerobic approach to the use of anaerobic bioreactor technology.
- ◆ Instrument the landfill bioreactor to permit in-situ monitoring of bioreactor activity and to measure previously unmeasured information (e.g. leachate head on the liner).
- ◆ Monitor the bioreactor in a manner to measure the impact of bioreactor activities and to allow control of the waste treatment process (e.g. leachate and gas composition and generation, waste characteristics, settlement).
- ◆ Collect data through instrumentation, field monitoring, and laboratory analysis that will enable the project team to assess the success of the project, and the feasibility of this technology for other sites. Develop standardized design and operation procedures for this technology.
- ◆ Further define and quantify the true costs and benefits of landfill bioreactors.
- ◆ Provide a resource and training ground for students in the State University System, landfill operators, and engineers in Florida.

## **Overview of the Project**

The NRRL serves sources in five surrounding counties, receiving primarily mixed residential, commercial, and industrial waste. Waste receipt presently averages 730 tonnes/day (800 tons/day). The landfill consists of three contiguous lined cells totaling approximately 10 ha (26 acres). Cell 1 is equipped with a composite bottom liner consisting of a 1.6-mm (60-mil) High Density Polyethylene synthetic geomembrane and 0.9 m (36 inches) of compacted clay soils overlain by 0.8 m (24 inches) of  $10^{-3}$ -cm/sec sand. Cell 2 is provided with a double liner system consisting of a primary leachate collection system overlaying a geomembrane with a leak detection system and geomembrane beneath the primary liner. Cell 3 was constructed with a unique liner described further below.

The landfill bioreactor demonstration project at the NRRL involves the modification of the existing landfill Cells 1 and 2 (see Figure 1). The recently constructed Cell 3 is not included as

part of the current work, but may be proposed for incorporation into the research project at a later date. Approximately 4 ha (10 acres), Cell 1 and part of Cell 2, will be dedicated as an active bioreactor area. A leachate recirculation system, an air injection system, and a gas extraction system will be installed in this area. Instrumentation will be installed within the waste mass to assist in monitoring and control. Environmental sample collection and analysis and field measurements will be routinely performed to monitor the progress of bioreactor treatment.

Cell 3 dimensions are 238 m by 146 m (780 ft by 480 ft). The entire 3.6-ha (8.6-acre) surface is sloped at 1% running west to the east and has a 0% slope north to south. This drainage slope terminates at the east side where a trench approximately 0.9 m (3 ft) deep has been excavated. This trench drains (0.5% slope) from both the north and south ends to the center of the eastern edge of the cell. Leachate is routed to a single sump from this central collection point. The leachate collection system configuration starting from the bottom is compacted clay, geomembrane, triplanar geonet, geomembrane, triplanar geonet, geotextile, and finally a granular drainage media. A second layer of geonet will be installed in the collection trench in both the primary and secondary leachate collection systems to help route leachate to the removal sump.

To accomplish the project goals, the landfill bioreactor at the NRRL is designed to allow operation and testing of both aerobic and anaerobic waste treatment regimes. The landfill bioreactor will be divided into two overall zones, a dedicated aerobic zone and a dedicated anaerobic zone. Because of the limited capacity to inject air and the desire to proceed in a controlled, careful manner, aerobic activities will not occur in all areas of the aerobic zone during the entire period. An area between the aerobic and anaerobic zones will serve as a transition zone. A second transition zone will be located between the anaerobic zone and the open working face of the landfill.

Solid waste sample collection will commence during the construction of the injection wells. When the construction of the bioreactor is completed, the first period of operation will consist of baseline data collection involving monitoring gas generation and composition, landfill temperature, and leachate quality. The startup of the anaerobic zone involves the controlled recirculation of leachate and/or other fluids (groundwater or wastewater treatment plant effluent and biosolids). Aerobic treatment will begin with controlled air injection into a small area of the aerobic zone. During the startup phase, the aerobic zone will be very carefully monitored for temperature, off-gas composition, and moisture content. The purpose of the start-up phase is to assess responses in landfill conditions as a function of limited air or leachate injection. Following the startup period, the routine operation phase will begin, with routine operation of the bioreactor. Activities during this phase will depend on the results gathered in the startup phase, but in general will include a targeted strategy of injecting leachate and/or air into appropriate areas of the landfill.

## **Bioreactor Components**

### Leachate Collection.

The existing leachate collection system for Cells 1 and 2 consists of nine leachate collection pipes (laterals) imbedded in the 61-cm (24-inch) leachate drainage layer that gravity drains to

