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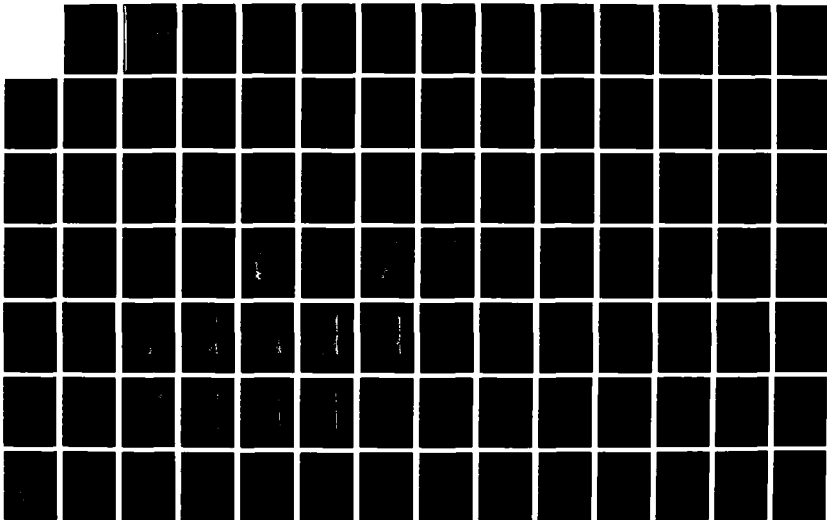
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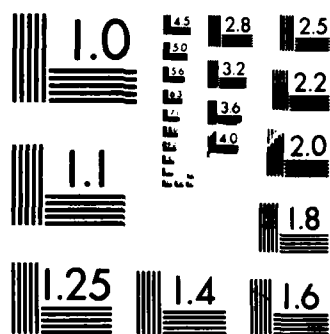
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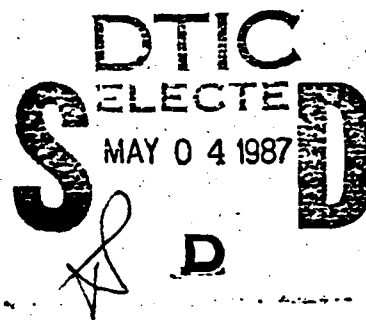
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**THE FATE OF SELECTED ORGANIC POLLUTANTS
DURING LANDFILL DISPOSAL OPERATIONS**

FINAL REPORT

by

Frederick G. Pohland
Thomas R. Schaffer
Simak Yari
Wendall H. Cross



March 1987

Supported by

U.S. ARMY MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Fort Detrick, Frederick, Maryland 21701-5012

Contract No. DAMD17-85-C-5024
School of Civil Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

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19. ABSTRACT (Continue on reverse if necessary and identify by block number) The codisposal of selected organic priority pollutants with municipal refuse was investigated with four pilot-scale simulated landfill cells operated under the influence of single pass leaching or leachate recycle. The acid formation and methane fermentation phases of landfill stabilization were established and described in terms of routine analyses performed on leachate and gas samples for a variety of indicator parameters. During a 15-month period, little evidence of release of butanone, trichloroethane, phenol, pentachlorophenol, 4,6-dinitrocresol, di-n-butyl phthalate, 2,6-dinitrotoluene, 2,4-dinitrotoluene, phenanthrene, hexachloroethane, 2,4'-dichlorobiphenyl, and hexachlorobiphenyl was obtained even after elution of as much as 20 bed volumes in the recycle cells. Moreover, patterns of microbially mediated conversion of substrate were not influenced by the presence of the organic priority pollutants and could be accelerated through leachate recycle. Assimilation of the organic priority pollutants throughout the phases of landfill stabilization was ascribed to physical-chemical and biochemical						
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attenuation and possible fractionation within the waste mass. Additional studies are indicated to further establish assimilative capacities for organic priority pollutants codisposed with municipal refuse in landfill disposal sites.



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INTRODUCTION

Hazardous wastes and their potential impact on the environment when disposed of on or in the land have become a major societal concern. In response to this concern, a significant amount of research has been conducted to investigate hazardous waste disposal practices. However, the impact of hazardous wastes disposed in sanitary landfills by small quantity generators exempt from the Resource Conservation and Recovery Act (RCRA), or by accidental inclusion of such wastes by commercial or industrial operations, has received little attention. Therefore, the effects of such disposal practices on human health and the environment requires additional inspection and appraisal.

The research reported herein was conceived to investigate the fate of selected organic priority pollutants codisposed with municipal refuse in landfills. This was accomplished by operating four laboratory-scale simulated landfill cells under the influence of single pass leaching and leachate recycle throughout both the acid formation and methane fermentation phases of landfill stabilization. The organic pollutants added with the municipal refuse were chosen because of their association with wastes generated from certain U.S. Army activities, their general presence in municipal refuse, being listed as hazardous or toxic by RCRA, their representative nature with regard to various functional groups and a range of physical properties, and their amenability to available analytical methodologies. Hence, the organic priority pollutants selected included butanone, trichloroethene, phenol, pentachlorophenol, 4,6-dinitrocresol, di-n-butyl phthalate, 2,6-dinitrotoluene, 2,4-dinitrotoluene, phenanthrene, hexachloroethane, 2,4'-dichlorobiphenyl, and hexachlorobiphenyl.

LITERATURE REVIEW

Landfills are the most widely used method of solid waste disposal in the United States and the world today. This is primarily due to their ability to be designed, installed and operated at lower costs than other solid waste management alternatives. In spite of their popularity, landfills are often poorly understood or managed, and usually provide minimal opportunity for operation as a controlled process. However, progress is being made to overcome these problems and this review will summarize some of the basic understanding of the stabilization sequences occurring within a landfill, compare landfill management options, discuss priority pollutants that have been identified with sanitary landfills, and examine the possible mechanisms of conversion and removal for the organic priority pollutants selected for investigation during these studies.

LANDFILL STABILIZATION

Most landfills proceed through a series of rather predictable events which are influenced by climatological conditions, operation variables, management options and control factors operative in the landfill environment (18). These events can be observed by monitoring certain leachate and gas parameters which serve to describe the following phases of stabilization:

Phase I: Initial Adjustment

This period prevails from initial waste placement through the closure of the landfill segment and to the time when environmental parameters first reflect the onset of stabilization processes. Incipient aerobic decomposition consumes oxygen and produces carbon dioxide.

Phase II: Transition

During this period, field capacity is exceeded and regular leaching begins. The oxygen entering the landfill with the waste is depleted and a transition from aerobic to anoxic and anaerobic conditions occurs. During this transition, the primary electron acceptor shifts from oxygen to nitrate and sulfate and then to carbon dioxide. Reducing conditions are established and intermediates such as volatile organic acids first appear in abundance.

Phase III: Acid Formation

During this period, the total volatile organic acids (TVA) formed by the hydrolysis and fermentation of the waste and leachate constituents become increasingly dominant. This increase results in a low pH, increased mobilization of metal species, and the release and utilization of nutrients in support of associated biomass development. Carbon dioxide and hydrogen gas are produced by acid forming microorganisms and influence further conversion as well as the type of intermediates formed.

Phase IV: Methane Fermentation

During this period, the intermediate products are converted to methane and excess carbon dioxide by the methane forming organisms. The pH increases to nearly neutral as the TVA are consumed and the carbonate-bicarbonate buffer system is again established. Oxidation-reduction potential are highly negative as reducing conditions flourish. Complexation and precipitation of heavy metals with sulfide result in their removal from the leachate. Leachate strength, as measured by chemical oxygen demand (COD), biochemical oxygen demand (BOD₅), or total organic carbon (TOC), is drastically decreased as TVA are consumed and methane is produced.

Phase V: Final Maturation

This period follows active biological stabilization of the readily available organics in the waste and leachate. Nutrients may become limiting, measurable gas production ceases, oxidation-reduction potential may slowly rise as more oxidizing conditions are reestablished, and the more resistant organics may slowly degrade and influence mobility of other species.

The events described for each of the five phases as illustrated in Figure 1 will occur in each portion or cell of a landfill if adequate moisture and nutrients are provided, and inhibition from toxic materials does not occur. However, since the waste is usually placed at different times and proceeds through the five phases at different rates, the combination of processes occurring in each portion of the landfill may obscure the sequential stabilization pattern discussed above. Adequate moisture content is critical for rapid stabilization to occur within a landfill, and optimum ranges for maximum methane

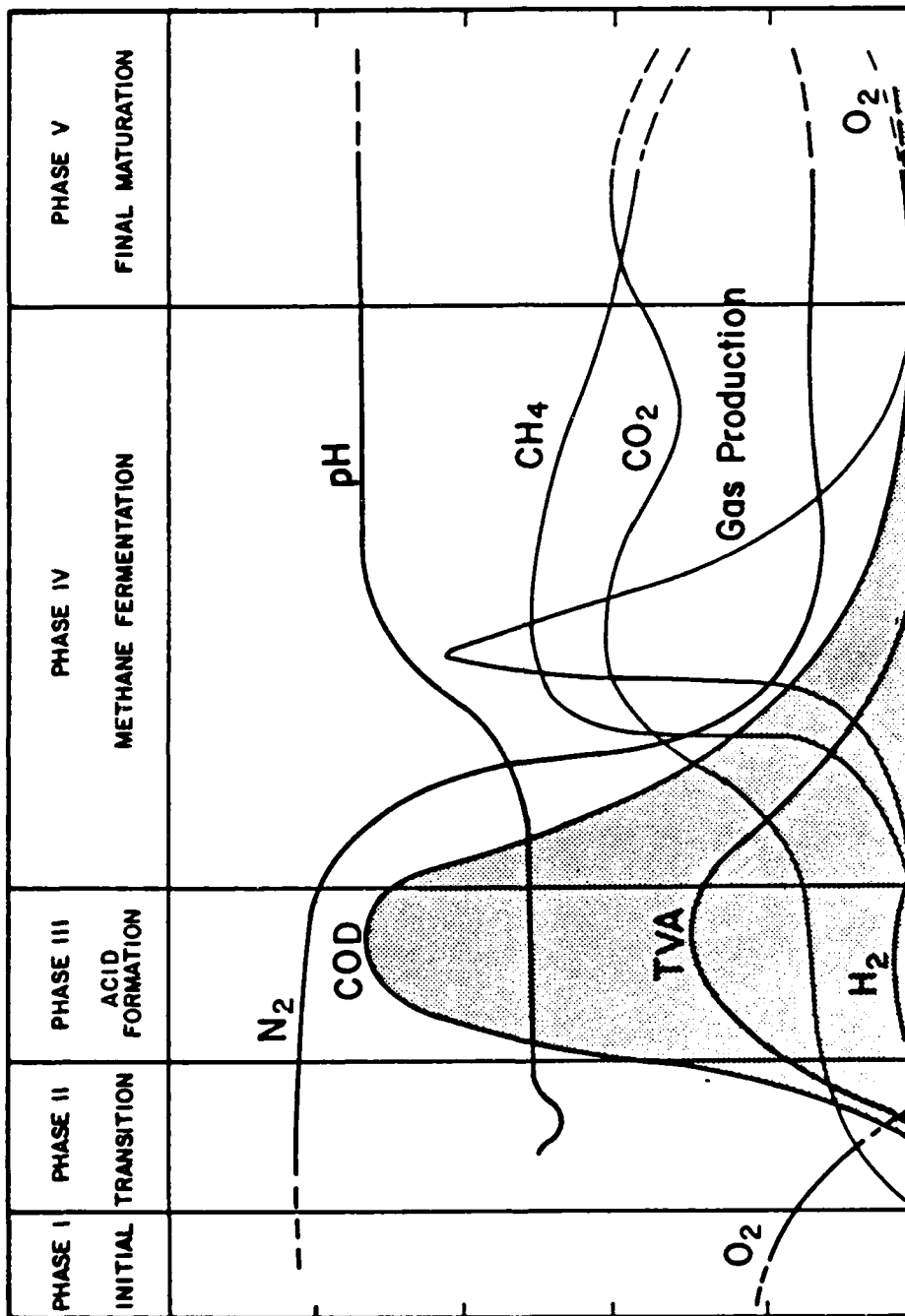


FIGURE 1 : CHANGES IN SELECTED INDICATOR PARAMETERS DURING THE PHASES OF LANDFILL STABILIZATION(18).

production have been observed by DeWalle, et al. (8) to vary between 60 and 78%. Typically, 25% moisture is required for decomposition to begin, and only 30 to 40% moisture will tend to retard gas production (31).

The availability of nutrients is also an important factor in landfill stabilization. Whereas a COD:P ratio of 2200:1 was determined adequate for anaerobic digestion of fatty acids by McCarty and Speece (14), Chian and DeWalle (5) concluded that the upper limits of leachate COD:P and COD:N were 4360:1 and 39:1, respectively. Trace levels of other micronutrients normally present in municipal refuse are also necessary for efficient stabilization. However, inhibition of stabilization processes has been known to result from the presence of certain toxic metals, low or high pH, or high concentrations of heavy and alkali and alkaline earth metals.

LEACHATE MANAGEMENT

Most landfills are constructed and operated to permit single pass leaching as infiltration from rainfall gradually permeates through the refuse mass. Due to this gradual leaching process, the previously described phases of landfill stabilization, particularly the acid formation and methane fermentation phases, are much less pronounced and extend over long periods of time. Stabilization in such a landfill may require many years, generating lower and less predictable rates of gas (CH_4) production throughout its active life (23). Under these circumstances, the methane gas is usually not economically recoverable and the landfill site will require continued maintenance to accommodate differential settling and repair of the cover system after closure. Ultimate productive use of such a site may also be delayed accordingly.

In contrast, leachate recycle requires the containment, collection and recirculation of leachate back through the landfill mass. Such a recycle strategy has been found to provide more rapid development of an active anaerobic bacterial population of methane formers, thereby increasing rates and predictability as well as compressing the required time of stabilization of the readily available organic constituents (15,17). This accelerated stabilization is enhanced by the more routine and complete exposure of the microorganisms to constituents in the leachate and providing the necessary contact time for efficient conversion and degradation.

Since landfills operate essentially as anaerobic leachate treatment systems, by accelerating the conversion of organic material to end-products with leachate recycle, methane gas may be generated in a more predictable and economically recoverable fashion (2,15,17,22). By completing this process in months rather than years, the landfill can be reclaimed for ultimate use much sooner than under single pass operation (23). Moreover, because recycle systems encourage containment and more complete degradation of the waste constituents rather than permitting them to be flushed out through single pass leaching, such a landfill possesses a much lower risk of environmental contamination provided that the quantity of leachate is restricted and removed when rapid stabilization is complete. This final removal of leachate deprives the system of an active transport phase which would promote an extension of leaching and possible remobilization of previously immobilized species. This reduced risk results in lower costs for closure and post-closure care for a recycle landfill as compared to a single pass landfill (19) and, although the the initial capital and operating costs of a recycle system are higher than for a single pass system, these increased costs are justified in terms of the benefits of accelerated stabilization (11).

TRACE ORGANIC CONTENT OF LANDFILL LEACHATES

Municipal refuse disposed of in sanitary landfills always contains trace amounts of organic and inorganic priority pollutants. Insecticides, pesticides, solvents and a variety of inorganic waste products accumulate in sanitary landfills as a result of household activities and conventional refuse collection and disposal practices. The presence of toxic organic compounds was confirmed by Pohland (16) in leachate samples from pilot-scale landfill cells containing only residential-type solid waste. Hazardous wastes disposed of by small quantity generators and the accidental inclusion by commercial and industrial operations are additional sources of priority pollutants in sanitary landfills. DeWalle and Chian (6) detected numerous volatile, acid extractable, and base/neutral extractable organic compounds in samples from wells adjacent to a landfill site. The organics identified in that study are listed in Table 1.

Table 1. Trace Organics Found in Well Water (6)

<u>Volatile Organics</u>	<u>Acid Extractable Organics</u>
Acetone	Methyl palmitate
Butanol	Dibutyl phthalate
Tetrahydrofuran	Di(2-ethylhexyl) phthalate
Diethylether	Terpineol C ₁₅
Chloroform	
Dichloroethane	<u>Base/Neutral Extractable Organics</u>
Pentanol	Diethoxyethane
1,4-Dioxane	Dichlorobutane
Trichloroethylene	Dibutyl phthalate
Benzene	Butylphthalylbutylglycolate
Hexane	Di(2-ethylhexyl) phthalate
Tetrachloroethylene	
Toluene	
Bis(2-chloroethyl)ether	
Xylene	
Propylbenzene	

Sawhney and Kozloski (25) reported that large quantities of many organic compounds, both volatile and non-volatile, can leach through landfill sites into the groundwater. Table 2 lists the organics found in that study.

Table 2. Trace Organics Found in Leachate (25)

<u>Volatile Organics</u>	<u>Non-Volatile Organics</u>
Dichloromethane	Toluene
Acetone	Phenol
Isopropyl alcohol	Cresol
Tetrahydrofuran	Ethyl phenol
Chloroform	C ₅ -C ₉ acids
Methylethylketone	
2-Butyl alcohol	
Benzene	
Methylisobutylketone	
1,2-Dichloroethane	

Robertson (24) reported the presence of toxic organic compounds in groundwaters leaching from a municipal landfill. It was concluded that even landfills which do not receive appreciable quantities of waste

from industrial operations may pollute the groundwater with synthetic organic compounds.

POSSIBLE REMOVAL MECHANISMS

The fate of organic priority pollutants within landfills is a function of the interacting effects of various mass transfer and removal mechanisms including adsorption, solubilization, stripping, chemical transformation, biosorption, and biodegradation. A substance is said to be adsorbed if the concentration in a boundary region is higher than in the bulk phase (27). Hydrophobic compounds prefer to be associated with solid particles rather than with water. Adsorption is also influenced by the physical and chemical characteristics of the adsorbent surface area and nature of available binding sites. Other chemical and physical properties such as pK, solubility, partition coefficient and polarity also influence adsorption.

Solubilization is the transfer of compounds from the gas or solid phase to the liquid phase. The solubility of compounds in water is of particular importance, since it predicts the tendency of compounds to leach. Likewise, volatile compounds are released from the liquid into the gaseous phase due to their high vapor pressure. There is always the potential for a compound to evaporate and diffuse into the gaseous phase. For some volatile compounds, the losses through volatilization can be significant.

Chemical transformation includes both photolysis and hydrolysis. Direct photolysis processes occur if the chemical absorbs light and then undergoes a transformation reaction from an excited state by some mechanism such as rearrangement or dissociation. Indirect photolysis processes occur if substances present in the aquatic system absorb light to form excited chemical species or radicals which interact with the chemical to induce a reaction. Hydrolysis results in the introduction of a hydroxyl group (-OH) into a chemical structure with concomitant displacement of another group (-X) (29).

Biosorption is the sorption of compounds onto the biomass. The compounds are then degraded while remaining attached to the biomass. In contrast, biodegradation is the biological transformation of compounds into intermediates and end-products such as CO₂, CH₄ and H₂O.

Synthetic compounds can be degraded biologically only in the presence of the relevant microbes which possess the appropriate enzyme complements necessary to bring about degradation of the original compound and intermediate metabolites.

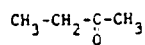
The predominant mechanisms of conversion or removal in a landfill setting will be determined by the physico-chemical properties and relative biodegradability or susceptibility to acclimation of each organic compound present as well as the associated physico-chemical and biological nature of the other landfill ingredients. As the landfill proceeds through the different phases of microbially mediated stabilization, the landfill environment can vary significantly and consequently alter the predominant transfer and removal mechanisms for each compound.

APPLICATION TO SELECTED ORGANIC PRIORITY POLLUTANTS

The selected priority organic pollutants examined in this study are listed with their chemical structures in Figure 2. Some of their important physical properties including solubility in water, vapor pressure, and log octanol/water partition coefficient are presented in Table 3. The solubility of the compound in water is important in determining the expected behavior of organic priority pollutants in a landfill, since infiltration from rainfall and groundwater encroachment provide opportunity for solubilization and possible transport and migration. Vapor pressure provides an indication of the tendency of a compound to volatilize into the gas phase. Here again, the tendency to volatilize into the gas phase in a landfill or through its confining layers would be of environmental concern. Likewise, the octanol/water partition coefficient indicates the potential of a compound to be adsorbed. Generally, the higher the log octanol/water partition coefficient, the greater the tendency to be adsorbed. Such adsorption would be expected to be particularly important for organic priority pollutants codisposed in a landfill setting.

Adsorption isotherms have been developed for many of the organic priority pollutants using activated carbon (9). Although refuse has a different structure than activated carbon, such isotherms can provide a basis for comparison of different organics and their adsorption

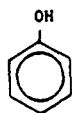
Butanone
(Methylethylketone)



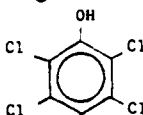
Trichloroethene
(Trichloroethylene)



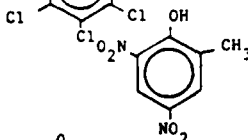
Phenol



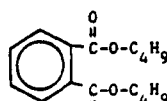
Pentachlorophenol



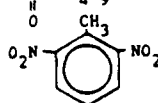
4,6-Dinitrocresol



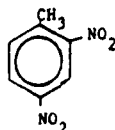
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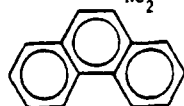
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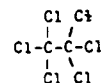
2,4-Dinitrotoluene



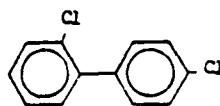
Phenanthrene



Hexachloroethane



2,4'-Dichlorobiphenyl



Hexachlorobiphenyl

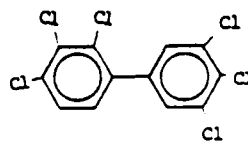


FIGURE 2: CHEMICAL STRUCTURES OF SELECTED ORGANIC PRIORITY POLLUTANTS.

Table 3. Physical Properties of Selected Organic Priority Pollutants (3,28)

Property Compound	Molecular Weight	Melting Point	Boiling Point	Vapor Pressure	Solubility in Water	Log Octanol/ Water Partition Coefficient
Butanone (Methylethylketone)	72.1	-86.4°C	79.6°C	77.5 Torr (20°C)	353 mg/L (10°C)	--
Trichloroethene (Trichloroethylene)	131.39	-73°C	87°C	57.9 Torr (20°C)	1100 mg/L (20°C)	2.29
Phenol	94.11	40.90°C	181.75°C	0.5293 Torr (20°C)	93,000 mg/L (25°C)	1.46
Pentachlorophenol	266.35	190°C	310°C	0.0011 Torr (20°C)	14 mg/L (20°C)	5.01
4,6-Dinitrocresol	198.13	85.8°C	--	--	250 mg/L (25°C)	4.35
Di-n-butyl phthalate	278.34	-35°C	340°C	0.1 Torr (115°C)	4500 mg/L (25°C)	5.2
2,6-Dinitrotoluene	182.14	65°C	285°C	--	--	2.05
2,4-Dinitrotoluene	182.14	70°C	300°C sl. decomp.	0.0013 Torr (59°C)	270 mg/L (22°C)	2.01
Phenanthrene	178.23	101°C	340°C	6x10 ⁻⁴ Torr (20°C)	1.29 mg/L (15°C)	4.46
Hexachloroethane	236.74	Sublimes	186°C	0.4 Torr (20°C)	50 mg/L (22°C)	3.34

Table 3 (Continued)

Property Compound	Molecular Weight	Melting Point	Boiling Point	Vapor Pressure	Solubility in Water	Log Octanol/ Water Partition Coefficient
2,4'-Dichlorobiphenyl*	223.10	--	--	4.1×10^{-3} Torr (25°C)	1.42 mg/L (25°C)	4.23
Hexachlorobiphenyl*	360.88	--	--	5.9×10^{-5} Torr (25°C)	.018 mg/L (25°C)	6.11

*All properties other than molecular weight are typical values for mixtures of PCBs containing primarily the specified amount of Cl.

tendencies. Table 4 lists the adsorption capacities for most of the organic priority pollutants chosen for the investigations reported herein.

Table 4. Carbon Adsorption Capacities for Selected Organic Priority Pollutants (9)

Compound	Adsorption Capacity, mg/g*
Heptachlor	1220
PCB-1232	630
PCB-1221	242
Di-n-butyl phthalate	220
Phenanthrene	215
4,6-Dinitro-o-cresol	169
Pentachlorophenol	150
2,4-Dinitrotoluene	146
2,6-Dinitrotoluene	145
Hexachloroethane	97
Trichloroethene	28
Phenol	21

*Adsorption capacities are calculated for an equilibrium concentration of 1.0 mg/L at neutral pH.

MATERIALS AND METHODS

CONSTRUCTION, LOADING AND OPERATIONAL PROCEDURES

Simulated Landfill Construction

Four identical, 208-liter, high-density polyethylene (HDPE) tanks with conical bottoms were used as simulated landfill cells during this study. They were mounted on stands in the Georgia Tech Environmental Engineering Laboratory, 92 cm above floor level to allow gravity draining of leachate from the center of the conical bottom to the smaller, flat-bottomed, 57-liter HDPE leachate reservoirs. Each of the four cells was connected to its own reservoir using 2.54-cm polyvinyl-chloride (PVC) pipe. A tee in this line provided an access point to obtain leachate samples directly from the cells. Figure 3 shows the configuration and dimensions of a typical cell with recycle capabilities.

The two landfill management options investigated during this study, single pass and recycle systems, are shown in Figure 4. The recycle cells were connected from the reservoir to a recycle pump and back to the top of the cell to allow for leachate recirculation. A tee on top of the cells allowed for introduction of the spike of selected organic priority pollutants at the appropriate time. The single pass cells were constructed without recycle and all water was added through the port on top of the cell in amounts simulating local annual rainfall. Gas lines of 0.64-cm ID tygon tubing were connected from the top of the cells to gas burets for collection and measurement of gas production. A tee in this line allowed the gas to be vented after production was recorded. In the recycle systems, the leachate reservoir was an integral part of the facility and gas production from leachate in storage was also measured. Therefore, the top of the leachate reservoir was also connected to the gas burets. For the single pass systems, the leachate was not stored but removed routinely from the system.

Thermocouples were mounted 35 cm from the bottom of each cell and placed in the center of the waste mass during loading. They were connected to temperature recorders to monitor temperature changes within the cells throughout the period of investigation.

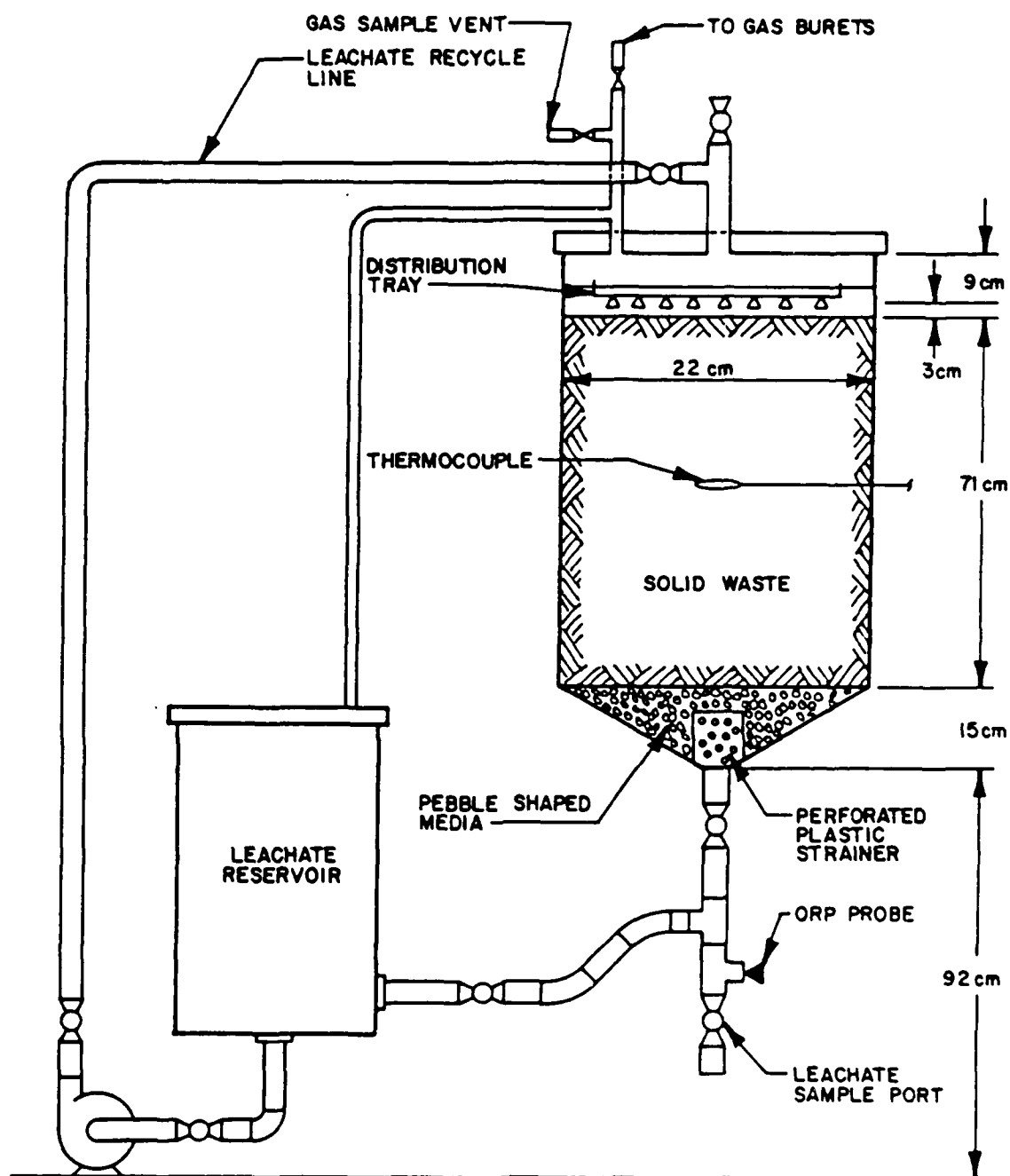
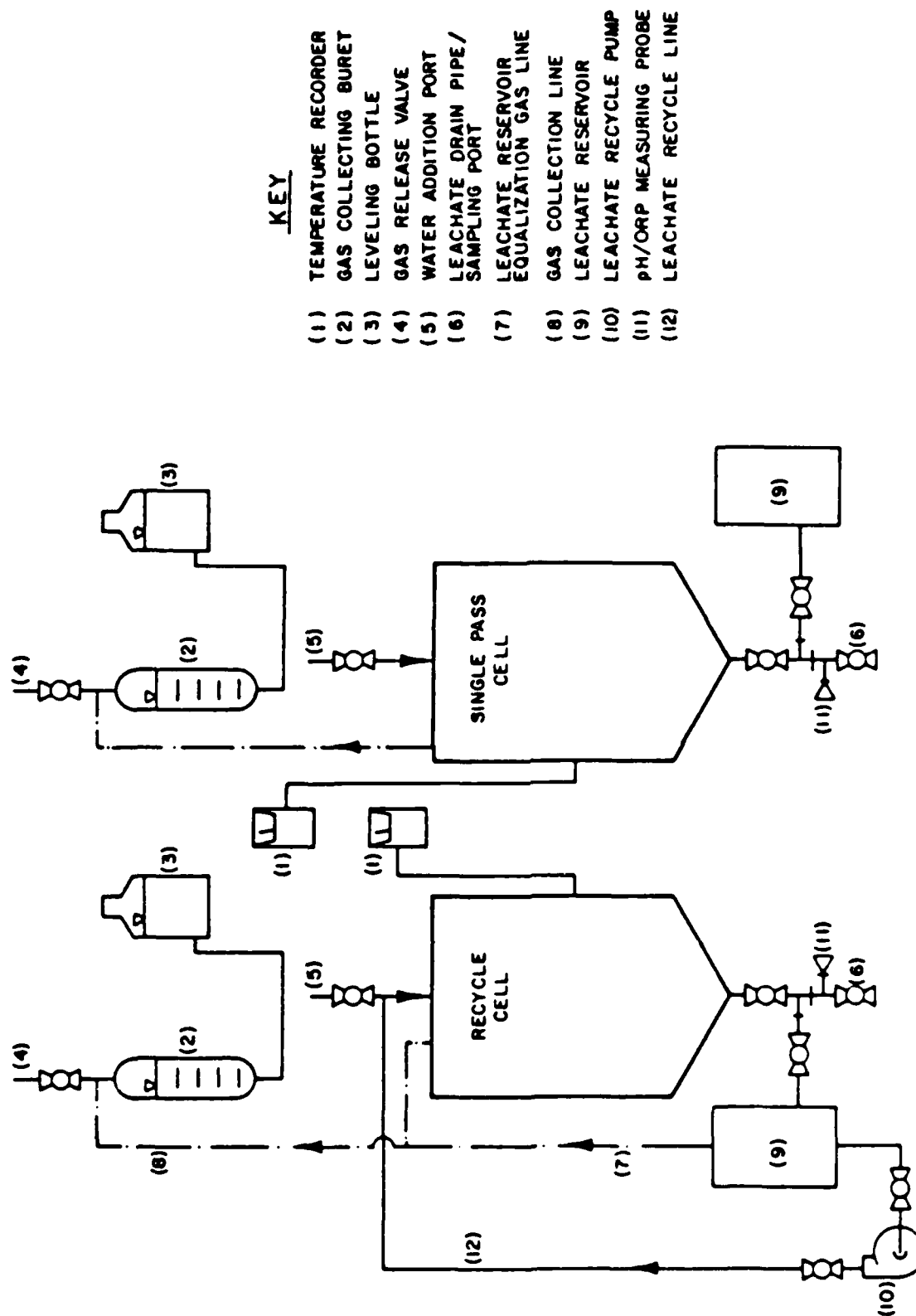


FIGURE 3: CONFIGURATION AND DIMENSIONS OF A TYPICAL LAB-SCALE
SIMULATED LANDFILL CELL.



KEY

- (1) TEMPERATURE RECORDER
- (2) GAS COLLECTING BURET
- (3) LEVELING BOTTLE
- (4) GAS RELEASE VALVE
- (5) WATER ADDITION PORT
- (6) LEACHATE DRAIN PIPE/
SAMPLING PORT
- (7) LEACHATE RESERVOIR
EQUALIZATION GAS LINE
- (8) GAS COLLECTION LINE
- (9) LEACHATE RESERVOIR
- (10) LEACHATE RECYCLE PUMP
- (11) pH/ORP MEASURING PROBE
- (12) LEACHATE RECYCLE LINE

FIGURE 4: OPERATIONAL FEATURES OF THE SIMULATED LANDFILL CELLS.

Distribution trays were fabricated for each cell to ensure even distribution of liquid across the entire surface area and to minimize the possibility of channeling during leaching. They were made of HDPE, 36-cm diameter x 0.4-cm thickness, with 0.52-cm holes drilled at equally spaced intervals in a square grid as shown in Figure 5.

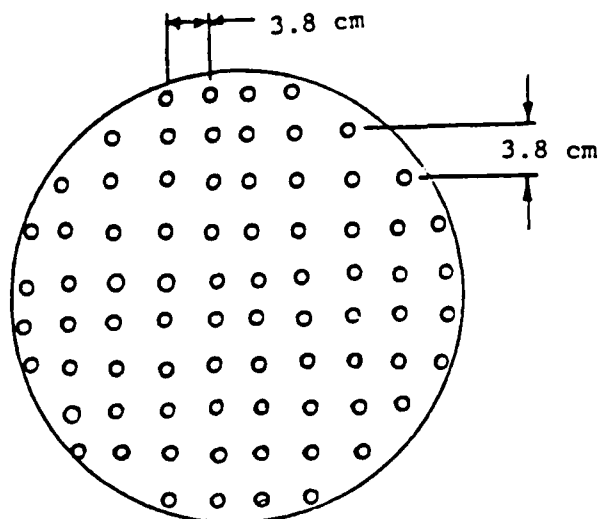


FIGURE 5: DISTRIBUTION TRAY FOR SIMULATED LANDFILL CELLS.

The trays were held in place by aluminum rods bolted into the sides of the cells and were installed after the cells were loaded with refuse. The trays were tested under both the single pass and recycle operations and were determined to adequately distribute the flow across the entire surface of the waste mass.

The discharge opening from the cells was covered by a perforated plastic strainer to prevent solids from entering the discharge piping. This strainer was buried in a 2.5-cm gravel layer which filled the cone of each cell to facilitate collection of leachate in the underdrain system and prevent clogging of the strainer.

After construction, the cells were rinsed with tap water and the final rinse water was left in the cells for several days. A sample of this final rinse water from each cell was obtained for analysis of trace organic priority pollutants. Although the HDPE tank may have adsorbed some insignificant amount of the organic priority pollutants examined in this study, the surface area available for adsorption on

the sides of the HDPE tank was a only small fraction of the total surface area available within the waste loaded into the cell. Therefore, its influence on the resultant fate of the organic priority pollutants was considered minimal.

Loading Procedure

The municipal solid waste loaded into the simulated landfill cells was obtained at the DeKalb County, GA Refuse Shredding Facility on March 1, 1985 and transported to Georgia Tech for loading into the cells. The refuse was removed from a "just loaded" semi-trailer into 30 large plastic bags. The contents of six-bag lots were first combined in a pile on plastic sheeting and then thoroughly spread out over the plastic and split into four equal piles. Pieces of plastic over 30 cm square were removed to avoid possible clogging and flow problems in the cells. After samples from each pile were taken and stored for analysis, each pile was weighed, placed in one of the cells, and compacted as it was loaded using an asphalt tamper. Another six bags were then dumped on the plastic sheet and this procedure was repeated twice until the level of waste in the cells approached 71 cm.

At the appropriate time, the thermocouples were placed in the center of the waste mass within each cell. The waste was left overnight, weighted down by a circular piece of plywood and two concrete blocks to hold it in place and compact it further. On the following day, the loading procedure was repeated again until a total compacted depth of 71 cm was provided in each cell. Consequently, a final total of 82 kg wet weight of refuse in 170 liters, or a density of 482 kg/m^3 , was loaded into each cell.

The distribution trays were bolted into place and sealed with silicone caulking. Twenty-five liters of deionized water were added to each cell to increase the moisture content of the waste mass. The lids to the cells and reservoirs were then welded in place using a Seelye electric plastic welder (Seelye, Inc., Minneapolis, MN). After cooling, the weld was covered with silicone caulking to ensure a gas-tight seal. The lids were trimmed to fit inside the lip of the tanks, since an inside corner was easier to weld and caulk as shown in Figure 6.

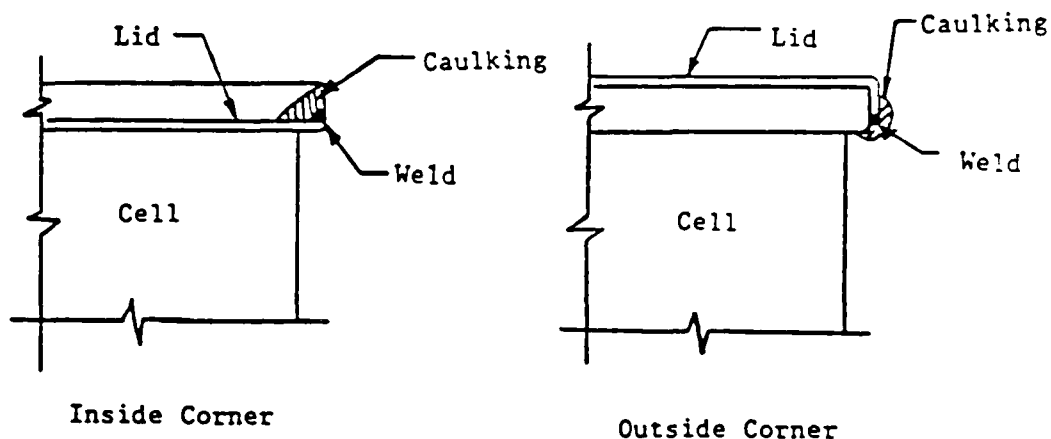


FIGURE 6: SEALING PROCEDURE FOR LIDS OF SIMULATED LANDFILL CELLS.

Preliminary moisture analysis performed on three waste samples indicated an average moisture content of about 25%. Since 45 to 50 liters of water were required to reach the 60% moisture content considered desirable to maximize stabilization, an additional 22 liters of deionized water were added to each of the cells. The following day, all water was drained from the bottom of each cell and returned to the top. This procedure was continued for several days until March 12, 1985 when the amount drained from the cell equalled the amount added the previous day. This date was then identified as Day 0 or when field capacity was reached and leachate production commenced. A sample of leachate from each cell was collected at that time and analyzed for all indicator parameters.

Operation of Simulated Landfills

The operational plan for the simulated landfill cells was developed to promote landfill stabilization and an adequate volume of leachate for analysis and recycle as soon as possible. This was accomplished by adding six liters of deionized water per week to the cells or an equivalent of 127.0 cm/year of simulated rainfall. The single pass cells (Cells 3 and 4) received six liters/week of deionized water throughout the study period of about 450 days. For the recycle cells (Cells 1 and 2), initially six liters of deionized water were added to the leachate reservoir each week and the entire volume was recycled once each week. On Day 37, water addition to the recycle

cells was discontinued, since an adequate leachate volume had been accumulated for recycling and sampling during the remainder of the study period. After Day 37, the leachate that drained to the reservoir from the recycle cells was recirculated once each week or less frequently depending on the operational strategy employed at the time.

Leachate samples (500 mL total) from all four cells were collected at least weekly for analysis of gross parameters, metals and organic priority pollutants. However, to monitor stabilization more closely during the acid formation and methane fermentation phases, COD and total and individual volatile organic acids were analyzed at least twice each week. Gas production was measured daily along with cell and ambient temperatures. Gas composition was analyzed at least twice each week when measurable gas was being produced.

Once the acid formation phase was established and the background level of priority pollutants determined, Cells 2 and 4 were deemed ready to receive the spike of selected organic priority pollutants. The 12 organic priority pollutants were selected based on five criteria:

1. presence in waste generated from U.S. Army activities;
2. general presence in municipal refuse;
3. listed as hazardous waste or toxic by the Resource Conservation and Recovery Act (RCRA);
4. representative of functional groups and a range of physical properties such as solubility, volatility and polarity; and,
5. amenable to current analytical methodologies.

Those organic priority pollutants selected were:

purgeable organics	- butanone (methylethylketone; MEK) - trichloroethene (trichloroethylene; TCE)
acid extractable organics	- phenol - pentachlorophenol - 4,6-dinitro-o-cresol
base/neutral extractable organics	- di-n-butyl phthalate - 2,6-dinitrotoluene - 2,4-dinitrotoluene - phenanthrene - hexachloroethane
polychlorinated biphenyls (PCBs)	- 2,4'-dichlorobiphenyl - hexachlorobiphenyl

The quantity of organic priority pollutants spiked was determined by several factors including:

1. detection limit of GC-MS (~1 mg/L);
2. mass of waste in cells (estimated initially at 60 kg dry weight);
3. anticipated dilution effects (maximum of 100 to 1); and,
4. physical/chemical properties and biodegradability of pollutants (compound specific).

Based on these criteria, a level of 10 mg/kg was chosen and approximately 600 mg each of ten of the pollutants were added as spikes to each single pass and recycle test cell. The two PCBs were spiked in lesser amounts of 75 mg per cell due to their relatively high cost.

In order to facilitate the addition of the selected organic pollutants to the spiked cells, they were placed in solution and added with the simulated rainfall at the top inside of Cells 2 and 4. Due to the differences in chemical properties of these organics, five solutions were prepared for each cell as described in Table 5.

These five solutions were added to Cells 2 and 4 on Day 30. For Cell 4 (single pass), the total volume of the solutions consisted of five liters followed by a 1-liter flush with deionized water to rinse the distribution tray. For Cell 2, (recycle cell) the solutions were followed by a 1-liter flush and the leachate in the reservoir was recycled. After spiking the cells, the leachate was sampled initially twice each week for trace organic priority pollutant analysis through Day 80 and at lesser intervals thereafter.

Tracer Study

Tracer studies were performed both initially and toward the end of the research investigations in order to gain an understanding of flow characteristics within the simulated landfill systems and to permit examination of dilution effects. Lithium (Li) was selected as the tracer due to its conservative properties. A lithium chloride solution containing 1000 mg/L lithium was added to all four cells on Day 30 along with the priority pollutant spikes. The amount added was based on three primary criteria:

1. detection limit of lithium by atomic absorption spectrophotometry (AA) (~0.2 mg/L);

Table 5. Trace Organic Priority Pollutant Spikes

	<u>Cell 2</u>	<u>Cell 4</u>
Solution 1:		
2,6-dinitrotoluene	600.15 mg	600.35 mg
2,4-dinitrotoluene	594.45	593.55
di-n-butyl phthalate	609.08	605.70
	Dissolve in about 8 mL of methanol. Then dilute with 1-liter deionized water.	
Solution 2:		
phenol	603.30 mg	604.92 mg
pentachlorophenol	600.20	601.60
4,6-dinitrocresol	540.90	539.46
	Dissolve in about 8 mL of methanol. Then dilute with 1-liter deionized water.	
Solution 3:		
methylethylketone	648.75 mg	595.80 mg
trichloroethylene	602.60	600.40
hexachloroethane	602.15	599.35
	Dissolve in about 5 mL of methanol. Then dilute with 1-liter deionized water.	
Solution 4:		
phenanthrene	600.06 mg	600.06 mg
	Dissolve in about 100 mL of hexane. Then while evaporating the hexane with N ₂ gas, dissolve in acetone. Then dilute with 1½-liter deionized water.	
Solution 5:		
2,4'-dichlorobiphenyl	75.00 mg	75.00 mg
hexachlorobiphenyl	75.00	75.00
	Dissolve in about 50 mL of hexane. Then while evaporating the hexane with N ₂ gas, dissolve in acetone. Then dilute with ½-liter deionized water.	