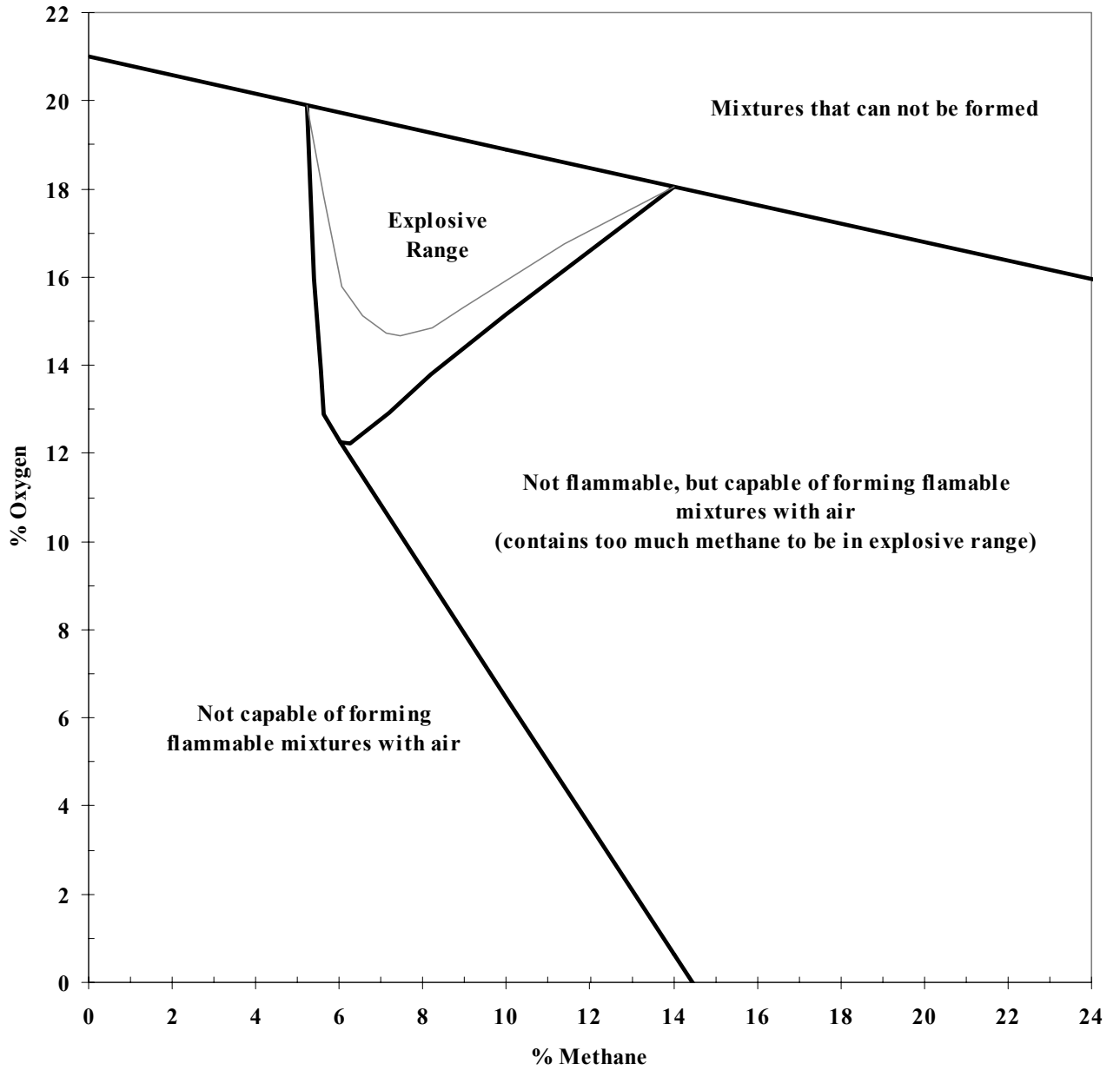


Figure 1. Schematic Elevation View Of The NRRL Bioreactor Project

manholes on the north side of the cells. The manholes drain to a wet well on the northwest corner of Cell 1, where the leachate is pumped to two aeration basins. Two existing leachate recirculation hydrants are installed north of Cells 1 and 2, respectively. These hydrants allow the leachate to be recirculated to the landfill or pumped to a nearby Florida Department of Corrections wastewater treatment plant for final stabilization. An electro-magnetic flow meter will measure the total amount of leachate collected from the landfill.

To collect leachate production data from each lateral, flow measurement and sample collection devices will be inserted into each manhole serving a lateral. These devices consist of a weir box, ultrasonic water level detector, and submerged leachate-sampling pump.

### Leachate and Air Injection

Two sources of liquid for moisture control within the landfill are provided - recirculated leachate and groundwater. Recirculated leachate is pumped from aeration tanks to injection wells using the existing 8.8-lps (140-gpm) primary pump as well as new booster pumps.

Injection wells will be installed at 15-m (50-ft) spacing in clusters of up to three wells. These wells are intended to deliver air and water to all depths of the bioreactor. At the maximum landfill depth, the wells reach staggered depths of 7.6 to 20 m (25 to 66 ft) utilizing well screen lengths of 4.9 to 6.1 m (16 to 20 ft). Injection wells consist of 5-cm (2-inch) diameter Schedule 40 PVC pipe screened with 2.5-mm (0.1-inch) slots.

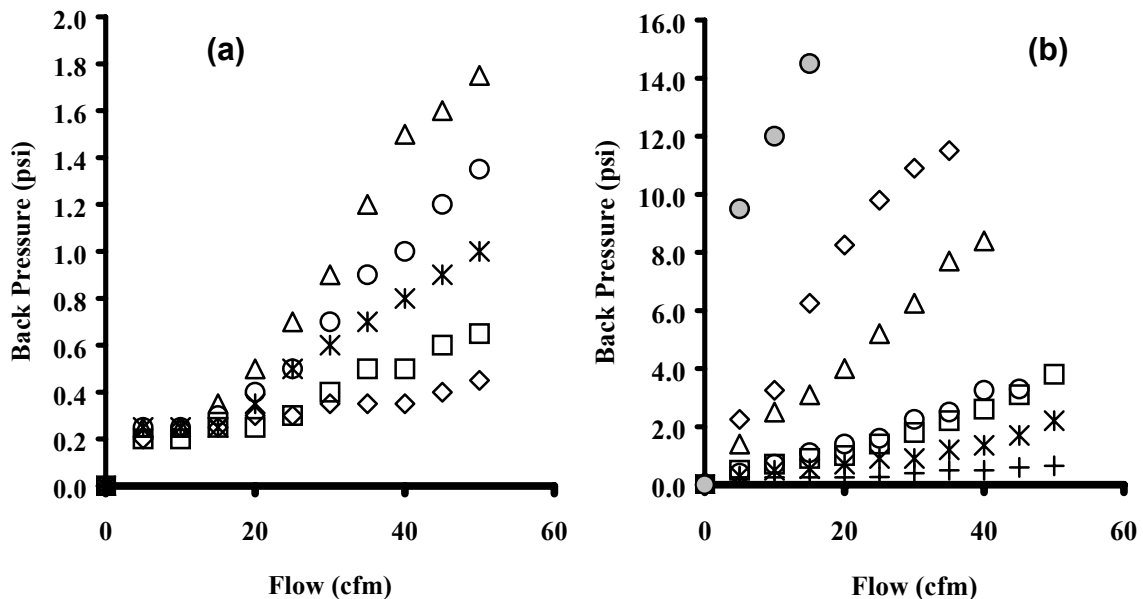
The area of the bioreactor to be operated aerobically is 1 ha (2.5 acres). Air is supplied to the injection wells in this area using two 37-kw (50-horsepower) positive displacement blowers, each with a capacity of 350 slps (750 scfm). Estimates of the average air injection rate required to aerobically stabilize the waste within the 1-ha (2.5-acre) aerobic area in a period of three years ranged from 470 to 700 slps (1,000 to 1,500 scfm). Experience from other aerobic bioreactor landfills indicates that stabilization times will be much more rapid than three years. Thus, aerobic treatment will be targeted to specific zones within the 1-ha (2.5-acre) area until stabilization is reached, at which time new zones will begin to receive treatment.

The positive displacement blowers supply up to 7030-kg/m<sup>2</sup> (10-psi) backpressure in the well field. Again, experience from other aerobic bioreactors indicates that 7030 kg/m<sup>2</sup> (10 psi) is a typical maximum backpressure encountered in air injection. Backpressures encountered in test wells at the NRRL were measured in a controlled pump test (see Figure 2). Fifteen temporary injection wells were installed and tested at flow rates up to 14 lps (50 cfm). Maximum backpressures of less than 3500 kg/m<sup>2</sup> (5 psi) were encountered in 12 of the 15 wells. Two wells produced maximum backpressures of greater than 7030 kg/m<sup>2</sup> (10 psi). It is anticipated that backpressures will increase after the waste becomes wetted. Determining the amount of pressure required to efficiently operate an aerobic bioreactor will be one of the objectives of the research.

### Landfill Gas Generation

Cells 1 and 2 are anticipated to generate up to 330 slps (700 scfm) of gas under typical landfill conditions (i.e. no aerobic bioreactor systems on line). However, since the temporary cap will be placed on only 4 ha (10 acres) of the total 65 ha (16 acres), only an estimated 220 slps (460

scfm) (or 65 percent of the 330 slps (700 scfm)) will be captured within the bioreactor system. Once the aerobic bioreactor system is brought on-line, an increase in exhaust gas flow of 700 slps (1,480 scfm) for the 1-ha (2.5-acre) aerobic area and the remaining anaerobic area of 160 slps (340 scfm) is expected (approximately 75 percent of the 217 slps (460 scfm) in the bioreactor area).



**Figure 2. Results Of Air Injection Tests At NRRL: Backpressure Versus Air Injection Rate**

Two 15-kw (20-horsepower) positive displacement (PD) type blowers that will serve both to collect landfill gas and to inject air. Each blower will be capable of providing a range of flows up to 700 slps (1500 scfm) under a pressure drop of approximately 1400 kg/m<sup>2</sup> (2 psi). The blower pair can provide flows up to 1400 slps (3000 scfm). A variable frequency drive will allow direct manual control of the pump flow rate.

#### Geomembrane Cap

The bioreactor will be covered with a temporary geomembrane cap and geocomposite subdrainage system. The geomembrane (either 1-mm (40-mil) polyethylene or 0.8 mm (30-mil) PVC) will comprise the outer-most layer of the landfill and will be fully exposed. The purpose of this liner is to minimize the potential for mass transfer (e.g. moisture, gas, or other) between the environment and the bioreactor.

#### Landfill Gas Collection and Treatment

The geomembrane will be underlain with a geocomposite sub-drainage layer consisting of a drainage net (geonet) bonded on the bottom of a nonwoven geotextile. The geonet will be the primary conduit for extracting gas exiting through the top of the landfill. A constant negative pressure applied from the blower station and subsurface gas collector ports located on the

geomembrane cap surface will maintain consistent gas flow from the geonet. The gas collector ports consist of a reinforcing collar, which fastens the port to the geomembrane and geonet, a thermometer for measuring the gas temperature, and an orifice-measuring element that allows for flow rate measurement or gas sampling.

A series of gas collection trenches will be installed below the geonet to help collect gas and remove leachate from the gas stream. A vertical slope of three percent will be provided for the gas collection trench, which will enable any leachate entering the trench to be directed to the leachate collection system.

LFG condensate is formed as a result of cooling in the landfill gas collection system. Condensate is removed and collected by traps, sumps and knockouts. The gas collection trench includes a 10-cm (4-inch) perforated corrugated drainage pipe that gravity drains to the leachate wet well near Cell 1. Moisture will either seep back into the landfill below the trench or drain through the pipe. The drainage pipe will remain below the geomembrane cap until exiting the landfill through a sealed boot near the wet well. The collected landfill gas is transported through high-density polyethylene (HDPE) piping to the blowers/compressors then flared.

#### Gas Collection from Existing Leachate Collection System.

A significant amount of landfill gas can be expected to escape from the existing leachate collection pipes and manholes. To allow for the collection and sampling of gases from the leachate collection system, manhole covers will be modified and tied to the gas collection pipe system.

### **Bioreactor Monitoring**

The research team will routinely monitor a number of landfill bioreactor parameters, including the leachate, gas, and waste characteristics and performance measurement at the site (e.g. leachate composition, gas flow, settlement). The specific monitoring parameters include the following, and are described in more detail in Table 1.