2. upper limit which will interfere with biological system (100+ mg/L); and,
3. maximum dilution effect based on total moisture present (90 L in recycle and 60 L in single pass cells).

Based on these criteria, the addition of 200 mg and 125 mg Li to the recycle and single pass cells, respectively, was expected to yield a minimum increase of about 2 mg/L Li in all cells, or well above the minimum detectable limit for the AA. Therefore, these spikes were added and the leachates were analyzed for lithium.

On Day 373, an additional lithium tracer study was conducted to again inspect flow patterns after the acid formation phase and most of the methane fermentation phase for the recycle cells and also washout for the single pass cells had been completed. Based upon AA analyses, the recycle cell leachate contained 6-10 mg/L Li, whereas in the single pass cells, leachate background levels were about 0.01 mg/L Li. Therefore, the single pass cells were selected for addition of 200 mg of Li to each cell. This addition was based on dilution rates (6 L per week) and indicated retention time (14-16 weeks) to yield an increase in leachate Li level of about 3.3 mg/L.

Sludge Seeding and Acclimation

To facilitate initiation of methane fermentation, supernatant from a digested sludge sample obtained from an anaerobic digester at the R. M. Clayton Wastewater Treatment Plant in Atlanta, GA was added to each of the four simulated landfill cells. The seed sludge supernatant characteristics are presented in Table 6. This seeding procedure was initiated on Day 209 when one liter of sludge supernatant was added to the top of the refuse in each of the four simulated landfill cells. On Day 210, approximately one liter of leachate was then recirculated in the recycle units, while the single pass cells received three liters of deionized water. Since no measurable gas was produced over the following 10 days, the cells were reseeded and approximately 10 liters of leachate were again recycled in Cells 1 and 2, while six liters of deionized water were added to Cells 3 and 4. This procedure was followed in 12 hours by the addition of 1.2 liters of digested sludge to each of the four cells.

Table 6. Analysis of the Digested Sludge Supernatant Added to All Four Simulated Landfill Cells during Seeding

Parameter	Analysis
Chemical oxygen demand, mg/L	546
Biochemical oxygen demand, mg/L	58
Total organic carbon, mg/L	200
Volatile acids	
Acetic, mg/L	52
Propionic, mg/L	14
Total solids, mg/L	16850
Volatile solids, mg/L	12350
Alkalinity, mg/L as CaCO ₃	2255
pH	7.51
Conductivity, μ mhos	3450

Since no measurable gas production was again observed throughout the following week, a new batch of digested sludge was obtained from R. M. Clayton Plant on Day 226. Using the new sludge, all four cells were similarly seeded on Day 227. Measurable gas production was observed almost immediately in all four cells. However, gas production rate decreased significantly in the recycle units shortly thereafter, indicating possible depletion of substrate in those units. Therefore, on Day 233, two liters of leachate were recycled in Cells 1 and 2, although measurable gas production ceased again on the following day. Since this behavior in the recycle cells indicated the possible inhibition of methane fermentation by the low pH and high strength leachate, all four cells were again reseeded on Day 238.

In order to provide a more effective seeding and acclimation and to stimulate methane fermentation without concomitant inhibition by the low pH and by high strength leachate, incremental increases of leachate recirculation were scheduled by observing associated increases in gas production. In addition, to help reduce the adverse effects of low pH on the methane forming bacteria, a 1.5 N sodium carbonate solution was utilized to raise the pH of the recycled leachate to 6.5. Accordingly,

a small initial recycle rate of 50 mL of leachate per day was followed by rate increases of 25-50% until on Day 297, the recycle rate maintained for the recycle cells equaled the rate used during the acid formation phase (nearly 25 liters per week) without apparent adverse effects on acclimation and development of a viable methane forming population. Therefore, between Day 297 and 304, sodium carbonate addition was also decreased incrementally until on Day 304, daily recirculation without sodium carbonate addition was initiated and the methane fermentation phase became firmly established.

ANALYTICAL METHODS

Waste Analysis

The shredded municipal refuse samples were stored in widemouthed, screw-topped glass jars at 4°C until analyzed. Just before analysis, the samples were ground using a Standard Model No. 3 Wiley Mill (Arthur H. Thomas Company, Philadelphia, PA) with a medium screen (5-mm opening). The ground sample was spread on a plastic sheet and split twice to reduce the sample size (refer to Figure 7).

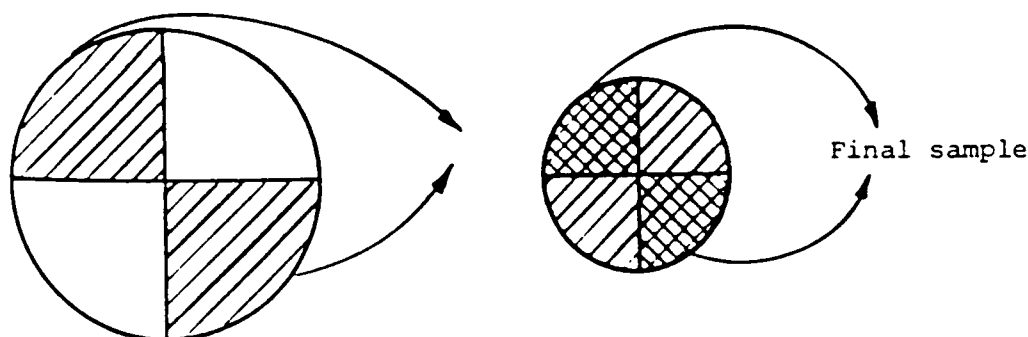


FIGURE 7: WASTE SAMPLE SPLITTING PROCEDURE.

This sample for analysis was placed in a polyethylene jar, while the unused portion was returned to the original glass container.

The moisture content of the refuse was measured as the difference between a 10-g portion before and after drying under a heat lamp (Ohaus Moisture Determination Balance) to a constant weight.

Volatile solids were measured by heating a weighed amount of refuse in a fired crucible to 550°C in a Fisher Isotemp Muffle Furnace

(Model 186) for 30 minutes. The remaining residue was reweighed after cooling.

Calorific values were obtained using an oxygen bomb calorimeter (Parr Manufacturing Company) following manufacturer instructions.

Elemental analysis (C, H and N) was performed with a F&M Carbon Hydrogen Nitrogen Analyzer (Model 185) using micromilled 0.5-mg samples of waste dried at 110°C. Blanks and standards of known elemental composition were also analyzed for calibration.

Gas Analysis

The gas produced by the simulated landfill cells was collected and analyzed for quantity and composition. The amount of gas was measured using Hastings Mass Flow Transducers during the initial period of the investigations, but these were replaced with gas burets to monitor gas production throughout the remainder of the experimental studies. The buret solution was a dyed solution of Na_2SO_4 acidified with H_2SO_4 as recommended in Standard Methods (26). The gas composition was analyzed using a Fisher Scientific Gas Partitioner (Model 25V) and a Fisher Scientific Thermal Stabilizer (Model 27) with helium or argon as the carrier gas. This procedure provided percentages of CO_2 , O_2 , N_2 , and CH_4 in the gas samples.

Leachate Analysis

Leachate samples from each of the simulated landfill cells were collected at least once a week and characterized for gross parameters, metals and trace organic priority pollutants when detectable.

Gross Parameters. The gross parameters included chemical oxygen demand (COD), five-day biochemical oxygen demand (BOD_5), total carbon (TC), total inorganic carbon (TIC), total organic carbon (TOC), total alkalinity, conductivity, pH, oxidation-reduction potential (ORP) and total and individual volatile organic acids. Sulfides were measured periodically to confirm their presence under reducing conditions and nutrients (PO_4 and NH_3) were also measured to determine sufficiency for biodegradation.

TC, TIC, and TOC were determined by injecting leachate samples filtered through a 0.45- μm membrane filter into a Beckman Total Organic Carbon Analyzer (Model 915, Fullerton, CA). pH and ORP were measured with a Fisher Accumet pH Meter (Model 610). Conductivity measurements

were performed using a Yellow Springs Instrument Company Conductivity Bridge (Model 31, Yellow Springs, OH). Sulfides were analyzed using the Fisher Accumet pH Meter (Model 619), an Orion Double Junction Reference Electrode (Model 90-02); and an Orion Sulfide Electrode (Model 941600).

The concentrations of volatile organic acids were measured using a Hewlett Packard Gas Chromatograph (GC) (Model 5710A, Avondale, PA) equipped with a Flame Ionization Detector (FID). Integration of the peaks was performed by an accompanying Hewlett Packard Integrator (Model 3380A). The glass packed column used to separate acetic, propionic, isobutyric, butyric, isovaleric, valeric, and hexanoic acids was 2m long x 2mm ID (3% carbowax 20 M, 0.5% phosphoric acid on carbopack B (60/80 mesh). Leachate samples were filtered through a 0.45- μ m membrane filter, acidified to pH 2 with concentrated HCl, and diluted prior to injection of 1- μ L samples. The typical operating conditions for the GC were:

Injection temperature	150°C
Detector temperature (FID)	250°C
Oven program	Initial temperature 110°C; increase to final temperature of 170°C at rate of 8°C/minute; and, hold 170°C for 32 minutes.
Carrier gas	N ₂ at 40 mL/minute

Remaining analyses of gross parameters were performed according to Standard Methods (26) and included:

- COD - Oxygen Demand (Chemical) - Method 508
- BOD₅ - Oxygen Demand (Biochemical) - Method 507
- Total Alkalinity - Alkalinity - Method 403 (titrate to pH 3.5)
- PO₄⁻³ - Ascorbic Acid Method - Method 425F
- NH₃ - Phenate Method - Method 418C

Metals. Leachate samples were also analyzed for the following metals: Ca, Na, K, Mg, Mn, Fe, Ni, Cr, Cd, Cu, Zn, Li and Pb. The concentration of each metal was determined using a Perkin Elmer Atomic Absorption Spectrophotometer (AA) (Model 303, Norwalk, CT). Weekly 50-mL samples of leachate were acidified to pH < 2 with concentrated HNO₃ and stored in polyethylene bottles. These samples were digested prior to total metal determination using a proven technique for leachate samples described in the Appendix A.

Organic Priority Pollutant Analysis

The analytical scheme for determination of trace quantities of selected organic pollutants in leachate samples was based on previous experiences with sewage and sludge samples (7). This scheme, shown in Figure 8, commences with pH adjustment of 100-mL samples to less than 2 using HCl. This promoted the recovery of acid and neutral extractable organics, the fraction of interest in this investigation.

A steam distillation vapor extractor was used to extract the organics with methylene chloride, because steam distillation has major advantages over the use of separatory funnels or other extraction methods in its ability to overcome emulsion problems and its excellent trace organic recoveries. With this apparatus (Figure 9), the aqueous sample and methylene chloride are boiled at ambient pressures in separate reservoirs. The vapors from each mix and the combined distillates fall into a separation chamber and the respective liquids return to their vessels.

The next step in the analytical scheme involved the concentration of the methylene chloride phase to 1 mL using a Kuderna-Danish (K-D) apparatus. Gel Permeation Chromatography (GPC) on BioBeads SX-12 was used to separate the phenolic priority pollutants from other co-extracted interferences such as the volatile organic acids. The effectiveness of this "cleanup" procedure has been demonstrated for synthetic solutions containing C₇, C₈ and C₉ volatile organic acids and phenolic priority pollutants, and for actual leachate samples during the acid formation phase (7). Next, the "phenol neutral" fraction was concentrated to 1 mL using the K-D apparatus and nitrogen evaporation. Lastly, the sample was analyzed with a Finnigan Automated Gas Chromatography/EI-CI Mass Spectroscopy System (GC-MS).

A Quality Assurance/Quality Control (QA/QC) Program for this trace organic analysis was maintained throughout this study. It consisted of initial method verification for selected organic priority pollutants and surrogates in leachate samples, determination of recovery efficiencies, and analysis of blanks and controls. Surrogate compounds (deuterated forms of organic priority pollutants under investigation such as phenol-d₅ and 1,4-dichlorobenzene-d₄) were used to monitor the analytical operations and were added to samples just before steam

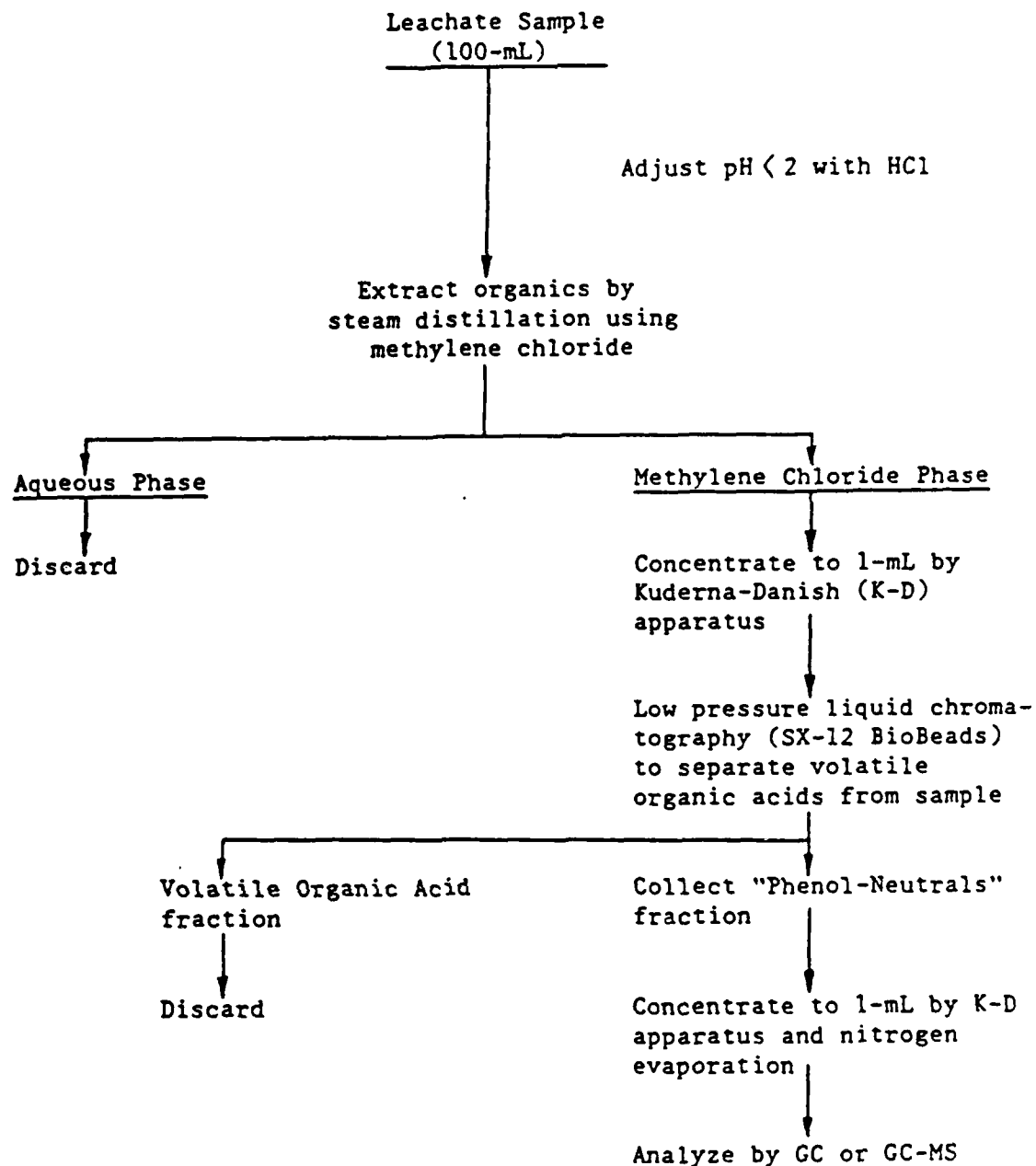


FIGURE 8: ANALYTICAL SCHEME FOR DETERMINATION OF TRACE LEVELS OF ORGANIC CONSTITUENTS IN LEACHATE.

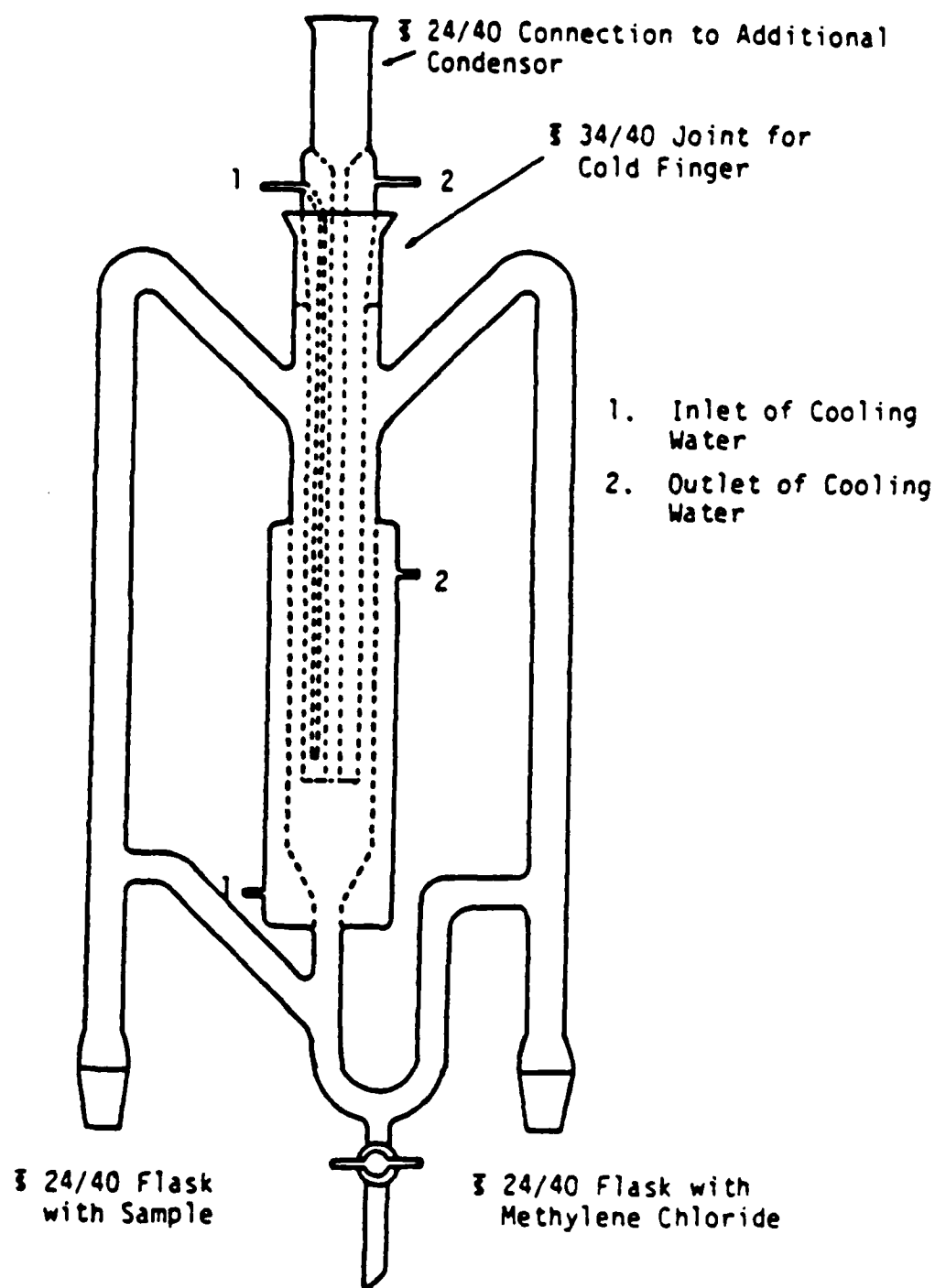


FIGURE 9: STEAM DISTILLATION VAPOR EXTRACTOR.

distillation. The majority of the QA/QC program followed steps established by EPA (10) and this laboratory in an early survey for the presence of priority pollutants (7).

RESULTS AND DISCUSSION

Graphical representations of the results of analyses performed on leachate and gas samples collected from the four simulated landfill cells during the acid formation and methane fermentation phases over a period of about 450 days are presented in this section and tabulated in Appendix B. Day 0 corresponds to March 12, 1985 or the time of initial leachate production.

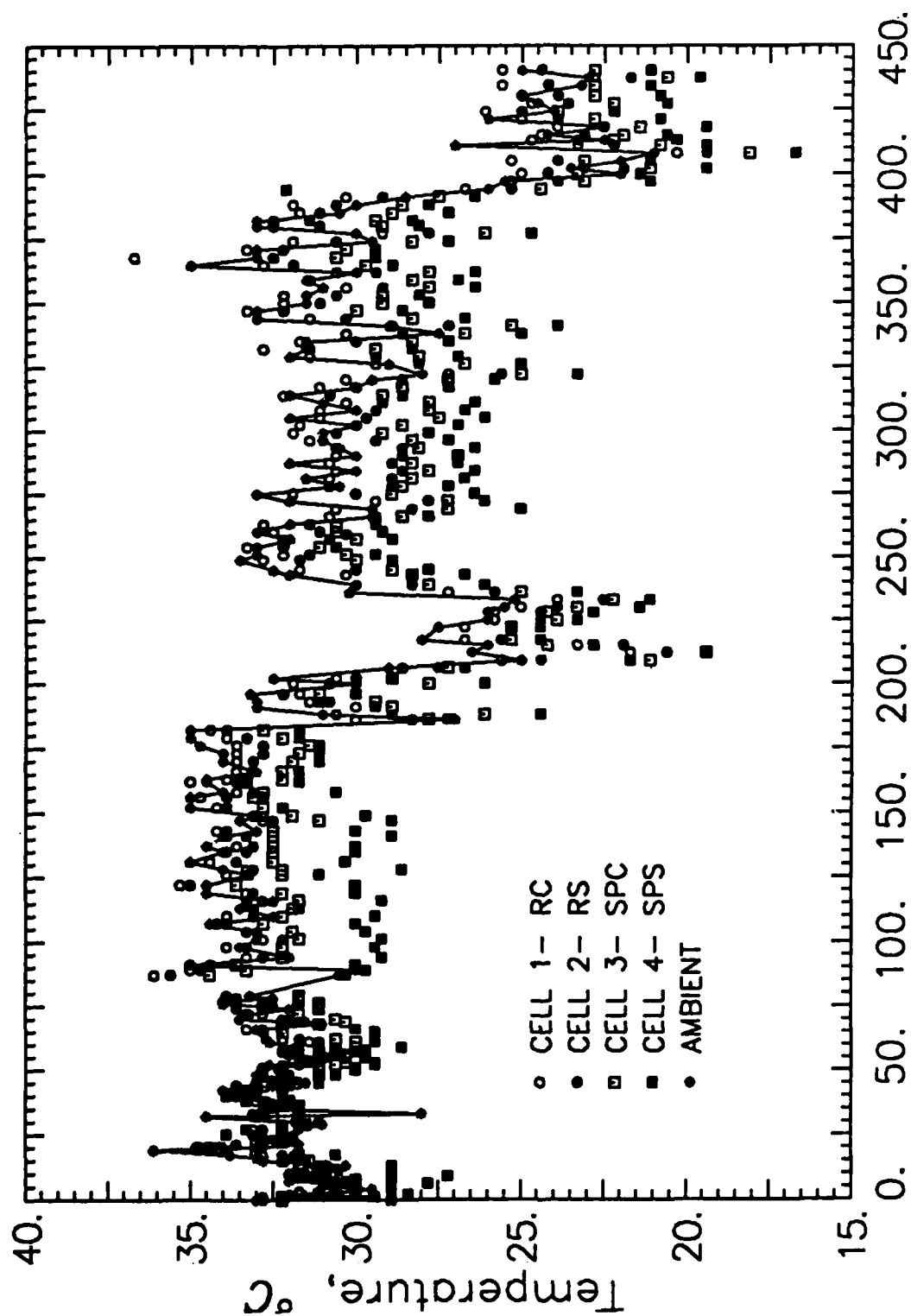
REFUSE COMPOSITION

The municipal solid waste from the DeKalb County, GA Refuse Shredding Facility had an average moisture content of 33.4%. This was determined from four triplicate samples with respective moisture contents for Cell 1 = 33.6%, Cell 2 = 35.0%, Cell 3 = 32.1% and Cell 4 = 33.0%. The volatile solids content averaged 81.2% for the dried waste or 86.3% as received. Calorific values of 4261, 4367, 4354 and 4488 calories/g dry solid waste for Cells 1, 2, 3 and 4, respectively, were also determined with corresponding elemental analyses for C, H, N averaging 46.63% C, 5.09% H, and 0.66% N. Each cell contained approximately 54.6 kg dry weight of solid waste packed in a volume of 170 liters (482 kg/m³ as loaded).

All of these waste parameters were comparable to past results for municipal refuse. In previous studies, Pohland (17) used the same waste source and determined an average moisture content of 33.5%, volatile solids of 75.5% (dry weight), 4310 calories/gram of dry waste, and elemental analysis of 45.3% C, 5.46% H, and 3.33% N.

TEMPERATURE

The internal cell temperatures varied with the ambient room temperature which was moderated by seasonal fluctuations as indicated in Figure 10 (Table B1 in Appendix B). However, temperatures remained between about 29 and 35°C throughout the majority of the study, with the greatest departure from this range being experienced during the winters of 1985 and 1986. Overall, this temperature range was considered satisfactory as has been shown for mesophilic anaerobic digestion systems (12).



Time Since Leachate Production Began, days

FIGURE 10: TEMPERATURE OF THE SIMULATED LANDFILL CELLS.

LEACHATE ANALYSIS

The leachate from the simulated landfill cells was sampled and analyzed for gross parameters, metals, and organic priority pollutants. The results of these analyses are presented and discussed in the following section.

Organic Strength Parameters

The concentrations of chemical oxygen demand (COD), 5-day biochemical oxygen demand (BOD₅) and total organic carbon (TOC) indicate the relative organic strength of the leachate generated throughout the phases of landfill stabilization. The results of COD, BOD₅, and TOC for the simulated landfill cells are shown in Figures 11 through 13 (Tables B2 through B5 in Appendix B).

As expected, all three of these indicators followed similar trends throughout both the acid formation and methane fermentation phases. For the single pass cells, the leachate COD initially decreased rapidly to a constant range near 32,000 mg/L by Day 10, followed by a small increase at Day 45 and a larger increase at Day 55. These initial increases were probably attributable to additional saturation of areas within the waste mass not previously saturated and leached, resulting in higher apparent concentrations of soluble organics in the leachate. This interpretation was also supported by an initial lithium tracer study which displayed similar background increases in concentration during this period, particularly for the single pass cells, as illustrated in Figure 14. The single pass cells were initially more susceptible to such fluctuations, since a smaller volume of water was spread over the same surface area and provided less opportunity for complete saturation of the waste mass.

The results of the initial lithium tracer study are displayed along with the predicted dilution effects in Figure 14 (Tables B6 through B9 in Appendix B). These predicted curves were based on an initial lithium concentration of 15 mg/L which was diluted throughout the tracer study based on water addition to the cells. As indicated in Figure 14, the background concentration of lithium in the leachate samples from all four cells was unexpectedly high at 6-15 mg/L. (To ensure that this response on the Atomic Absorption Spectrophotometer was not due to interference from other sources, ion chromatography was

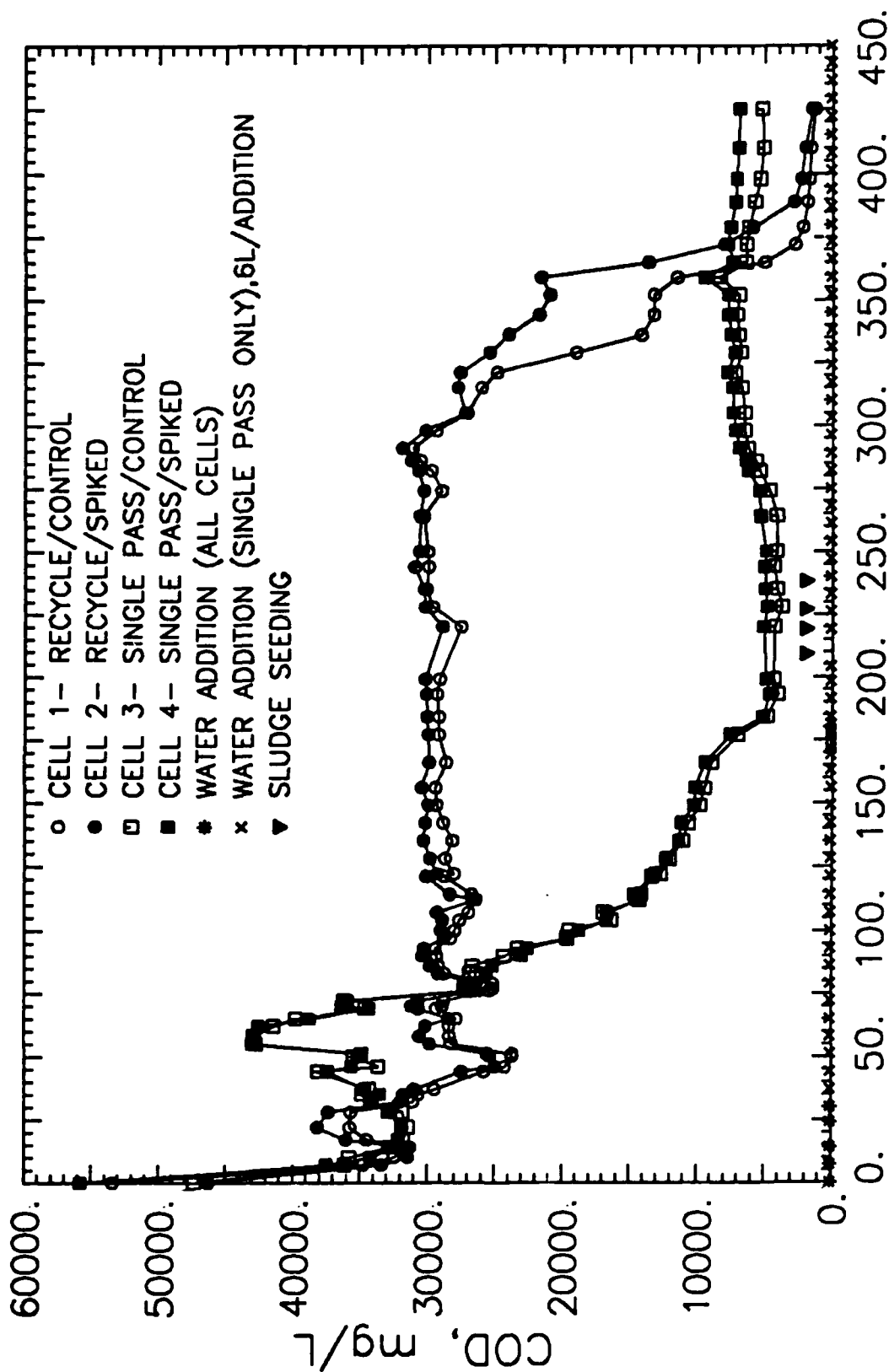


FIGURE 11: CHEMICAL OXYGEN DEMAND OF LEACHATE FROM THE SIMULATED LANDFILL CELLS.

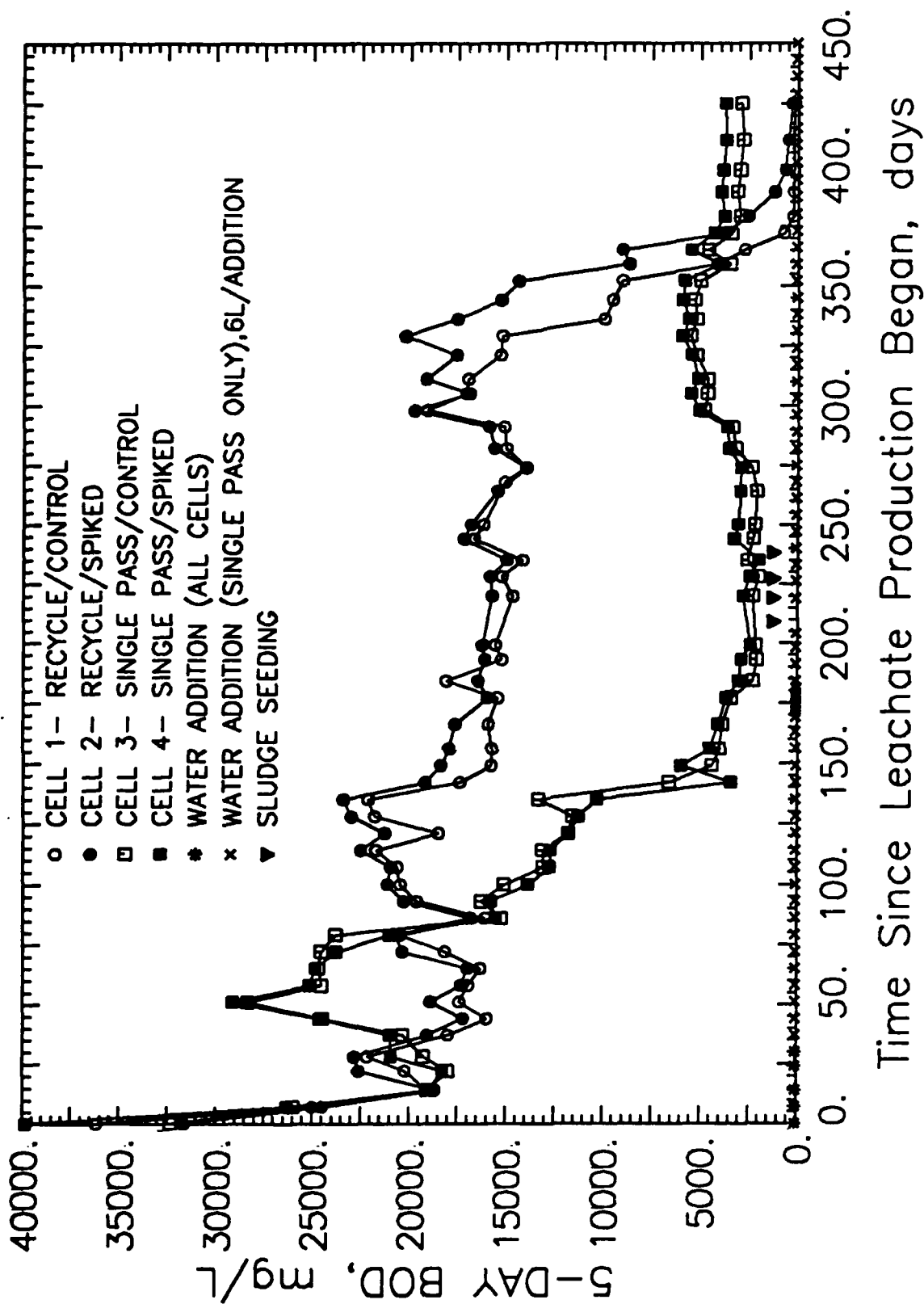


FIGURE 12: BIOCHEMICAL OXYGEN DEMAND OF LEACHATE FROM THE SIMULATED LANDFILL CELLS.

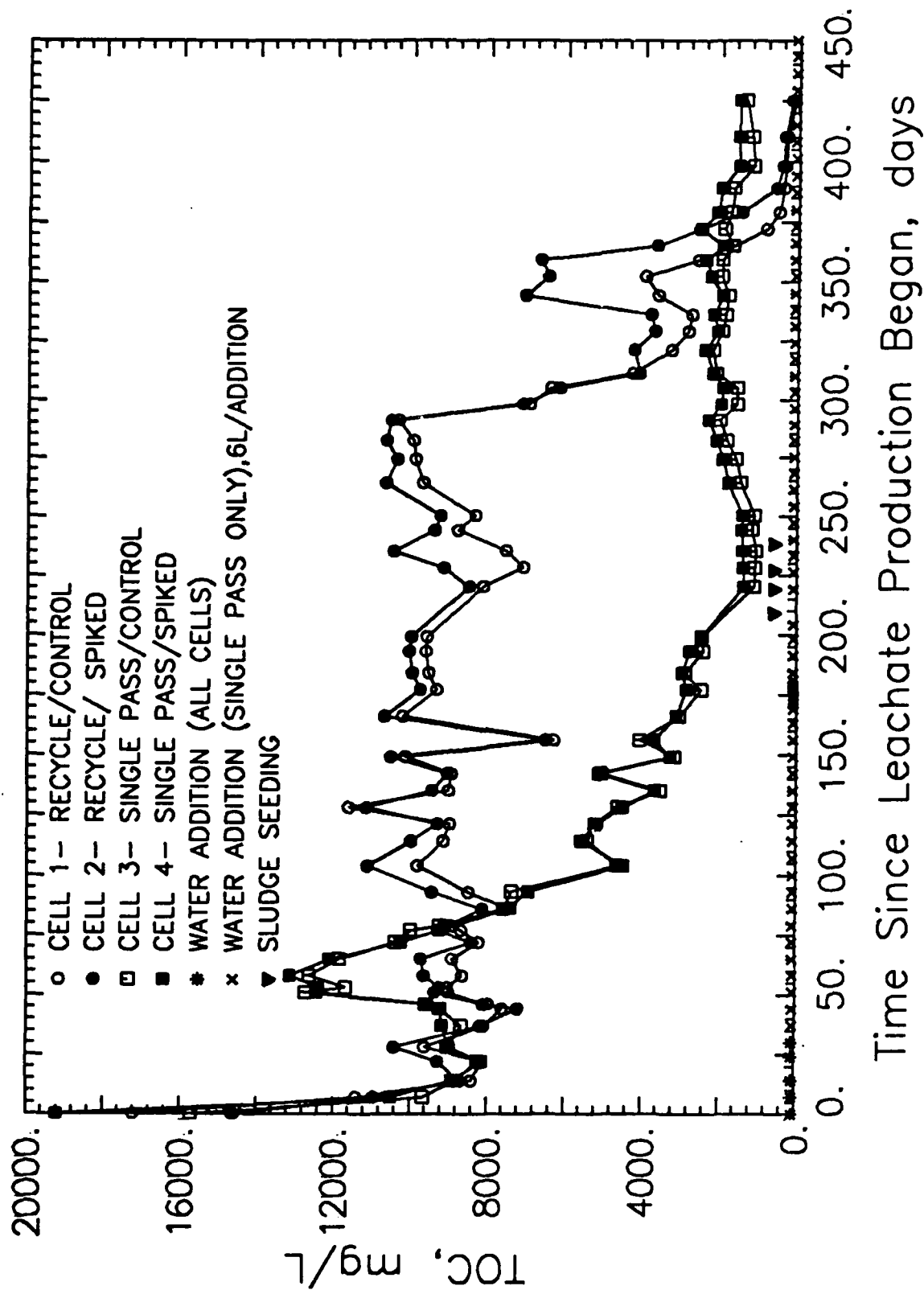


FIGURE 13: TOTAL ORGANIC CARBON OF LEACHATE FROM THE SIMULATED LANDFILL CELLS.

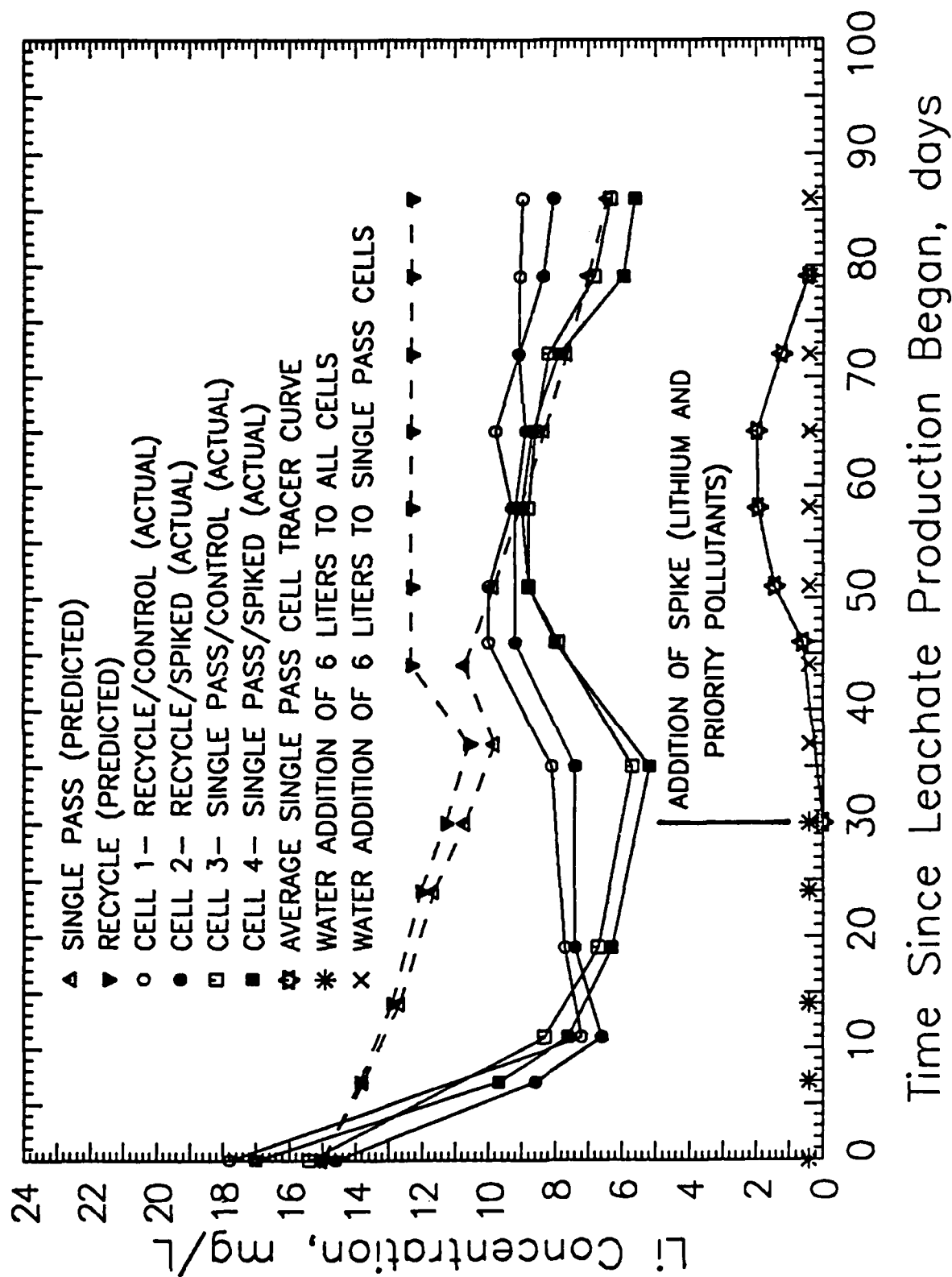


FIGURE 14: LITHIUM TRACER STUDY ON SIMULATED LANDFILL CELLS.

used and the presence of greater than 5 mg/L lithium was confirmed.)

Although this background lithium concentration complicated the tracer study, valuable information could still be obtained from the study. If all the liquid in the system was exposed to the lithium spike, the average increase in lithium concentration would have been 2.0 mg/L for the recycle cells and 1.7 mg/L for the single pass cells. During operation, the recycle cells both experienced a 2 mg/L increase in lithium concentration, indicating total or very nearly total dilution took place. As has been already mentioned and will be illustrated subsequently for the single pass cells for the other measured parameters, increases in concentration around Day 45 were probably due to the leaching of additional areas of waste within the single pass cells. This increase had to be separated from the increase due to the addition of the lithium spike. Therefore, using sodium (Figure 15) as another conservative tracer, the increase due to the leaching of additional solid waste mass was subtracted from the total single pass lithium curves in Figure 14. The remaining increase in lithium concentration resulted in an average of 1.9 mg/L increase due to the lithium tracer spike. This increase means that 81% dilution of the lithium spike occurred throughout the liquid within the cell. Although 81% is less than for the recycle cells, it indicates excellent distribution and minimal shortcircuiting considering the small volume of water (6 liters) added weekly to the single pass cells.

After the increase in lithium concentration due to the spike (Day 30), the concentration of lithium in the recycle cells remained steady as would be expected with no new water addition. The concentration of lithium in the single pass cells decreased as predicted based on 6 liters/week water addition and the predicted curve remained parallel to the actual single pass curve.

The initial tracer study can be used to help explain dilution effects on all leachate analyses, including effects on organic priority pollutants concentrations. Based on the plot shown in Figure 14, the residence time for the single pass cells at this point of the study appeared to be about five weeks (35 days).