- ◆ Leachate quality and quantity
- ◆ Gaseous emissions quality and quantity
- ◆ Amount of leachate recirculated
- ◆ Amount of air injected
- ◆ Landfill settlement (using GPS survey techniques)
- ◆ Waste characterization
- ◆ In situ measurements

### **Cost Issues**

Bioreactor cost impacts are difficult to predict, although several researchers have attempted to model life cycle costs with varied results. Benefits that may have economic consequences include enhanced and more rapid gas production, recovered landfill space, reduced



**Table 1. Analytical Parameters To Be Measured – NRRL Bioreactor Landfill Demonstration Project**

<b>Monitoring Activity</b>	<b>Description</b>
Leachate Quality	<p>Samples of leachate will be collected from each leachate flow measuring device on a routine basis. The leachate will be analyzed for the following parameters.</p> <ul style="list-style-type: none"> <li>➤ pH</li> <li>➤ Conductivity</li> <li>➤ Dissolved Oxygen</li> <li>➤ Dissolved Solids</li> <li>➤ Biochemical Oxygen Demand</li> <li>➤ Chemical Oxygen Demand</li> <li>➤ Organic Carbon</li> <li>➤ Nutrients (NH<sub>3</sub>, TKN, TP)</li> <li>➤ Common Ions (Cl<sup>-</sup>, NO<sub>3</sub><sup>-</sup>, NO<sub>2</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>)</li> <li>➤ Volatile Fatty Acids</li> <li>➤ Organic Priority Pollutants</li> <li>➤ Heavy Metals</li> </ul>
Landfill Gas Composition	<p>Gas emissions from the landfill will be measured routinely as part of the operation of the bioreactor for CH<sub>4</sub>, CO<sub>2</sub>, O<sub>2</sub>, CO, and N<sub>2</sub>. Samples will also be collected to measure NMOCs, H<sub>2</sub>S, and N<sub>2</sub>O.</p>
Solid Waste Sampling	<p>Solid waste samples will be collected to directly assess the degree of stabilization. Parameters to be evaluated include:</p> <ul style="list-style-type: none"> <li>➤ Moisture content</li> <li>➤ Volatile Solids</li> <li>➤ Methane Yield</li> <li>➤ Cellulose</li> <li>➤ Lignin</li> </ul> <p>On occasion, the waste samples will also be analyzed for organic priority pollutants and heavy metals (total and leachable).</p>
Landfill Settlement	<p>The bioreactor landfill will be surveyed routinely to measure the degree of waste settlement (an indicator of biological decomposition).</p>

environmental impact, and reduced post-closure care. Offsetting these cost benefits would be the capital and operating costs of implementing bioreactor technology. Aerobic bioreactor could have cost benefits over anaerobic bioreactors due to reduced leachate volume and/or organic strength, potential greenhouse gas emission offset credits, and reduced methane emissions. Anaerobic bioreactors may find it necessary to prematurely provide gas collection and treatment due to increased gas emissions and odors.

When comparing and contrasting aerobic and anaerobic landfills, energy is probably the most important cost issue. Aerobic landfills have the advantage of much more rapid waste degradation rates, but the oxygen must be supplied to the landfill. While semi-aerobic landfills utilizing natural venting of air into the landfill have been proposed and applied (Fukuoko Environmental Bureau, 1999), full-scale aerobic operations in the U.S. have focussed on pumping air into the landfill.

For the purpose of comparing aerobic and anaerobic bioreactors with respect to energy requirements, it is assumed that energy necessary for leachate collection, recirculation, and all other normal landfill power needs are the same for both cases. For an anaerobic bioreactor, a gas collection system equipped with mechanical blowers to extract the gas under vacuum is used. For an aerobic landfill, power is required for blowers to “push” air into the waste. It is assumed that the exhaust from the aerobic landfill is vented to the atmosphere. It is further assumed that the same extent of destruction of organic waste will occur. In the anaerobic scenario, all of the biodegradable carbonaceous waste is converted to carbon dioxide and methane, while in the aerobic scenario the same material is converted to carbon dioxide and water.

Under steady state operating conditions, the amount of anaerobic biogas ( $\text{CH}_4$  plus  $\text{CO}_2$ ) will be approximately equal to the amount of aerobic exhaust ( $\text{CO}_2$  plus  $\text{H}_2\text{O}$ ). A notable addition to the aerobic exhaust gas is the nitrogen present in the air supply. Since nitrogen occurs in air at 79%, the amount of air added to a landfill for steady state treatment will be approximately 4.75 times as much as the gas exiting the anaerobic landfill at steady state. In addition to the gas handling capacities of blowers for each type of landfill, the blowers for the aerobic bioreactors must be able to supply a greater amount of energy (in the form of pressure) to push the air through the compacted waste. For the NRRL, a 37-kW (50-HP) blower was needed for the aerobic system while a 15 kW (20 HP) blower was needed for the anaerobic system. The 37-kW (50-HP) blower was selected to supply  $1400 \text{ kg/m}^2$  (10 psi) of air pressure to the air injection wells. If one considers the additional gas volume needed to be moved and the difference in horsepower required to provide additional pressure, the power requirement for the aerobic landfill is approximately 12 times higher than the anaerobic landfill. This does not factor in the possible value of the gas produced from the anaerobic bioreactor. When deciding on aerobic versus anaerobic bioreactor landfills, one must weight the benefits of the extra cost required to achieve waste treatment much more rapidly.

### **Moisture Balance Issues**

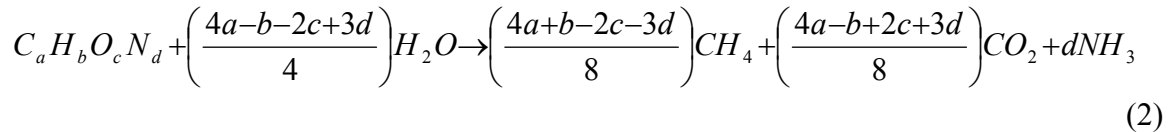
Moisture control is an essential element to optimize bioreactor operations. Moisture must be added to the landfill to maintain a target moisture level (typically field capacity). A moisture balance calculation can be performed as shown in equation 1.

$$\Delta S = M_D - M_E + M_I \quad (1)$$

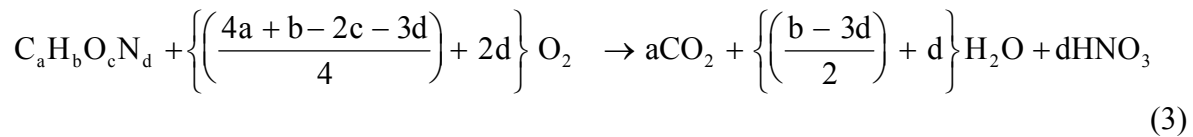
Where:

$\Delta S$	=	Change in moisture storage
$M_D$	=	Moisture loss/gain during biological degradation
$M_E$	=	Moisture removed in exhaust gas
$M_I$	=	Moisture input

Moisture input is adjusted to maintain steady state conditions ( $\Delta S = 0$ ) according to equation 1. For anaerobic operations, water is consumed according to equation 2.



For aerobic operations water is produced during degradation according to equation 3.



For comparison purposes we can calculate the moisture required to maintain field capacity at the NRRL for a waste having a composition  $C_{16}H_{27}O_8N$ . The following assumptions were made:

- Biodegradable fraction of the solid waste has the chemical formula  $C_{16}H_{27}O_8N$ .
- 100% efficiency of reaction.
- Lignin content for food is 0.4% of biodegradable volatile solids.
- Lignin content of mixed paper is 5.8% of biodegradable volatile solids.
- Oxygen is equally distributed throughout the landfill pore space.
- All calculations are made at STP ( $0^\circ C$ , and 1 atm).
- Volume of bioreactor is  $184,000 \text{ m}^3$  ( $240,660 \text{ yd}^3$ ).
- Density =  $3500 \text{ kg/m}^3$  ( $1,200 \text{ lb/yd}^3$ ).
- Treatment time is 3 years.
- Inlet air temperature is  $25^\circ C$ .
- Inlet air relative humidity is 0.5.
- Outlet air temperature is  $65^\circ C$ .
- Outlet air relative humidity is 1.0.

Moisture requirements for aerobic and anaerobic operations are summarized in Table 2. As can be seen moisture input for an aerobic operation is greater than an anaerobic facility, primarily as a result of losses in the exhaust gas.

**Table 2. Comparison of Moisture Requirements for Aerobic and Anaerobic NRRL Operation**

<b>Moisture Pathway</b>	<b>Aerobic, lps/ha</b>	<b>Anaerobic, lps/ha</b>
Loss/Gain – Biodegradation	-0.08	0.038
Removed in Exhaust Gas	0.18	0.033
Required Input	0.10	0.071

**Flammability Issues Related To Gas Composition**

Dealing with explosive gases is a common consideration for the design and operation of traditional sanitary landfills. In these systems, methane is produced, which when mixed with the oxygen in air, may result in explosive or flammable gaseous mixtures. In the past, such a concern would be most likely encountered during off-site migration of landfill gas into structures. Modern landfills greatly reduce the potential for this to occur, and gas flammability is more often a concern with gas extraction systems. A gas extraction system is an integral part of any anaerobic bioreactor landfill. The concern over flammability is magnified when air is purposely introduced into the landfill as a means to rapidly accelerate the waste decomposition. Operators of aerobic bioreactors therefore must have a thorough understanding of what conditions result in a gas being explosive and how to use this information to control the bioreactor.

Anaerobic landfill biogas consists of approximately equal parts of carbon dioxide and methane. The gas components occurring within aerobic landfills include nitrogen, carbon dioxide, oxygen, and possibly methane, if anaerobic activity is also occurring within the landfill. Methane, of course, is flammable when mixed with an appropriate amount of oxygen, a characteristic many landfills take advantage of when converting landfill gas to energy. When the right amount of oxygen and methane mix, the gas becomes explosive (also referred to as flammable). This condition means that enough of each chemical is present to sustain a flame. In conditions where the oxygen is too low, a flame cannot be sustained without an external source of oxygen. An example of this condition is typical landfill gas. In the landfill, the gas has too little oxygen to sustain a flame. At the flare, it is mixed with oxygen (air) to enter the flammable range, and the gas ignites. In conditions where the methane is too low, there is simply not enough fuel to sustain the flame.

The explosive or flammable range most often quoted in the industry is 5% to 15% methane, referring to 5 to 15% methane in air. It should be noted, however, that the presence of other gases such as carbon dioxide, nitrogen, and water vapor, changes this range. Figure 3 shows a flammability chart that indicates the ranges where the gas is truly flammable, and illustrates the impact of a diluent gas. Two explosive ranges are presented; one considers CO<sub>2</sub> as the sole diluent gas (the inner line), while the other considers N<sub>2</sub> as the lone diluent gas (the outer line). Although the 5 to 15% range is frequently cited, in reality, the oxygen concentration has to be above 12% for the gas to be in the flammable or explosive range. There are many situations that can exist where methane concentrations will be in the 5% range but the gas will not be flammable.