After Day 55, the production of COD in the single pass cells appeared to be dominated by the washout of organics and the COD

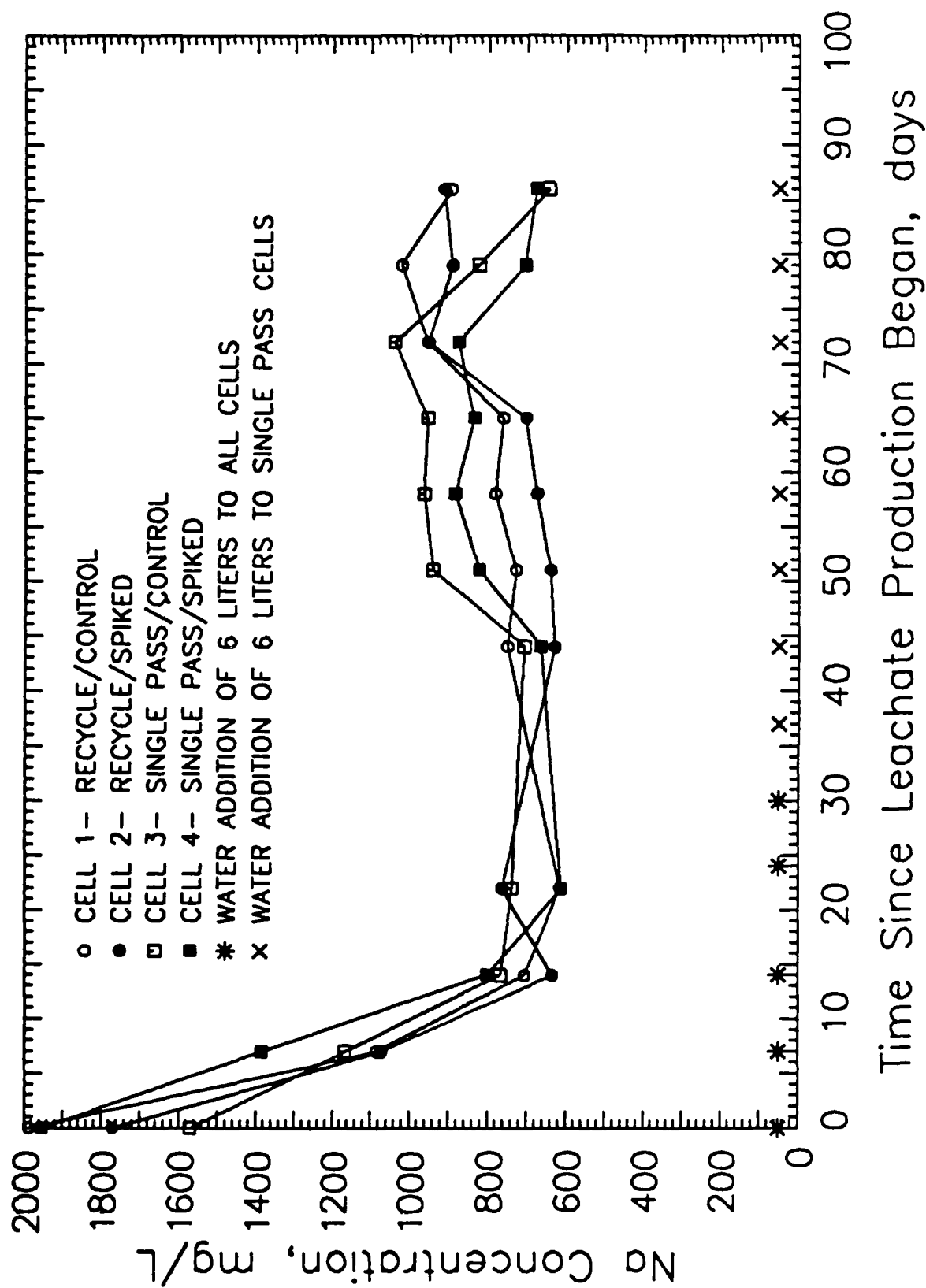


FIGURE 15: SODIUM CONCENTRATION IN LEACHATE FROM SIMULATED LANDFILL CELLS DURING INITIAL TRACER STUDY.

concentration decreased accordingly to about 4000-5000 mg/L by Day 190. A small but perceptible and sustained increase was also noted on Day 280, which may have been due to further degradation of more refractory organics after the onset of active methane fermentation (around Day 275).

The early increase in COD for the recycle cells around Day 20 was probably due to more complete saturation of the waste mass. However, after Day 30, the COD values for the recycle cells remained fairly constant at about 26,000-30,000 mg/L for an extended period of time, thereby indicating that the system had equilibrated in the acid formation phase which is further substantiated by the prevailing high concentrations of volatile acids (Figure 16). However, on about Day 298, after the systems had been seeded with digested sludge, a dramatic decrease in COD to the 1,000-1,500 mg/L range occurred. As will be discussed later, this was attributed to in situ treatment provided by leachate recycle under conditions conducive to methane fermentation. The rapid rates of COD removal observed for the recycle Cells 1 and 2 were, thereby, enhanced by the continuing exposure of the bacterial populations to the daily recirculated leachate. Since CO_2 and CH_4 constitute the major final products of such a process during anaerobic stabilization, the amount of gas produced also paralleled the rate and degree of organic removal as also indicated by the weekly and cumulative gas produced by the recycle cells (Figures 17 and 18 and Tables B10 and B11 in Appendix A).

It is interesting to note that the rapid rate of COD removal for the recycle cells was curtailed somewhat between Days 330 and 350. This same change was also indicated and magnified by the BOD_5 (Figure 11), TOC (Figure 12), and total volatile acids (Figure 16) concentrations as well as pH (Figure 19). During this period, propionic acid specifically increased (Figures 20 and 21) as hexanoic acid decreased as compared to the single pass cells (Figures 22 and 23). Since the possibility of a system upset was first suspected, daily recirculation was curtailed for a period of about a week (Day 346 to Day 352). Through the following week, only half of the collected leachate in each recycle cell's reservoir was recirculated daily. Furthermore, possible clogging-induced shortcircuiting was considered

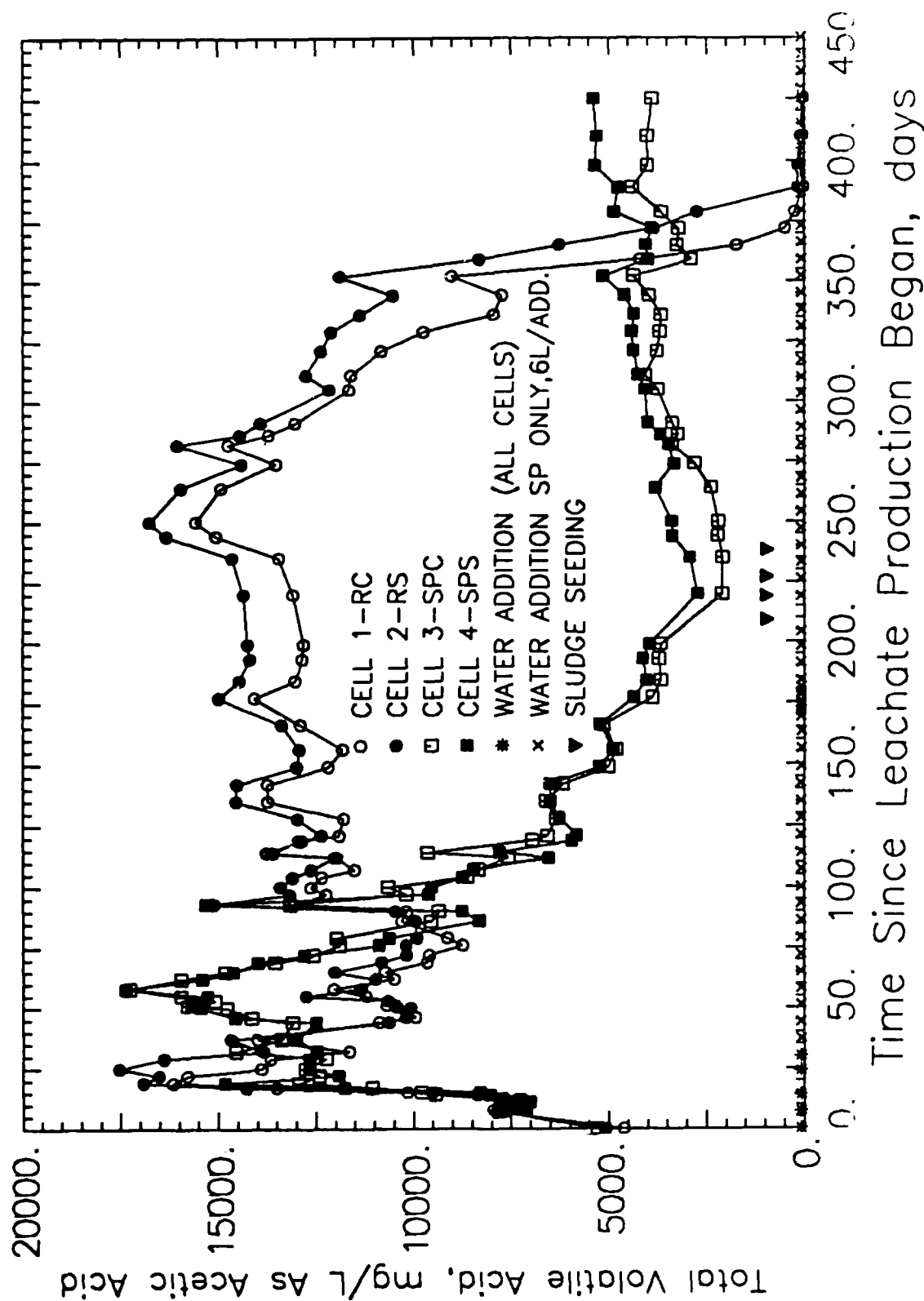


FIGURE 16: TOTAL VOLATILE ACIDS IN LEACHATE FROM THE SIMULATED LANDFILL CELLS.

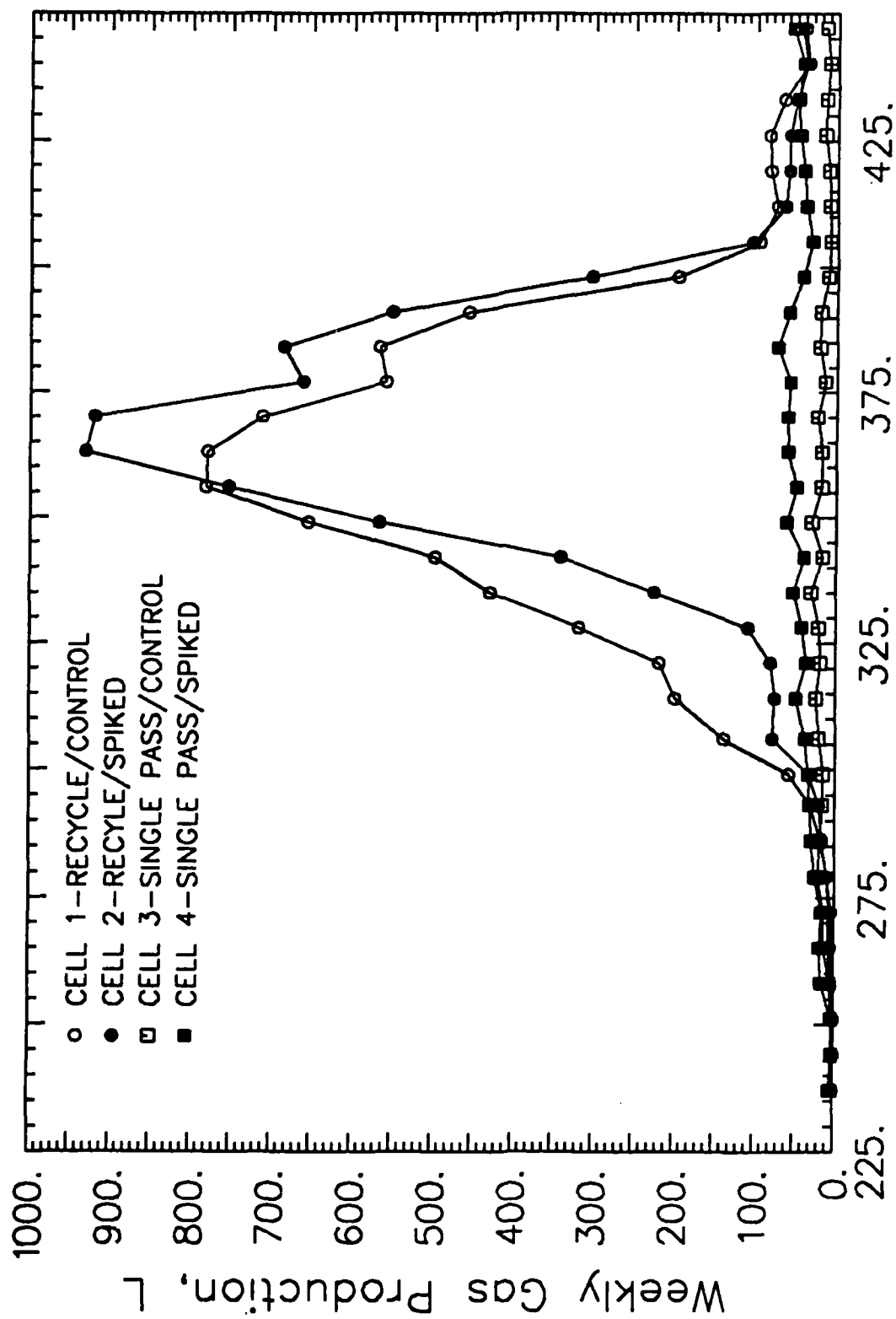
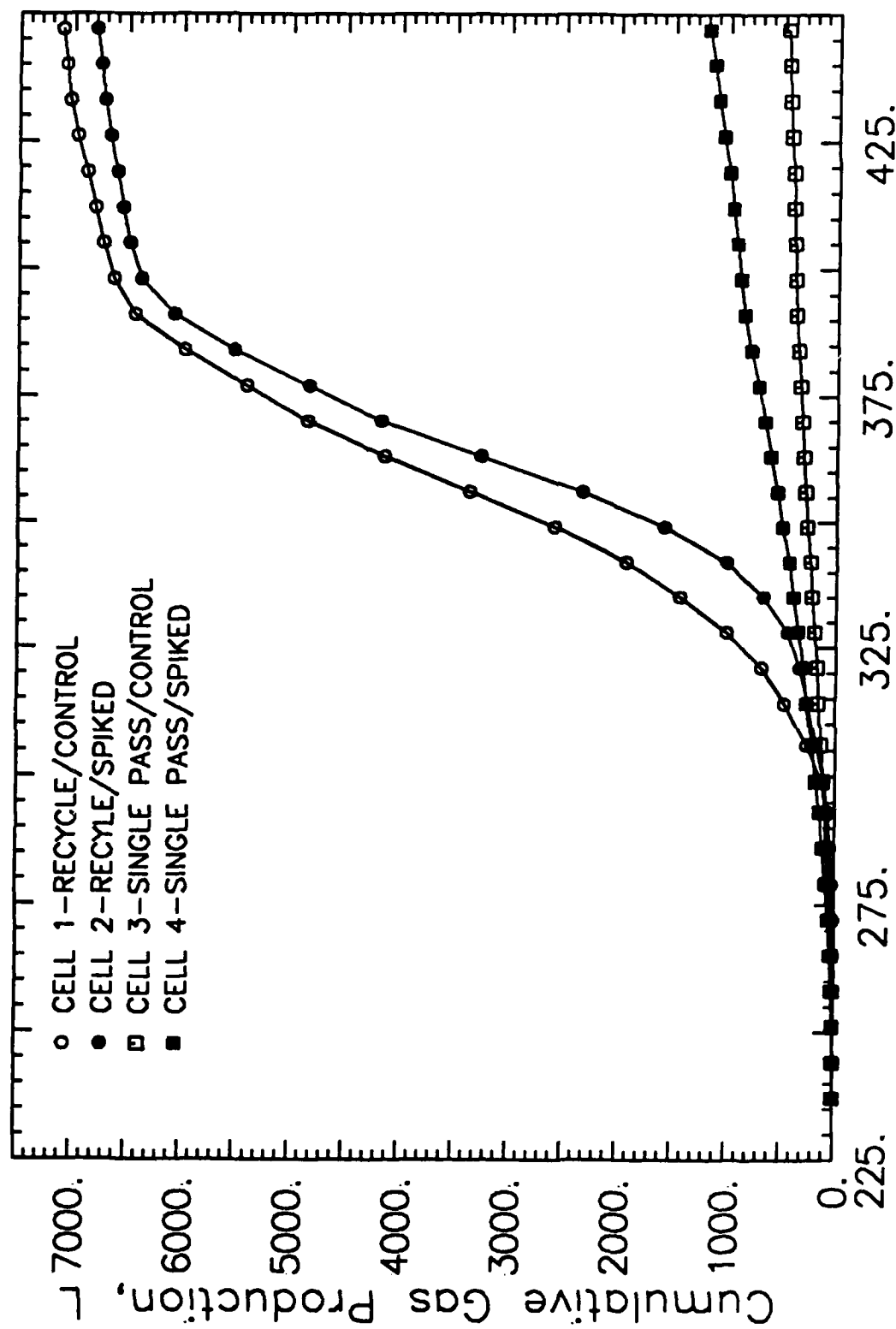
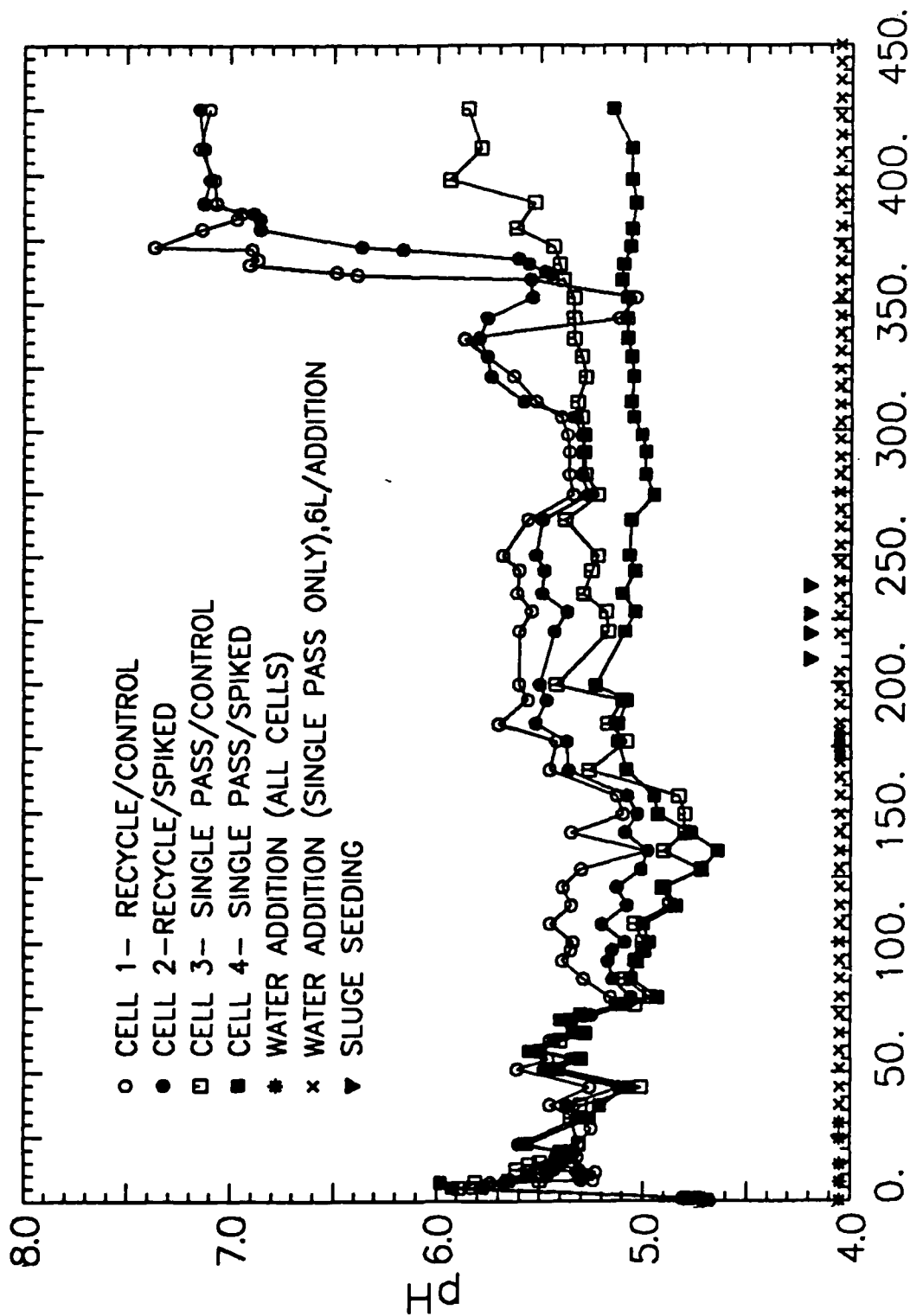


FIGURE 17: WEEKLY GAS PRODUCTION FROM THE SIMULATED LANDFILL CELLS.



Time Since Lechate Production Began, days

FIGURE 18: CUMULATIVE GAS PRODUCTION FROM THE SIMULATED LANDFILL CELLS.



Time Since Leachate Production Began, days

FIGURE 19: pH OF LEACHATE FROM THE SIMULATED LANDFILL CELLS.

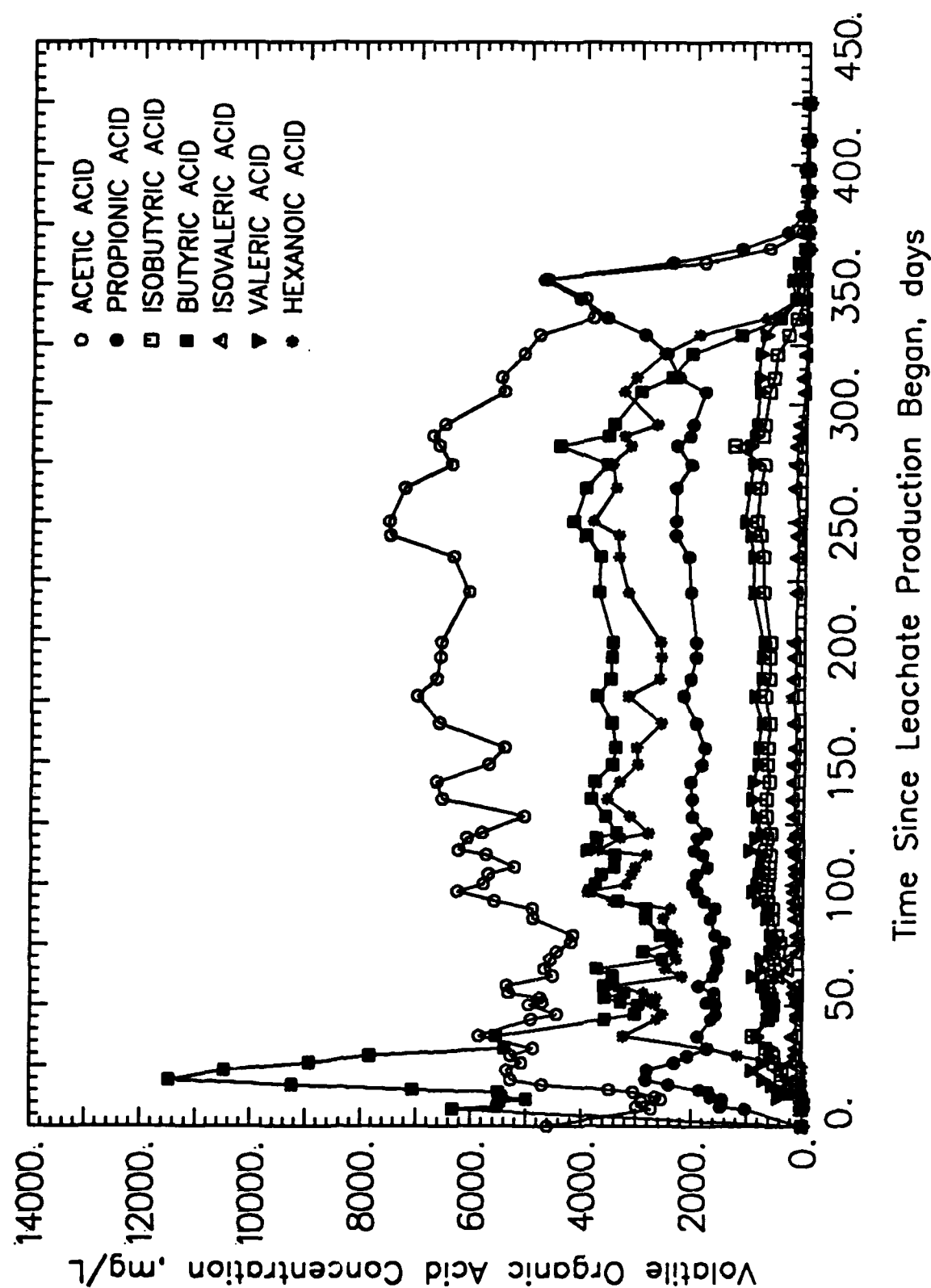


FIGURE 20: VOLATILE ORGANIC ACIDS IN LEACHATE FROM THE CONTROL RECYCLE CELL.

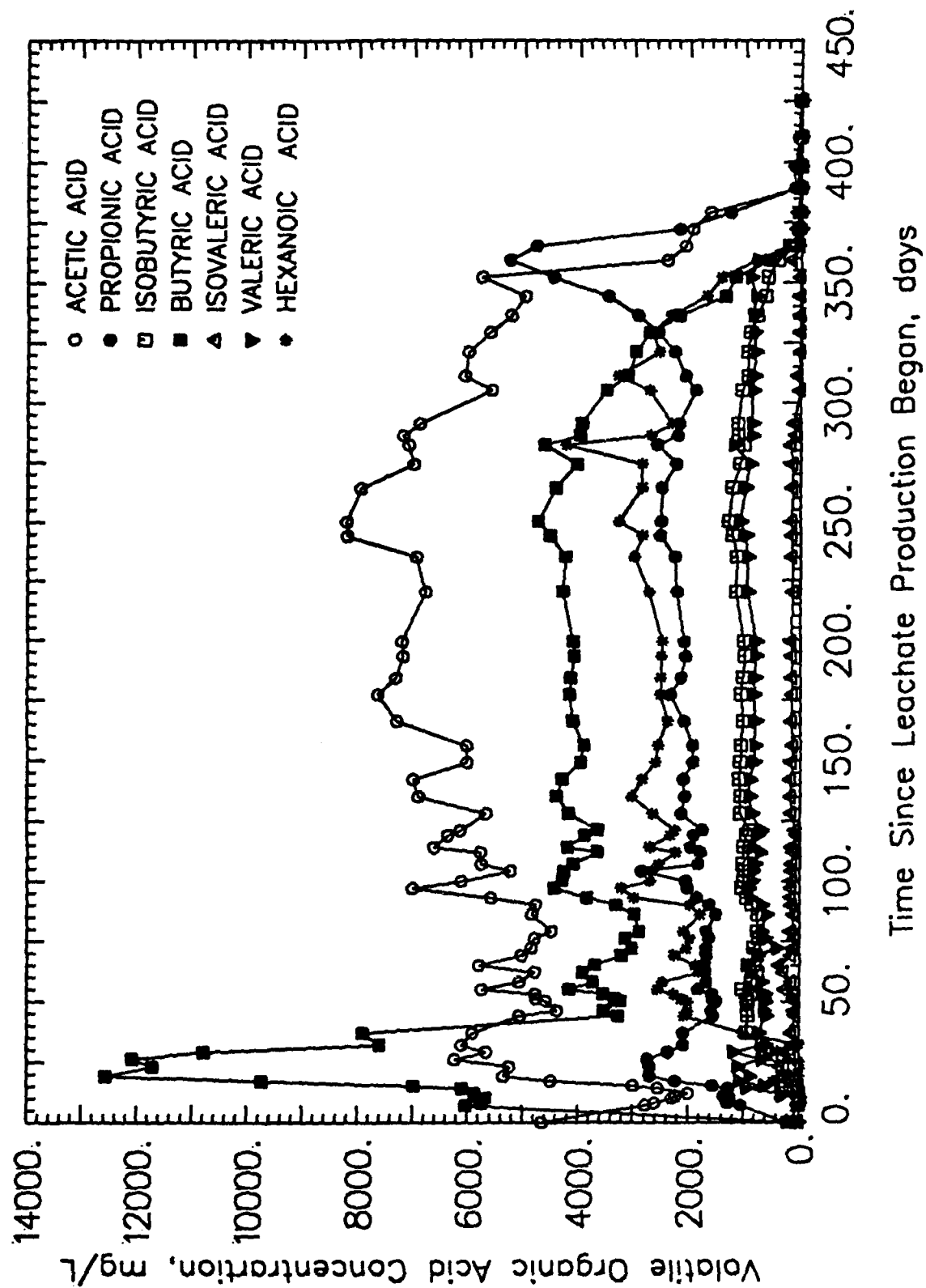


FIGURE 21: VOLATILE ORGANIC ACIDS IN LEACHATE FROM THE SPIKED RECYCLE CELL.

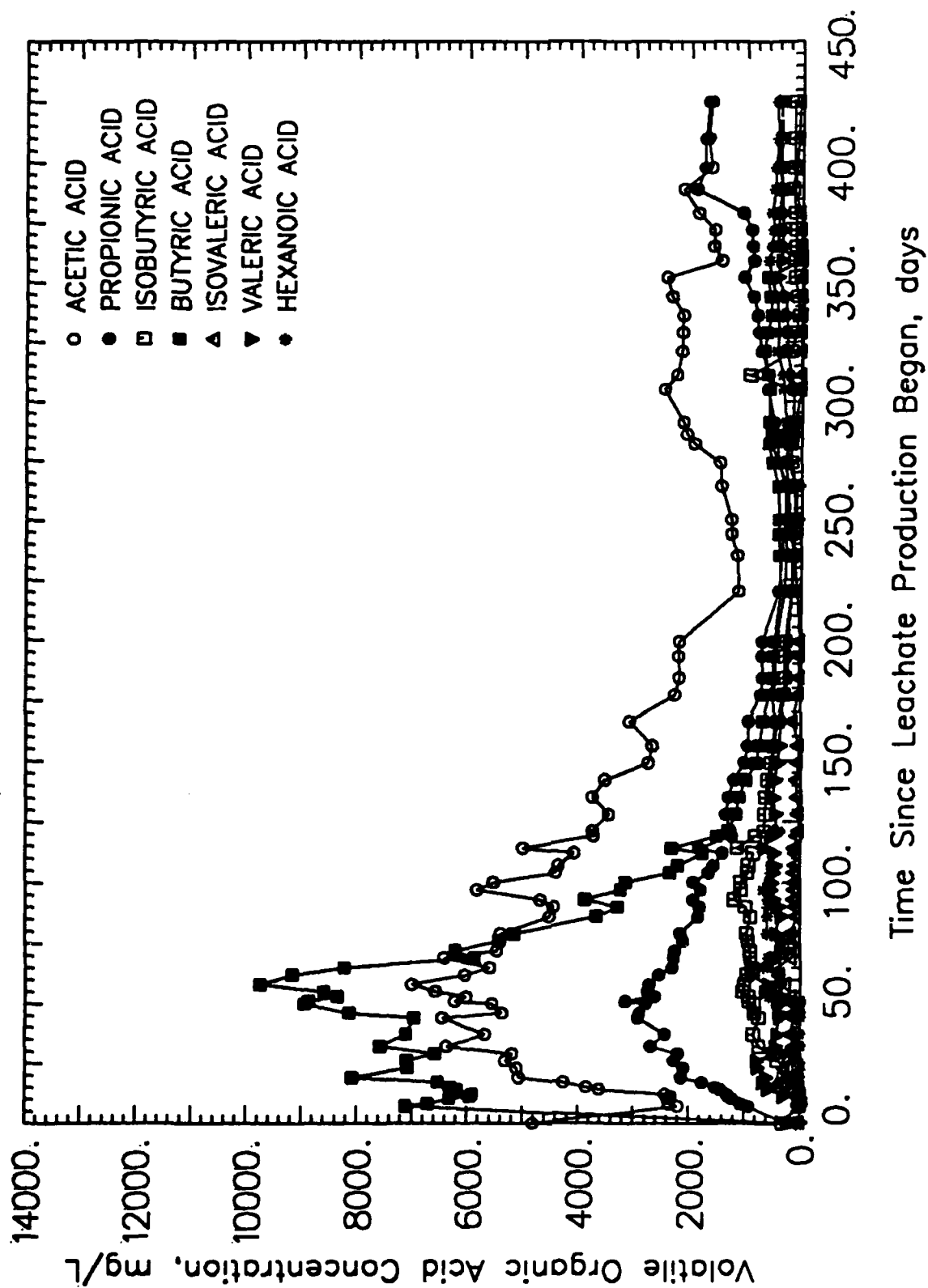


FIGURE 22: VOLATILE ORGANIC ACIDS IN LEACHATE FROM THE CONTROL SINGLE PASS CELL.

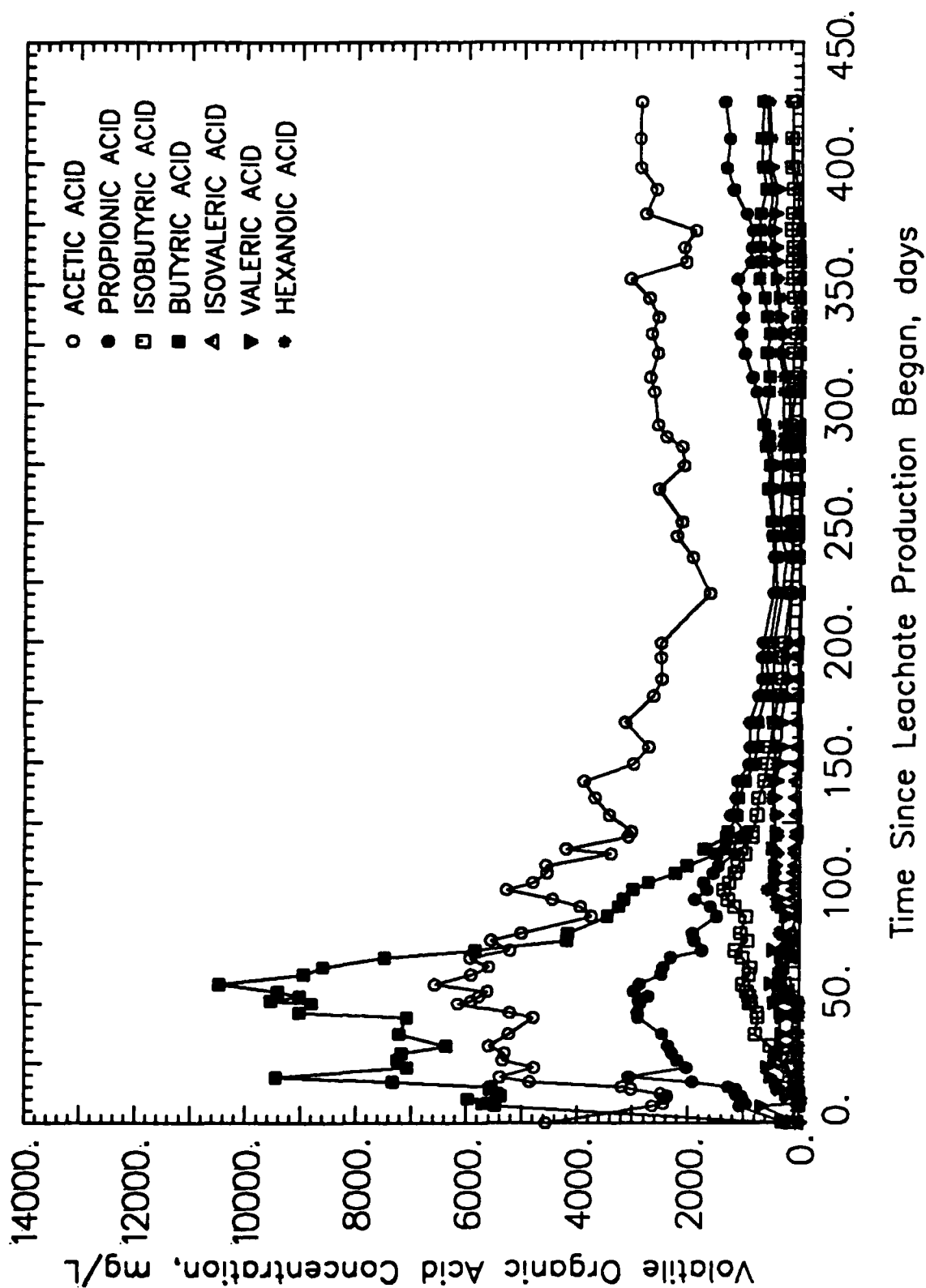


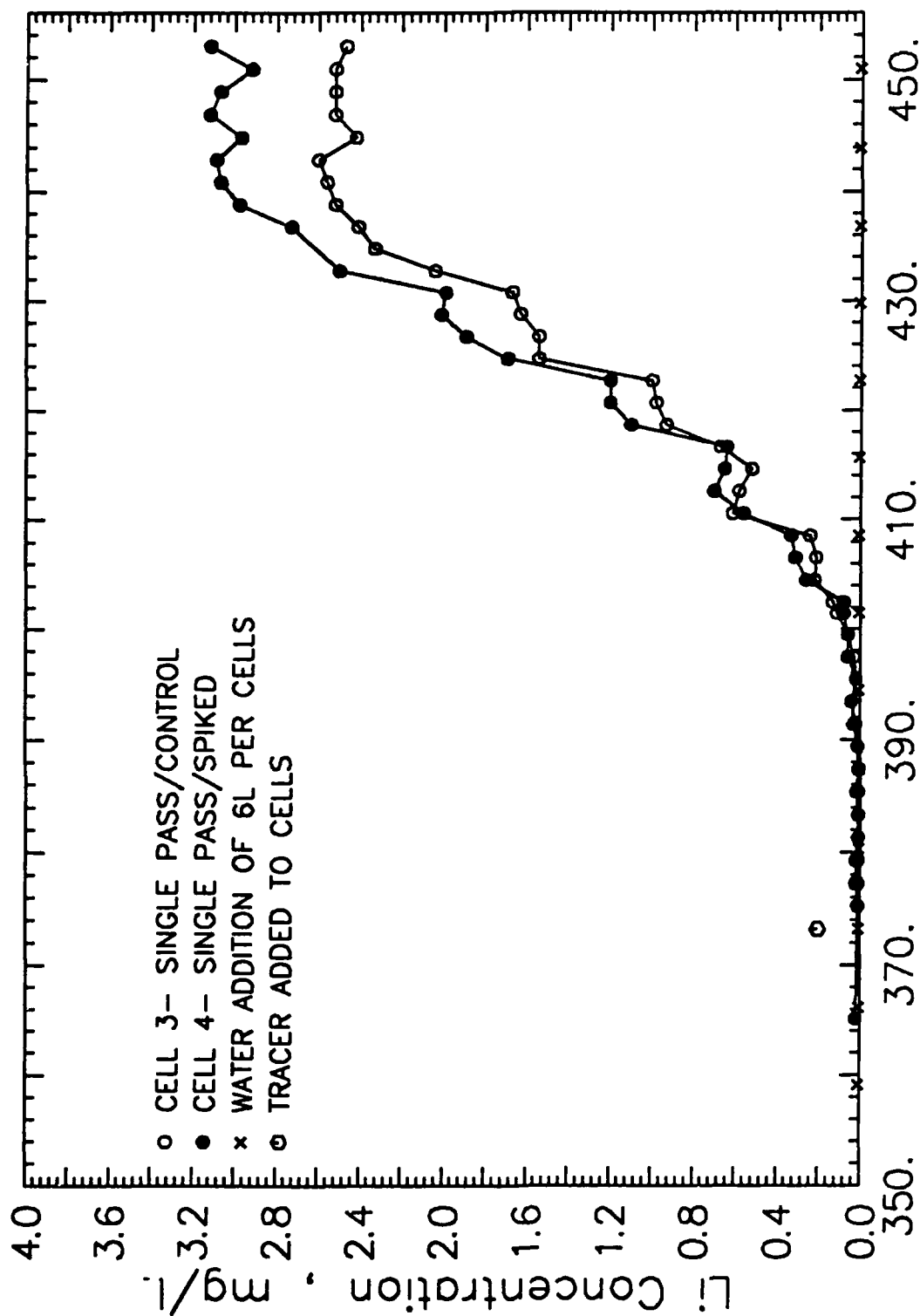
FIGURE 23: VOLATILE ORGANIC ACIDS IN LEACHATE FROM THE SPIKED SINGLE PASS CELL.

as another possible explanation for the aforementioned behavior. Therefore, a second tracer study was initiated on Day 373 for the simulated landfill system.

Although the tracer study was primarily intended to provide a better understanding of flow characteristics within the systems and also to permit an examination of dilution effects, it could also be used as a basis for comparing residence times during the acid formation and methane fermentation phases of stabilization. Unfortunately, lithium concentration existing in the recycle cells had remained high and in the range of 6-10 mg/L as compared to a 0.01 mg/L concentration for the single-pass cells. Also, it was possible to determine the moisture balance for the single pass cells more easily than for the recycle cells. Therefore, it was decided to initiate the Li tracer study on the single pass cells, with the assumption that flow patterns could be considered similar during the terminal phase of stabilization for the single pass and recycle cells.

Based on moisture content of the waste placed in the simulated landfill cells and the weekly schedule of water addition to the single pass cells (6 L per week), 200 mg of Li was added to each single pass cell. If all the liquid in the system was exposed to the Li spike, the average increase in Li concentration would have been 3.3 mg/L in each cell. Also a residence time of 14-16 weeks was determined based on the volume of solid waste and the scheduled water addition for the single pass cells.

The results of this Li tracer study for the single pass cells are presented in Figure 24 (Table B12). The peak increase in Li concentration for the control single pass cell (Cell 3) was approximately 1.7 mg/L, whereas the peak Li concentration for the spiked single pass cell (Cell 4) was nearly 3.2 mg/L. Both peaks were observed nearly 12 weeks after the tracer study was initiated and, although the tracer study was not totally complete at the time of this report, an increase of 2.7 mg/L in Cell 3 indicated a 76% dilution of the Li spike had occurred as compared to an increase of 3.2 mg/L or 99% dilution in Cell 4. Therefore, both cells demonstrated an excellent distribution and minimal shortcircuiting considering the small volume of water (6 liters) added weekly to each one.



Time Since Leachate Production Began, days

FIGURE 24: LITHIUM TRACER STUDY PERFORMED ON THE SIMULATED LANDFILL CELLS.

Based on the results of the second tracer study, clogging or shortcircuiting was not considered a major factor in influencing changes in parametric analyses despite an indicated three-fold increase in residence time from the five weeks initially measured. This increase was no doubt due to biological growth and consolidation within the landfill cells.

To provide for more meaningful comparison of single pass and recycle management options, the organic strength or concentration should be multiplied by the volume of leachate involved to obtain total masses of contaminants. Therefore, the cumulative mass of COD produced by each system was calculated in accordance with the procedure included in Appendix C. As shown in Figure 25 (Tables B2 through B5 in Appendix B), the mass of COD generated from the single pass cells was about four times that of the residual mass for the recycle cells. Likewise, the COD concentration (mostly TVA) in the recycle cells appears to have reached an initial saturation level and then declined significantly as methane fermentation became operative. The total mass available, as reflected by the single pass cells, suggested additional production (COD and TVA) as gas production proceeded. The delay or dampening of the magnitude of waste conversion because of the accumulation of conversion products such as the volatile organic acids is often acknowledged when end-product repression occurs (32). Figures 26 through 28 show similar trends for masses of BOD₅, TOC and TVA where the same pattern was noted.

Some researchers have advocated the use of ratios of the organic strength parameters rather than actual concentrations (4). The BOD₅/COD ratio has been used as an indicator of biochemical treatability, and leachate with high BOD₅/COD ratios (greater than 50%) would be presumed amenable to biological conversion. The single pass and recycle cell leachate BOD₅/COD ratios of 55 to 75% declined dramatically to about 20% by the end of the study period, thereby indicating a removal of readily biodegradable substrates by washout and microbially mediated stabilization.

The COD/TOC ratio is sometimes used as an indicator of the oxidation state of the organic carbon and the degree of stabilization that has occurred. Low COD/TOC ratios indicate that the organic carbon

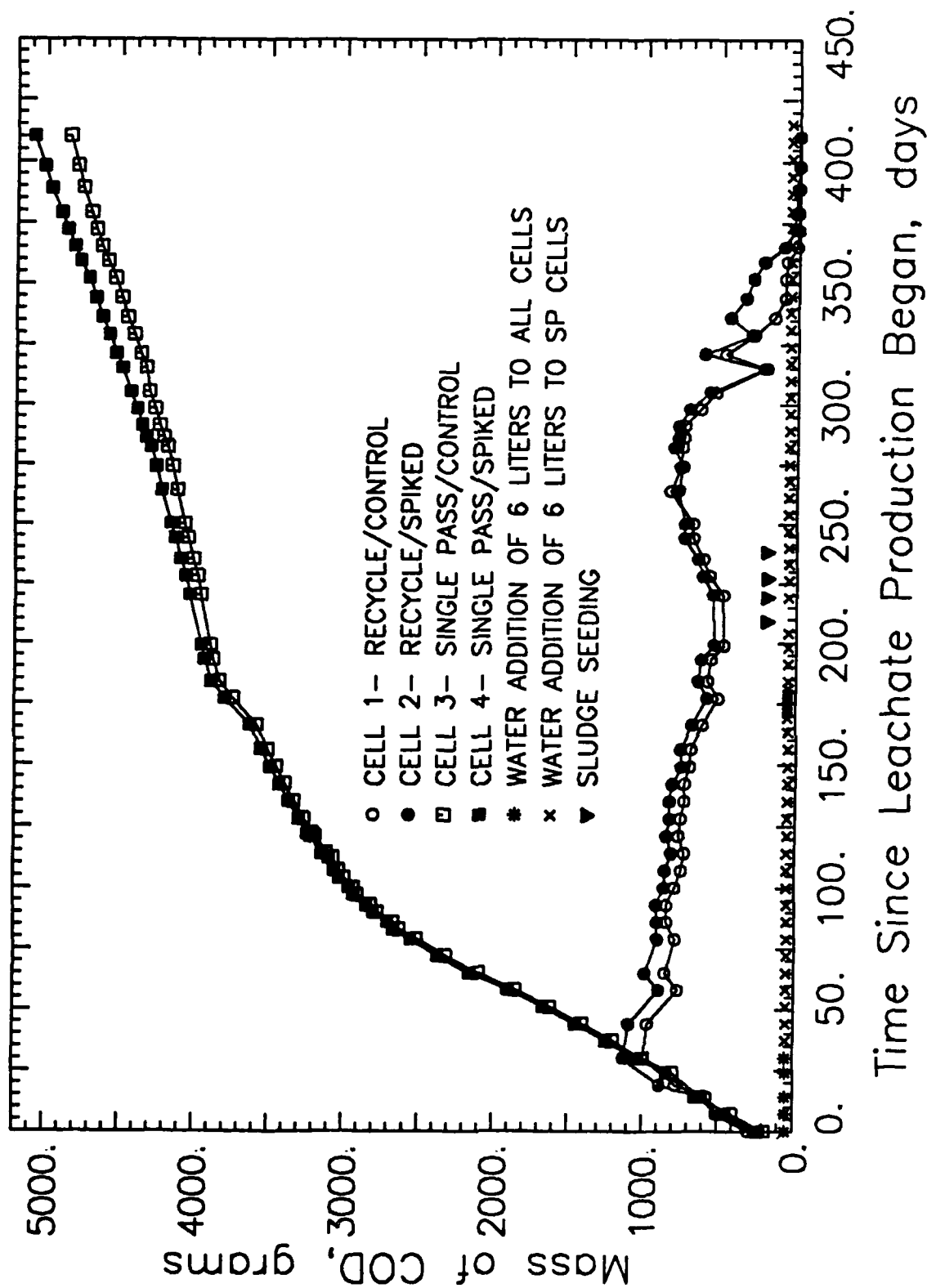


FIGURE 25: MASS OF CHEMICAL OXYGEN DEMAND OF LEACHATE FROM THE SIMULATED LANDFILL CELLS.

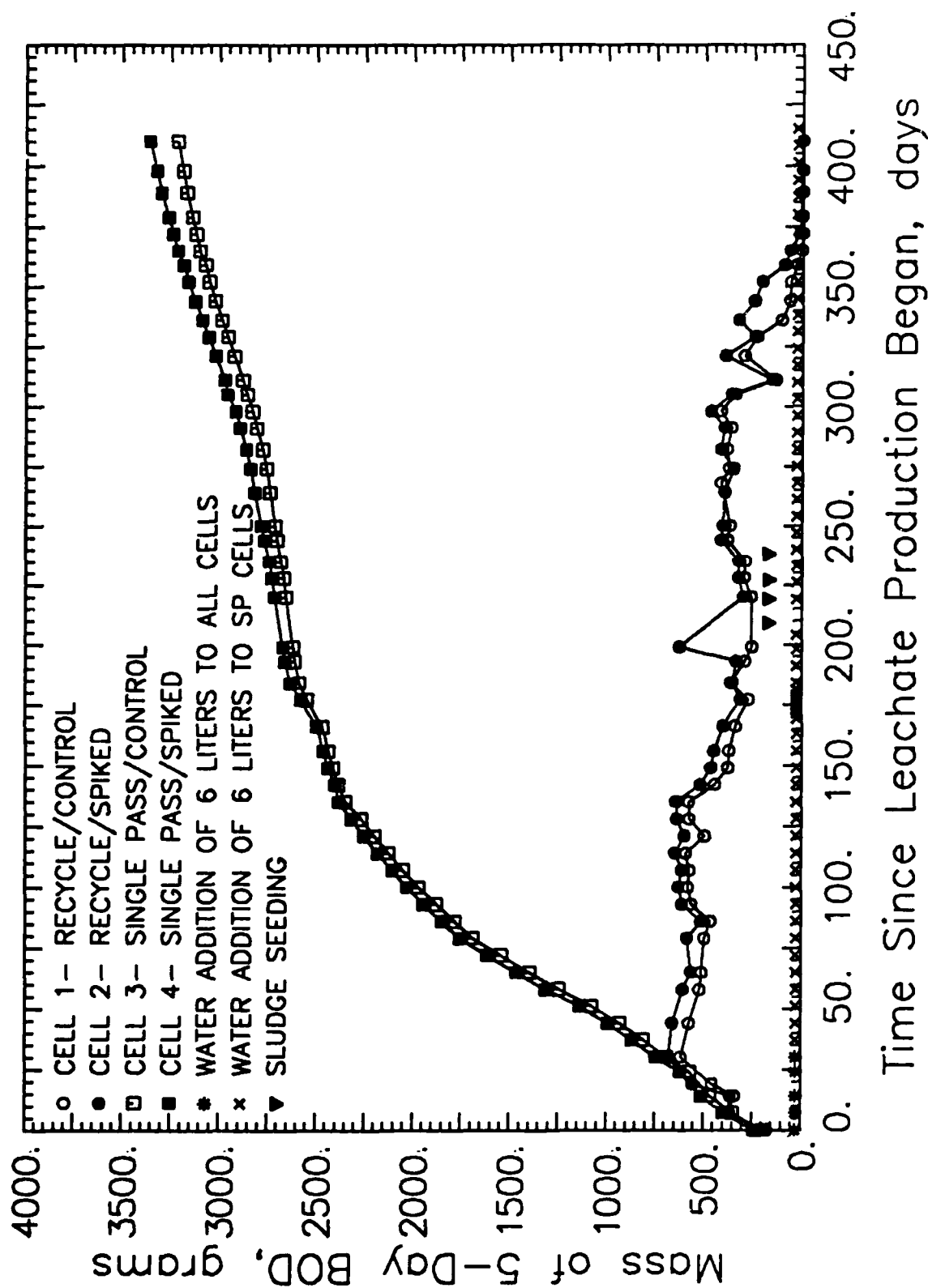


FIGURE 26: MASS OF BIOCHEMICAL OXYGEN DEMAND OF LEACHATE FROM THE SIMULATED LANDFILL CELLS.

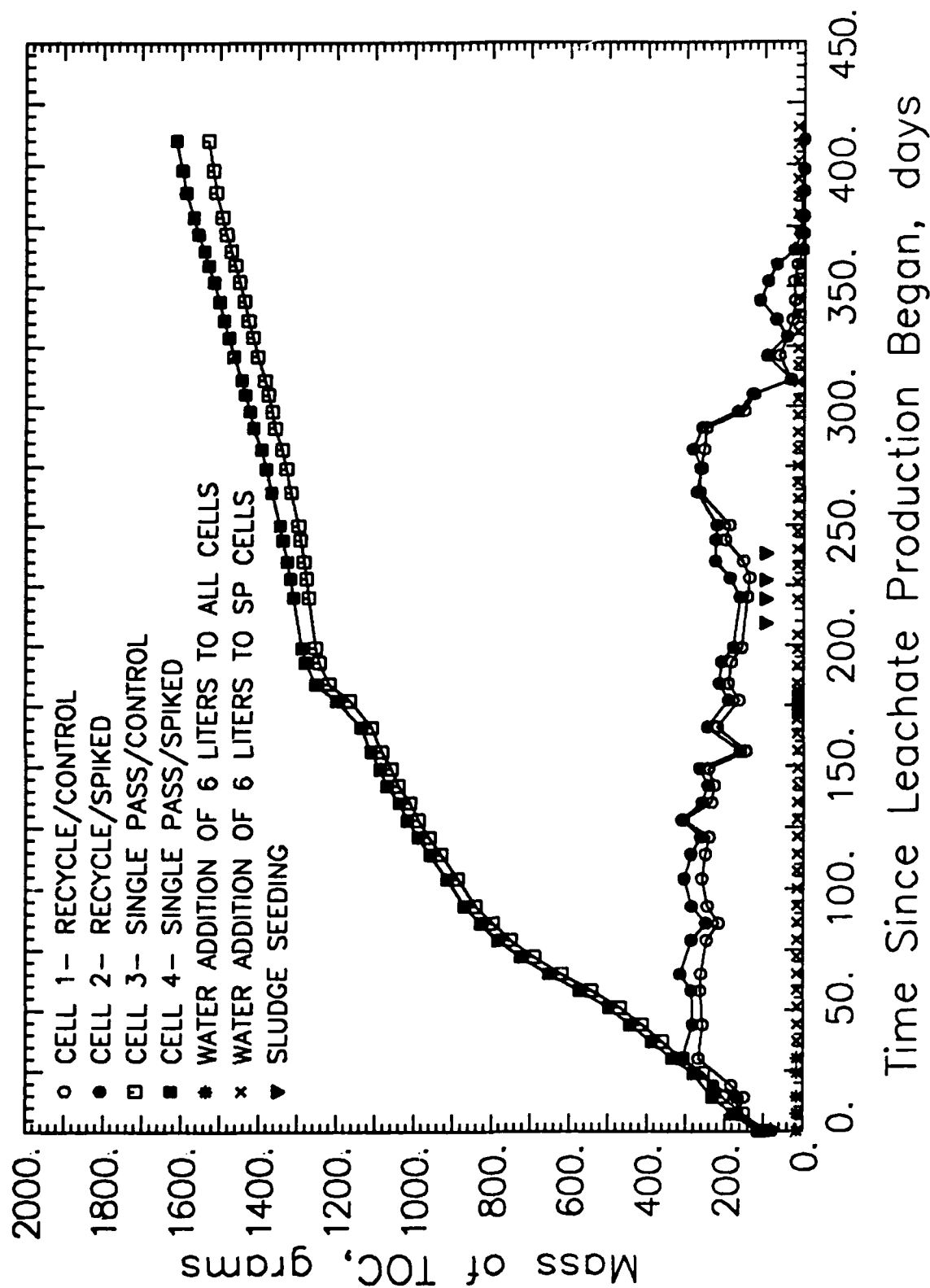


FIGURE 27: MASS OF TOTAL ORGANIC CARBON OF LEACHATE FROM THE SIMULATED LANDFILL CELLS.

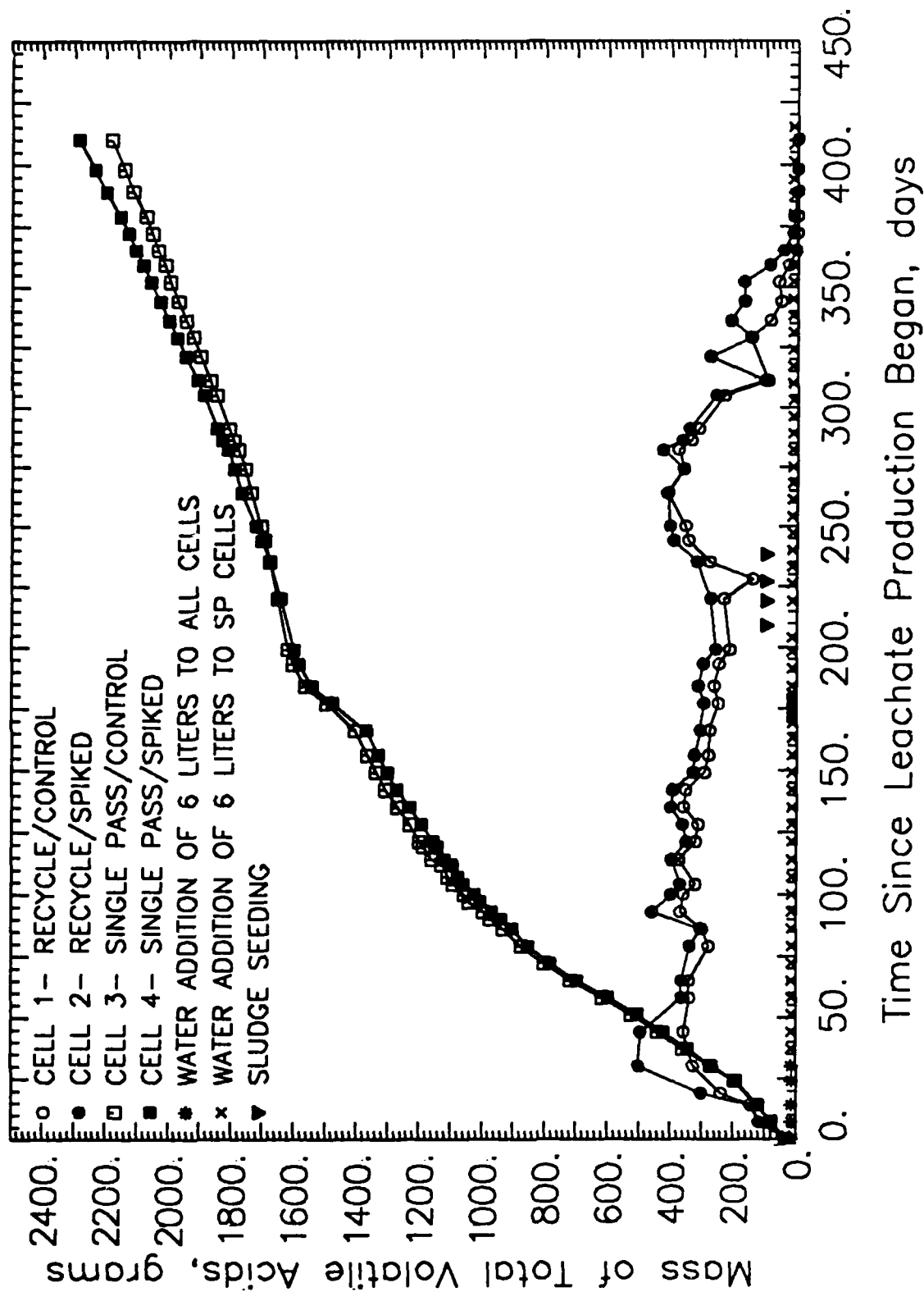


FIGURE 28: MASS OF TOTAL VOLATILE ACIDS IN LEACHATE FROM THE SIMULATED LANDFILL CELLS.

is in a higher oxidation state, with less energy available for growth. The COD/TOC ratio for the single pass and recycle cell leachates was high at the onset of the investigation, indicating an abundance of energy available for growth. Toward the end of the studies, this ratio changed but was influenced by the chemically reduced conditions prevailing in each cell.

Volatile Organic Acids

The most identifiable and abundant leachate intermediates formed during the initial stages of landfill stabilization are the volatile organic acids (VOA). Those monitored in this study included acetic, propionic, isobutyric, butyric, isovaleric, valeric and hexanoic acids. The total volatile acids (TVA) represent the accumulation of the individual volatile organic acids converted to "mg/L as acetic acid" by adjusting for differences in molecular weight.

As introduced previously, the TVA concentrations in the leachates from the simulated landfill cells (Figures 16 and 28) showed trends similar to the other organic strength indicators (COD, BOD₅, and TOC). The recycle cells appeared to have achieved more complete saturation around Day 20-40, generating higher TVA corresponding to higher COD during that time. After Day 40, TVA concentrations leveled off as the recycle cells equilibrated in the acid formation phase. These concentrations then decreased from maximum levels of about 15,000 to 16,000 mg/L on Day 250 to 50 to 100 mg/L on about Day 450 as methane fermentation became active (Figures 17 and 18). This removal of TVA was also accompanied by an increase in pH (Figure 19) to a near neutral range as will be discussed subsequently.

The leachate TVA concentrations for the single pass cells also leveled off from Day 20-45 and then increased from Day 45-58 as more complete saturation of the waste mass seems to have occurred and increased quantities of organics were leached from the refuse. After Day 58, the TVA of the single pass cells steadily decreased, indicating that washout of the easily leached organics had become dominant. The single pass cells reached their maximum TVA of 17,500 and 17,400 mg/L as acetic acid for Cells 3 and 4, respectively, just before washout began dominating around Day 58. This later date for maximum TVA was another indication of less complete saturation in the single pass cells

during the early part of the experimental studies. Thereafter, concentrations tended to remain nearly constant at 2,500 to 5,000 mg/L which corresponded to the slower development of methane formers and the possible further conversion of the more resistant fractions of the refuse mass.

Volatile organic acids constituted the majority of the chemical oxygen demand during the acid formation stage. For example, 75-90% of the leachate COD from the recycle and single pass cells were accountable to the volatile organic acids. As the TVA were removed either by washout or methane fermentation, less impact on COD (or BOD₅ and TOC) was noted.

Figures 20 through 23 and 29 through 32 (Tables B2 through B5 in Appendix B) display the individual volatile organic acids (VOA) in the leachates from Cells 1, 2, 3 and 4, respectively. The cells with similar management strategies, i.e., recycle or single pass, had very comparable trends for individual VOA. The recycle cells, Cells 1 and 2, showed initial increases in all VOA from Days 15-20 with maximum values for the primary volatile organic acids being measured around Day 20 (11,500 and 12,600 mg/L butyric acid, 5,900 and 6,200 mg/L acetic acid, and 2,800 and 2,700 mg/L propionic acid for Cells 1 and 2, respectively). From Day 20 to 45, the butyric acid concentration decreased dramatically to 3,000-4,000 mg/L at which point it leveled off. Propionic acid decreased slightly after Day 25 to 1,600-1,800 mg/L after which it was relatively constant. The acetic acid concentration increased slightly as butyric acid concentration started to decrease; however, it quickly leveled off and accounted for little of the decrease in butyric acid. Since no gas production or other indication of further degradation to final end-products was evident, at this stage of the investigations, the butyric acid concentration peaks were difficult to account for. However, their presence was consistent with the increase in COD during Days 15-30. After about Day 275, active methane fermentation led to a dramatic decrease in all VOA concentrations as also reflected in the TVA.

The VOA concentrations in the single pass cells gradually increased to maximum values around Day 58 at which point washout began dominating. Butyric acid was the primary VOA with maximum

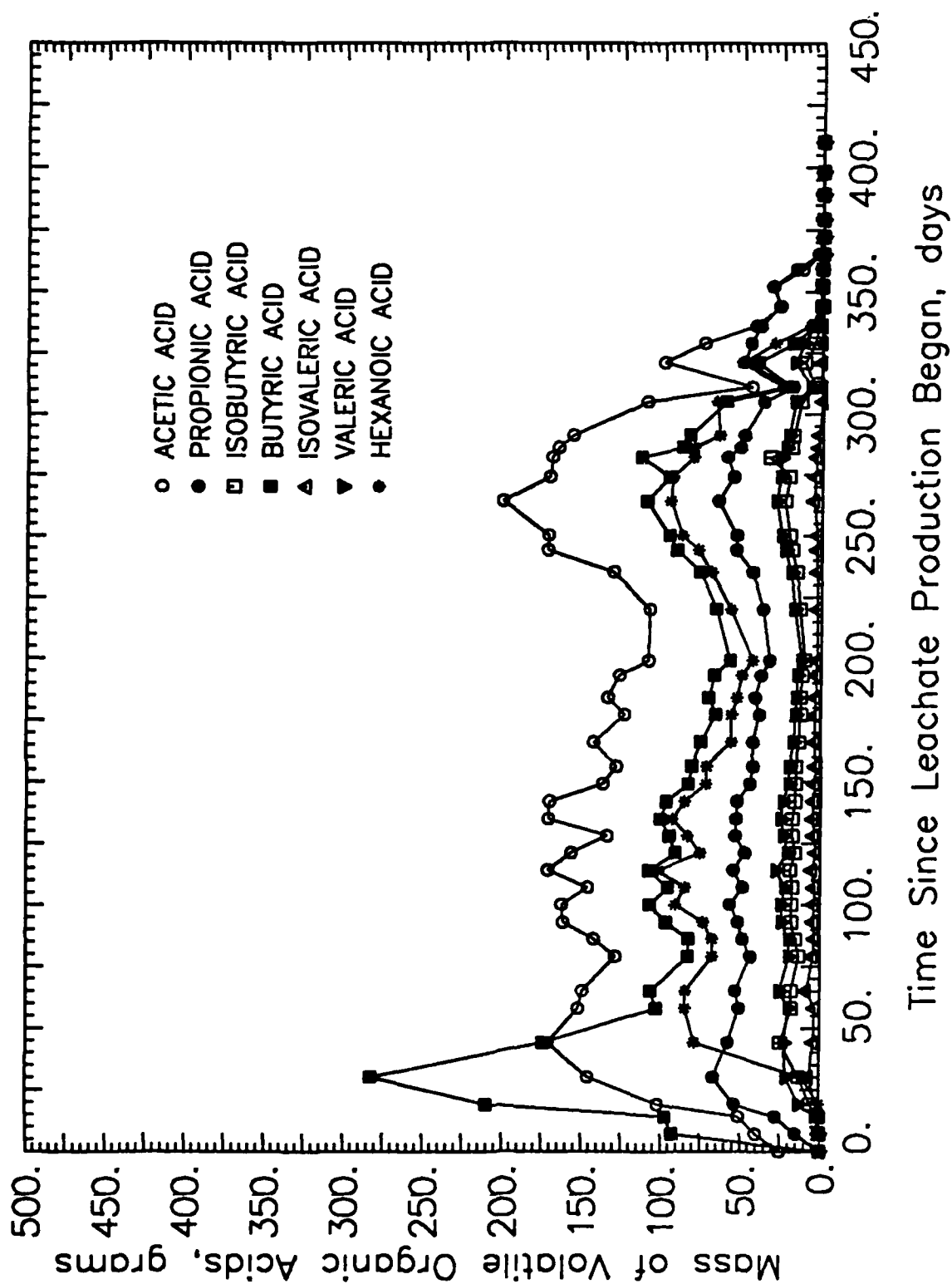


FIGURE 29: MASS OF VOLATILE ORGANIC ACIDS IN LEACHATE FROM THE CONTROL RECYCLE CELL.

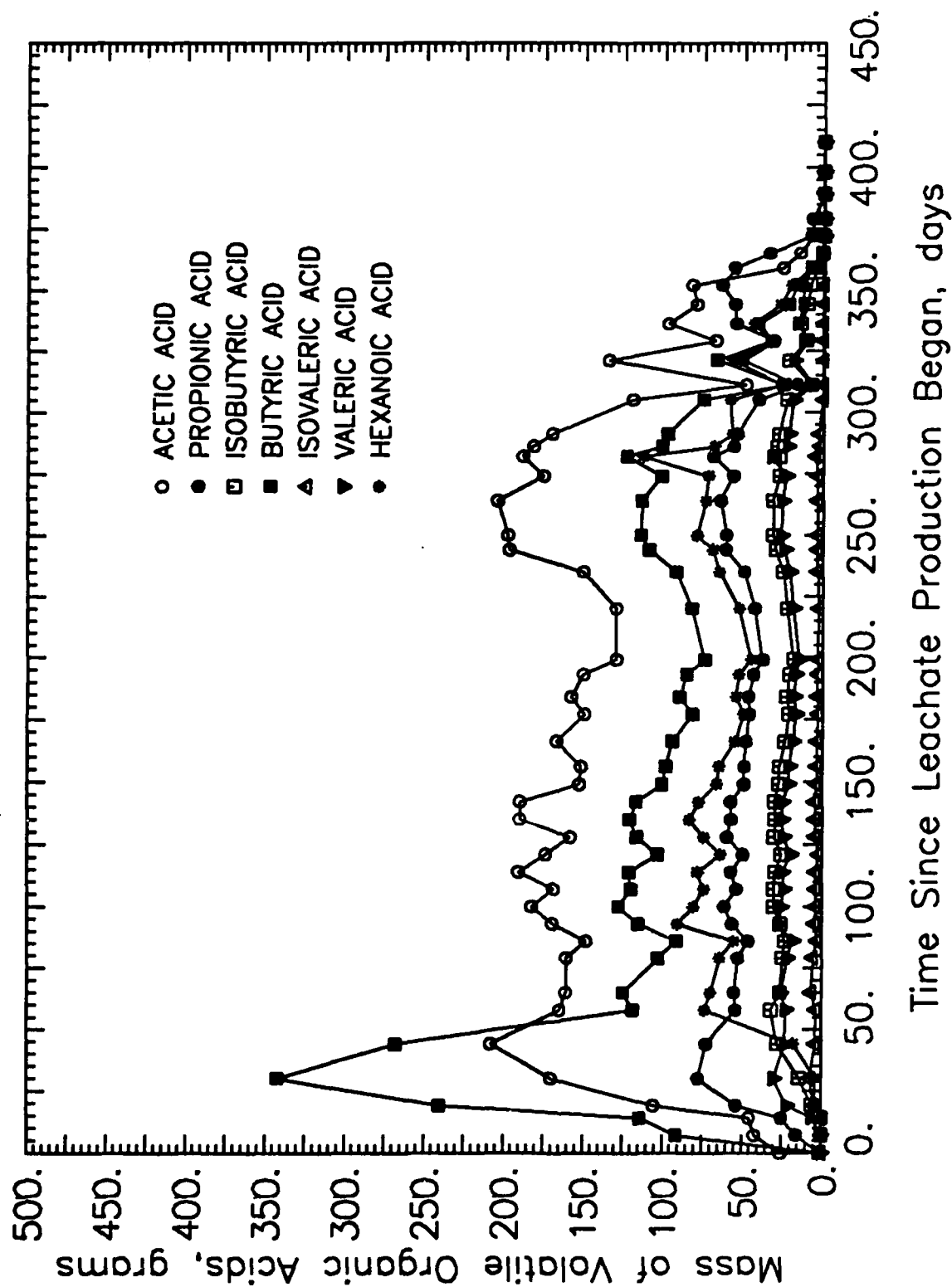


FIGURE 30: MASS OF VOLATILE ORGANIC ACIDS IN LEACHATE FROM THE SPIKED RECYCLE CELL.

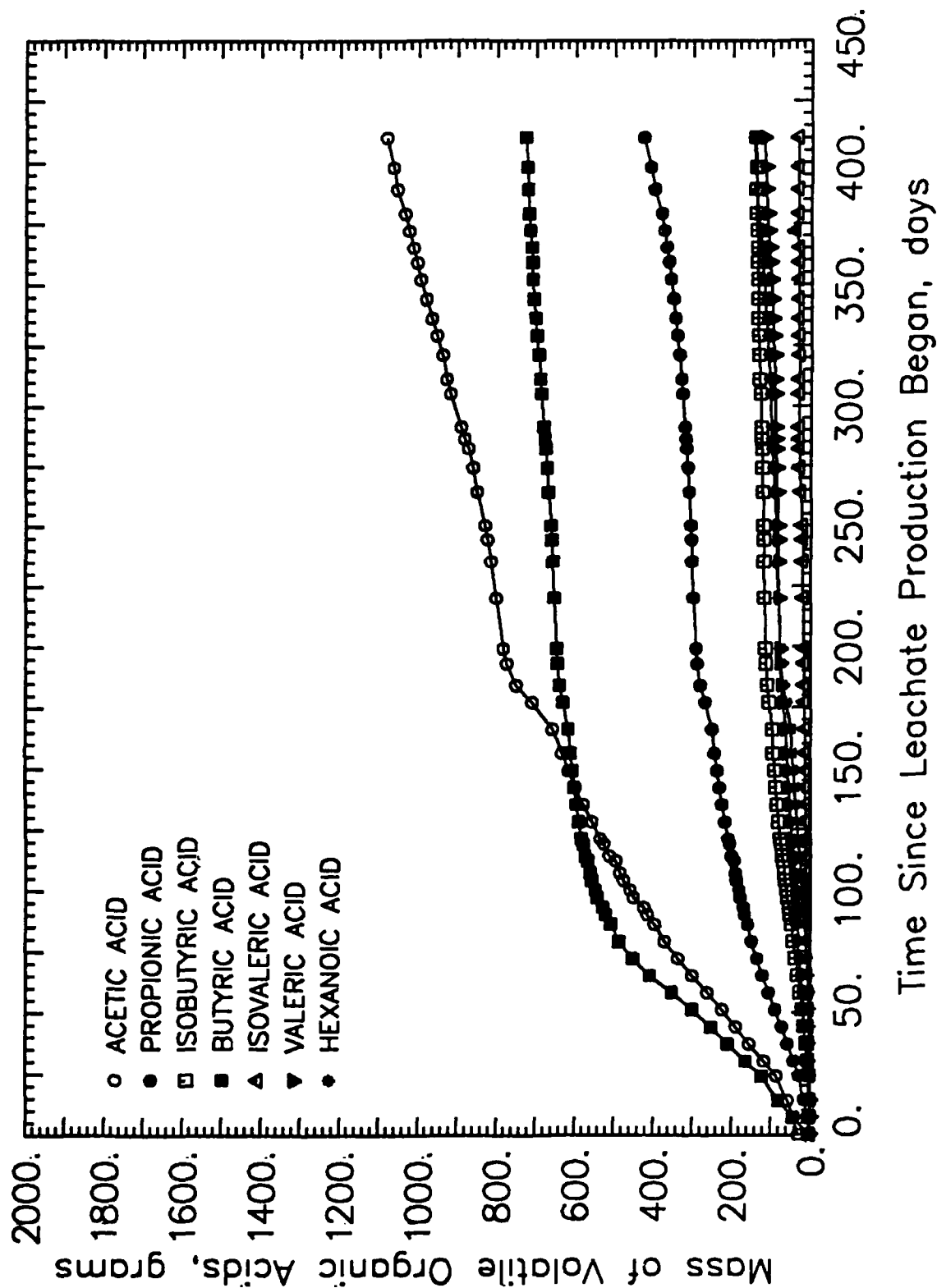


FIGURE 31: MASS OF VOLATILE ORGANIC ACIDS IN LEACHATE FROM THE CONTROL SINGLE PASS CELL.

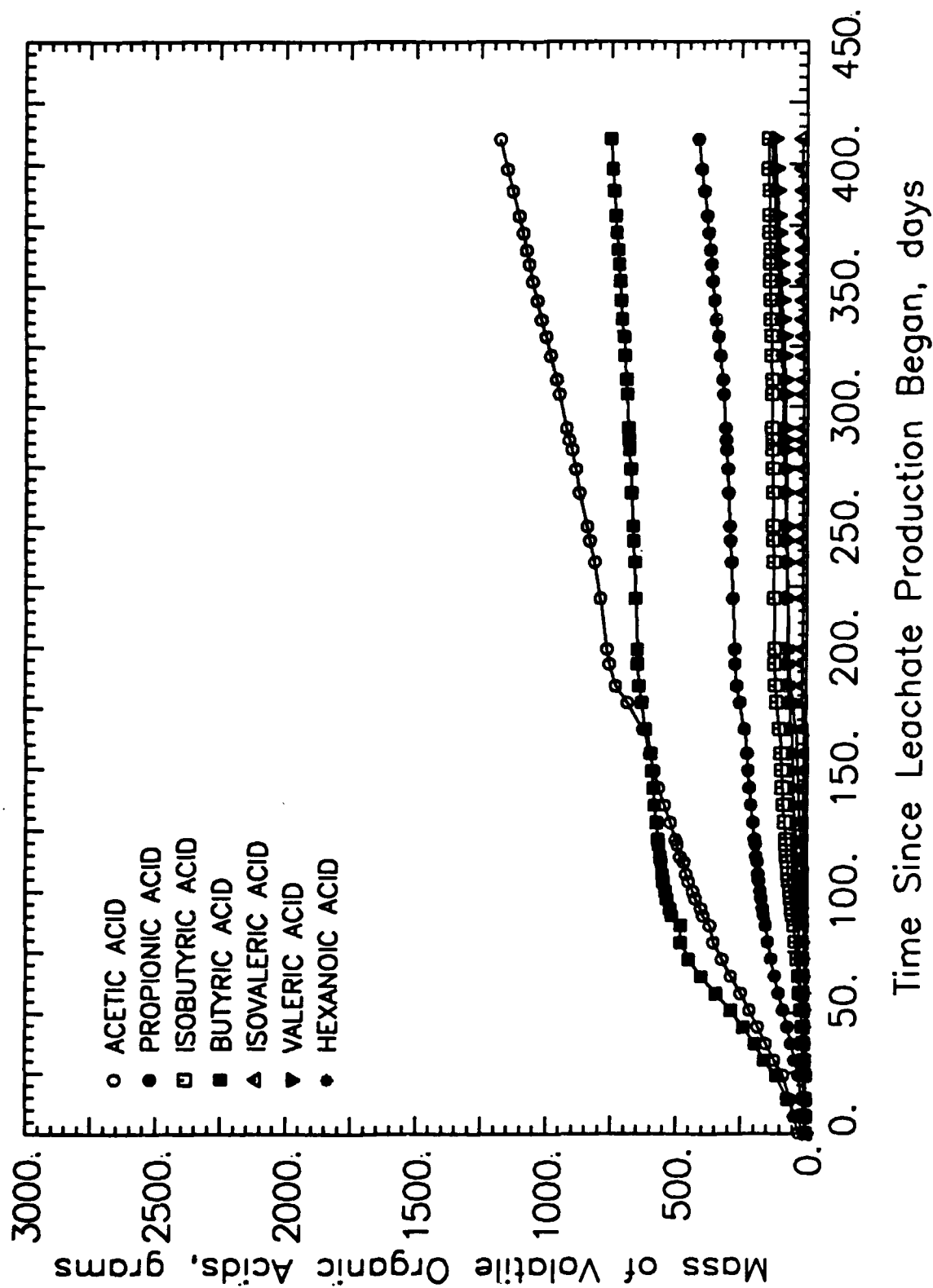


FIGURE 32: MASS OF VOLATILE ORGANIC ACIDS IN LEACHATE FROM THE SPIKED SINGLE PASS CELL.

concentrations of 9,700 and 10,500 mg/L for Cells 3 and 4, respectively. Maximum acetic acid concentrations of 7,000 and 6,600 mg/L and propionic acid concentrations of 3,200 and 3,000 mg/L for Cells 3 and 4, respectively, were also measured. Between Day 250 and 450, a slight increase in concentrations of the primary acids (acetic, propionic and butyric) was observed for both cells. This behavior corresponded to the onset of the methane fermentation phase. Acetic acid was the primary VOA with maximum concentrations of 3,744 and 4,207 mg/L for Cells 3 and 4, respectively. Between Day 68 and 120, the concentration of butyric acid was measured as the next highest leachate acid in both cells. However propionic acid concentration measured higher than butyric after Day 120 in both single pass cells.

As previously discussed for organic strength indicators, the concentration of TVA or VOA does not always reflect the actual quantity of volatile organic acids present or generated, since it does not include the volume of leachate involved. Therefore, the mass of TVA as well as mass of VOA for each cell were calculated. These data (Figures 28 through 32) again indicate that the recycle cells were saturated with VOA which repressed further production as indicated previously for COD. As microbial conversion to methane was initiated, the TVA and VOA concentrations remained nearly constant for a period of about 25 days, indicating that additional concentrations of VOA were produced by the acid formers for ultimate conversion to gas. As methane production rates increased, the relative concentrations of VOA began to be depleted.

In the single pass cells (Figures 28, 31 and 32), the VOA were flushed out of the system each week and, although the concentration tended to be the same as for the recycle cells during active acid formation, the total mass of TVA produced and released without conversion to gas from the single pass cells was much greater. Such a release would have important environmental impact ramifications.

Hexanoic acid was of particular interest due to the differences in levels observed between the two management alternatives. The concentration of hexanoic acid in the recycle cells was negligible until Day 25, after which it increased to 2,000-3,000 mg/L. This concentration was then maintained until methane fermentation was

established and flourished. However, in the single pass cells, the hexanoic acid concentration was negligible until Day 50. Even after this point, concentrations were less than 500 mg/L. Therefore, when converted to mass terms, the recycle cells generated far more hexanoic acid than the single pass cells during the acid formation phase of landfill stabilization.

The production of hexanoic acid, although not usually reported, has been measured in other studies (1,13,22). However, the high concentrations which developed in the leachate from the recycle cells during acid formation was unusual. Therefore, to confirm its presence, the GC peak labeled as hexanoic acid was checked by analysis on a GC with a capillary column and matching the retention time of the peak against a hexanoic acid standard.

High concentrations of hexanoic acid have been detected in leachate from freshly placed refuse by others. Rees (22) mentioned a concentration of 3,700 mg/L of hexanoic acid and its probable generation from the cellulose fraction of the waste. Andrews and Pearson (1) discussed volatile acid production in anaerobic fermentation processes and found that hexanoic acid was formed, but only in low concentrations. McCarty, Jeris and Murdock (13) reported that the formation of several higher acids may be expected. However, these acids were expected to be at lesser concentrations than the major volatile organic acids (acetic, propionic and butyric acids).

Examining the volatile organic acid concentrations for the recycle cells, it appears that the increase in hexanoic acid corresponded to the decrease in butyric acid. One possible explanation would be the formation of hexanoic acid by the condensation of butyric acid with acetic acid. McCarty, Jeris and Murdock (13) noted that the result of suddenly increasing the rate of butyric acid feed to an anaerobic digester was the appearance of the next higher even carbon acid, hexanoic acid. The possibility of a process upset due to too high leachate loading as previously mentioned is in agreement with this finding. It was also reported that the higher acids were formed during the breakdown of the major volatile organic acids.

On Day 14 of this study, about 90 grams of butyric acid were present in the leachate of each of the recycle cells. On Day 24, this

had increased to about 240 grams of butyric acid. Therefore, this increase in butyric acid may have promoted the formation of hexanoic acid and the concomitant decrease in the concentration of butyric acid. Moreover, the additional contact opportunity provided by leachate recycle may also have encouraged a greater degree of hydrolysis of the cellulosic fractions of the waste. Sludge seeding to encourage the onset of methane fermentation may also have favored more effective acclimation to the available substrates, including the hexanoic acid.

pH

The pH throughout the acid formation phase was less than 6.0 as illustrated in Figure 19. After an initial low of 4.8, the pH increased to 5.8-6.0 on Day 5. The pH then decreased to 5.3 as the volatile organic acid concentrations increased and persisted. After Day 20, the pH remained constant between 5.0 and 5.5 until Day 300. This low pH is typical of the acid formation phase and, if the system is totally saturated with acids as appeared to be the case for the recycle cells during the extended acid formation phase, the anaerobic methane forming microorganisms may be inhibited and the conversion of VOA to methane will be delayed. The limited number of methane formers originally present in the refuse, the exclusion of soil as a cover material to provide such a seed, and the introduction of air during loading also may have limited the establishment of a viable population of methane formers to the extent that seeding with digested sludge was indicated as necessary to encourage the onset of the methane fermentation phase. Likewise, with the single pass cells, the low pH reflected also a washout of available buffer capacity as alkalinity was removed (see Figure 33).

Since the pH is moderated by the presence of volatile organic acids, it also reflects the predominant buffer system. At low pH, the leachate may be characterized by an abundance of low molecular weight volatile organic acids and its buffer capacity may be governed by the pK values of the conglomerate of volatile acids present. For acetic, propionic and butyric acids, these pK values are near 4.5 or the mid-point of the buffer curve. In a sense, therefore, the generation of volatile organic acids during acid formation is analogous to an

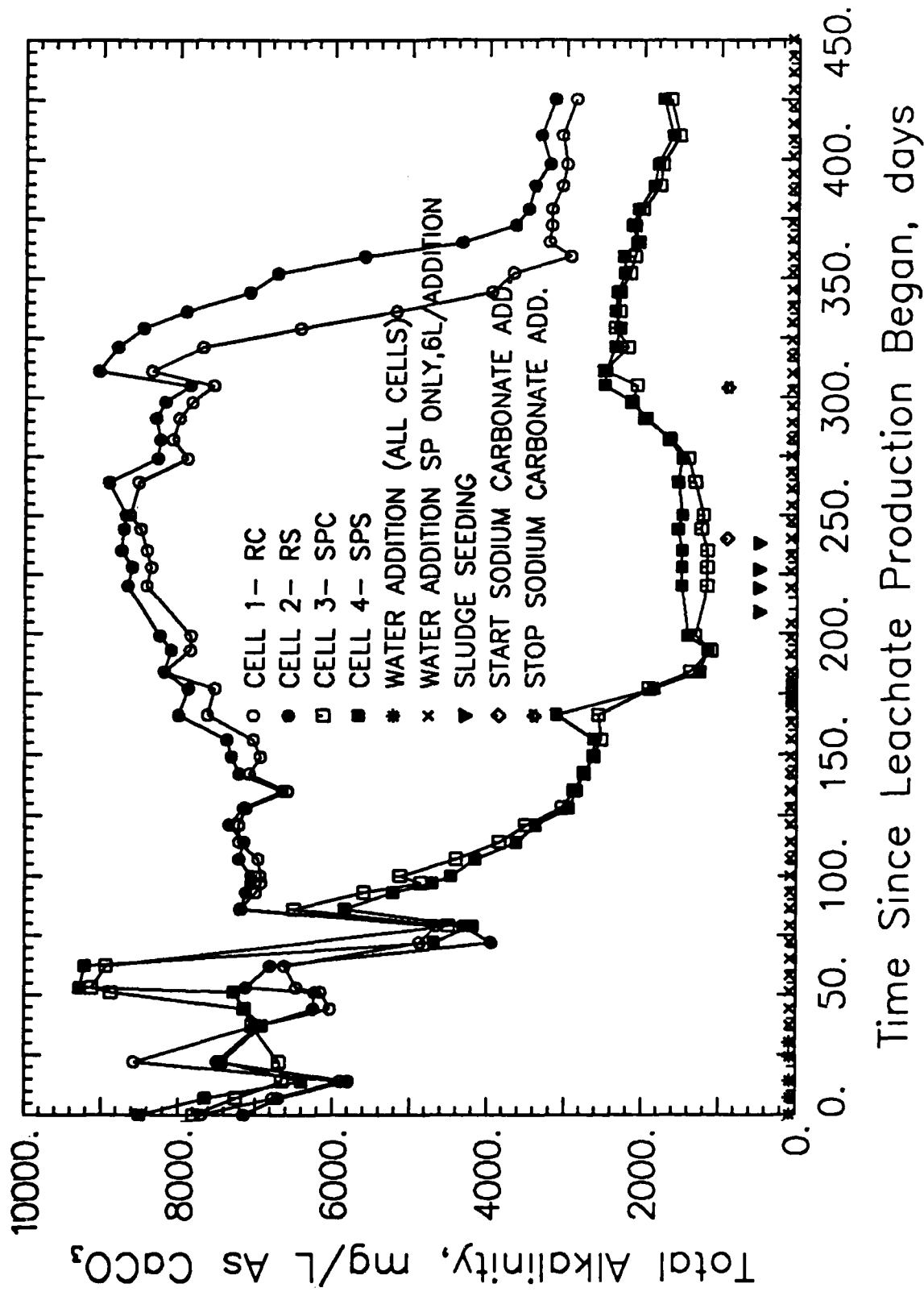


FIGURE 33: ALKALINITY OF LEACHATE FROM THE SIMULATED LANDFILL CELLS.

in situ acid-base titration with the pH decreasing as the acids concentrations increase and displace the normal bicarbonate buffer system. In contrast, increases of pH to near neutral as occurred during methane fermentation reflect decreasing volatile organic acid concentrations accompanied by a shift of buffer system from that of the VOA (acetate) to bicarbonate.

After sludge seeding, an increase in pH from 5.5 to near 5.9 was observed for both cells between Day 300 to 350. However, the period between Day 330 and 350 was marked by a decrease of pH from 5.9 to the 5.0-5.5 range. This change corresponded to the period when both acetic and propionic acid concentrations increased in Cells 1 and 2 (Figures 20 and 21) and could be attributed to possible upset or additional production of VOA in these systems as discussed previously. However, the pH increased steadily from the 5-5.5 range to near neutral range within a two-week period following Day 350. This increase was attributed to the establishment of a viable methane producing population which in turn utilized the existing pool of volatile organic acid to produce CO_2 and CH_4 (Figures 17 and 18) and allowed for increased pH values as the dominant buffer system shifted from acetate to bicarbonate.

Alkalinity

For landfill leachate, total alkalinity measurements reflect the relative presence of acids and bases such as H_2CO_3 , HCO_3^- , CO_3^{2-} , TVA, phosphorus and ammonia. The total alkalinity of leachate during the acid formation phase is dominated by the volatile organic acids and the associated buffer system due to the high concentrations present and the fact that they are stronger acids than those constituting the bicarbonate buffer system. The total alkalinity concentrations are presented in Figure 33 (Tables B2 through B5 in Appendix B).

For the single-pass cells, the total alkalinity fluctuated with changes in TVA during the period of equilibration and between Day 70 and 100. However, total alkalinity declined from 5,800-6,400 to 1,000-1,500 mg/L as CaCO_3 between Day 100 and 275 due to washout. Subsequently, a small increase followed by a nearly constant total alkalinity was observed between Days 275 and 425 for the single-pass cells. The increase in alkalinity corresponded to the increase

observed for TVA values during this period and was probably related to some increase in bioconversion, including methane production.

After an initial equilibration, the total alkalinity measured for the recycle cells increased steadily from 7,000 to 9,000 mg/L as CaCO_3 between Day 140 and 240. The exhibited trend for the recycle cells closely paralleled the steady increase observed in TVA during the same period (Figure 16) and would be expected, since the TVA contribute to the total alkalinity as measured.

As indicated previously (MATERIALS AND METHODS), Day 240 was the first day of the period when sodium carbonate solution was added to the leachate of the recycle cell for pH adjustment purposes and Day 304 was the last day on which this alkalinity addition was provided. The added alkalinity during this period accounted for an increase followed by a period of slight decrease in the measured total alkalinity when the corresponding TVA exhibited a continuing declining trend. A small increase was also noted around Day 300. This increase was attributable to an increase in acetic and propionic acid concentrations in both cells (Figures 20 and 21). After Day 310, the total alkalinity in both recycle cells declined rapidly as volatile organic acids were converted to CH_4 and CO_2 by the methane forming bacteria. This behavior, accompanied by an increase in pH, also indicated a shift of buffer system from acetate to bicarbonate in both recycle cells.

Conductivity

Conductivity is a measure of the ability of a solution to conduct a current. Electrical current is transported through the solution by the movement of ions and the conductivity increases as the ionic strength increases. The activity coefficient for reactive species decreases as ionic strength increases, resulting in greater solubility of ions in solutions such as leachate than in more dilute systems. Therefore, conductivity is a measure of the ionic species present and exhibits a direct relationship with TVA and alkalinity and an inverse relationship with pH. The conductivity of the leachate samples collected from the recycle and single pass cells is included in Figure 34 (Tables B2 through B5 in Appendix B). For the single pass cells the conductivity started increasing on Day 34 to a maximum value of 14,000 μmhos on Day 51 and remained higher than the recycle cells until Day 70.