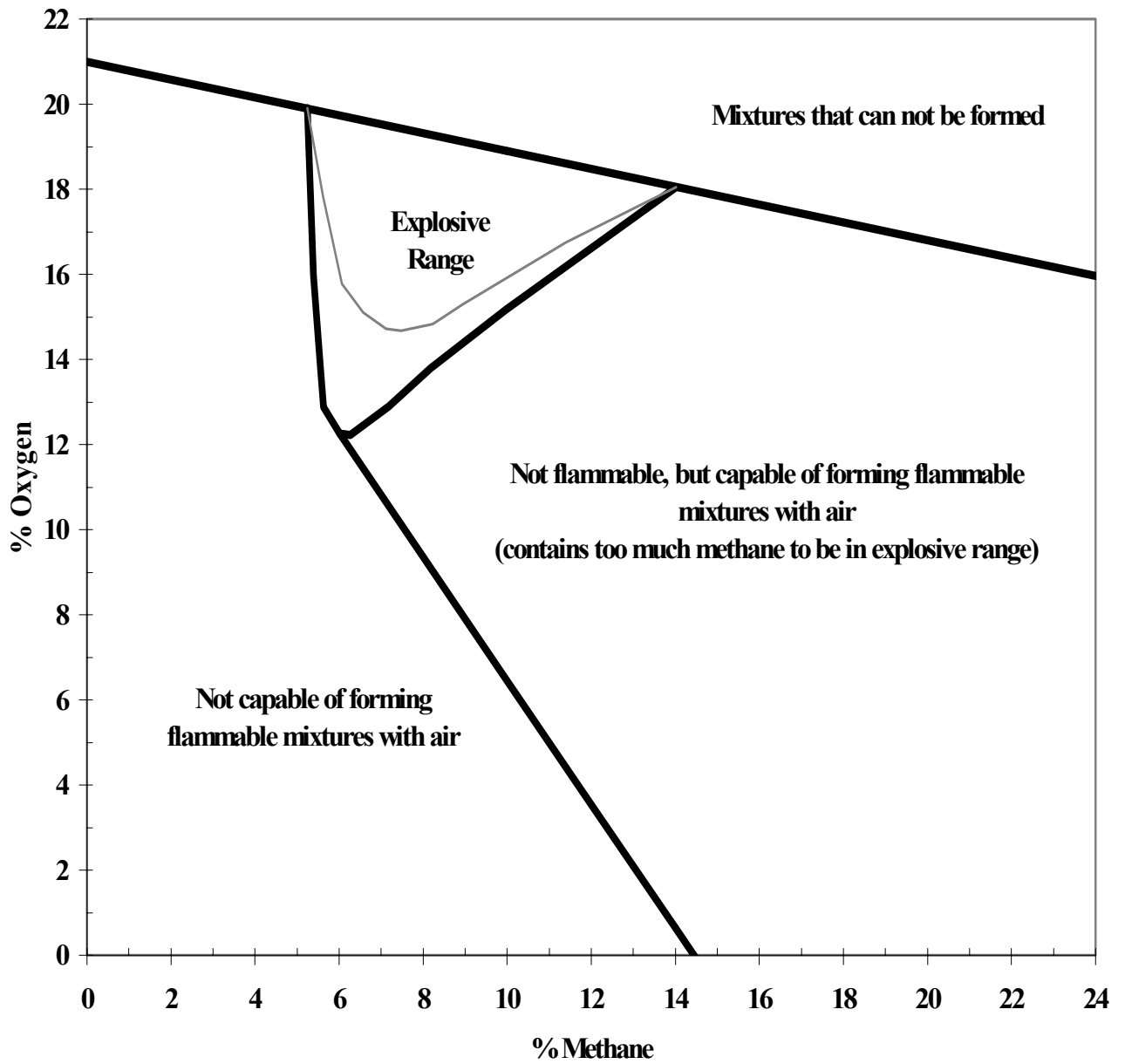


Figure 3. Range Flammability for Potential Gas Mixtures

In reality, flammable conditions occur at every anaerobic landfill where the methane enters the explosive range as gas leaves the landfill. The concern for explosion and subsequent landfill fires increases when the gases accumulate within confined spaces that might be exposed to an ignition source. For this reason, landfill leachate lift stations are constructed with explosion-proof equipment. The addition of air to landfills creates additional possible paths for the explosive range of gas to be exceeded if not operated properly. Critical to operating an aerobic bioreactor is to avoid formation of explosive mixtures by ensuring that the oxygen is totally consumed and to carefully monitor conditions within the landfill.

## **Waste Degradation Issues**

Metabolic pathways for organic substrates under aerobic and anaerobic conditions are quite different. Pathways exist for degradation of many compounds under aerobic conditions that are recalcitrant under anaerobic conditions (e.g. aromatic hydrocarbons and lignins). Conversely highly chlorinated compounds, such as chlorinated solvents, are only degraded under anaerobic conditions, although complete mineralization of these compounds requires sequencing of anaerobic and aerobic conditions.

Aerobic reactions tend to yield more energy than anoxic or anaerobic reactions. Since more energy-yielding reactions take precedence over less energy yielding ones, the presence of oxygen or sulfate will inhibit processes occurring exclusively under anaerobic conditions. Under low moisture conditions, higher energy yields often result in elevated temperatures, which can result in inhibition of the organisms or even spontaneous combustion. Degradation byproducts of the two metabolic pathways are also quite different, most notably the production of H<sub>2</sub>S under sulfidogenic conditions and methane under anaerobic (methanogenic) conditions.