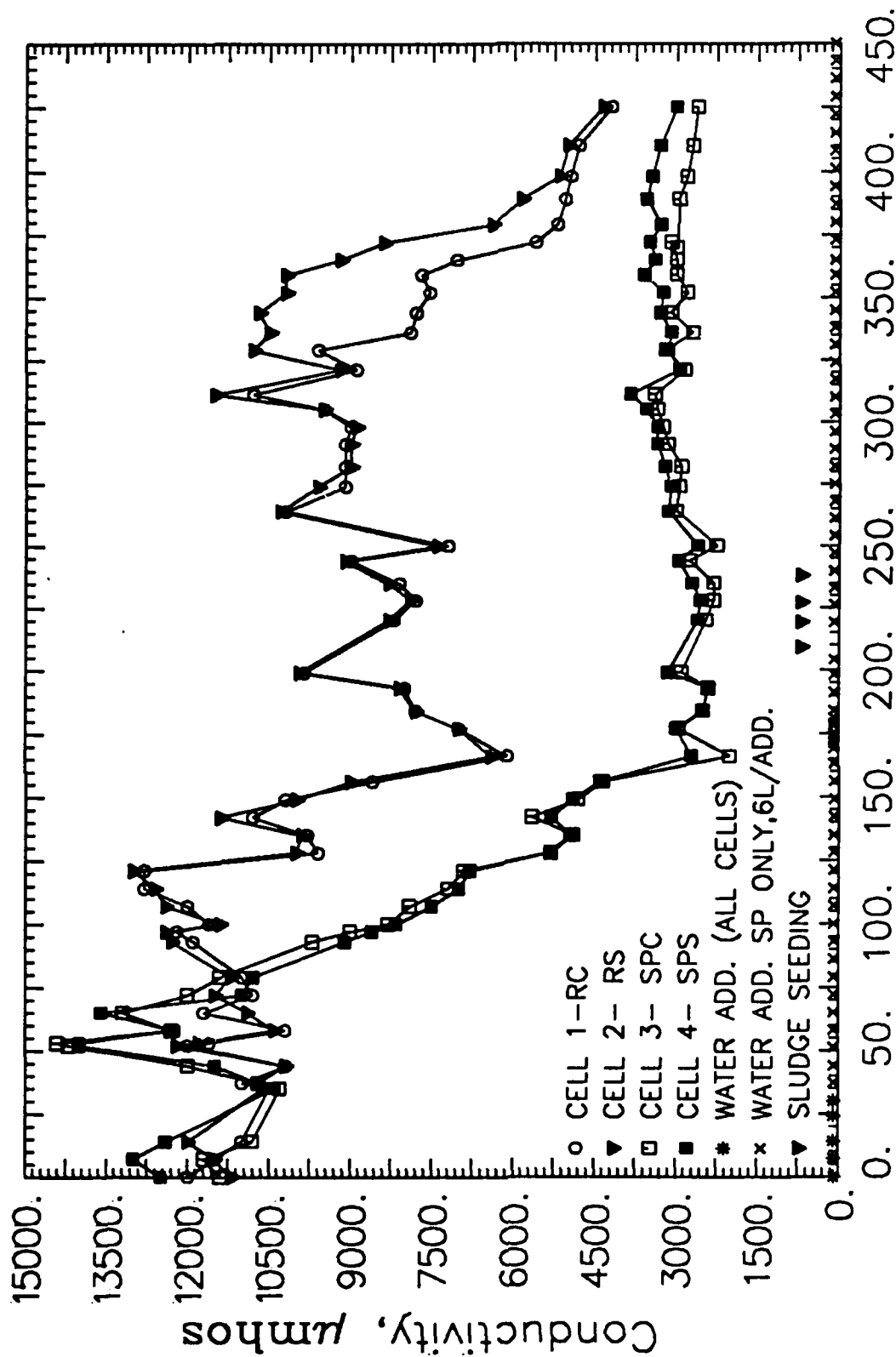


FIGURE 34: CONDUCTIVITY OF LEACHATE FROM THE SIMULATED LANDFILL CELLS.

At this point, washout began to dominate the single pass cells and the conductivity decreased from about 11,000 to 2,300 μ hos on Day 165. The rapid decline in conductivity coincided with the rapid washout of VOA; washout and precipitation/sorption of other ionic species also contributed. After Day 165, conductivity remained relatively constant at 2,300 to 3,000 μ hos as some microbially mediated activity promoted conversion and release of constituents to the leachate to offset dilution effects.

After an initial period of equilibration, leachate conductivity for the recycle cells varied between 6,000 and 12,500 μ hos from Day 75 to Day 325, which variation tended to parallel trends exhibited for the TVA during the acid formation phase. Thereafter, methane fermentation removed the TVA and the conductivity decreased concomitantly.

Oxidation-Reduction Potential

Oxidation-reduction potential (ORP) is a measure of the oxidation state of the system. Once the trapped air introduced with the refuse was depleted, the simulated landfill systems became anoxic or anaerobic and the ORP became negative.

The leachate ORP for this study indicated reducing conditions immediately on Day 0 as shown in Figure 35 (and Tables B2 through B5 in Appendix B). However, the readings for all four cells gradually increased toward positive values as the study progressed. Possible air leaks in the cells were initially suspected to account for these increases; however, pressure testing confirmed the integrity of all cells. Since eventual introduction and use of new ORP probes yielded more negative readings, the increases noted were considered due to analytical difficulties even though the old probes had been conditioned before use. Therefore, although the initial ORP readings presented in Figure 35 were not as negative as expected, reducing conditions within the cells were generally prevalent, particularly when methane fermentation was established. Decreases in the ORP for the single pass and recycle cells from -75 mV on Day 235 to a generally constant value of -200 mV on Day 300 and -75 mV on Day 235 to -250 mV on Day 350, respectively, ensured reducing conditions conducive to conversion of leachate and waste constituents during the anaerobic methane fermentation phase.

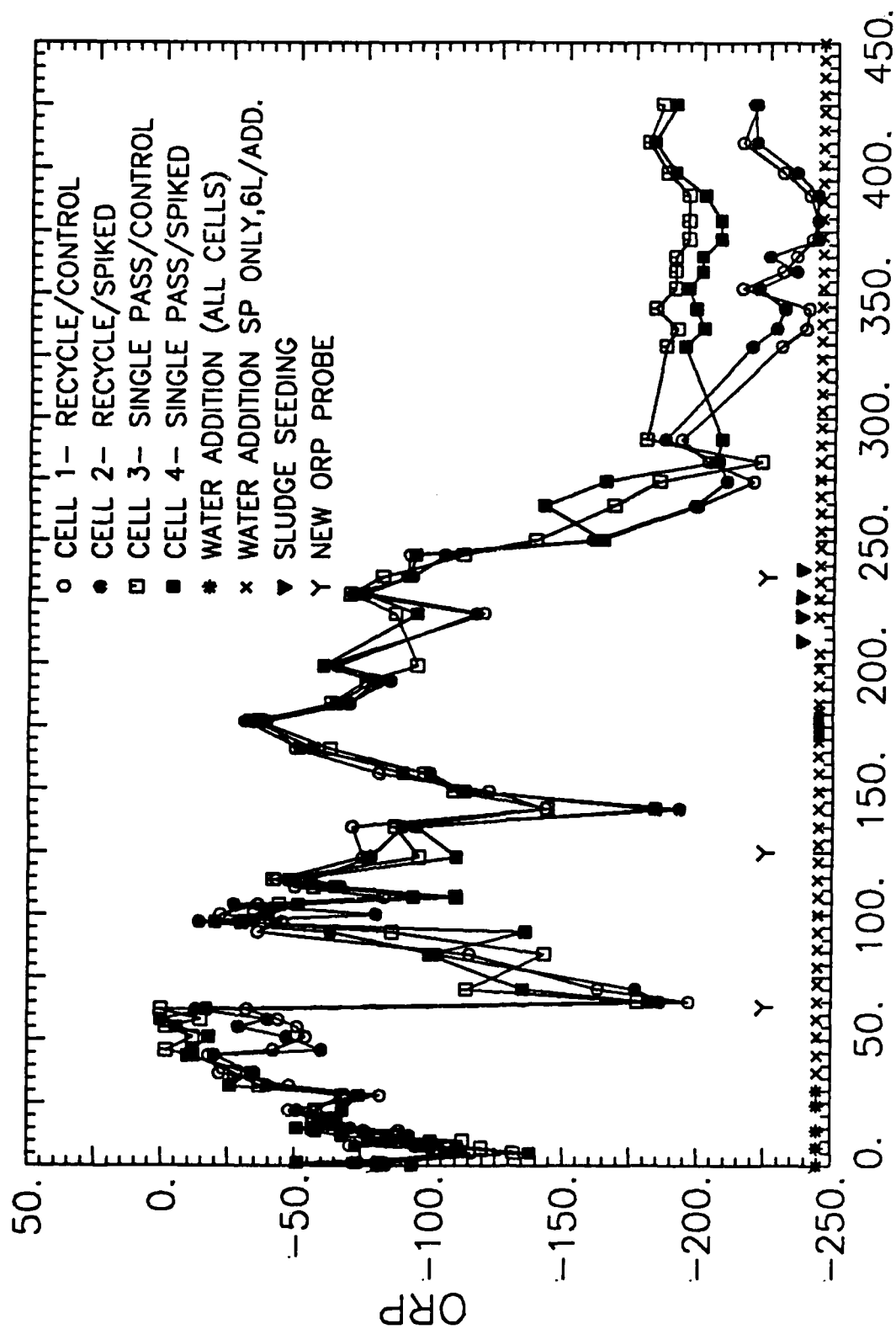


FIGURE 35: OXIDATION-REDUCTION POTENTIAL OF LEACHATE FROM THE SIMULATED LANDFILL CELLS.

Sulfides

Sulfides are another indicator of the presence of reducing conditions within the landfill environment. Sulfides are produced during anaerobic decomposition from the reduction of sulfates and other sulfur-containing inorganic compounds as well as from anaerobic protein degradation. In the S^{-2} form, sulfide is such a powerful precipitating agent that even at low pH values and very low sulfide concentrations, most of the sulfide generated is bound to heavy metals as metal sulfides. Therefore, sub-milligram per liter levels of total dissolved sulfides at relatively low pH provides an in situ reservoir of a strong precipitating potential.

Since reducing conditions are particularly prevalent during the later stages of landfill stabilization, sulfides were only periodically analyzed during the acid formation phase until the presence of sulfides was detected. The results of the sulfide analysis are included in Figure 36 (Tables B6 through B9 in Appendix B). These results confirm that reducing conditions were prevalent within the landfill cells and that sulfide was present throughout the studies. Also, the precipitation of heavy metals as metal sulfides had begun and would be expected to continue to influence the solubility of the heavy metals as is subsequently discussed.

Sulfide concentrations remained at or below 0.1-0.3 mg/L in the leachate from all four cells through Day 250. However, starting on Day 250, sulfide concentrations in both single pass cells increased steadily until the maximum detected levels of 1.85 and 2.56 mg/L for Cells 3 and 4, respectively, were reached on Day 313. Subsequently, a rapid decline in sulfide concentrations in both single pass cells was detected on Day 320. The observed decline culminated with concentration levels of 0.1 mg/L or below on Day 354 for both cells. The maximum sulfide concentration measured for both single pass cells also corresponded to ORP values near -200 mV which is necessary for microbial sulfate reduction.

For the recycle cells, the sulfide concentration increased to 4.21 and 5.59 mg/L on Day 354 for Cells 1 and 2, respectively. The maximum sulfide concentration detected in the recycle cells corresponded to ORP values near -250 mV. A subsequent rapid decline in sulfide

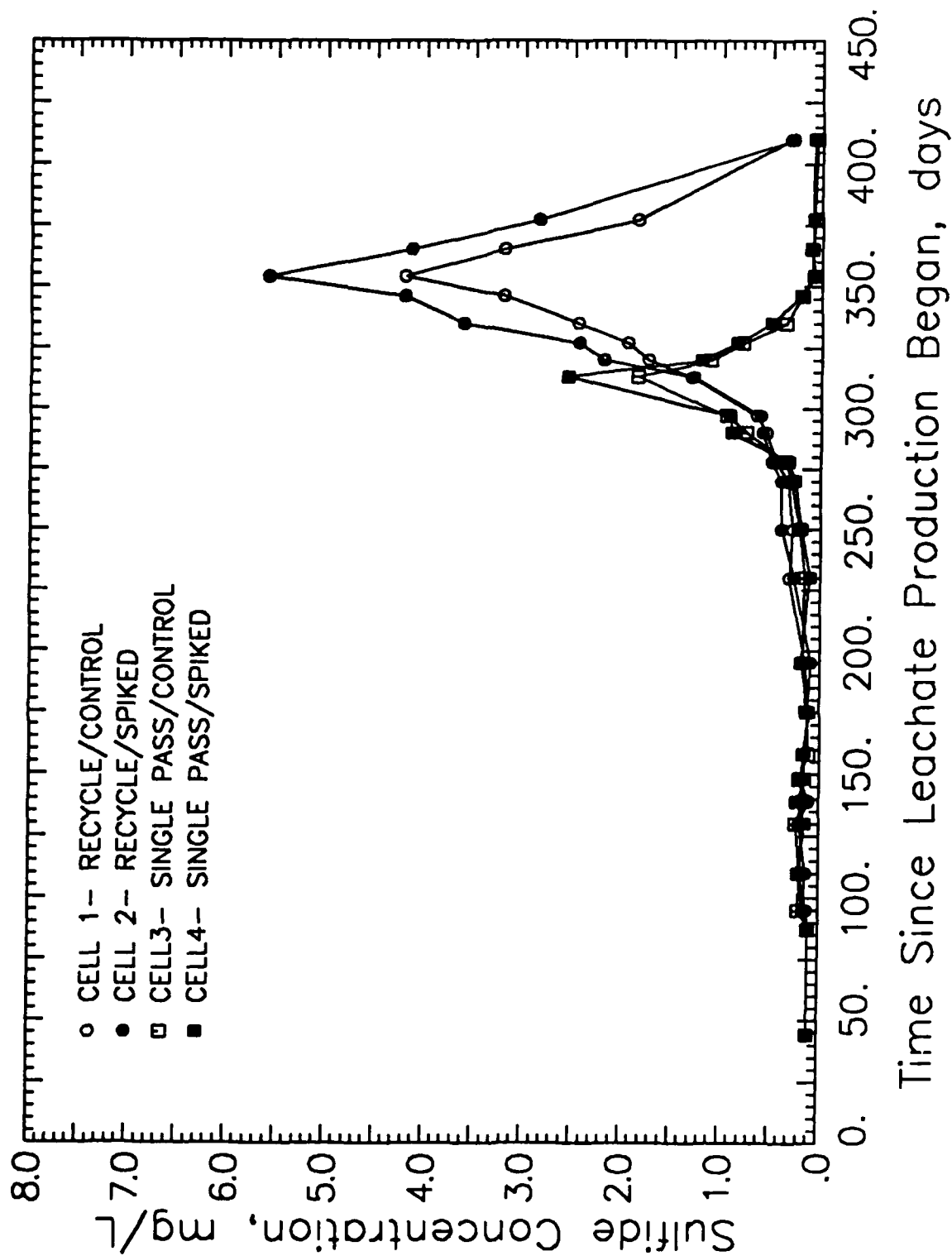


FIGURE 36: SULFIDE CONCENTRATION OF THE LEACHATE FROM THE SIMULATED LANDFILL CELLS.

concentrations was also observed in the leachate from the recycle cells starting on Day 365.

The detection of larger maximum concentrations of sulfides in the leachate of the recycle cells as compared to the single pass cells may be attributed to a more complete conversion of sulfates and sulfites to sulfides. Furthermore, the single pass operation of Cells 3 and 4 accounted for lower detected sulfide concentrations through the probable washout of organics, sulfates, and sulfate-reducing bacteria in these simulated landfill cells.

As will be discussed in more detail subsequently, heavy metals (Fe, Ni, Mn, Zn and Pb) present in the leachate of the single pass and recycle cells would be subject to precipitation, particularly when sudden increases in sulfide concentrations were detected. At the same time, a pH shift from 5.5 to 7 was observed, at least for the recycle cells. Such a shift in pH would allow for the formation of sulfide species under less soluble and less mobilizing conditions. For the single pass cells, however, the precipitation of heavy metals would be obscure by washout events.

Nutrients (Orthophosphate and Ammonia)

The availability of nutrients is essential to the microbially mediated processes of landfill stabilization. In order to ensure that adequate nutrients were available for biodegradation, orthophosphate and ammonia nitrogen concentrations were periodically measured as indicated in Figures 37 and 38 (Tables B2 through B5 in Appendix B).

The orthophosphate concentrations in both the single pass and recycle cells decreased steadily throughout the experimental studies. This was attributed to microbial utilization, washout (dilution) and possible complexation reactions. However, as long as the supply of orthophosphate was not totally depleted, the prevailing minimum concentration of 0.1 mg/L on Day 400 indicated sufficiency for biodegradation. In addition, it is also likely that a reservoir of orthophosphate was present as hydroxyapatite or metal phosphates which were in equilibrium with the soluble orthophosphate. Accordingly, as the concentration of soluble orthophosphate was consumed as nutrient, insoluble forms were released to maintain equilibrium. Such a balance between the generation and consumption of soluble orthophosphate

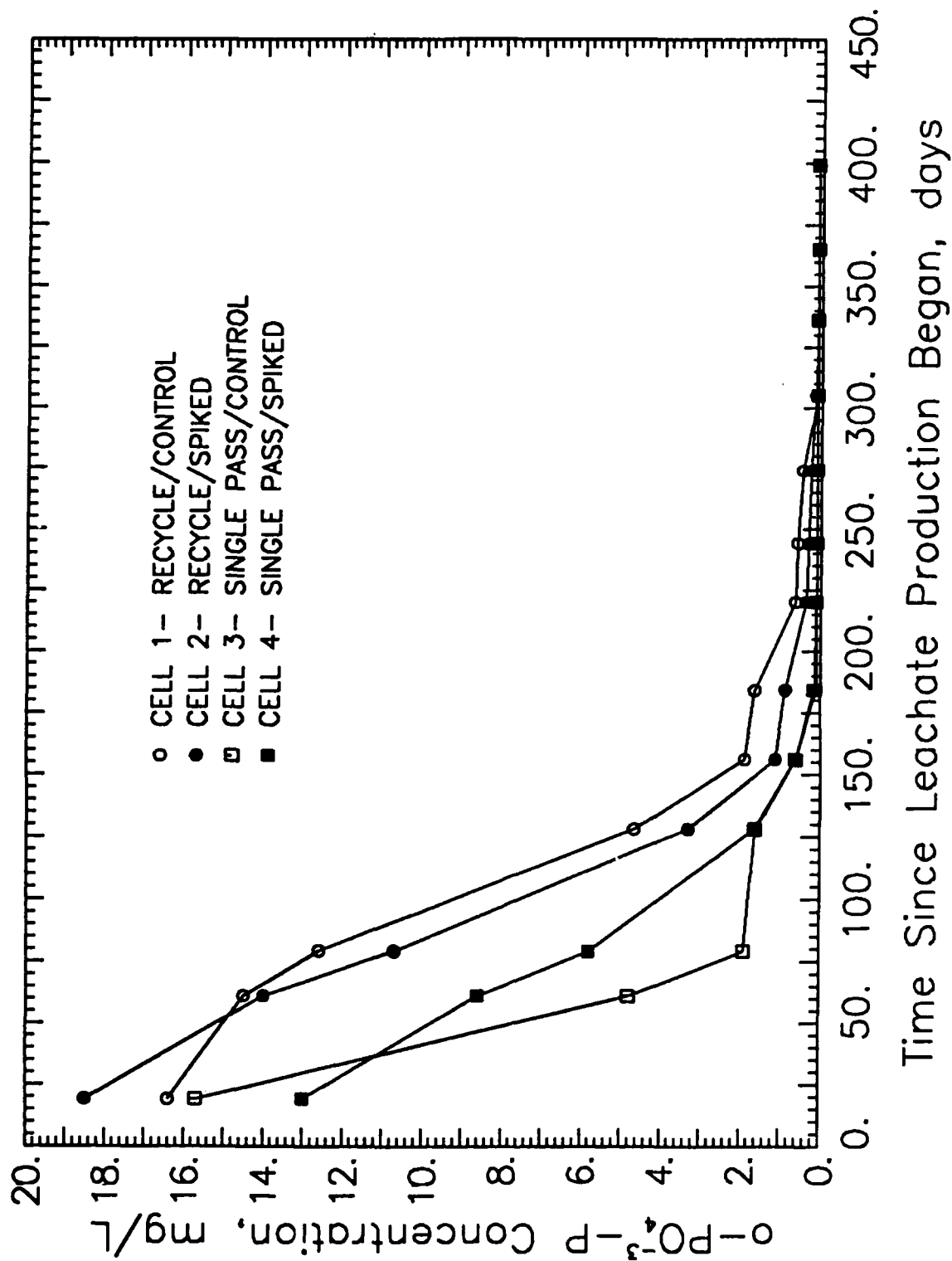


FIGURE 37: o-PO₄³⁻-P CONCENTRATION OF LEACHATE FROM THE SIMULATED LANDFILL CELLS.

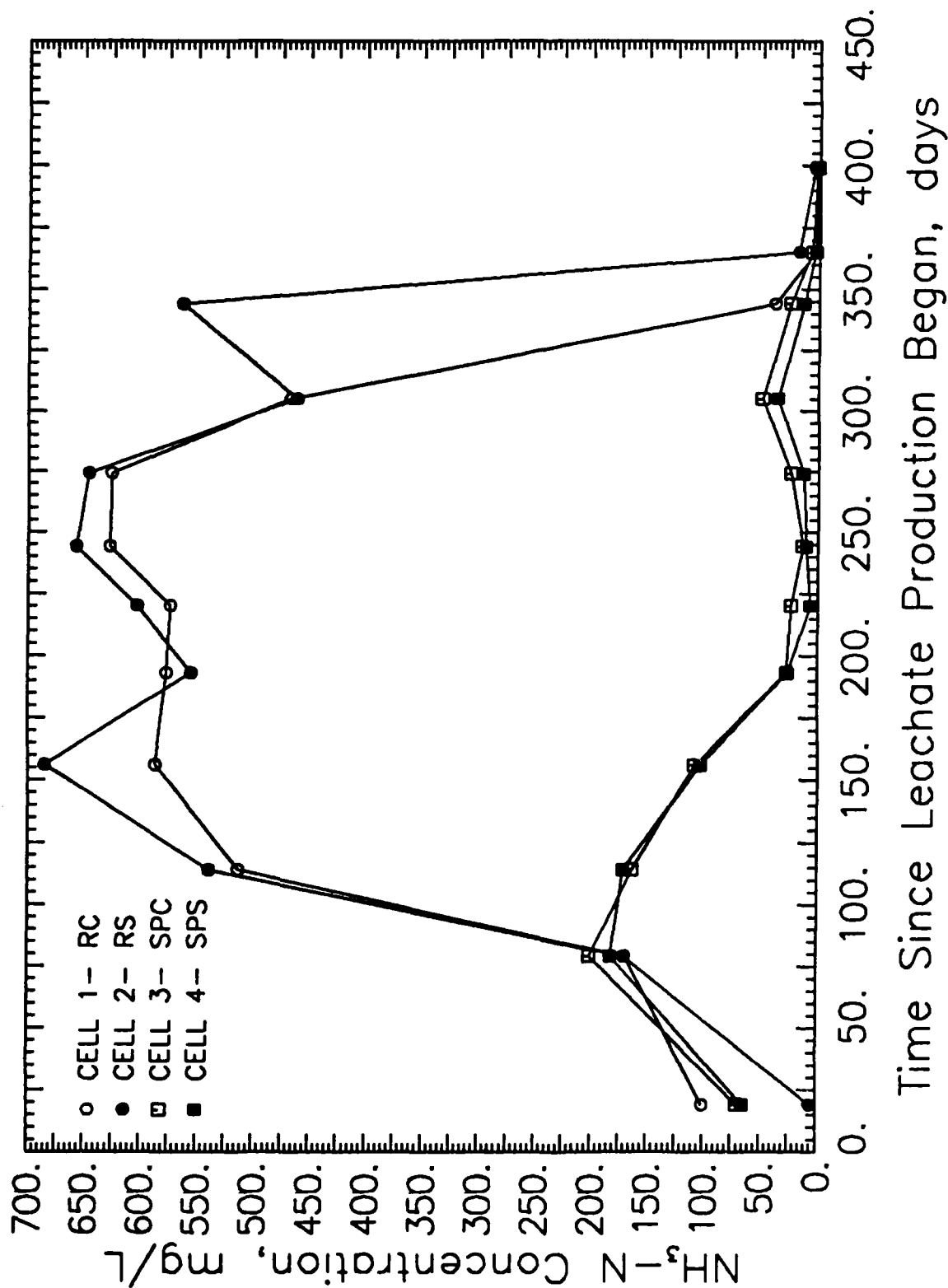


FIGURE 38: $\text{NH}_3\text{-N}$ CONCENTRATION OF THE LEACHATE FROM THE SIMULATED LANDFILL CELLS.

probably was established in the simulated landfill systems. This generation was apparently rapid enough to maintain an available orthophosphate pool for biological activity as indicated by the dissolved concentrations of orthophosphate that remained.

After establishing relatively low initial concentrations, the ammonia nitrogen ($\text{NH}_3\text{-N}$) in the recycle cells increased drastically between Days 75 and 114. This change was attributed to an increased conversion of NO_3^- and NO_2^- to NH_3 in the presence of a reducing environment. Furthermore, an increase in the ammonia nitrogen pool in the recycle cells could have been achieved through possible deamination of proteins present. Moreover, recirculation of leachate preserved the existing $\text{NH}_3\text{-N}$ pool in addition to enhancing its additional formation. Between Days 114 and 275, ammonia nitrogen concentrations fluctuated in the 550-650 mg/L range as an apparent balance between biological consumption and new formation of ammonia nitrogen was established in both recycle units. However, with the onset of methane fermentation around Day 275, $\text{NH}_3\text{-N}$ concentration declined rapidly as microbial methane formation activity increased dramatically and resulted in greater utilization of the existing nutrient pool.

In contrast, after an initial leaching of ammonia nitrogen, concentrations decreased steadily between Days 75 and 190 as washout dominated the action of the single pass cells. However, some concentration remained thereafter as additional leaching and possible microbially mediated production and utilization progressed under less active methane formation conditions than experienced with the recycle cells.

Metals

Two groups of metals were analyzed during the experimental investigations: the alkali and alkaline earth metals (Na, K, Mg and Ca) and the heavy metals (Mn, Fe, Cr, Cd, Cu, Ni, Zn and Pb). The most important factor in determining the presence of a metal in leachate is its solubility under the conditions prevailing within the landfill environment. Several factors influence metal solubility in leachate, including concentration of precipitant species (hydroxide, carbonate or sulfide), presence of complexing agents (ligands), ORP, pH, ionic strength and washout effects.

Investigations have shown that, with the exception of trivalent chromium which is controlled by the solubility of its hydroxide, metal hydroxides rarely control the solubility of heavy metals in landfill leachate (21). In addition, carbonate species have the potential for controlling the solubility of heavy metals in those circumstances where sulfide is not present. However, it is generally a modest precipitant at pH 8 or lower. Sulfide, on the other hand, is a powerful precipitant even at low pH values and very low sulfide concentrations. Because of the low solubility products of metal sulfides, there is a high probability that sulfide was controlling the solubility of heavy metals throughout the experimental studies.

Complexing agents can counteract the impact of precipitant ions and increase the solubility of metals. Usually, the complexing capabilities of inorganic ligands, carboxyls, carbohydrates and volatile acids, all recognized as present in landfill leachates, are considered too weak to have a substantial influence. Humic-like substances found in leachate are the one exception as they seemed to be important in the control of solubility of certain heavy metals (19). Moreover, oxidation-reduction potentials of leachate have a significant impact on metals speciation. Reducing conditions usually encourage conversion of Fe^{+3} to Fe^{+2} and Cr^{+6} to Cr^{+3} and would have an impact on solubility. Likewise, high ionic strength increases the concentration of metals in solution by increasing the solubility over that of dilute systems.

The addition of water to all four simulated landfill cells for the first 30 days of the study resulted in dilution effects for all metals. For the single pass cells, this dilution continued throughout the study period. Figures 39 through 42 (and Tables B6 through B9 in Appendix B) display the sodium, potassium, magnesium and calcium concentrations in the leachate from the four simulated landfill cells. The washout effect for all four cells over the first 30 days of water addition is apparent; after Day 30, the leachate concentrations for the recycle cells remained relatively steady because of leachate recirculation (except when sodium carbonate was added for pH adjustment), whereas the concentrations for the single pass cells continued to decrease due to additional washout effects. However, all four cells indicated some

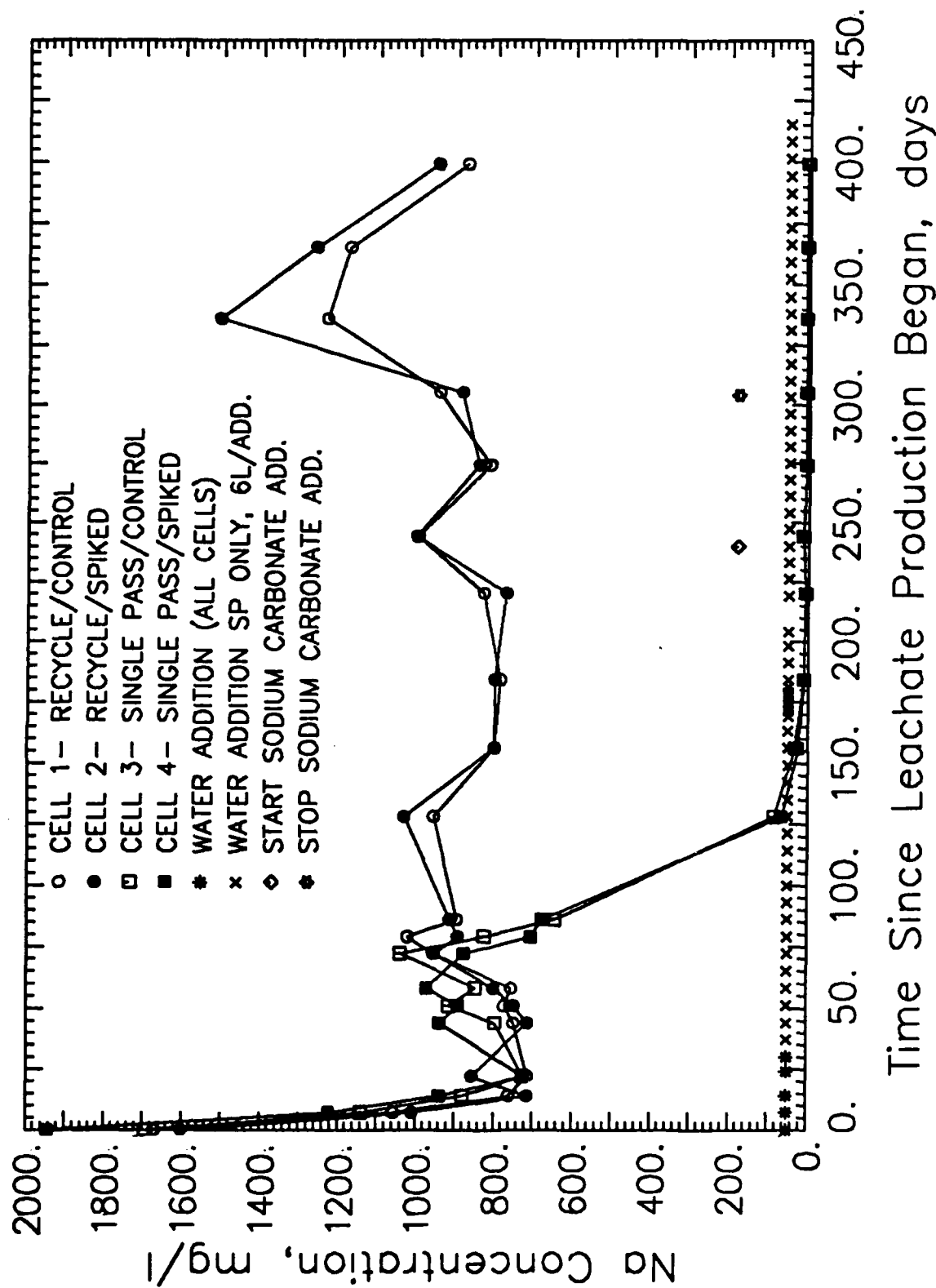
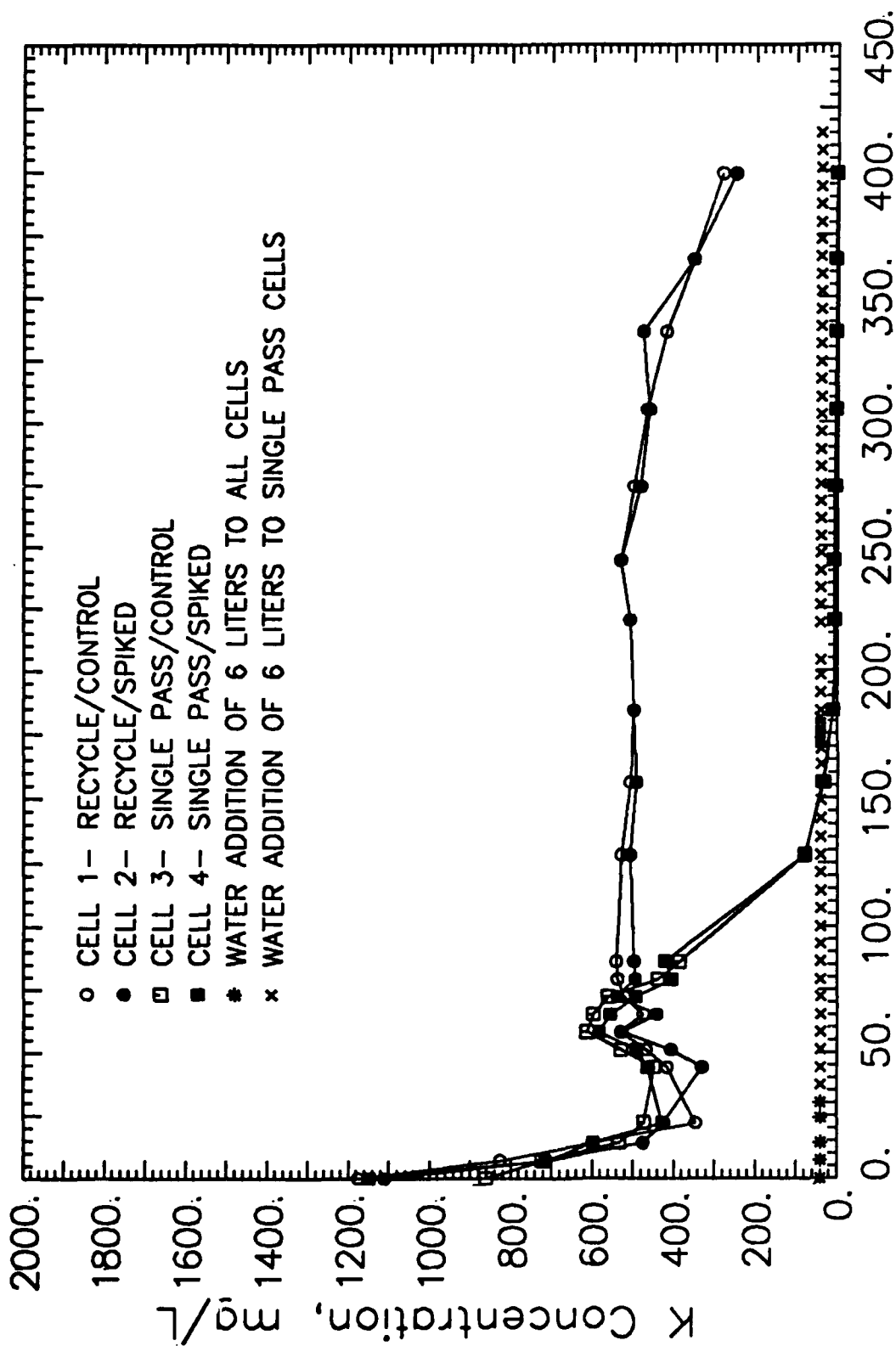


FIGURE 39: SODIUM CONCENTRATION IN LEACHATE FROM THE SIMULATED LANDFILL CELLS.



Time Since Leachate Production Began, days

FIGURE 40: POTASSIUM CONCENTRATION IN LEACHATE FROM THE SIMULATED LANDFILL CELLS.

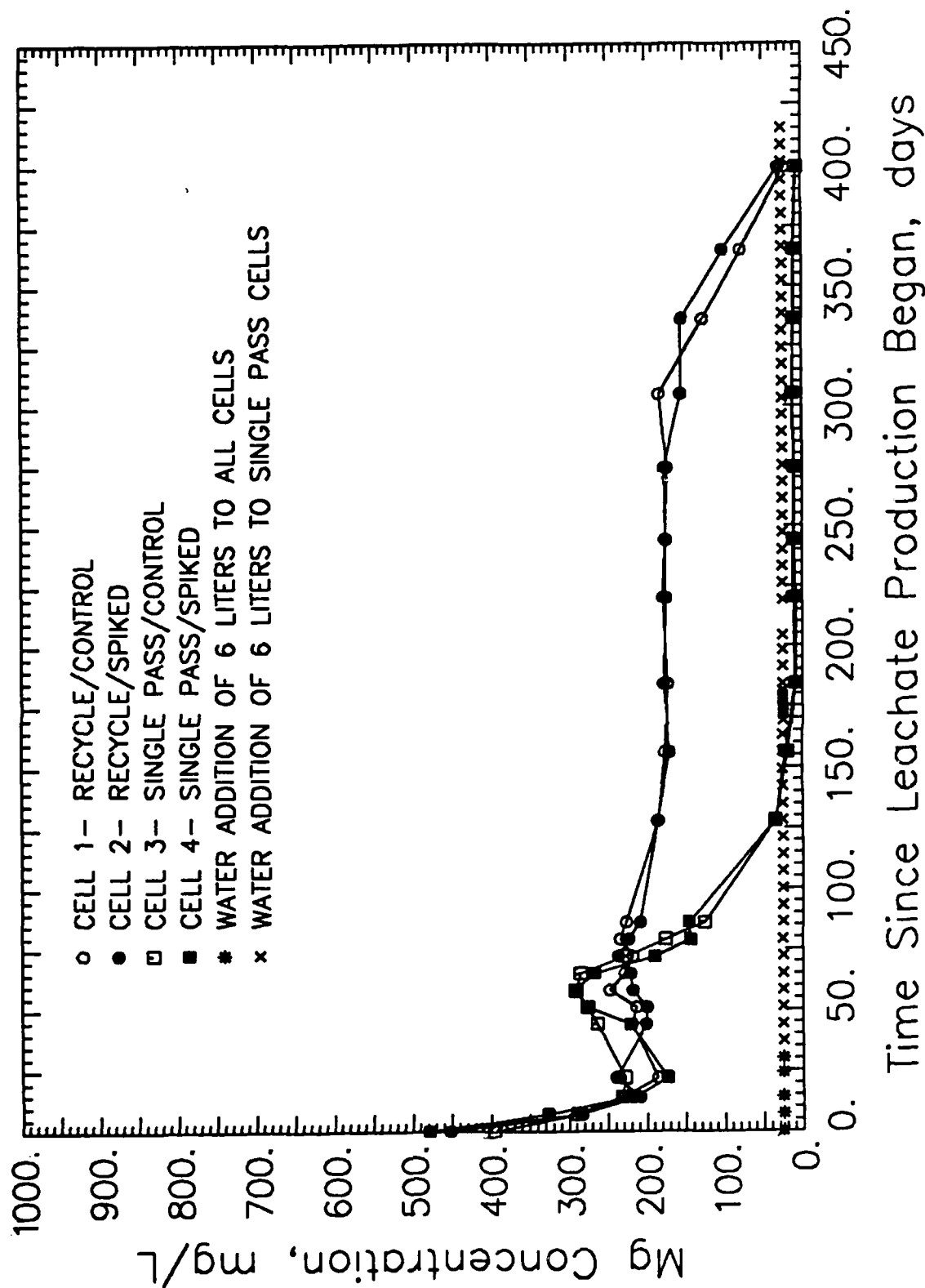


FIGURE 41: MAGNESIUM CONCENTRATION IN LEACHATE FROM THE SIMULATED LANDFILL CELLS.

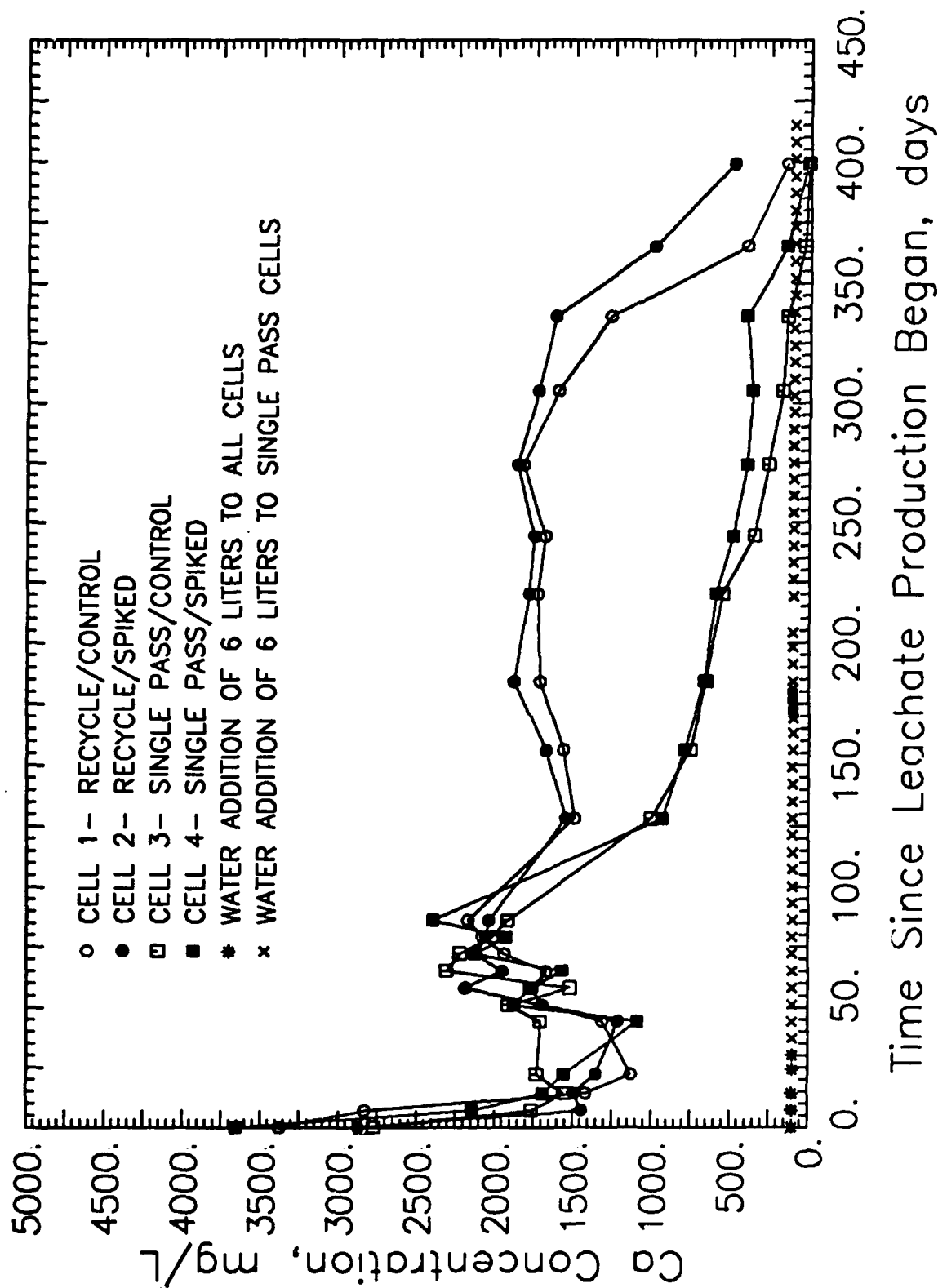


FIGURE 42: CALCIUM CONCENTRATION IN LEACHATE FROM THE SIMULATED LANDFILL CELLS.

increased metals concentration around Day 51. This was consistent with the initial lithium tracer (Figure 14) and COD plots (Figure 11) which both increased around this date. The previously proposed reason for the increase due to further saturation of the waste mass and the opportunity for leaching additional components from the waste would be expected to apply also to the leaching of the metals. Following this increase, the single pass cells re-established the effects of washout after Day 70.

Sodium concentration declined from 650 mg/L on Day 85 to nearly 10 mg/L on Day 400 as washout occurred in the single pass cells. For the recycle cells, sodium concentration remained nearly constant at 800-950 mg/L between Days 85 and 305 as the systems neared an equilibrated condition. However, sodium concentration increased between Days 305 and 335 in both recycle cells. This behavior was attributed to increased sodium concentrations in leachate of both recycle cells through introduction of sodium carbonate solution used between Days 261 and 304 for pH adjustment purposes during methane fermentation phase start-up. Between Days 335 and 400, the concentration of sodium in both recycle cells decreased once again. The concentration reduction in both cells may be attributed to an increased opportunity for ion exchange and formation of organometallic complexes within these environments as methane formation initiated around Day 275.

Potassium concentrations (Figure 40) followed much the same trend as sodium in the single pass cells. Concentrations declined from 400 mg/L on Day 85 to near 5 mg/L on Day 400 as washout dominated. For the recycle units, potassium concentrations remained nearly constant around 500 mg/L between Days 85 and 250 as the systems neared equilibration. However, between Days 250 and 400, concentrations declined in both recycle cells which could also be attributed to the opportunity for organometallic complexation and ion exchange in both environments.

The concentration of leachate magnesium (Figure 41) declined from nearly 150 mg/L on Day 85 to below 20 mg/L on Day 400 in the leachate from both single pass cells. During this period the concentration of calcium (Figure 43) also declined from 2,250-2,500 mg/L on Day 55 to below 50 mg/L on Day 400 as washout controlled the action of both metals in the single pass cells.

Magnesium concentrations in the recycle cells remained nearly constant around 200 mg/L between Days 85 and 275. However, these concentrations declined below 25 mg/L on Day 400. At the same time, calcium concentrations remained nearly constant around 1,500-1,700 mg/L between Days 85 and 275, and declined to the 125-500 mg/L range on Day 400. Since analyses indicated that both magnesium and calcium behaved much the same as potassium in the recycle cells, it is suggested that the primary removal mechanism would be similar to that discussed for potassium.

In general, the four previously discussed cations could be considered as rather conservative metals and assumed mostly affected by washout and dilution. Although in a complex environment such as a landfill, the formation of organometallic complexes for calcium and magnesium, possible ion-exchange, and effects of carbonate formation should also be considered.

As indicated in Figure 43, and Tables B6 through B9 in Appendix B, manganese concentrations followed the trends of the alkali and alkaline earth metals. After the initial dilution effects, the manganese concentration in the leachate from recycle cells remained at about 45 mg/L. The concentrations from the single pass cells increased to 68 mg/L, probably due to further saturation of the waste mass. After Day 70, the manganese concentrations from the single pass cells decreased as washout effects continued to dominate and the concentrations in the recycle cells held constant until the active methane fermentation phase when opportunities for complexation were apparently enhanced.

Leachate iron concentrations from all four cells displayed the initial decrease due to dilution (Figure 44 and Tables B6 through B9 in Appendix B). However, after Day 30, a gradual increase in iron concentration occurred. This was probably due to the dissolution of metal components within the simulated landfill cells under acid formation conditions. Whereas, the iron in the single pass cells slowly decreased due primarily to washout, that for the recycle cells tended to increase and then decrease precipitously.

Iron concentration increased from 700 mg/L on Day 85 to 1,000 mg/L on Day 155 in the leachate from the single pass cells. After Day 150, iron concentration decreased steadily to 500 mg/L on Day 275.

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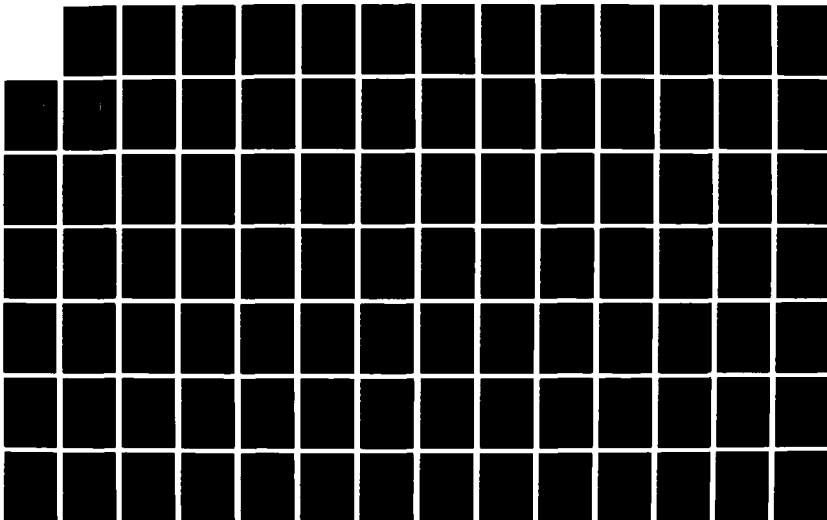
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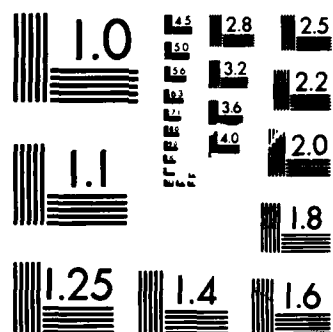
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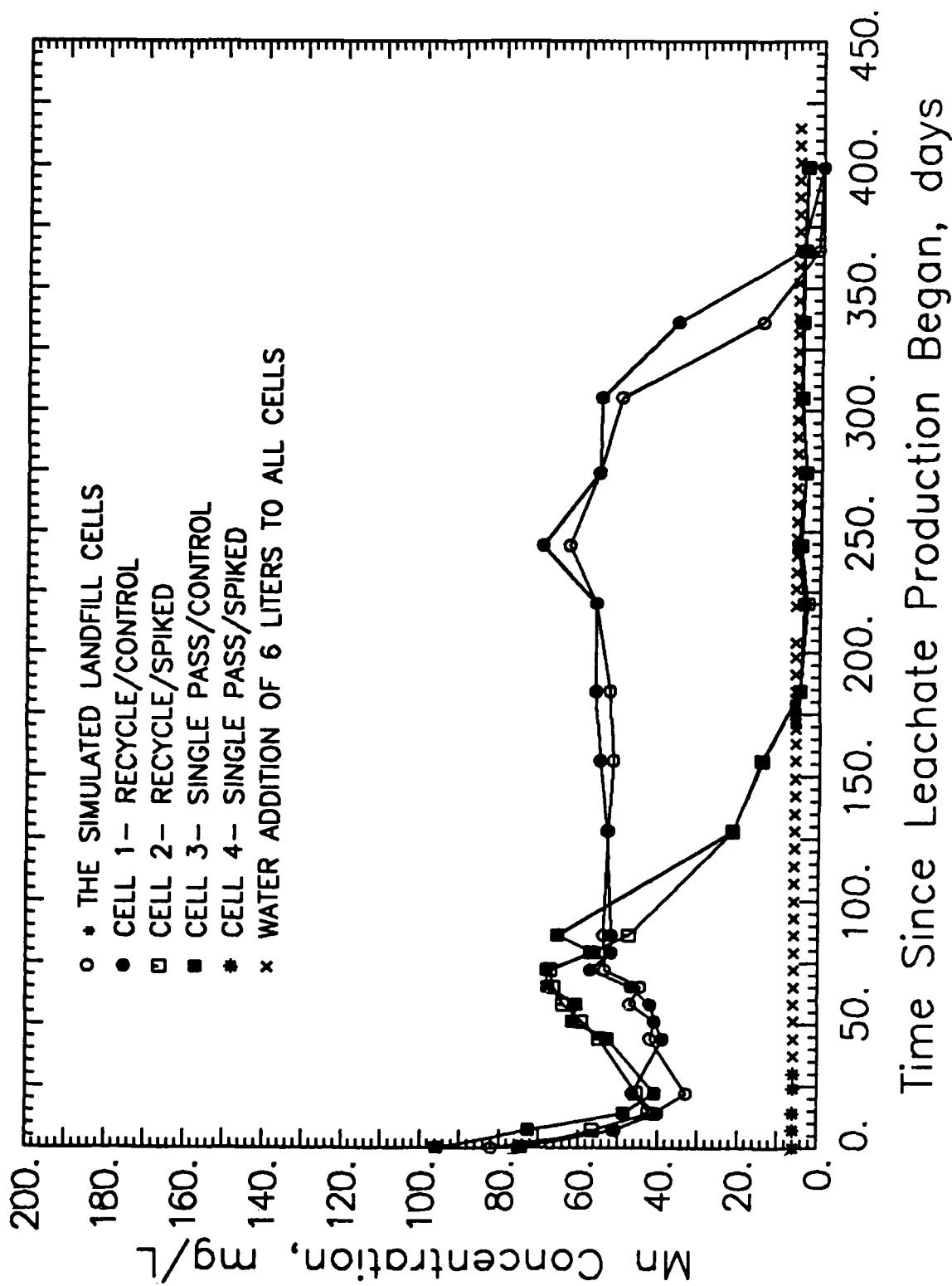


FIGURE 43: MANGANESE CONCENTRATION IN LEACHATE FROM THE SIMULATED LANDFILL CELLS.

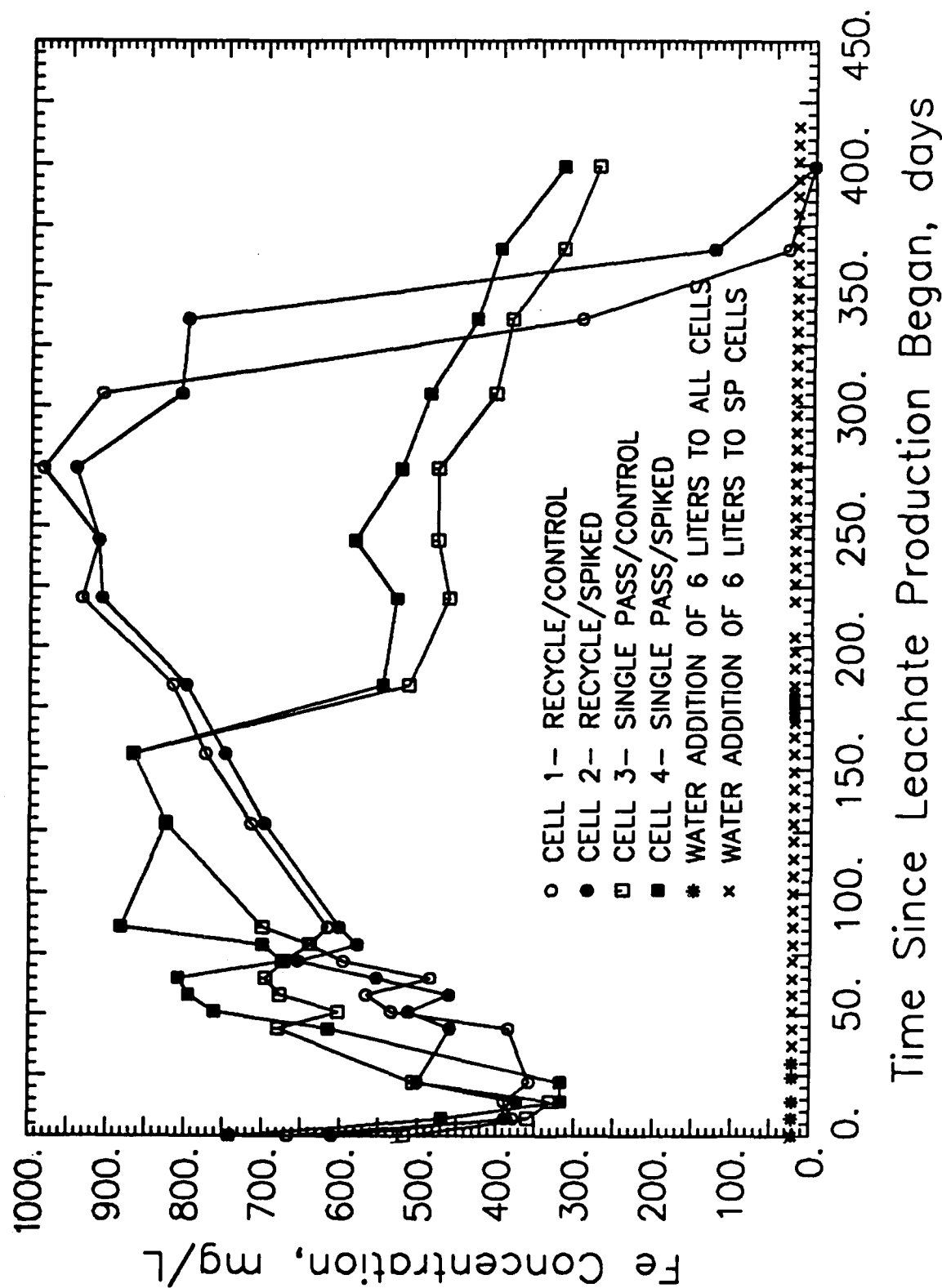


FIGURE 44: IRON CONCENTRATION IN LEACHATE FROM THE SIMULATED LANDFILL CELLS.

the recycle cells, however, iron concentration increased steadily from near 600 mg/L on Day 85 to 950-1000 mg/L on Day 275. However, iron concentration thereafter declined until concentrations below 10 mg/L was achieved on Day 400 or when methane fermentation had been firmly established.

The increases observed in iron concentration for both management options is contributed to the existence of highly reducing conditions in which Fe^{+3} ions were reduced to more soluble Fe^{+2} species in both environments. The decline in concentration of iron is attributed to the effect of washout and the presence of sulfides with subsequent precipitation of iron in all simulated landfill cells.

The remaining heavy metals including chromium, cadmium, copper, nickel, lead and zinc displayed similar trends during the acid formation phase of landfill stabilization (Figures 45 through 50 and Tables B6 through B9 in Appendix B). The first days were dominated by dilution effects due to water addition to all cells. Increased metals concentrations around Day 50 were typical, probably due to the saturation of additional waste mass. Around Day 70, washout effects dominated the single pass cells again, and the metal concentrations in the recycle cells held relatively constant. Chromium and copper concentrations decreased below the minimum detection levels. Concentrations declined steadily and particularly after reducing conditions were established and many of the heavy metals could be precipitated as sulfides. Although heavy metal concentrations were relatively low, this precipitation and removal as sulfides was particularly evident in the recycle cell leachates for Cd, Ni, Pb and Zn.

GAS PRODUCTION AND ANALYSIS

Initial Gas Production Phase

Some gas production began immediately after moisture addition to the cells and leachate production began on Day 0. Thereafter, it had decreased to zero by Day 10 as indicated in Tables B13 and B14 (Appendix B). This initial gas production resulted from aerobic decomposition with consumption of the oxygen introduced with the refuse during placement. The maximum gas production rate during this period

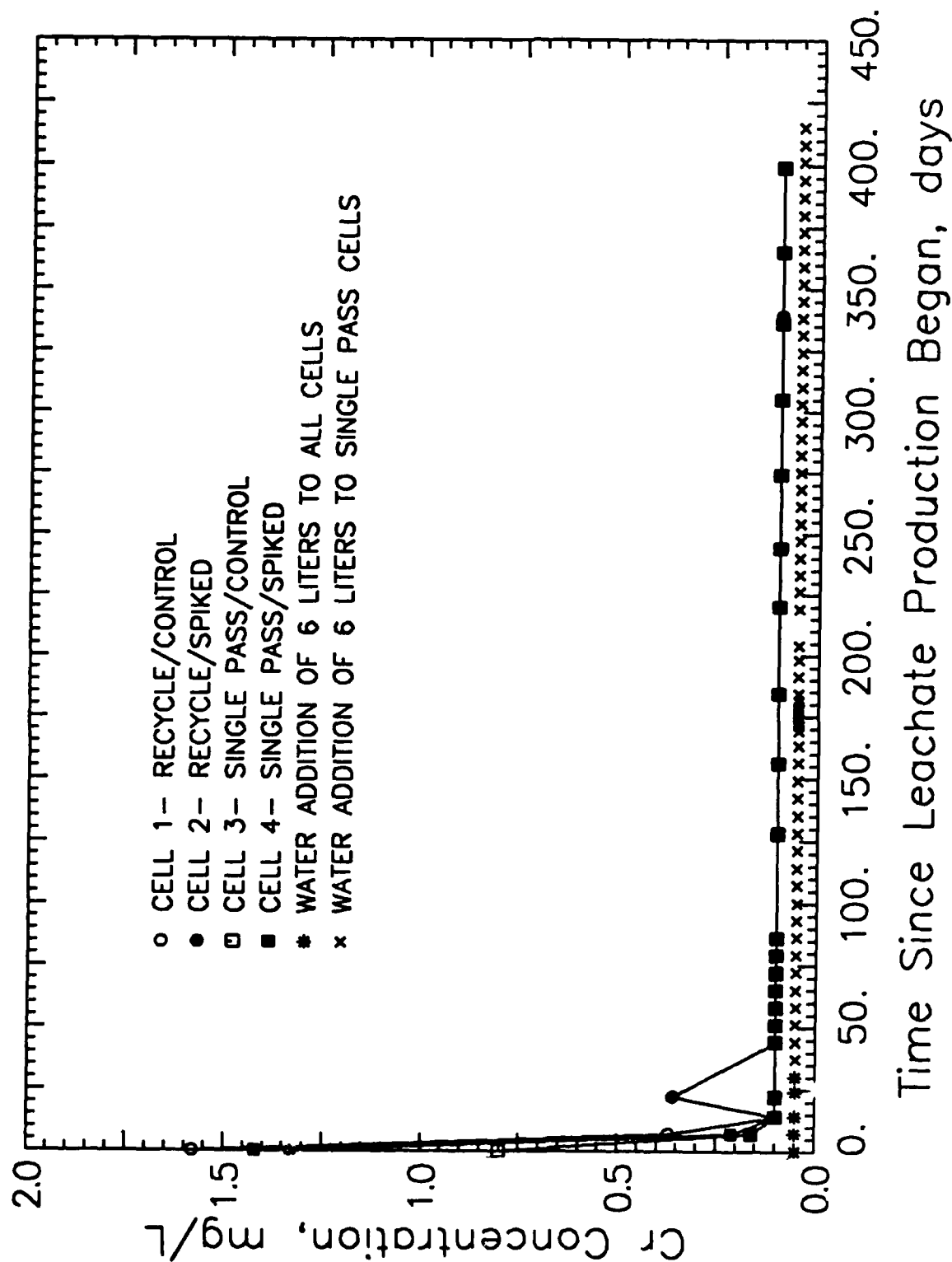


FIGURE 45: CHROMIUM CONCENTRATION IN LEACHATE FROM THE SIMULATED LANDFILL CELLS.

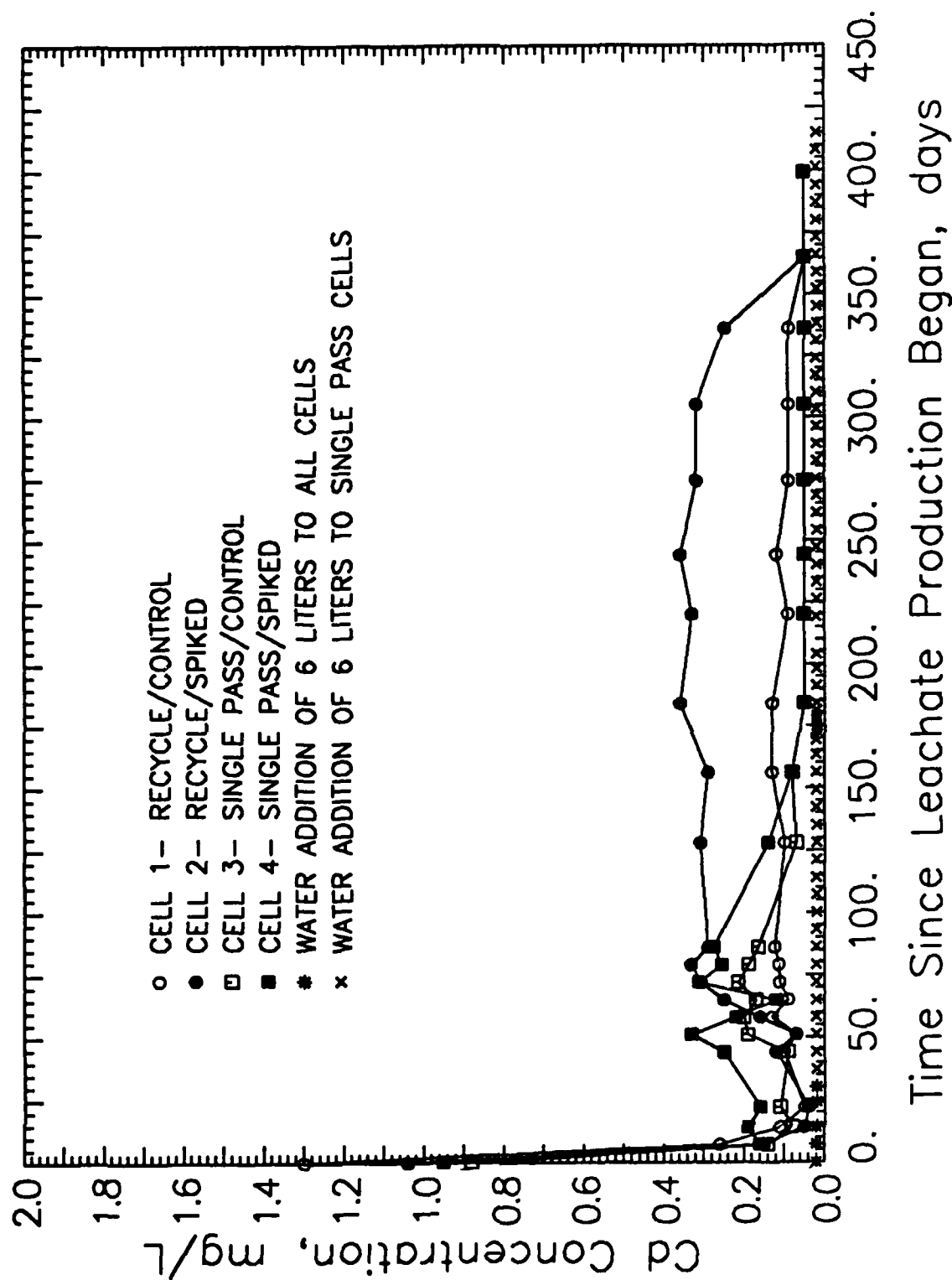


FIGURE 46: CADMIUM CONCENTRATION IN LEACHATE FROM THE SIMULATED LANDFILL CELLS.

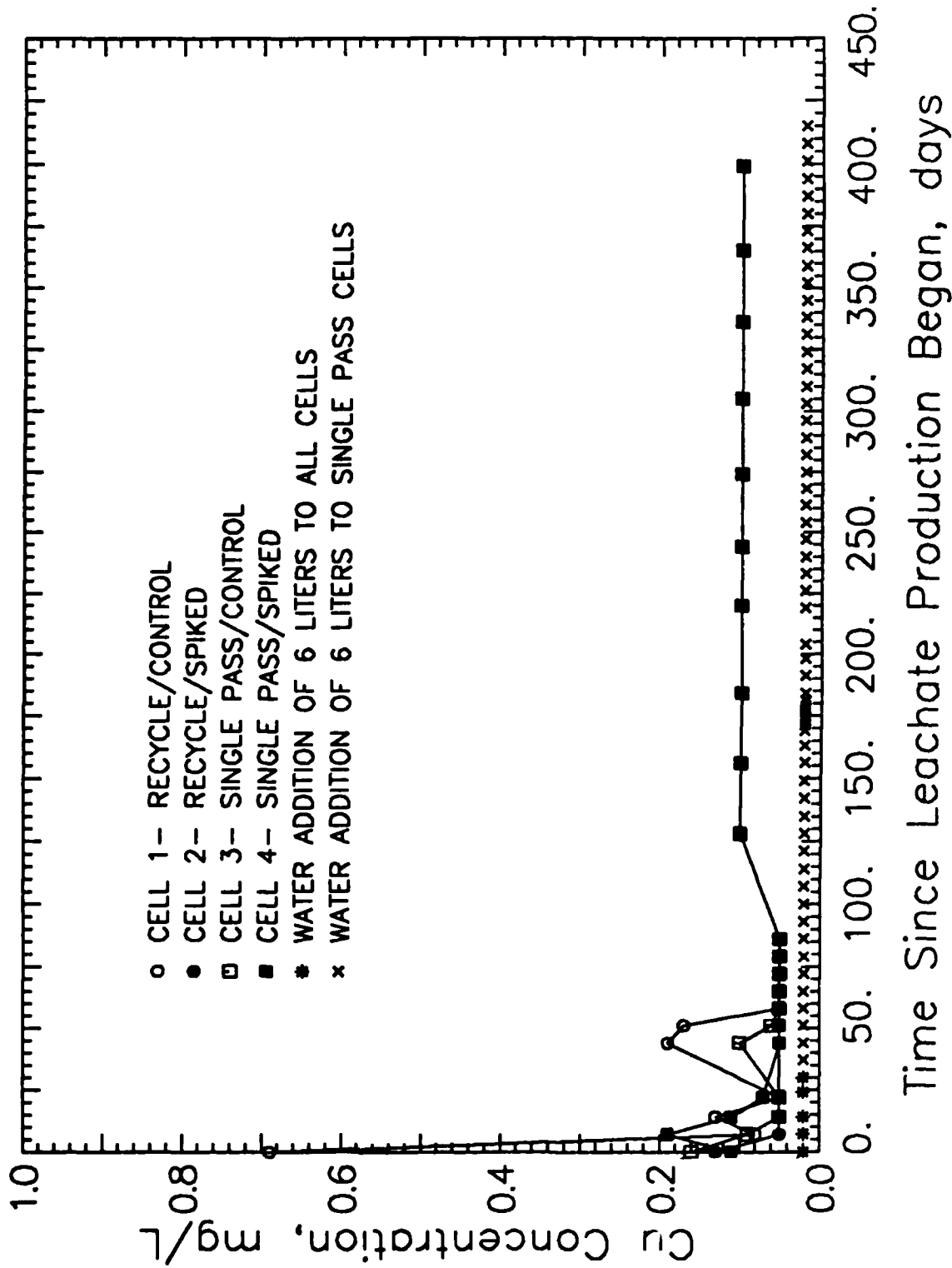


FIGURE 47: COPPER CONCENTRATION IN LEACHATE FROM THE SIMULATED LANDFILL CELLS.

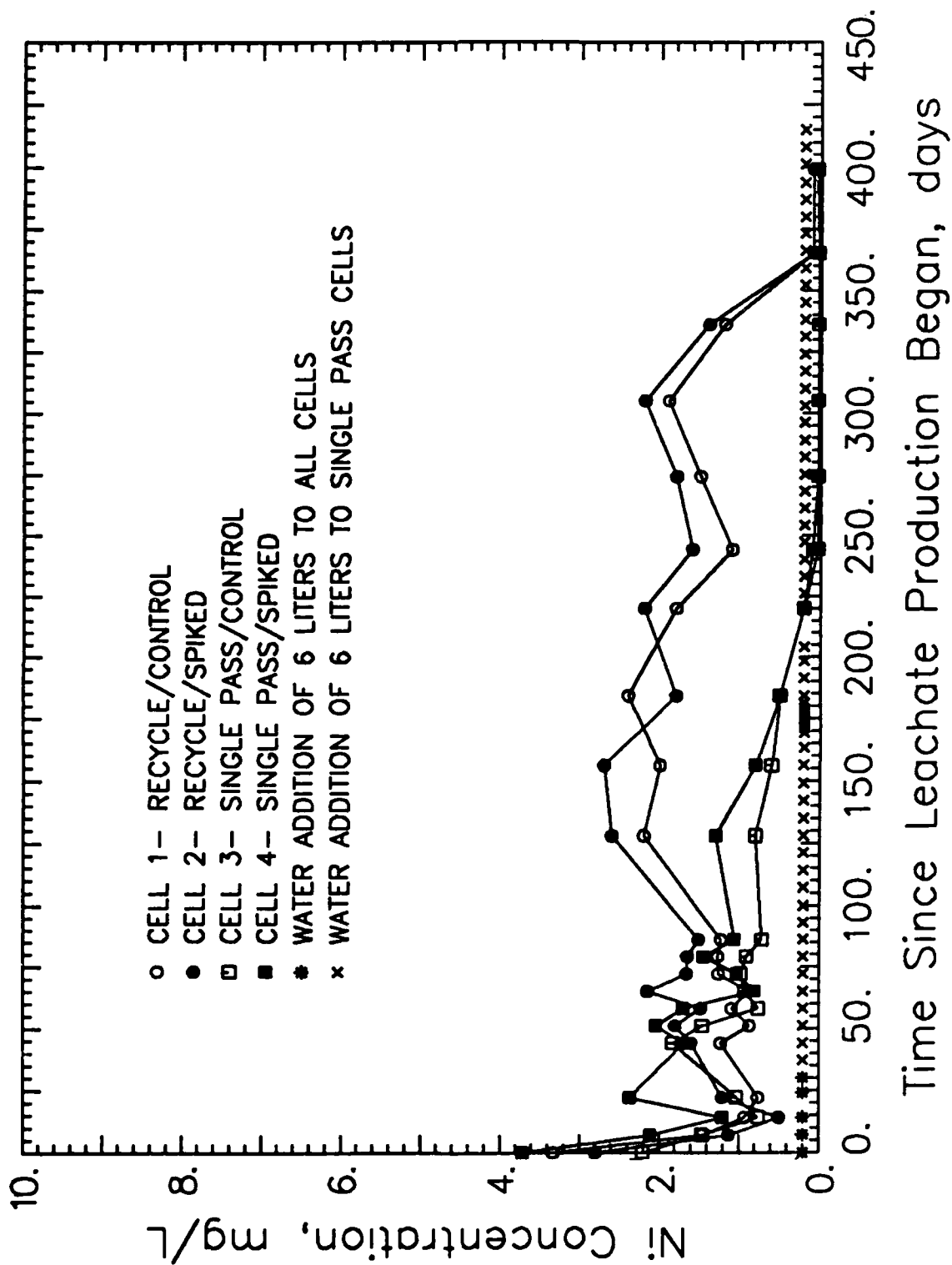


FIGURE 48: NICKEL CONCENTRATION IN LEACHATE FROM THE SIMULATED LANDFILL CELLS.

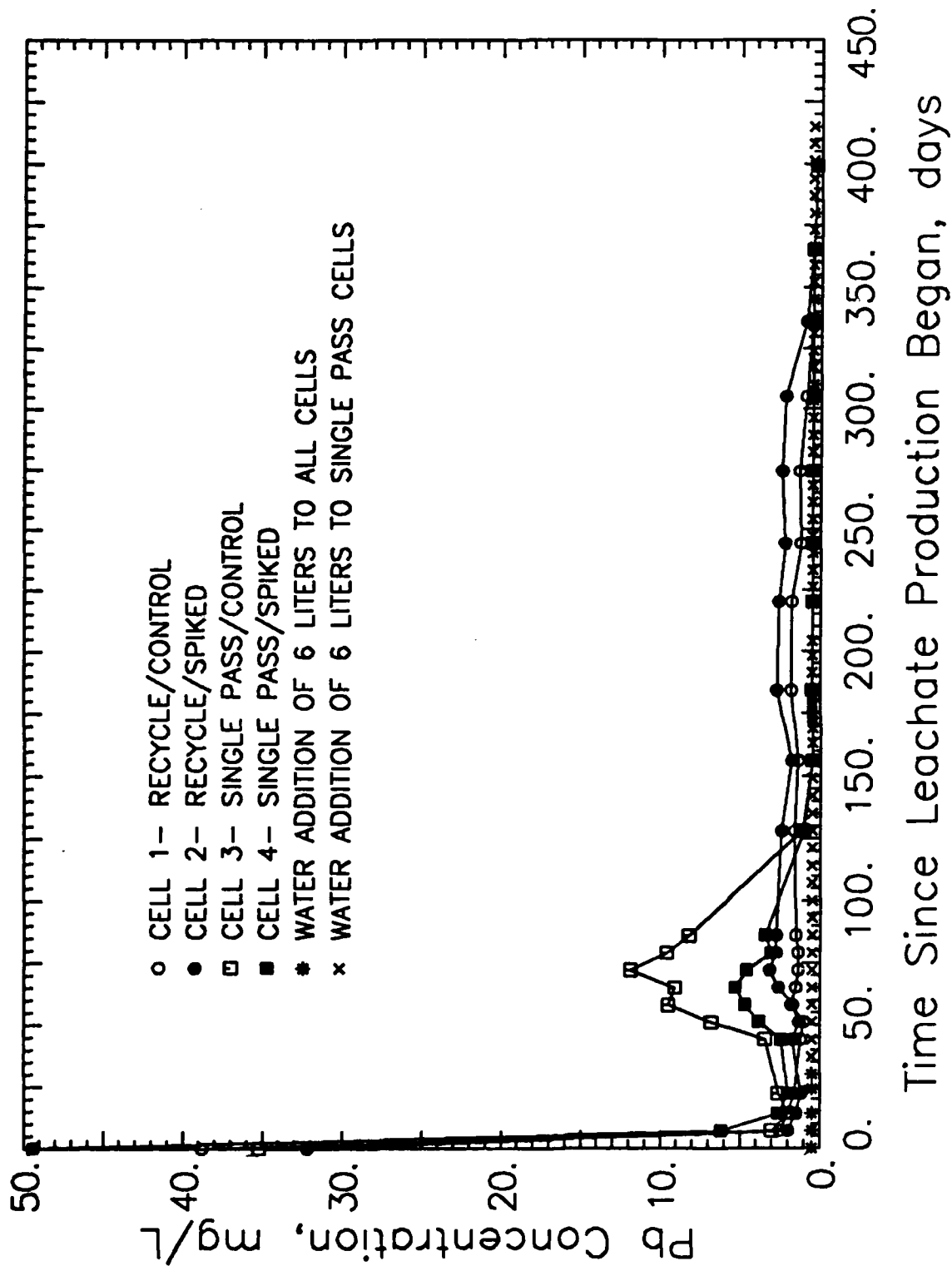


FIGURE 49: LEAD CONCENTRATION IN LEACHATE FROM THE SIMULATED LANDFILL CELLS.

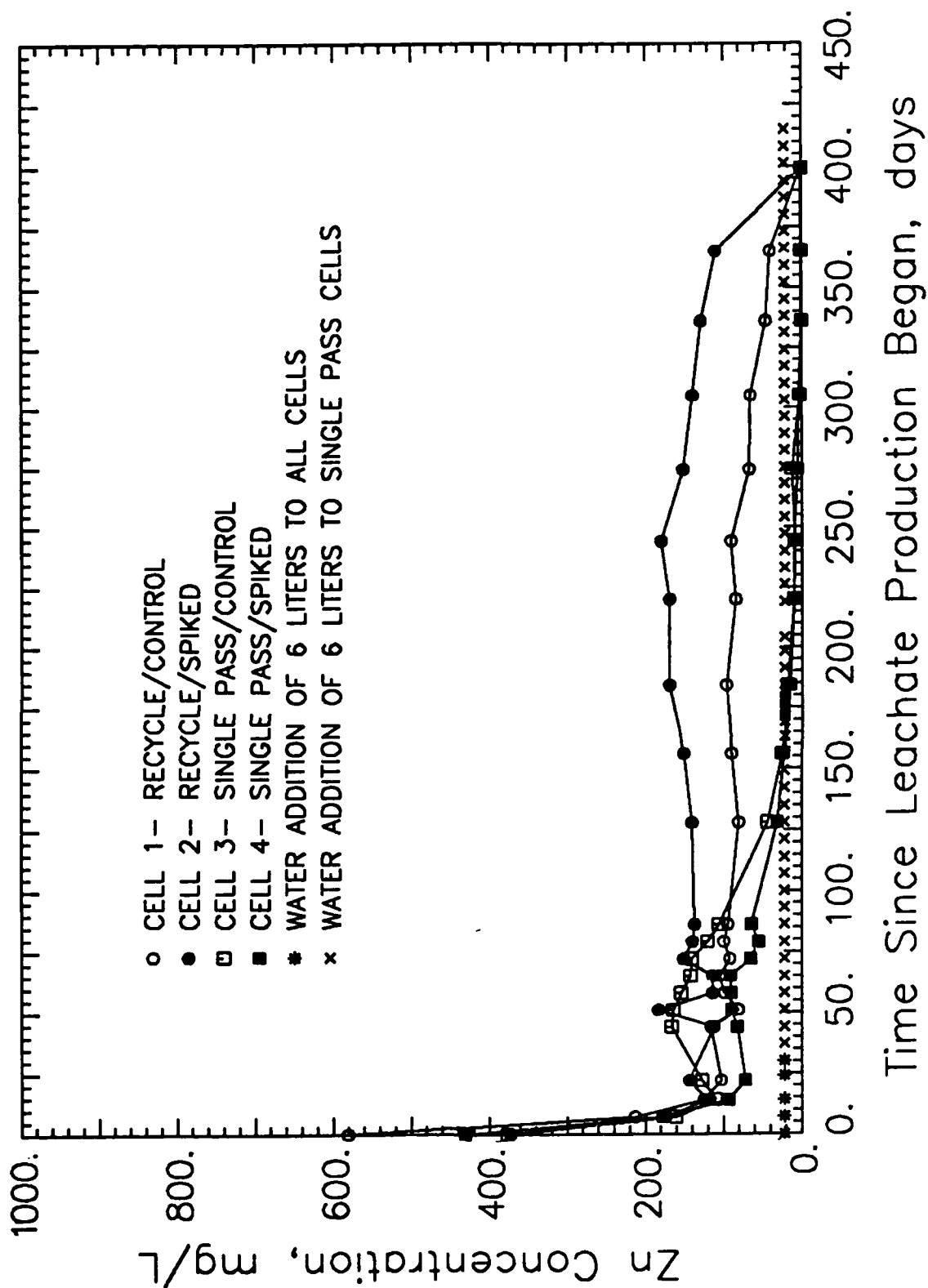


FIGURE 50: ZINC CONCENTRATION IN LEACHATE FROM THE SIMULATED LANDFILL CELLS.

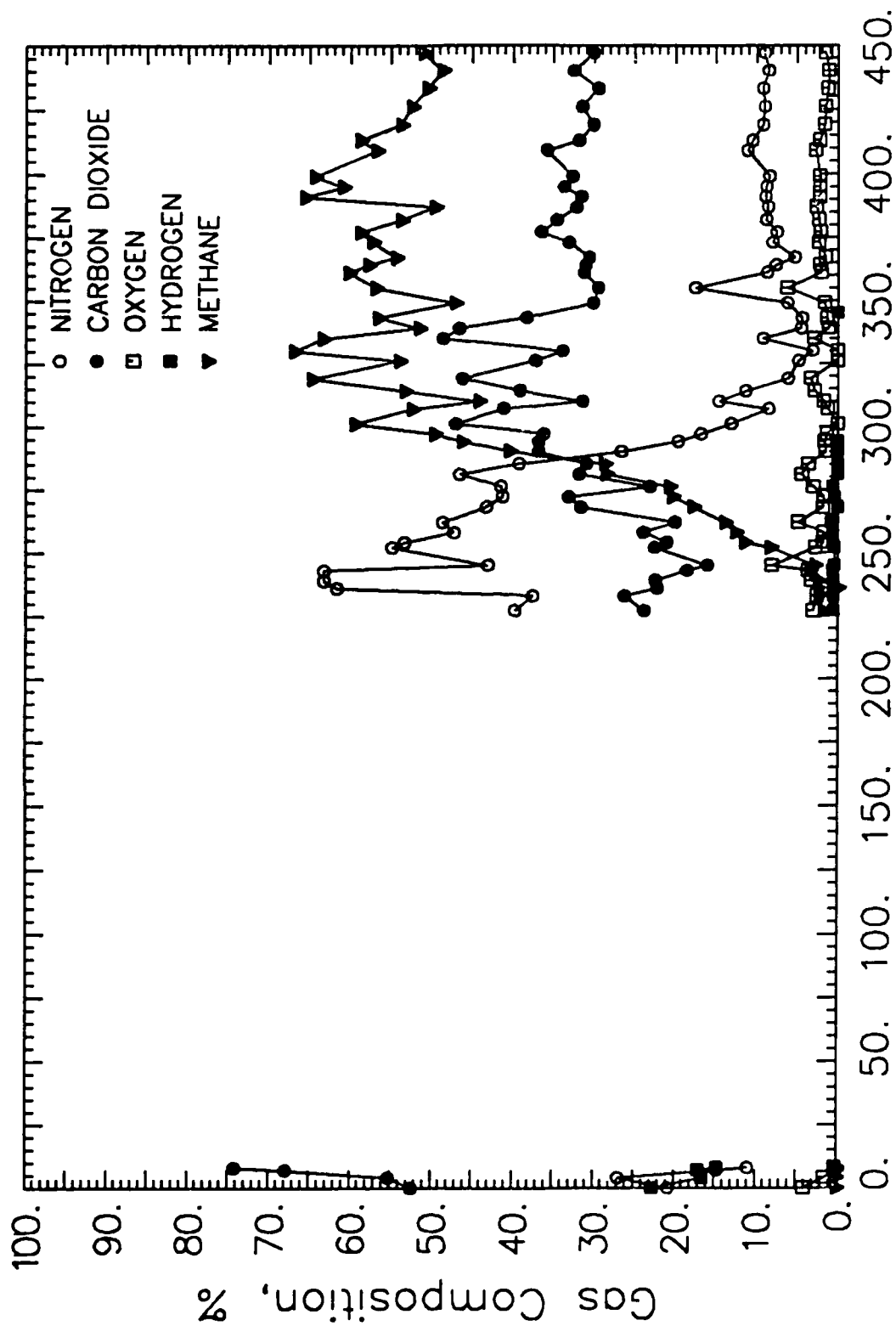
reached 50-70 liters/day before decreasing to zero by Day 10. As the oxygen was depleted, facultative and anaerobic acid forming bacteria further hydrolyzed the waste organic matter with the generation of carbon dioxide and hydrogen gas, thereby displacing some of the gaseous nitrogen present. The acidic conditions generated during the ensuing acid formation phase of stabilization delayed the onset of active methane fermentation and precluded further measurable gas production and displacement.

The gas composition for each of the cells during this initial period is displayed with the gas composition for production incurred during the methane fermentation phase (Figures 17 and 18) in Figures 51 through 54. On Day 8, the gas from all of the cells had similar compositions with 74% CO₂, 16% H₂, 10% N₂ and minimal O₂. These values are typical of the acid formation phase of landfill stabilization (23).

Final Gas Production (Methane Fermentation) Phase

The weekly and cumulative gas production for the recycle and single pass cells during the methane fermentation phase were previously presented in Figures 17 and 18 (Tables B10 and B11). Measurable gas production began on Day 235 in all four simulated landfill cells. Although the rate of gas production remained nearly comparable for all cells through Day 305, gas production rate for the recycle cells increased dramatically thereafter. Maximum daily gas productions of 110-130 and 120-140 liters/day were recorded for control and spiked recycle cells, respectively. However, maximum daily gas productions of only 5-10 and 15-20 liters/day were noted for the control and spiked single pass cells, respectively.

In terms of gas composition (Figures 51 through 54; Tables B10 and B11 in Appendix B), carbon dioxide (CO₂) content in the gas produced by both recycle and single pass cells increased to a maximum near Day 325. Subsequently, CO₂ composition decreased in all cells and then remained nearly constant after Day 350. The maximum carbon dioxide level recorded for the recycle cells was nearly 50%, whereas the maximum CO₂ level recorded for the single pass cells was at 52%. Following the decline in CO₂ concentration in all four cells, the recycle units remained at 30-35%, whereas the single-pass cells remained at nearly 35% CO₂.



Time Since Leachate Production Began, days

FIGURE 51: GAS COMPOSITION FROM THE CONTROL RECYCLE CELL.

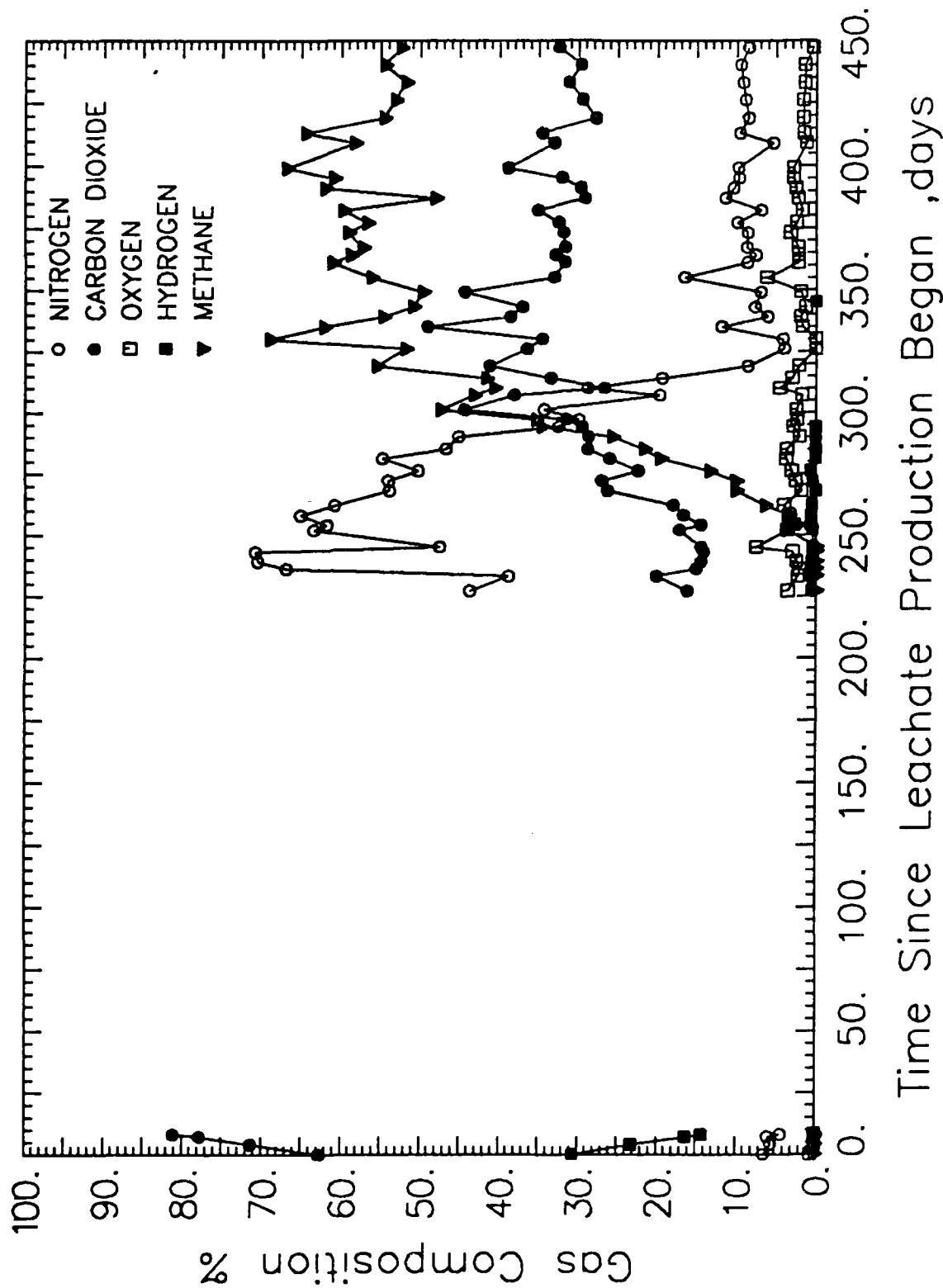


FIGURE 52: GAS COMPOSITION FROM THE SPIKED RECYCLE CELL.