Data reported in the literature clearly demonstrates that recirculation of leachate significantly increases the rate of the transformation of organic matter in leachate and by inference, the rate of waste stabilization. Data from the literature were analyzed to calculate the rate of decline in leachate COD for aerobic and anaerobic landfills (recirculating and conventional) in order to quantify the impact of leachate recirculation on leachate treatment. Because of the limited available operational information for these studies, a rigorous kinetic analysis of the sequential reactions was not possible. However, a non-linear regression of chronological, declining COD data was performed for a series of laboratory, pilot and full-scale studies. These data are provided in Table 3. The data support the acceleration of COD reduction rates by the addition of moisture as well as the increased rates under aerobic and semi-aerobic conditions as compared with conventional operation.

These data compare favorably with similar analysis reported in the literature. Chian and Dewalle (1977) calculated effective conventional landfill lives of ten to fifteen years based on gas production data and cited half-lives of 36 to 100 years from the literature. Suflita et al. (1992) calculated a half-life of just over a decade for the Freshkills Landfill in New York City based on cellulose to lignin ratios. Hudgins and March (1998) reported a 70% decline in organic strength of leachate within one year of aerobic operation at a landfill in Georgia.

**Table 3. Leachate COD Reduction Half-Lives for Various Operational Regimes**

Scale	COD Half-Life, days
Laboratory (anaerobic, recirculation) <sup>a</sup>	26 – 157
Laboratory (anaerobic, conventional) <sup>a</sup>	150 – 1369
Laboratory (aerobic, recirculation) <sup>b</sup>	24
Laboratory (semi-aerobic, recirculation) <sup>b</sup>	26
Pilot (anaerobic, recirculation) <sup>a</sup>	117 – 234
Pilot (anaerobic, conventional) <sup>a</sup>	99
Full (anaerobic, recirculation) <sup>a</sup>	285 – 383
Full (anaerobic, conventional) <sup>a</sup>	3650

<sup>a</sup>Reinhart and Townsend (1998)

<sup>b</sup>BOD data reported by Fukuoka City Environmental Bureau (1999)

### Process Control Approaches

A primary objective of the bioreactor research at the NRRL is to maintain the landfill under optimal conditions for biological treatment of the waste. Additionally, the landfill must be operated in a manner that minimizes risk of landfill fires and mixing of gas in the explosive range. Landfill gas composition and landfill temperature will be monitored at numerous points within the bioreactor landfill. The frequency of monitoring is dictated by the particular phase of the research. Figures 4 and 5 provide an overview of process control decisions necessary for anaerobic and aerobic operations. As can be seen, critical parameters are oxygen content of the gas and internal temperature controlled by airflow for aerobic operation, and moisture addition for both operational regimes.

### References

Chian, E.S. and F.B. DeWalle, Characterization of soluble organic matter in leachate.

*Environmental Science and Technology*, 11(2): 159, (1977).

Fukuoko Environmental Bureau, “The Fukuoko Method, What is the Semi-Aerobic Landfill?”  
March 1999.

Hudgins, M. & J. March, In-Situ Municipal Solid Waste Composting Using an Aerobic Landfill System. American Technologies, Inc., Aiken, SC, USA (1998).

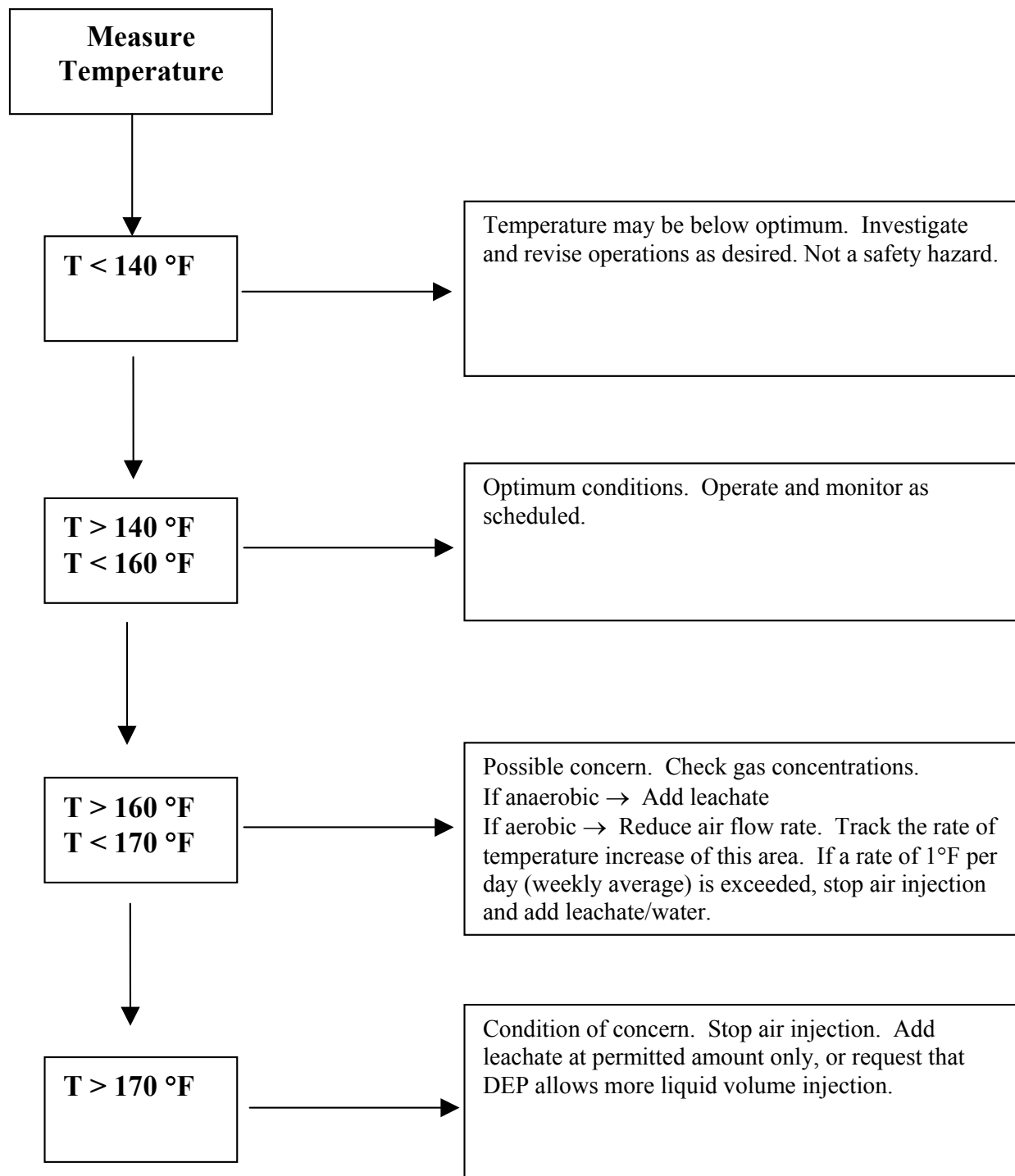
Johnson, W. H. and J. Baker (1999) Operational Characteristics and Enhanced Bioreduction of Municipal Waste Landfill Mass by a Controlled Aerobic Process. Proceedings from SWANA’s 4th Annual Landfill Symposium, Denver, CO., June 28-30.