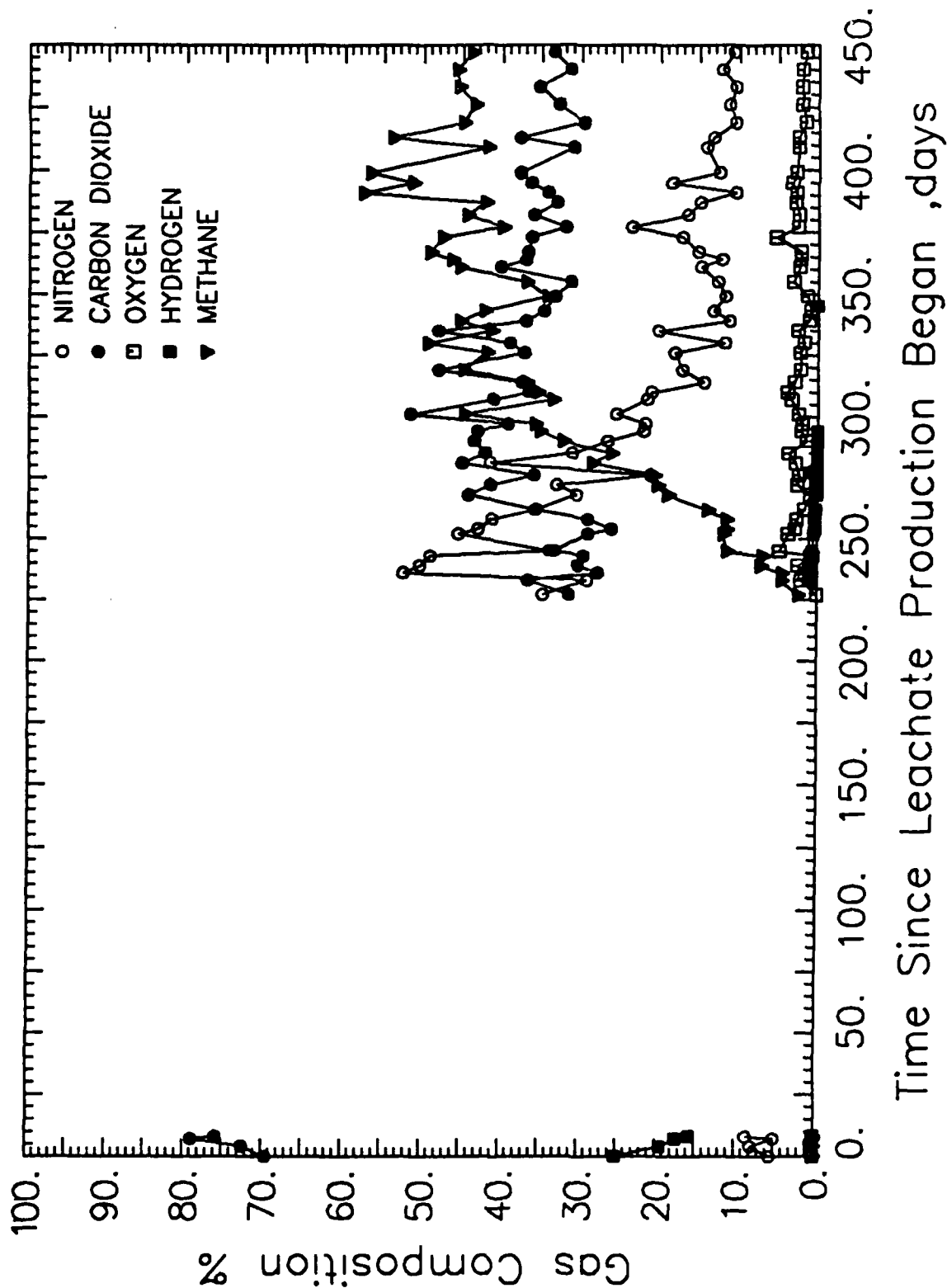


FIGURE 53: GAS COMPOSITION FROM THE CONTROL SINGLE PASS CELL.

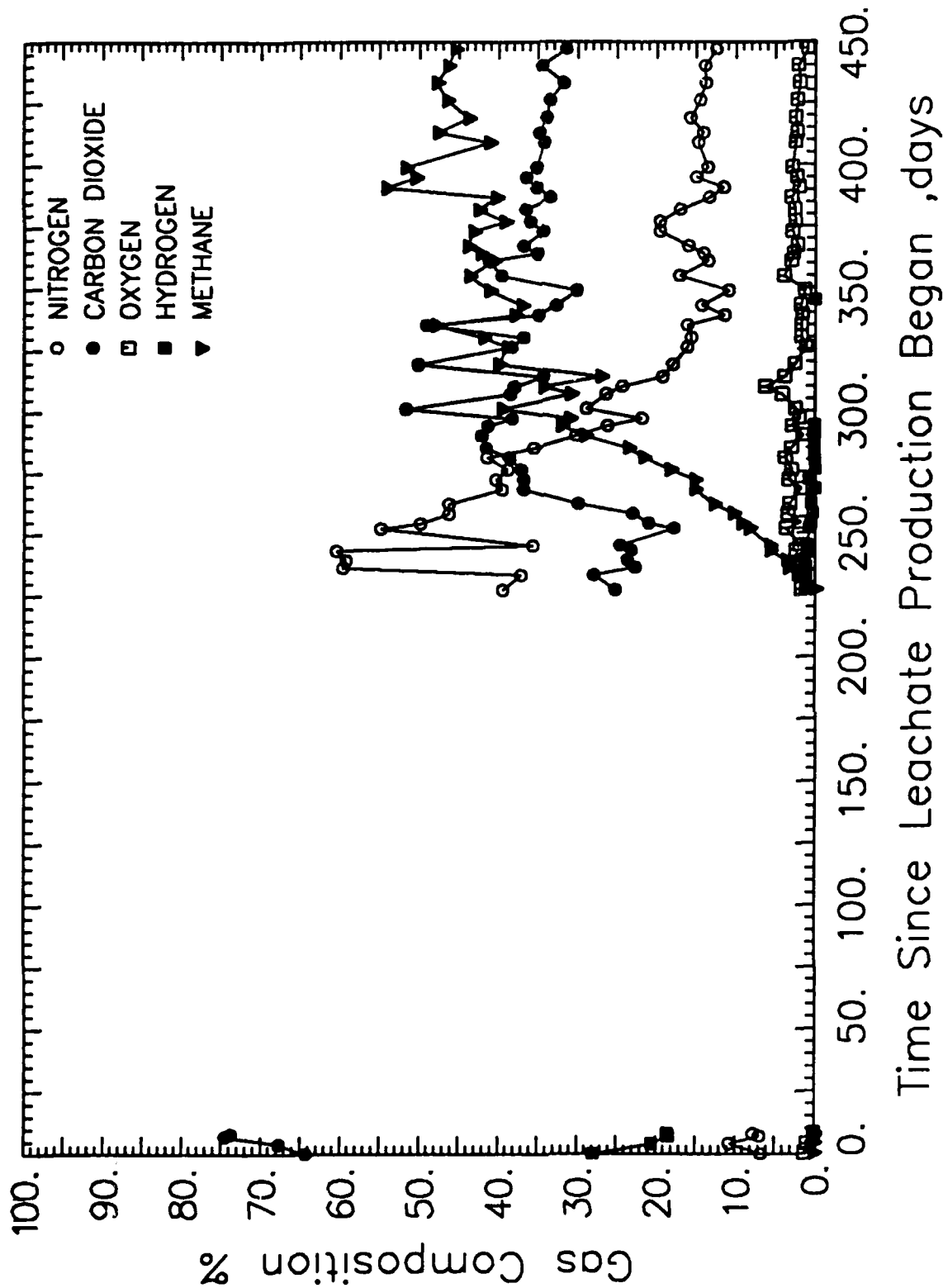


FIGURE 54: GAS COMPOSITION FROM THE SPIKED SINGLE PASS CELL.

Methane (CH_4) content also increased in the gas produced by all four simulated landfill cells. However, unlike carbon dioxide, the CH_4 composition merely leveled off after reaching a peak for all cells. The maximum CH_4 content for both recycle units measured in the 65-70% range. However, the maximum methane content measured for the single pass cells only reached the 45-50% range.

After the onset of methane fermentation, the levels of nitrogen present in the gas from all four simulated landfill cells decreased as the newly produced gases displaced the original nitrogen content. The nitrogen level measured for the recycle cells was at 8-10% after Day 380. However, the nitrogen content for the single pass cells remained near the 12-15% after Day 380.

Although small amounts of oxygen were detected continuously in the gas produced from all the simulated landfill cells, its presence was mainly attributed to difficulties encountered during gas sampling. Based on the amount, rate, and composition of gas production from the cells with different management options, it could be concluded that the recycle units had more rapidly and completely stabilized the organic constituents of the leachate when compared with the single pass cells. This observation and results presented on gas analysis indicated similar results as reported by Pohland, *et al.* (22).

TRACE ORGANIC PRIORITY POLLUTANT ANALYSIS

The results of the trace organic priority pollutant analysis indicated that only two of the 12 trace organic priority pollutants were identified initially in the leachate; phenol and di-n-butyl phthalate. Both of these priority pollutants were present in the leachate from the simulated landfill cells before and after the spiking of the cells with selected priority pollutants. The concentrations of phenol and di-n-butyl phthalate measured in this study are presented in Figures 55 and 56 (and Tables B6 through B9 in Appendix B), respectively.

Figure 55 indicates that all four cells, single pass and recycle, had increased phenol concentrations in the leachate between Day 37 and Day 67. This corresponded to the increased organic strength indicators and metal concentrations which appeared to be due to additional

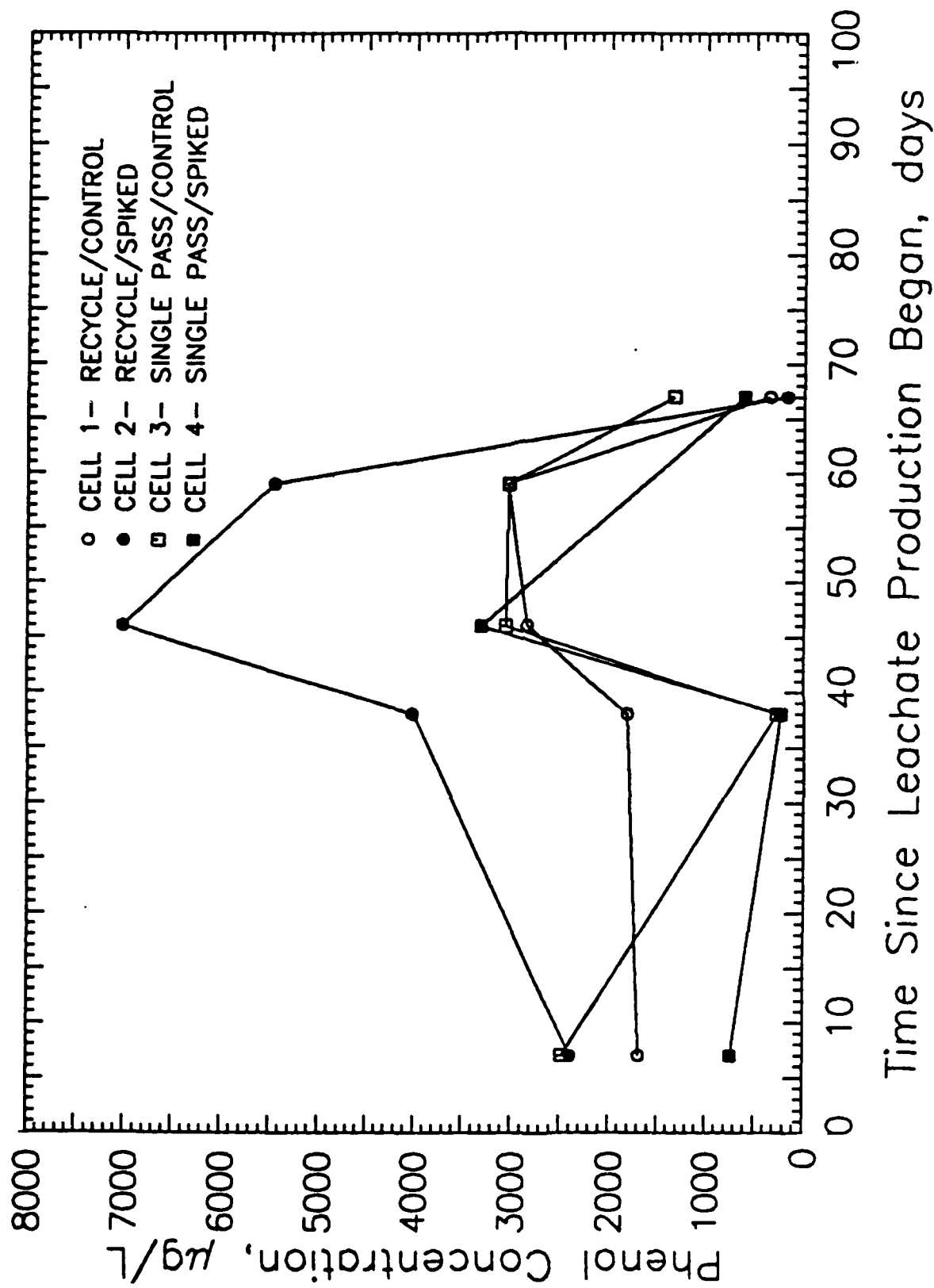


FIGURE 55: INITIAL PHENOL CONCENTRATION IN LEACHATE FROM SIMULATED LANDFILL CELLS.

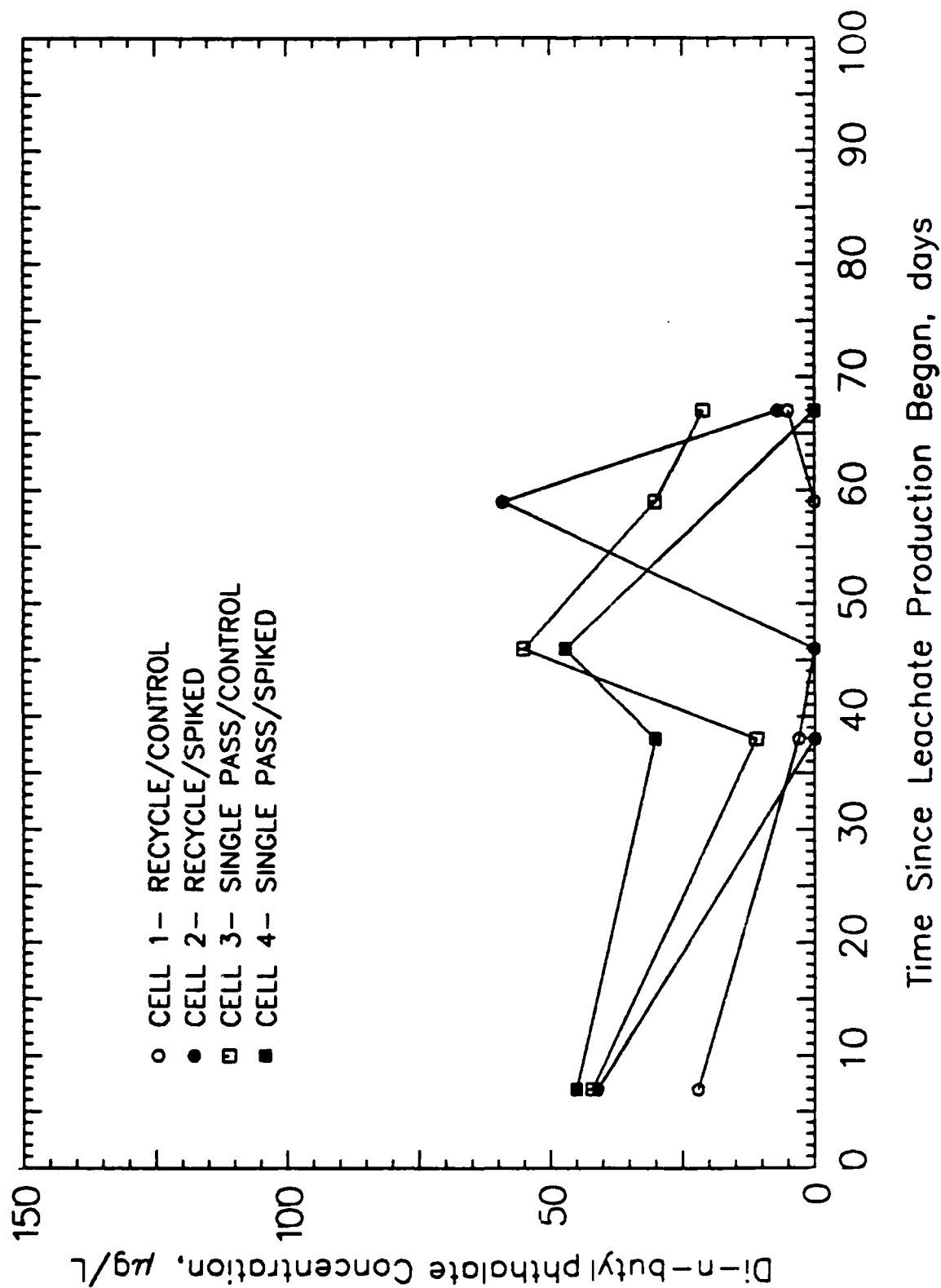


FIGURE 56: INITIAL DI-N-BUTYL PHTHALATE CONCENTRATION IN LEACHATE FROM SIMULATED LANDFILL CELLS.

saturation of the waste mass. Comparing the unspiked and spiked recycle cells (Cells 1 and 2, respectively), it appears that some of the phenol spike added on Day 30 may have eluted through the refuse and was identified in the leachate between Day 37 and Day 67. Although the leachate from both cells had an increased phenol concentration, that from the spiked cell increased about 3500 g/L, while the single pass cell leachate increased about 1200 g/L. In the single pass cells (Cells 3 and 4), the spike did not appear to have eluted through the solid waste.

In Figure 56, the di-n-butyl phthalate concentrations display an increased concentration in three of the four cells, probably again due to the additional saturation of the waste mass. The difference between the unspiked and spiked recycle cells (Cells 1 and 2, respectively) from Day 44 to Day 67 may indicate that the spike had appeared in the leachate. Cell 2 leachate increased 50 g/L, while that from Cell 1 showed no change in di-n-butyl phthalate concentration. Further inspection during the remaining portions of the research investigations up to Day 433 indicated that none of the selected organic priority pollutants had emerged in measurable quantity in the leachate samples from the test cells.

To demonstrate the technique used to determine the presence of the selected priority organic pollutants spiked to the test single-pass and recycle cells, Figures 57 and 61 present examples of reconstructed ion chromatographs (RIC) obtained for leachate sample extracts determined by GC-MS procedures. Accordingly, Figure 57 presents the RIC of an extracted sample of leachate collected from Cell 2 on Day 147. Peaks appearing at scan numbers of 1590, 1690 and 1892 represent hexamethylbenzene, diethyl phthalate, and anthracene-d₁₀, respectively. Hexamethylbenzene was introduced as the internal standard in the analysis and anthracene-d₁₀ was used as a surrogate compound in the analyses. Diethyl phthalate is a common ingredient of leachates, often originating from the variety of plastic materials contained in municipal refuse.

Peaks appearing in Figures 58 through 60 represent the previously named compounds and Figure 61 is a RIC for a control (blank) sample carried through the analysis. Moreover, peaks appearing at scan

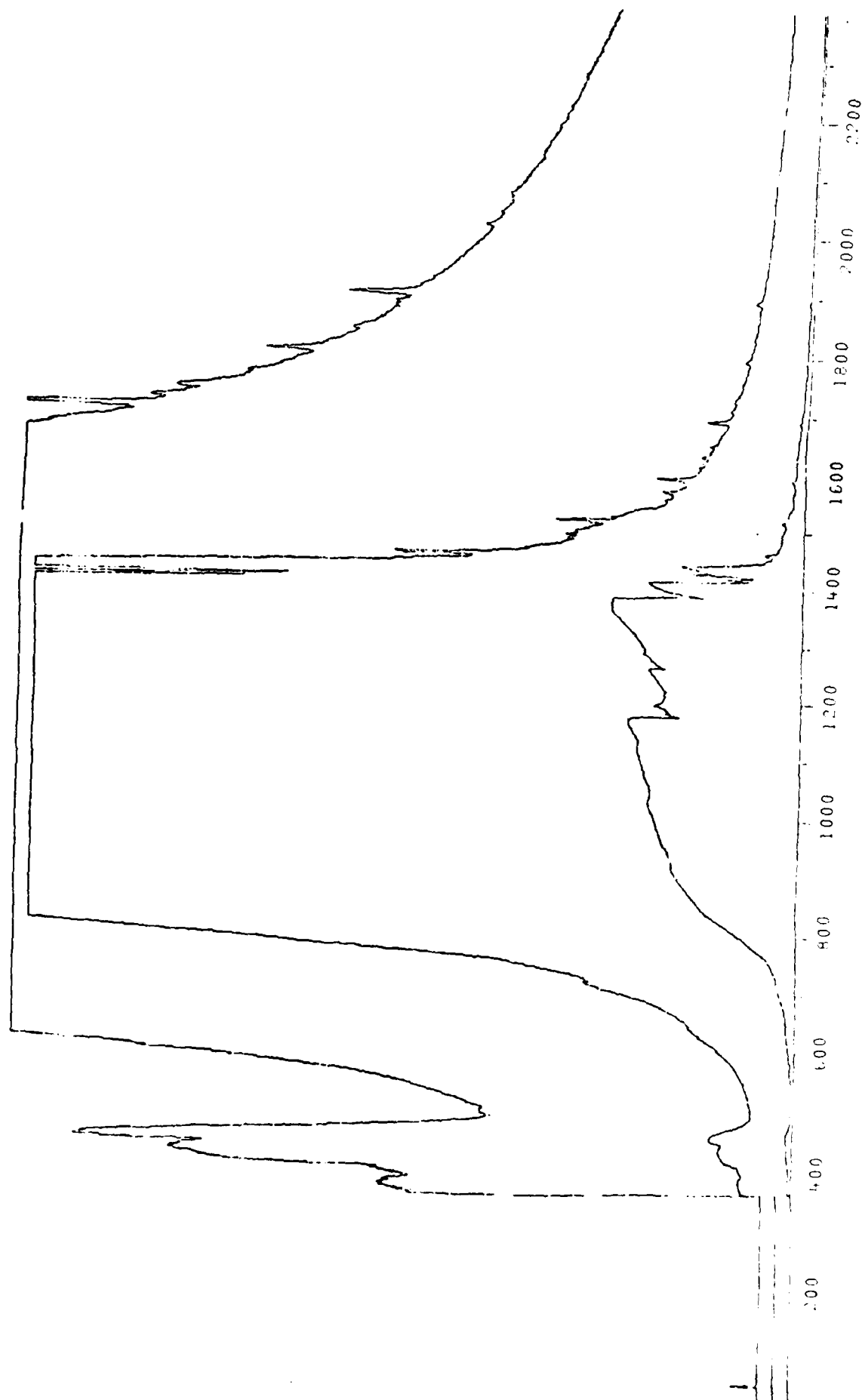


FIGURE 57: RIC FOR CELL 2 LEACHATE EXTRACT (DAY 174).

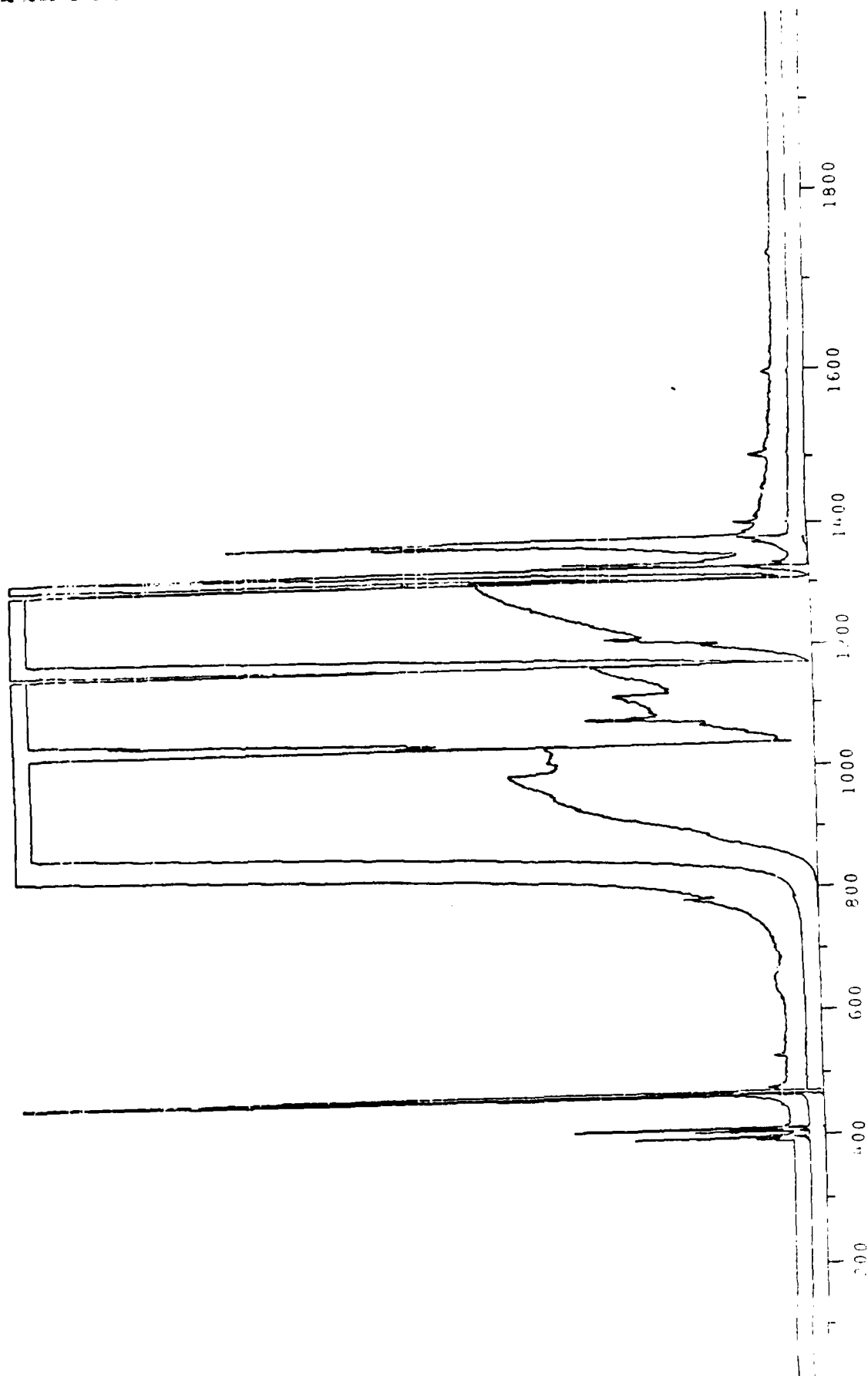


FIGURE 58: RIC FOR CELL 4 LEACHATE EXTRACT (DAY 174).

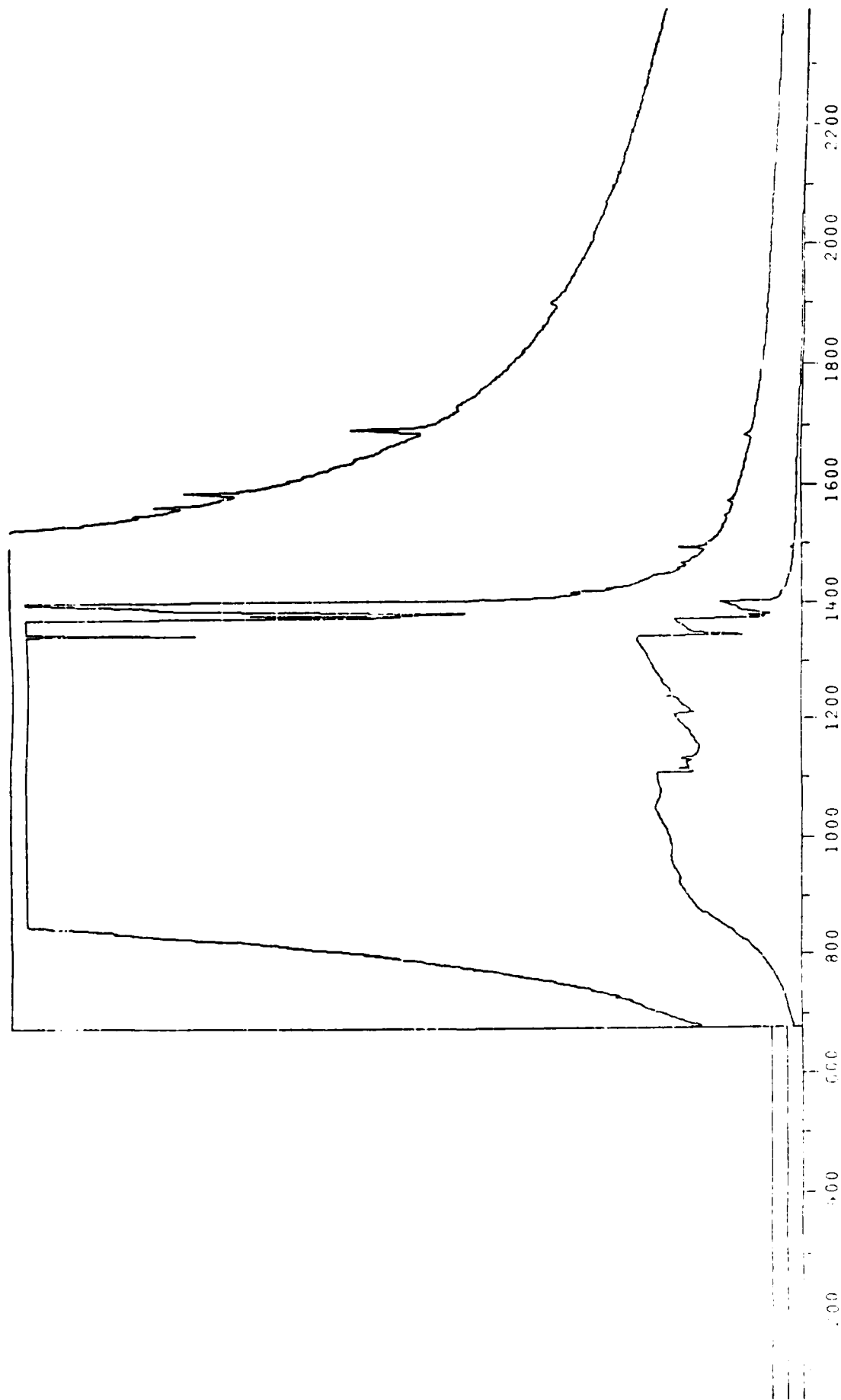


FIGURE 59: RIC FOR CELL 2 LEACHATE EXTRACT (DAY 244).

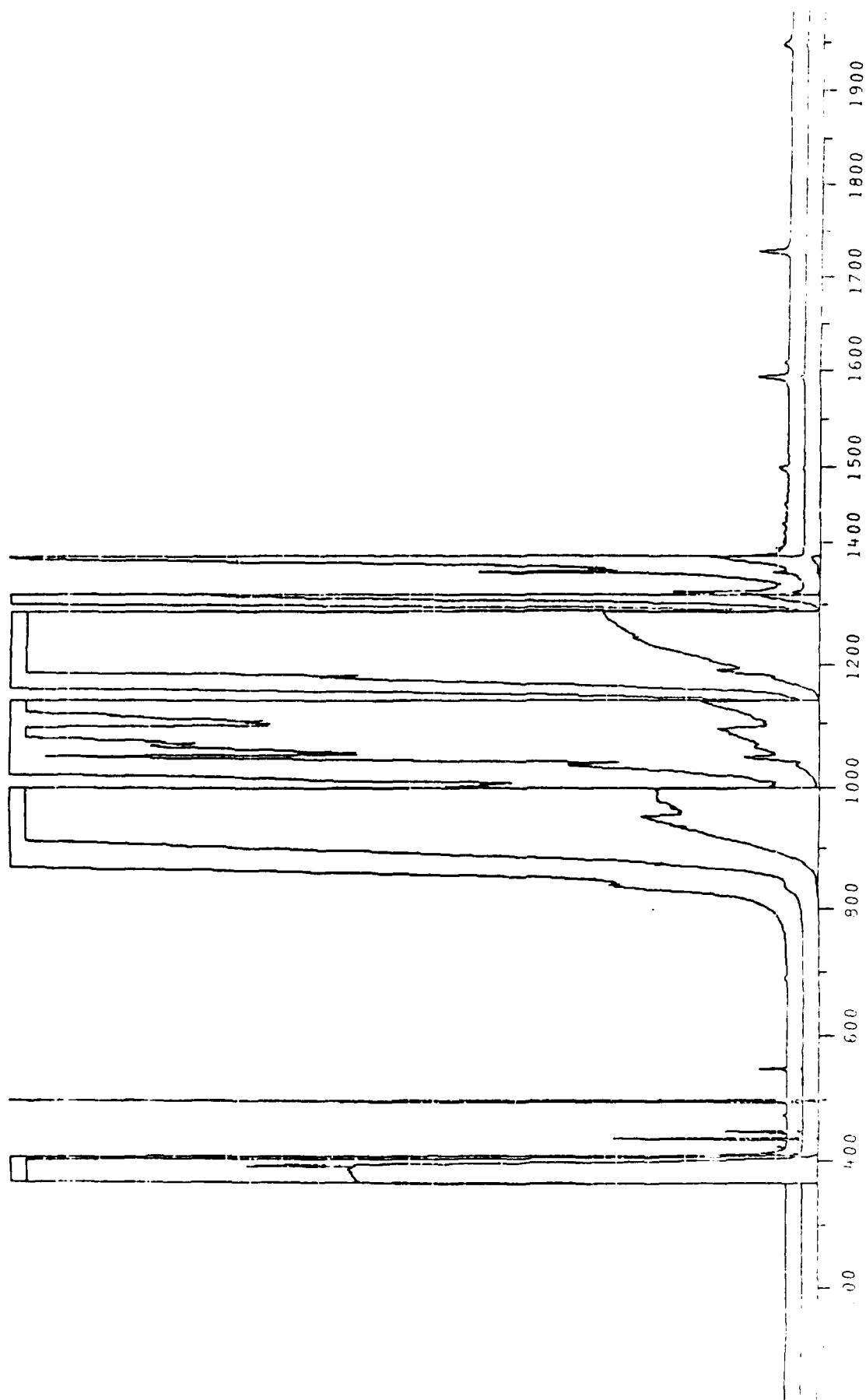


FIGURE 60: RIC FOR CELL 4 LEACHATE EXTRACT (DAY 244).

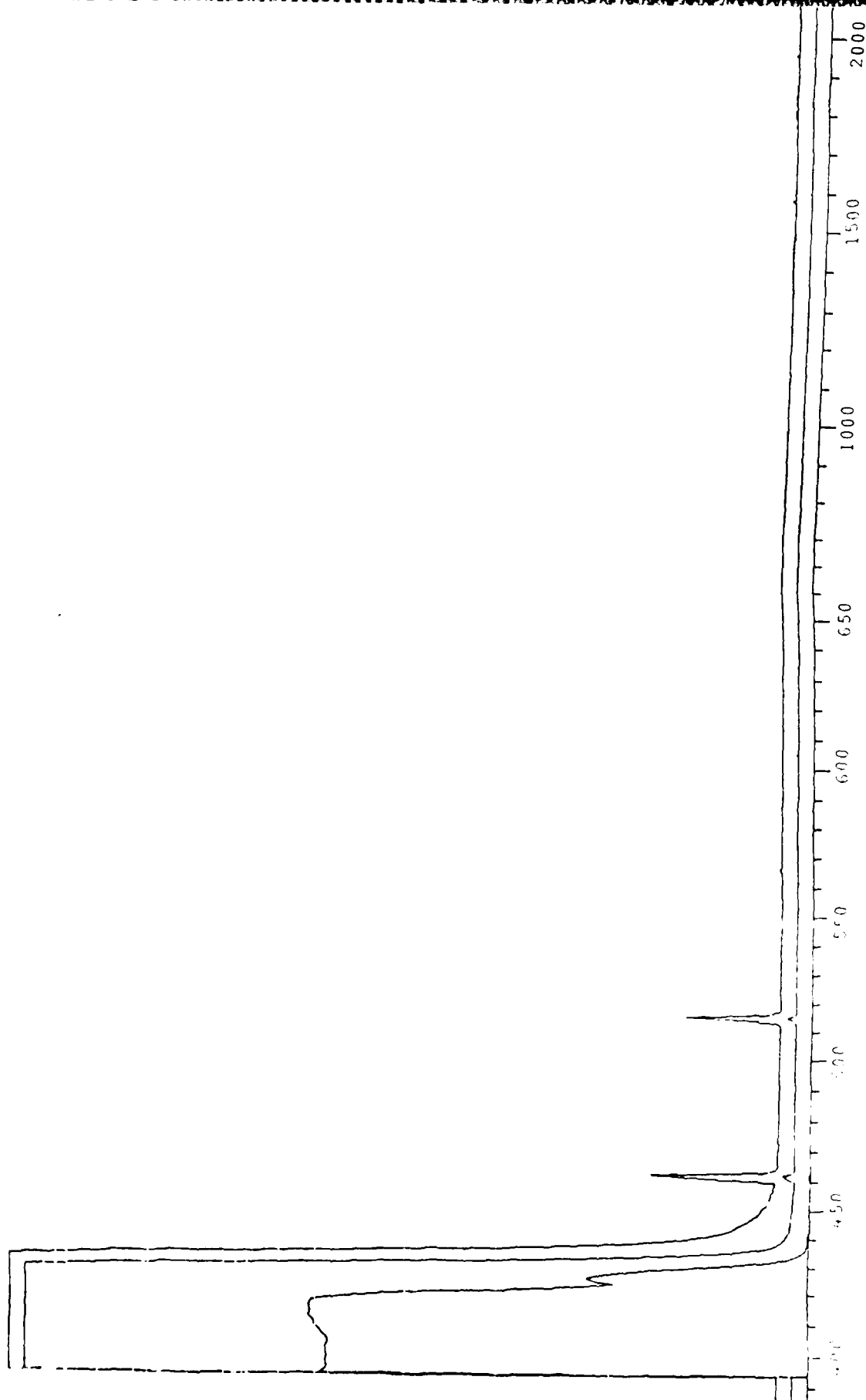


FIGURE 61: RIC FOR STANDARD BLANK.

numbers of 462 and 512 represent chloroform and cyclohexane, respectively. Both of these compounds were introduced as contaminants in the solvent used in the extraction procedures.

Elution Potential

In an effort to better understand the elution potential of the selected organic priority pollutants, a small-scale laboratory test was performed. This study investigated the elution of 10 of the 12 selected priority pollutants with water through a column of sterilized refuse (see Figure 62). The test was repeated with a second column of solid waste using leachate to elute the compounds.

Stored samples of refuse from the loading of the four simulated landfill cells were mixed and ground using a Wiley mill and a 6-mm screen. Biological activity was minimized by irradiating the ground waste with UV light, baking all glassware at 400 °C for at least six hours, and filtering the leachate used in the second column through a 0.45-µm membrane filter.

The column was packed with 17 grams of refuse and a glass wool layer placed above and below the waste. Deionized water was then siphoned into the bottom of the column to saturate the waste. The water level was maintained at the surface of the waste layer, while 1 mL of priority pollutant spike was added to the top of the column with a syringe (see Table 7 for exact quantities). Water was added to the top of the column to obtain 60 cm of water head. The column was then eluted with deionized water at a rate of 5-6 bed volumes per hour (100 mL per 10-12 minutes). One hundred mL samples were collected until 20 bed volumes had flowed through the column. The samples were extracted using steam distillation followed by concentration with K-D apparatus and nitrogen purging prior to final analysis on the GC-MS.

These procedures were repeated with a second column of solid waste eluted with 16 bed volumes of filtered leachate as well as a third column containing unspiked solid waste eluted with eight bed volumes of deionized water.

The results of the first column test (Table 7) using water as the mobile phase included the appearance of phenol in the first bed volume, di-n-butyl phthalate and 2,6-dinitrotoluene in the second bed volume, 2,4-dinitrotoluene in the third bed volume, trichloroethene,

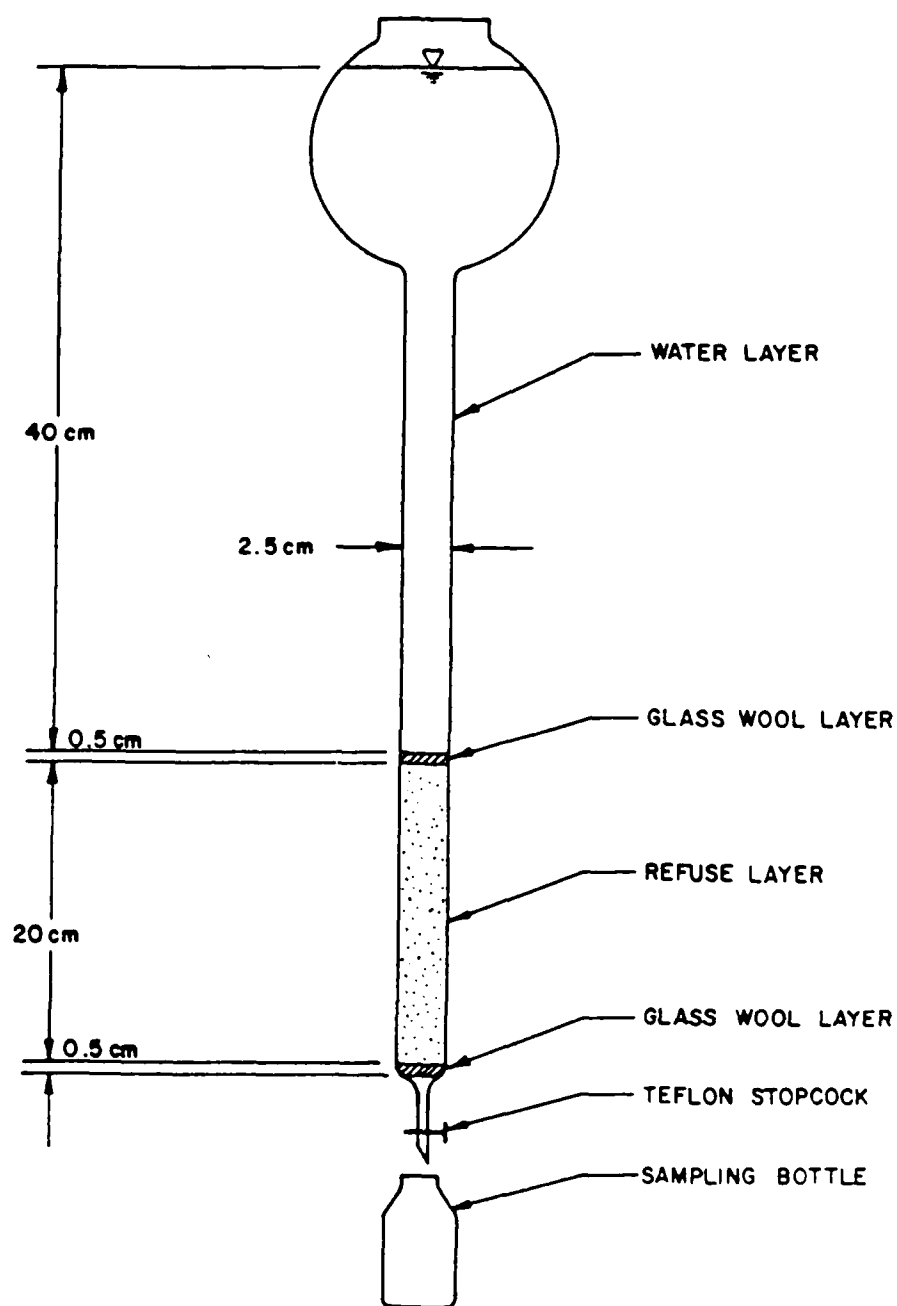


FIGURE 62: SMALL SCALE ELUTION COLUMN PACKED WITH SOLID WASTE.

Table 7. Column Elution Test: Elution of Selected Priority Pollutants with Deionized Water

Compound (spiking level)	Bed Volume							
	1	2	3	4	5-8	9-12	13-16	17-20
Butanone (660 µg)	ND	ND	ND	ND	ND	ND	ND	ND
Trichloroethene (660 µg)	ND	ND	ND	ND	22.1	5.3	ND	ND
Phenol (1237 µg)	563.2	429.5	67.1	31.3	55.7	ND	ND	ND
Hexachloroethane (1115 µg)	ND	ND	ND	ND	ND	ND	ND	13.2
2,6-Dinitrotoluene (635 µg)	ND	110.2	197.4	119.8	174.5	74.0	30.1	ND
2,4-Dinitrotoluene (678 µg)	ND	ND	137.6	93.7	183.5	72.9	25.7	ND
4,6-Dinitro-o-cresol (644 µg)	ND	ND	ND	ND	23.5	ND	ND	ND
Pentachlorophenol (670 µg)	ND	ND	ND	ND	824.7	231.8	ND	ND
Phenanthrene (680 µg)	ND	ND	ND	ND	ND	ND	ND	ND
Di-n-butyl phthalate (660 µg)	2.0	ND	ND	ND	10.0	6.7	6.3	8.5

All values in this table are in µg.