Reinhart, D. R. & T. G. Townsend, *Landfill Bioreactor Design & Operation*. Lewis Publishers, Boca Raton, FL (1997).

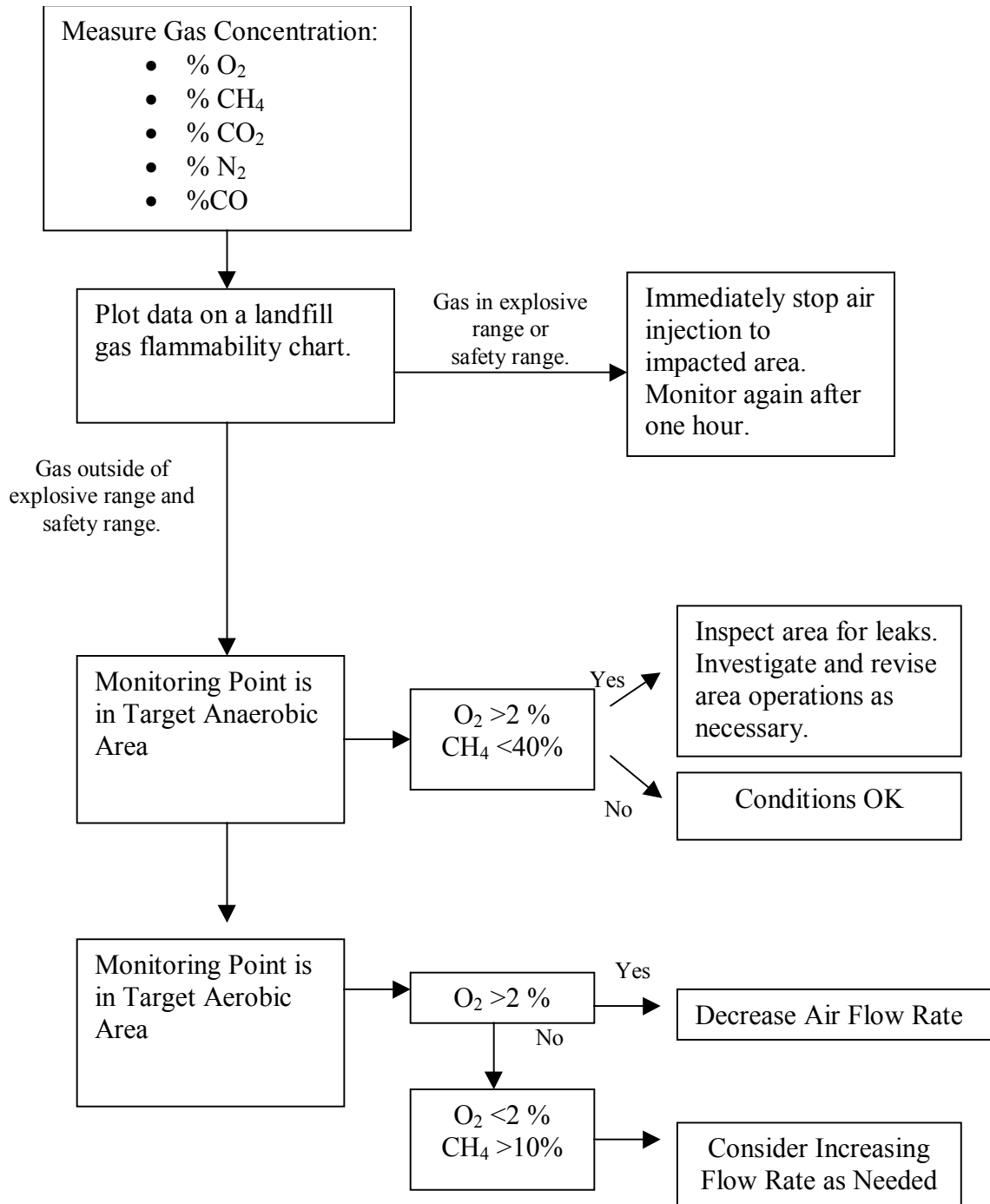
Sulfita, J., C. Gerba, R. Ham, A. Palmisano, W. Rathje, and J. Robinson. The world's largest landfill. *Environmental Science & Technology* 26(8):1486-1495 (1992).







**Figure 4. Temperature Control Chart**



**Figure 5. Gas Composition Control Chart**