ND = Not Detected

4,6-dinitro-o-cresol and pentachlorophenol in the fifth bed volume. Hexachloroethane was found in the bed volumes 17-20. Butanone and phenanthrene were not found in the column effluent after the passage of 20 bed volumes.

The second column (Table 8) was eluted with leachate and phenol, di-n-butyl phthalate, 2,6-dinitrotoluene and 2,4-dinitrotoluene appeared in the first bed volume and trichlorethene in the fourth bed volume. 4,6-Dinitro-o-cresol, pentachlorophenol, hexachloroethane, butanone and phenanthrene were not detected in the column discharge through 16 bed volumes. A summary of the results of both column tests is presented in Table 9.

Table 9. Summary of Column Elution Tests

Compound	Bed Volumes in which Compound Was Found	
	Deionized Water	Leachate
Phenol	1-8	1-16
Di-n-butyl phthalate	2,5-20	1-16
2,6-Dinitrotoluene	2-16	1-16
2,4-Dinitrotoluene	3-16	1-16
Trichloroethene	5-12	4
4,6-Dinitro-o-cresol	5-8	(>16)*
Pentachlorophenol	5-12	(>16)*
Hexachloroethane	17-20	(>16)*
Butanone	(>20)*	(>16)*
Phenanthrene	(>20)*	(>16)*

*Compound was not identified in samples throughout the study period.

Examination of the percent of the spike recovered for both elution tests indicates that some spiked priority pollutant recoveries were greater than 100 percent. For phenol this may be expected, since it is a degradation product of many compounds. However, over 100 percent recoveries for pentachlorophenol and 2,6-dinitrotoluene in the deionized water elution, and 2,6-dinitrotoluene and 2,4-dinitrotoluene

Table 8. Column Elution Test: Elution of Selected Priority Pollutants with Leachate

Compound (spiking level)	Bed Volume						
	1	2	3	4	5-7	8-10	11-13 14-16
Butanone (660 µg)	ND	ND	ND	ND	ND	ND	ND
Trichloroethene (660 µg)	ND	ND	ND	3.7	ND	ND	ND
Phenol (1237 µg)	763.0	674.7	495.3	460.6	2130.0	1188.5	154.4 1147.3
Hexachloroethane (1115 µg)	ND	ND	ND	ND	ND	ND	ND
2,6-Dinitrotoluene (635 µg)	80.8	265.7	264.7	194.4	166.3	102.1	57.7 34.8
2,4-Dinitrotoluene (678 µg)	71.4	231.9	258.7	186.1	184.3	98.9	54.7 33.7
4,6-Dinitro-o-cresol (644 µg)	ND	ND	ND	ND	ND	ND	ND
Pentachlorophenol (670 µg)	ND	ND	ND	ND	ND	ND	ND
Phenanthrene (680 µg)	ND	ND	ND	ND	ND	ND	ND
Di-n-butyl phthalate (660 µg)	12.9	ND	6.0	ND	ND	16.5	ND 22.7

All values in this table are in µg.

ND = Not Detected

in the leachate elution were probably due to analytical technique.

As discussed in the literature review, adsorption isotherms have been developed for many of the organic priority pollutants using activated carbon. From this information, the indicated order of elution with adsorption is: phenol > trichloroethene > hexachloroethane > 2,6-dinitrotoluene > 2,4-dinitrotoluene > pentachlorophenol > 4,6-dinitro-o-cresol > phenanthrene > di-n-butyl phthalate > polychlorinated biphenyls. Although it is recognized that solid waste has a different character than activated carbon, such isotherm information can provide a basis for comparison of different organics and their adsorption tendencies.

This order of elution was generally consistent with the small-scale column tests described above. Based on the column eluted with leachate, the order of elution was: phenol, di-n-butyl phthalate, 2,6-dinitrotoluene, 2,4-dinitrotoluene > trichloroethene > 4,6-dinitro-o-cresol, pentachlorophenol, butanone, phenanthrene.

Using the adsorption data collected for activated carbon and the above described test using solid waste, the following tentative sequence of elution was predicted: phenol > trichloroethene, hexachloroethane, 2,6-dinitrotoluene, 2,4-dinitrotoluene, di-n-butyl phthalate > 4,6-dinitro-o-cresol, butanone, pentachlorophenol, phenanthrene > 2,4'-dichlorobiphenyl, hexachlorobiphenyl. However, continuation of the simulated landfill studies through the methane fermentation phase of stabilization did not reveal further evidence of preferential elution and the associated behavior of the selected organic priority pollutants included in the investigations was not revealed even after 450 days and passage of 2.1 to 2.3 and 15-17 bed volumes through the single pass and recycle cells, respectively. Such an observation suggests that the landfill environment provides a finite assimilative capacity for organic priority pollutants. The magnitude of this capacity and whether it can be ascribed to sorption, biodegradation, complexation or other physical-chemical mechanisms remains to be determined. Therefore, continuing operation and monitoring of the simulated landfill systems is advised.

SUMMARY AND CONCLUSIONS

Based on the results of this phase of the research study, the following conclusions may be drawn:

1. Both acid formation and methane fermentation phases of stabilization were established in the four simulated landfill cells. This was confirmed by the indicator parameters examined, and included conversion or washout of initially high leachate COD, BOD₅ and TOC composed primarily of volatile organic acids, with low pH, to greatly reduced concentrations at negative ORPs and methane production. Mobilization and fixation of metal species and release and utilization of nutrients in support of biomass production was also noted. Tracer studies using lithium demonstrated that uniform distribution and minimal shortcircuiting were achieved in both the single pass and recycle cells, with some indication of increasing retention times as microbial populations were developed during both acid formation and methane fermentation phases.
2. During the acid fermentation phase of stabilization of the simulated landfill cells, hexanoic acid was identified in the leachate. The concentration of hexanoic acid in the leachate of the recycle cells was five times greater than for the single pass cells. This higher concentration of hexanoic acid may have been the result of saturation with volatile organic acids (VOA) with recirculation in the recycle cells which resulted in its formation possibly from the condensation of butyric and acetic acid. This may explain the simultaneous decrease in butyric acid, although a greater degree of cellulose hydrolysis due to longer contact times with leachate recycle may also have contributed.
3. During the acid formation phase, the mass of COD generated in the single pass leachate was about three times that of the recycle cells. Since this mass was removed and not converted to methane to any appreciable extent, it would

pose adverse environmental impacts, given an opportunity to migrate from the landfill site.

4. For the recycle cells, the COD concentration appeared to reach an initial saturation level and remain there without conversion by methane forming microorganisms to lower concentrations possibly due to end-product (VOA) repression. The utilization of pH adjustment and sludge seeding were effective in establishing a viable methane forming population with a concomitant production of additional intermediates and their collective conversion to CH_4 and CO_2 . No evidence of inhibition by the organic priority pollutant loadings to the simulated landfill systems was detected.
5. Early trace organic priority pollutant analysis identified two of the 12 selected priority pollutants added as spikes to the simulated landfill cells; phenol and di-n-butyl phthalate. These two compounds were also found in the leachate prior to the addition of the spike to the cells. However, some of the spike appears to have eluted through the waste mass in the spiked recycle cells. Since the leachate was collected and recirculated in the recycle option, the eluted priority pollutants were contained and additional opportunity for removal was provided. Under single pass management, the priority pollutants would be available for possible migration from the site with associated adverse environmental impact. Since none of the spiked priority pollutants were detected in any of the leachate samples from the single pass or recycle test cells, they were either removed within the landfill cell through physical-chemical or bioconversion processes or are still in the progress of partitioning through the refuse mass.
6. Adsorption characteristics of organic priority pollutants using activated carbon provided a basis for comparison of the adsorption tendencies of different priority pollutants on solid waste. The order of elution predicted by adsorption studies with activated carbon was very similar to the order observed in a small-scale supplementary elution test

performed using a column of refuse without the influence of biological activity. This evidence was used to predict a tentative sequence of elution of the selected priority pollutants: phenol > trichloroethene, hexachloroethane, 2,6-dinitrotoluene, 2,4-dinitrotoluene, di-n-butyl phthalate > 4,6-dinitro-o-cresol, butanone, pentachlorophenol, phenanthrene > 2,4'-dichlorobiphenyl, hexachlorobiphenyl. Although the elution tests with both distilled water and leachate to permit 20 bed volumes of displacement provided some indication of fractionation tendencies, operation of the simulated landfill cells for 450 days and an associated displacement of as much as 17 bed volumes in the recycle cells without release of the spiked priority pollutants emphasizes the impressive assimilative capacity of the landfill setting for these constituents.

7. Since a finite assimilative capacity for organic priority pollutants was indicated during these investigations and ascribed to various in situ attenuation mechanisms including sorption, bioconversion and complexation, additional studies on allowable loadings in codisposal circumstances are warranted. Information from such studies would provide both retrospective and prospective guidance for management and control of existing and proposed landfill disposal systems.

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APPENDIX A

Digestion Procedure for Metal in Leachate (27)

Acid soak all glassware with 2 N HNO_3 to minimize contamination. Place 50 mL of sample in a 250-mL beaker and add 5 mL of 1:1 diluted ultrapure HNO_3 (Ultrex). Cover the beaker with a watchglass and evaporate the solution on a hot plate at just under 100°C (not boiling) until the volume is near dryness. After cooling, repeat the procedure of adding HNO_3 and heating twice more. Then add 2 mL of concentrated (30%) H_2O_2 and heat until effervescence is observed. Cool the sample and repeat the step once. Add 1 mL of concentrated Ultrex to complete the digestion. Rinse the watchglass into the beaker and bring the volume to 50 mL with deionized water. Transfer the sample to a polyethylene bottle. Rinse the beaker with 5 mL of deionized water and add this rinse to the sample.

Prepare a deionized water blank using the digestion procedure along with the leachate samples for correction of possible metal introduction due to digestion procedures.

Dilute the samples appropriately to allow analysis within the optimum detection range for the various metals with the Atomic Absorption Spectrophotometer.

APPENDIX B
Tabulated Data

Table B1. Temperature Variations during Simulated Landfill Investigations

Time Since Leachate Production Began, days	Temperature, °C			
	Cell 1	Cell 2	Cell 3	Cell 4
0	32.8	32.8	32.2	28.9
1	32.8	32.8	32.2	29.4
2	31.7	31.1	31.1	28.4
3	31.7	31.1	30.6	30.6
4	30.6	30.6	30.0	28.9
5	30.6	30.6	30.3	30.0
6	30.9	30.6	30.9	27.8
7	30.6	30.3	30.0	28.9
8	31.1	30.9	30.9	30.0
9	31.7	30.9	31.1	27.2
10	32.0	31.7	31.7	28.9
11	31.4	31.1	31.4	28.9
12	30.9	30.9	30.9	28.9
13	31.1	30.9	31.7	28.9
14	31.7	31.5	31.4	32.2
15	32.2	32.2	31.8	31.7
16	32.8	32.2	31.7	30.6
17	34.1	33.9	33.0	33.9
18	34.7	34.8	34.1	34.4
19	33.6	33.6	33.0	32.8
20	32.8	32.8	32.2	32.5
21	32.2	31.9	32.2	31.8
22	32.8	31.9	31.9	31.8
23	32.8	33.1	32.2	33.0
24	33.1	32.8	32.2	32.2
25	31.7	31.5	31.5	33.9
26	31.8	31.1	31.7	33.3
27	32.8	32.8	32.2	31.7
28	31.7	31.5	31.5	31.0
29	31.8	31.1	31.7	31.7
30	32.8	32.8	32.5	31.7
31	33.1	32.8	31.7	34.5
32	31.7	31.7	31.7	28.0
33	32.5	32.0	31.7	32.8
34	32.5	32.0	31.7	32.2
35	33.0	32.7	32.0	32.5
36			32.0	32.8
37			32.3	
38				

Table B1 (Continued)

Time Since Leachate Production Began, days	Temperature, °C				
	Cell 1	Cell 2	Cell 3	Cell 4	Ambient
40	33.6	33.3	33.3	33.9	33.8
41	33.6	33.0	33.3	32.2	33.8
42	33.6	33.0	33.3	32.2	34.0
43	33.6	33.0	33.0	32.2	33.6
44	33.6	33.0	32.8	32	32.5
45	33.0	32.5	31.8	31.1	31.5
46	32.5	32.5	32.2	32.2	32.0
48	32.8	32.0	31.1	30.6	33.0
50	32.8	32.3	31.1	30.6	32.8
51	32.8	32.2	31.1	30	--
52	32.2	31.7	30.6	29.4	32.6
53	31.9	31.4	30.3	29.4	31.5
55	31.7	30.9	30.3	29.7	31.0
56	31.7	31.1	30.3	30.6	32.0
57	32.2	32.2	31.1	30	32.0
58	32.2	31.7	30.6	29.7	32.2
59	31.1	30.6	30.0	28.6	31.8
61	31.4	31.1	30.0	29.4	32.6
62	32.2	31.7	30.6	29.4	32.7
65	32.8	32.8	32.2	29.4	32.8
66	33.3	32.8	32.2	29.4	33.0
68	32.2	32.2	31.1	30	31.0
69	32.2	31.7	30.3	--	31.5
70	32.2	32.0	30.6	--	33.5
72	32.8	33.3	31.7	--	33.2
74	33.6	32.8	31.1	--	52.0
75	33.6	32.5	31.1	--	32.8
76	33.6	32.8	31.1	--	34.0
77	33.6	33.9	31.7	--	34.0
78	33.6	33.6	31.7	--	32.5

Table B1 (Continued)

Time Since Leachate Production Began, days	Temperature, °C				
	Cell 1	Cell 2	Cell 3	Cell 4	Ambient
87	36.1	35.6	34.4	30.3	30.5
89	35.0	34.7	33.3	29.7	30.0
91	35.0	34.4	33.6	30.0	35.0
94	33.3	32.8	32.2	29.2	32.0
98	33.9	33.3	32.2	29.4	33.5
101	32.8	32.2	31.7	29.2	33.0
104	33.3	33.3	31.9	29.7	33.0
107	34.2	33.9	32.8	30.0	34.5
110	33.9	33.1	32.2	29.4	32.5
113	33.1	33.1	31.9	31.7	33.5
116	32.8	33.3	31.7	29.2	32.5
119	33.3	33.1	32.2	30.0	34.5
122	35.3	35.0	33.6	30.0	34.5
126	33.9	33.3	32.2	31.1	33.2
128	33.3	33.1	32.2	28.6	34.0
131	34.4	33.6	32.5	30.3	35.0
135	33.9	33.3	32.5	30.0	34.0
137	33.6	33.1	32.5	30.0	34.5
141	33.9	33.3	32.5	28.9	34.0
143	34.2	33.9	32.5	30.0	33.0
147	32.8	32.5	31.1	28.9	33.5
149	33.1	33.1	31.9	29.7	33.0
152	34.2	33.9	32.8	32.2	35.0
156	34.7	33.9	33.1	32.8	35.0
158	33.6	33.1	32.8	31.4	34.0
162	35.0	33.9	33.3	30.6	34.5
163	33.9	33.3	32.2	31.7	34.5
166	33.6	33.1	32.2	31.7	33.0

Table B1 (Continued)

Time Since Leachate Production Began, days	Temperature, °C				
	Cell 1	Cell 2	Cell 3	Cell 4	Ambient
170	33.6	33.1	31.9	31.1	34.0
173	33.6	32.8	31.7	31.1	34.0
176	33.6	32.8	31.4	31.1	34.7
179	33.9	33.3	32.2	31.7	35.0
182	34.4	33.9	32.8	31.7	35.0
186	30.0	28.3	27.8	27.2	27.0
188	30.6	28.9	26.1	24.4	31.0
191	30.0	29.4	28.9	29.4	33.0
193	31.4	30.8	29.4	31.1	33.0
196	31.7	32.2	31.1	30.0	33.2
200	31.9	30.8	27.8	26.1	30.0
202	30.6	30.0	28.9	28.9	32.5
206	28.6	27.5	27.2	26.7	29.0
209	25.6	24.4	21.1	21.7	25.0
212	21.7	20.6	19.4	19.4	26.5
215	23.3	21.9	24.2	22.8	26.0
217	26.7	25.6	25.3	24.4	28.0
222	26.7	25.3	25.3	24.4	27.5
225	25.8	24.4	23.9	23.3	26.0
228	25.8	24.4	24.2	22.8	26.0
230	25.0	23.9	23.3	21.4	25.5
233	23.9	22.5	22.2	21.1	25.2
236	27.2	25.8	25.0	23.3	30.2
239	30.0	28.3	27.8	26.1	30.0
243	30.3	28.3	28.3	26.7	32.0
245	31.7	30.0	28.9	27.8	32.5
249	32.8	31.7	30.0	28.9	33.5
251	32.2	31.4	30.3	29.4	33.0
254	33.3	32.2	31.1	30.6	33.0
257	32.2	30.8	30.0	28.9	32.0

Table B1 (Continued)

Time Since Leachate Production Began, days	Temperature, °C				
	Cell 1	Cell 2	Cell 3	Cell 4	Ambient
260	32.5	31.1	30.6	29.2	33.0
263	32.8	31.4	30.6	29.4	32.0
266	30.8	29.4	28.6	27.8	29.5
269	30.6	28.3	27.2	25.0	29.5
272	29.4	27.8	27.2	26.1	32.0
275	31.9	30.0	28.9	26.4	33.0
278	30.8	28.9	28.6	27.2	30.5
281	30.8	28.9	28.3	26.7	31.5
284	30.6	28.6	27.8	26.4	30.0
287	30.8	28.9	28.3	26.9	32.0
290	30.6	28.6	26.9	26.9	30.0
293	30.6	28.6	28.1	26.4	30.5
296	31.4	29.4	28.3	27.2	31.0
299	31.9	30.6	29.2	27.8	31.0
302	31.7	30.0	28.6	26.9	30.0
305	31.1	29.7	27.5	26.1	32.0
308	31.1	29.4	27.8	26.7	30.0
311	30.3	29.2	27.8	26.4	31.0
314	32.2	30.8	29.2	28.6	32.0
317	31.1	30.0	28.6	27.2	30.0
320	30.3	28.6	27.2	25.8	29.5
322	27.2	25.6	25.0	23.3	28.0
326	29.4	28.1	26.7	25.0	29.0
329	31.4	29.4	28.1	26.9	32.0
332	32.8	31.4	29.4	28.3	31.5
335	31.7	30.0	28.3	27.2	31.5
338	30.3	28.6	26.7	25.0	27.5
341	28.9	27.2	25.3	23.9	29.0
344	31.4	30.3	28.3	26.7	33.0
347	33.3	32.2	30.0	28.6	33.0

Table B1 (Continued)

Time Since Leachate Production Began, days	Temperature, °C			
	Cell 1	Cell 2	Cell 3	Cell 4
350	32.2	31.1	29.2	27.8
353	32.2	30.6	29.2	28.1
356	30.3	29.2	27.8	26.4
359	31.4	30.3	28.3	26.9
362	30.6	29.4	27.8	26.4
365	32.8	31.9	29.7	28.9
368	36.7	32.5	30.6	29.4
371	33.3	32.2	30.3	29.4
374	31.9	30.6	28.3	27.2
377	29.2	27.8	26.1	24.7
380	32.5	31.1	29.2	28.1
382	32.5	31.4	29.4	28.3
385	31.7	31.1	28.9	27.2
388	31.9	30.6	28.6	27.8
391	30.3	29.2	27.5	26.4
394	26.7	25.3	24.4	23.1
397	25.3	23.9	23.1	21.1
400	25.0	24.2	23.3	21.4
402	23.1	21.9	21.1	19.4
405	25.3	23.9	23.1	21.1
408	20.3	19.4	18.1	16.7
411	23.3	22.2	20.8	19.4
413	24.7	23.3	22.2	20.3
415	24.4	23.1	21.9	20.6
418	23.9	22.5	21.4	19.4
421	25.0	23.9	22.8	20.8
424	26.1	25.0	23.9	22.2
427	24.7	23.6	22.2	20.6
				Ambient
				31.5
				31.5
				31.0
				31.5
				30.0
				35.0
				33.0
				33.0
				29.5
				30.0
				33.0
				33.0
				30.5
				30.0
				28.5
				26.0
				25.5
				22.0
				23.5
				22.0
				21.0
				27.0
				22.5
				24.2
				22.5
				26.0
				24.0
				24.5

Table B1 (Continued)

Time Since Leachate Production Began, days	Temperature, °C			
	Cell 1	Cell 2	Cell 3	Cell 4
430	25.0	23.9	22.8	20.8
434	25.6	24.2	22.8	21.1
437	22.8	21.7	20.6	19.6
440	25.6	24.4	22.8	21.1
				Ambient
				25.0
				23.2
				23.0
				25.0

Cell 1 - Control Recycle Cell; Cell 2 - Test Recycle Cell;

Cell 3 - Control Single Pass Cell; Cell 4 - Test Single Pass Cell

Table B2. Gross Parameter Analyses on Leachate Samples from Control Recycle Simulated Landfill Cell *

Time Since Leachate Production Began, days	0	1	5	7	8	10	11	12	14	15	17	19	23	26
COD, mg/L	53400	--	--	34750	--	32475	--	--	31293	--	34474	--	35740	--
COD mass, g	294	--	--	509	--	--	--	--	574	--	--	781	--	--
BOD ₅ , mg/L	36167	--	--	25000	--	--	--	--	19040	--	--	--	20200	--
BOD ₅ mass, g	199	--	--	366	--	--	--	--	343	--	--	457	--	--
TOC, mg/L	17200	--	--	11400	--	--	--	--	8400	--	--	--	8100	--
TOC mass, g	94.6	--	--	167	--	--	--	--	151	--	--	183	--	--
TVA, mg/L	4610	--	--	7885	7952	7818	7138	7700	8370	10150	13502	16145	15782	13896
TVA mass, g	25.4	--	--	116	--	--	--	--	140	--	--	239	--	--
Acetic acid, mg/L	4610	--	--	2785	2938	2900	2554	2650	3048	3489	4704	5272	5340	5076
Acetic acid mass, g	25.4	--	--	40.1	--	--	--	--	50.9	--	--	102	--	--
Propionic acid, mg/L	0	--	--	1030	1482	1452	1454	1656	1682	1848	2408	2817	2802	2308
Propionic acid mass, g	0	--	--	15.1	--	--	--	--	27.8	--	--	53.3	--	--
Isobutyric acid, mg/L	0	--	--	0	0	0	0	0	86	167	206	367	363	493
Isobutyric acid mass, g	0	--	--	0	--	--	--	--	0.3	--	--	5.6	--	--
Butyric acid, mg/L	0	--	--	6333	5515	5482	4990	5435	5495	7045	9236	11470	10464	8922
Butyric acid mass, g	0	--	--	92.8	--	--	--	--	96.9	--	--	209	--	--
Isovaleric acid, mg/L	0	--	--	0	0	0	0	0	0	0	127	163	400	164
Isovaleric acid mass, g	0	--	--	0	--	--	--	--	0	--	--	2.2	--	--
Valeric acid, mg/L	0	--	--	0	0	0	0	452	255	411	558	708	930	728
Valeric acid mass, g	0	--	--	0	--	--	--	--	2.5	--	--	12.6	--	--
Hexanoic acid, mg/L	--	--	--	--	--	--	--	--	--	--	0	0	0	0
Hexanoic acid mass, g	0	--	--	0	--	--	--	--	0	--	--	0	--	--
pH	4.70	4.77	5.83	5.74	5.24	5.27	5.23	5.31	5.40	5.43	5.32	5.33	5.31	--
Alkalinity, mg/L as CaCO ₃	7700	--	--	6775	--	--	--	--	5900	--	--	--	8575	--
Conductivity, μ mhos	12000	--	--	11500	--	--	--	--	11000	--	--	--	--	--
ORP, mV E _c	-84	-72	-116	-101	-71	-87	-78	-91	-89	-69	-59	-57	-48	--

Table B2 (Continued)

Time Since Leachate Production Began, days	28	29	30	32	35	37	44	46	50	51	52	53	55	58
COD, mg/L	35667	--	--	31071	30666	29464	25806	24242	23728	23718	--	--	28195	28330
COD mass, g	--	--	993	--	--	--	970	--	--	--	--	--	--	772
BOD ₅ , mg/L	22159	--	--	--	--	18000	16001	--	--	17399	--	--	--	16954
BOD ₅ mass, g	--	--	616	--	--	--	575	--	--	--	--	--	--	523
TOC, mg/L	9600	--	--	--	--	8080	7610	7975	--	9000	--	9030	--	8648
TOC mass, g	--	--	267	--	--	--	258	--	--	--	--	--	--	263
TVA, mg/L	--	13654	--	11643	--	13996	10869	9939	10407	10674	--	10661	11214	12043
TVA mass, g	--	--	327	--	--	--	356	--	--	--	--	--	--	339
Acetic acid, mg/L	--	5272	--	4868	--	5848	4912	4452	4956	4712	--	4760	5328	5360
Acetic acid mass, g	--	--	145	--	--	--	171	--	--	--	--	--	--	152
Propionic acid, mg/L	--	2069	--	1722	--	1886	1646	1577	1576	1738	--	1598	1604	1884
Propionic acid mass, g	--	--	66.5	--	--	--	57.6	--	--	--	--	--	--	50.8
Isobutyric acid, mg/L	--	517	--	654	--	885	616	547	530	578	--	558	600	627
Isobutyric acid mass, g	--	--	12.7	--	--	--	24.6	--	--	--	--	--	--	17.9
Butyric acid, mg/L	--	7832	--	5376	--	5532	3577	3036	2972	3296	--	3583	3227	3602
Butyric acid mass, g	--	--	282	--	--	--	174	--	--	--	--	--	--	103
Isovaleric acid, mg/L	--	104	--	88	--	152	78	80	79	83	--	96	146	124
Isovaleric acid mass, g	--	--	6.2	--	--	--	3.8	--	--	--	--	--	--	2.9
Valeric acid, mg/L	--	600	--	579	--	831	606	606	610	656	--	604	684	750
Valeric acid mass, g	--	--	20.9	--	--	--	22.5	--	--	--	--	--	--	19.6
Hexanoic acid, mg/L	--	1162	--	1699	--	3233	2639	2540	2672	2860	--	2654	2881	3404
Hexanoic acid mass, g	--	--	10.8	--	--	--	78.7	--	--	--	--	--	--	84.7
pH	5.25	--	--	5.32	--	5.45	5.26	--	5.61	--	--	--	5.46	5.54
Alkalinity, mg/L as CaCO ₃	--	--	--	--	--	7000	6031	--	--	6156	--	6469	--	--
Conductivity, μ mhos	--	--	--	--	10500	11000	10200	--	--	--	12000	11600	--	10200
ORP, mV E _c	-82	--	--	-48	--	-22	-18	-42	--	-54	--	--	-51	-44

Table B2 (Continued)

Time Since Leachate Production Began, days	62	65	69	70	72	76	77	79	83	84	86	90	93	97	100
COD, mg/L	28356	27824	29302	28898	28764	25398	25124	25125	28706	--	29172	29319	29401	28278	27984
COD mass, g	--	856	--	--	--	--	--	793	--	--	848.9	--	849.7	--	794.7
BOD ₅ , mg/L	--	16333	--	--	18171	--	--	20446	--	--	16082	--	19617	--	20467
BOD ₅ mass, g	--	512	--	--	--	--	--	497	--	--	468.0	--	566.9	--	581.3
TOC, mg/L	--	8900	--	--	8215	--	8660	8895	--	--	7459	--	8497	--	--
TOC mass, g	--	2.1	--	--	--	--	--	248	--	--	217.1	--	245.6	--	--
TVA, mg/L	10495	10714	9637	--	9587	8738	--	9128	--	--	10293	10172	13043	12227	12621
TVA mass, g	--	340	--	--	--	--	--	279	--	--	299.5	--	367.9	--	358.4
Acetic acid, mg/L	4528	4676	4556	--	4448	4188	--	4156	--	--	4880	4892	5587	6256	5783
Acetic acid mass, g	--	149	--	--	--	--	--	129	--	--	142.0	--	161.5	--	162.2
Propionic acid, mg/L	1626	1564	1524	--	1556	1419	--	1582	--	--	1667	1586	1782	1915	1991
Propionic acid mass, g	--	53.0	--	--	--	--	--	43.7	--	--	48.5	--	51.5	--	56.5
Isobutyric acid, mg/L	564	505	511	--	433	402	--	454	--	--	534	542	620	656	631
Isobutyric acid mass, g	--	18.0	--	--	--	--	--	13.3	--	--	15.5	--	17.9	--	17.9
Isobutyric acid, mg/L	3442	3729	2532	--	2882	2364	--	2571	--	--	2840	2832	3348	3853	3758
Butyric acid, mg/L	--	106	--	--	--	--	--	83	--	--	82.6	--	96.8	--	106.7
Butyric acid mass, g	--	--	--	--	--	--	--	84	--	--	112	121	138	--	130
Isovaleric acid, mg/L	416	254	243	--	75	53	--	4.5	--	--	3.3	--	4.0	--	3.7
Isovaleric acid mass, g	--	8.2	--	--	--	--	--	592	--	--	667	661	831	927	957
Valeric acid, mg/L	924	762	772	--	609	550	--	19.4	--	--	19.4	--	24.0	--	24.3
Valeric acid mass, g	--	25.3	--	--	--	--	--	2380	--	--	2524	2390	3438	3897	3197
Hexanoic acid, mg/L	2189	2491	2273	--	2352	2267	--	67.6	--	--	73.4	--	99.4	--	90.8
Hexanoic acid mass, g	--	84.5	--	--	--	--	--	5.16	--	--	5.29	--	5.39	5.35	5.34
pH	5.45	5.31	--	5.39	5.30	5.10	--	6550	--	--	7200	--	7000	6931	6938
Alkalinity mg/L as CaCO ₃	6625	--	--	--	10800	--	--	11000	--	--	--	--	11900	12200	11600
Conductivity, μ mhos	--	11700	--	--	--	--	--	--	--	--	--	--	--	--	--
ORP, mV E _c	-32	-197	--	-163	--	--	--	--	--	-115	--	--	-36	-45	-22

Table B2 (Continued)

Time Since Leachate Production Began, days	104	107	111	112	114	119	121	122	123	128	135	142	149	156
COD, mg/L	27625	26940	--	26640	26726	--	28752	28031	--	28704	28168	28848	29329	29430
COD mass, g	--	751.6	--	--	732.3	--	773.4	--	--	760.7	735.2	738.5	703.9	697.5
BOD ₅ , mg/L	--	20613	--	--	21707	--	18500	--	--	21800	22133	17400	15800	15750
BOD ₅ mass, g	--	575.1	--	--	594.8	--	497.7	--	--	577.7	577.7	445.4	379.2	373.3
TOC, mg/L	9824	--	--	--	9147	--	8988	--	--	11623	9024	8956	10151	6291
TOC mass, g	259.4	--	--	--	250.6	--	241.8	--	--	308.0	235.5	229.3	243.6	149.1
TVA, mg/L	12344	11504	--	11962	13609	12938	11893	--	--	11780	13731	13724	12170	11805
TVA mass, g	--	321.0	--	--	372.9	--	319.9	--	--	312.2	358.4	351.3	292.1	279.8
Acetic acid, mg/L	5704	5233	--	5747	6246	6087	5815	--	--	5050	6539	6655	5706	5426
Acetic acid mass, g	--	146.0	--	--	171.1	--	156.4	--	--	133.8	170.7	170.4	136.9	128.6
Propionic acid, mg/L	1930	1740	--	1826	1980	1916	1759	--	--	2007	2017	2049	1855	1904
Propionic acid mass, g	--	48.5	--	--	54.3	--	47.3	--	--	53.2	52.6	52.5	44.5	42.8
Isobutyric acid, mg/L	610	617	--	602	687	647	580	--	--	661	666	620	663	660
Isobutyric acid mass, g	--	17.2	--	--	18.8	--	15.6	--	--	17.5	17.4	15.9	15.9	15.6
Butyric acid, mg/L	3659	3423	--	3411	3919	3738	3379	--	--	3577	3836	3787	3469	3413
Butyric acid mass, g	--	95.5	--	--	107.4	--	90.9	--	--	94.8	100.1	96.9	83.3	80.9
Isovaleric acid, mg/L	122	126	--	130	184	137	98	--	--	147	168	169	165	144
Isovaleric acid mass, g	--	3.5	--	--	5.0	--	2.6	--	--	3.9	4.4	4.3	4.0	3.4
Valeric acid, mg/L	828	788	--	772	1002	876	762	--	--	856	941	918	936	830
Valeric acid mass, g	--	22.0	--	--	27.5	--	20.5	--	--	22.7	24.6	23.5	20.1	19.7
Hexanoic acid, mg/L	3111	3038	--	2843	3716	3315	2802	--	--	3144	3554	3343	3010	3035
Hexanoic acid mass, g	--	84.8	--	--	101.8	--	75.4	--	--	83.3	92.8	85.6	72.2	71.9
pH	--	5.45	--	--	5.35	--	5.39	--	--	5.30	4.98	5.35	5.10	5.13
Alkalinity, mg/L as CaCO ₃	--	6969	--	--	7219	--	7219	--	--	7125	6594	7088	6938	7031
Conductivity, μ mhos	--	12000	--	--	12800	--	12800	--	--	9600	9800	10800	10200	8600
ORP, mV E _c	-36	-83	-50	--	-43	--	--	--	-75	--	-71	-143	-122	-81

Table B2 (Continued)

Time Since Leachate Production Began, days	166	177	184	193	199	220	228	235	244	250	264	268	274	282
COD, mg/L	28636	29201	29185	29325	29127	27543	29666	30124	29964	30050	30327	--	28985	29754
COD mass, g	615.7	513.9	586.6	563.0	480.6	487.5	578.5	617.5	686.2	685.1	837.0	--	773.9	761.7
BOD ₅ , mg/L	15920	15467	18100	15250	15587	14680	15253	14200	16700	16200	--	15100	14013	15053
BOD ₅ mass, g	342.3	272.2	363.8	292.8	257.2	259.8	297.4	291.1	382.4	369.4	--	416.8	374.1	385.4
TOC, mg/L	10211	9327	9536	9610	9585	8127	7092	7548	8793	8345	9710	--	9910	9965
TOC mass, g	219.5	164.2	191.7	184.5	158.2	143.8	138.3	154.7	201.4	190.3	268.0	--	264.6	255.1
TVA, mg/L	12885	14063	13018	12851	12812	13086	--	13456	15055	15576	14933	--	13519	14748
TVA mass, g	277.0	247.5	261.7	246.7	211.4	231.6	--	275.8	344.8	355.1	412.2	--	361.0	377.5
Acetic acid, mg/L	6607	6999	6650	6585	6570	6081	--	6359	7509	7531	7263	--	6408	6632
Acetic acid mass, g	142.1	123.2	133.7	126.4	108.4	107.6	--	130.4	172.0	171.1	200.5	--	171.1	169.8
Propionic acid, mg/L	1963	2179	2050	1960	1957	2065	--	2103	2339	2342	2350	--	2076	2332
Propionic acid mass, g	42.2	38.4	41.2	37.6	32.3	36.6	--	43.1	53.6	53.4	64.9	--	55.4	59.7
Isobutyric acid, mg/L	621	702	625	620	618	747	--	746	806	878	833	--	753	1284
Isobutyric acid mass, g	13.4	12.4	12.6	11.9	10.2	13.2	--	15.3	18.5	20.0	23.0	--	20.1	32.9
Butyric acid, mg/L	3483	3737	3500	3480	3463	3724	--	3702	3963	4189	3982	--	3590	4443
Butyric acid mass, g	74.9	65.8	70.4	66.8	57.1	65.9	--	75.9	90.8	95.5	109.9	--	95.8	113.7
Isovaleric acid, mg/L	161	177	159	155	160	136	--	126	121	114	177	--	152	144
Isovaleric acid mass, g	3.5	3.1	3.2	3.0	2.6	2.4	--	2.6	2.8	2.6	4.9	--	4.1	3.4
Valeric acid, mg/L	773	895	768	775	745	940	--	932	995	1096	1024	--	967	1021
Valeric acid mass, g	16.6	15.8	15.4	14.9	12.3	16.6	--	19.1	22.8	25.0	28.3	--	25.8	26.1
Hexanoic acid, mg/L	2594	3177	2612	2585	2598	3196	--	3364	3374	3835	3439	--	3503	3169
Hexanoic acid mass, g	55.8	55.9	52.5	49.6	42.9	56.6	--	69.0	77.3	87.4	94.9	--	93.5	81.1
pH	5.45	5.42	5.70	5.56	5.60	5.60	5.54	5.61	5.60	5.68	5.56	--	5.34	5.36
Alkalinity, mg/L as CaCO ₃	7625	7531	9188	7850	7844	8415	8360	8415	8498	8635	8525	--	7893	8085
Conductivity, umhos	6100	7000	7800	8000	9850	8200	7800	8100	9000	7200	10200	--	9100	9100
ORP, mV E _c	-50	-39	-70	-80	-60	-120	-76	-91	-92	-162	-199	--	-220	-203

Table B2 (Continued)

Time Since Leachate Production Began, days	286	291	298	305	311	315	321	329	336	344	352	359	361	362
COD, mg/L	30577	31149	29397	27118	--	26056	24915	19032	14199	13274	13263	11561	--	--
COD mass, g	752.2	747.6	643.8	545.1	--	208.4	480.9	291.2	153.3	87.6	87.5	78.6	--	--
BOD ₅ , mg/L	--	15147	19120	17133	17020	--	15347	15253	10000	9573	9033	4150	--	--
BOD ₅ mass, g	--	363.5	418.7	344.4	136.2	--	296.2	233.4	108.0	63.0	59.6	28.2	--	--
TOC, mg/L	--	10355	6950	6401	4271	--	3271	2845	2750	3623	3966	2584	--	--
TOC mass, g	--	248.5	152.2	128.7	34.2	--	63.1	43.5	29.7	23.9	26.2	17.6	--	--
TVA, mg/L	13718	13040	--	11653	11600	--	10824	9743	7946	7728	9013	4197	--	--
TVA mass, g	337.5	313.0	--	234.2	92.8	--	208.9	149.1	85.8	51.0	59.5	28.5	--	--
Acetic acid, mg/L	6744	6532	--	5461	5522	--	5119	4845	3866	4008	4704	1858	--	--
Acetic acid mass, g	165.9	156.8	--	109.8	44.2	--	98.8	74.1	41.8	26.5	31.0	12.6	--	--
Propionic acid, mg/L	2099	2045	--	1830	2316	--	2539	2939	3614	4112	4758	2450	--	--
Propionic acid mass, g	51.6	49.1	--	36.8	18.5	--	49.0	45.0	39.0	27.1	31.4	16.7	--	--
Isobutyric acid, mg/L	778	753	--	669	593	--	548	342	186	50	90	93	--	--
Isobutyric acid mass, g	19.1	18.1	--	13.4	4.7	--	10.5	5.2	2.0	0.3	0.6	0.6	--	--
Butyric acid, mg/L	3566	3471	--	2995	2442	--	2088	1196	479	175	218	105	--	--
Butyric acid mass, g	87.7	83.3	--	60.2	19.5	--	40.3	18.3	5.2	1.2	1.4	0.7	--	--
Isovaleric acid, mg/L	102	92	--	15	40	--	10	15	10	10	10	48	--	--
Isovaleric acid mass, g	2.5	2.2	--	0.3	0.3	--	0.2	0.2	0.1	0.1	0.1	0.3	--	--
Valeric acid, mg/L	941	893	--	850	874	--	858	767	529	226	284	196	--	--
Valeric acid mass, g	23.1	21.4	--	17.1	7.0	--	16.6	11.7	5.7	1.5	1.9	1.3	--	--
Hexanoic acid, mg/L	3286	2694	--	3294	3086	--	2592	1950	736	184	136	145	--	--
Hexanoic acid mass, g	80.8	64.7	--	66.2	24.7	--	50.0	29.8	7.9	1.2	0.9	0.9	--	--
pH	--	5.36	5.37	5.40	5.52	--	5.63	5.76	5.87	5.12	5.04	5.55	6.39	6.49
Alkalinity, mg/L as CaCO ₃	--	8003	7837	7563	8360	--	7700	6435	5198	3960	3685	2943	--	--
Conductivity, μ mhos	--	9100	9000	9500	10800	--	8900	9600	7900	7800	7550	7700	--	--
ORP, mV E _c	--	-193	--	--	--	--	--	-230	-239	-240	-215	-230	--	--

Table B2 (Continued)

Time Since Leachate Production Began, days	365	367	371	372	379	383	385	389	398	410	425
COD, mg/L	5045	--	--	2772	2180	--	--	1841	1704	1600	1275
COD mass, g	13.6	--	--	5.8	4.6	--	--	2.9	1.0	0.5	--
BOD ₅ , mg/L	2750	--	--	726	228	--	--	223	215	200	180
BOD ₅ mass, g	7.4	--	--	1.5	0.5	--	--	0.4	0.1	0.06	--
TOC, mg/L	1664	--	--	817	500	--	--	386	350	280	100
TOC mass, g	4.5	--	--	1.8	1.1	--	--	0.6	0.2	0.08	--
TVA, mg/L	1731	--	--	486	233	--	--	36	104	47	26
TVA mass, g	4.7	--	--	1.0	0.5	--	--	0.06	0.06	0.01	--
Acetic acid, mg/L	695	--	--	123	104	--	--	17	62	24	10
Acetic acid mass, g	1.9	--	--	0.3	0.2	--	--	0.03	0.04	0.007	--
Propionic acid, mg/L	1198	--	--	373	122	--	--	7	20	10	10
Propionic acid mass, g	3.2	--	--	0.8	0.3	--	--	0.01	0.01	0.003	--
Isobutyric acid, mg/L	52	--	--	20	10	--	--	5	6	5	5
Isobutyric acid mass, g	0.1	--	--	0.04	0.02	--	--	0.008	0.004	0.002	--
Butyric acid, mg/L	10	--	--	20	10	--	--	5	12	5	2
Butyric acid mass, g	0.03	--	--	0.04	0.02	--	--	0.008	0.007	0.002	--
Isovaleric acid, mg/L	20	--	--	20	10	--	--	5	6	5	2
Isovaleric acid mass, g	0.05	--	--	0.04	0.02	--	--	0.008	0.004	0.002	--
Valeric acid, mg/L	10	--	--	20	10	--	--	2	10	5	2
Valeric acid mass, g	0.03	--	--	0.04	0.02	--	--	0.003	0.006	0.002	--
Hexanoic acid, mg/L	10	--	--	20	10	--	--	5	8	5	2
Hexanoic acid mass, g	0.03	--	--	0.04	0.02	--	--	0.01	0.005	0.002	--
pH	6.91	6.87	6.90	7.37	7.14	6.97	6.95	7.07	7.08	7.15	7.10
Alkalinity, mg/L as CaCO ₃	3218	--	--	3190	3190	--	--	3053	2998	3053	2875
Conductivity, μ mhos	7050	--	--	5600	5200	--	--	5050	4950	4800	4200
ORP, mV E _c	-235	--	--	-241	-243	--	--	-240	-230	-215	-220

*Cell 1

Table B3. Gross Parameter Analyses on Leachate Samples from Spiked Recycle Simulated Landfill Cell *

Time Since Leachate Production Began, days	0	1	5	7	8	10	11	12	14	15	17	19	23	26
COD, mg/L	46300	--	--	33380	--	31420	--	--	31424	--	36031	--	28156	--
COD mass, g	255	--	--	506	--	--	--	--	613	--	--	887	--	--
BOD ₅ , mg/L	31667	--	--	24500	--	--	--	--	18667	--	--	--	22600	--
BOD ₅ mass, g	174	--	--	371	--	--	--	--	364	--	--	556	--	--
TOC, mg/L	14600	--	--	10950	--	--	--	--	8700	--	--	--	9260	--
TOC mass, g	80.3	--	--	166	--	--	--	--	170	--	--	228	--	--
TVA, mg/L	5068	--	--	7751	7324	7631	7521	7354	8374	9508	14284	16911	16508	17534
TVA mass, g	27.9	--	--	117	--	--	--	--	145	--	--	302	--	--
Acetic acid, mg/L	4650	--	--	2782	2613	2300	2225	2012	2556	3002	4496	5348	5252	6236
Acetic acid mass, g	25.6	--	--	42.1	--	--	--	--	42.7	--	--	105.4	--	--
Propionic acid, mg/L	218	--	--	1050	1291	1254	1360	1317	1272	1566	2245	2704	2704	2742
Propionic acid mass, g	1.2	--	--	15.9	--	--	--	--	25.3	--	--	53.5	--	--
Isobutyric acid, mg/L	176	--	--	0	0	0	0	0	85	137	284	270	301	502
Isobutyric acid mass, g	1.0	--	--	0	--	--	--	--	0.3	--	--	5.7	--	--
Butyric acid, mg/L	178	--	--	6035	5742	5672	5875	5875	6100	6980	9732	12568	11718	12088
Butyric acid mass, g	1.0	--	--	91.4	--	--	--	--	114	--	--	240	--	--
Isovaleric acid, mg/L	0	--	--	0	0	0	0	0	0	0	423	141	343	134
Isovaleric acid mass, g	0	--	--	0	--	--	--	--	0	--	--	4.6	--	--
Valeric acid, mg/L	0	--	--	0	0	0	313	346	964	647	1088	898	1124	690
Valeric acid mass, g	0	--	--	0	--	--	--	--	6.3	--	--	21.6	--	--
Hexanoic acid, mg/L	--	--	--	--	--	--	--	--	--	--	--	0	0	0
Hexanoic acid mass, g	0	--	--	0	--	--	--	--	0	--	--	0	--	--
pH	4.68	4.81	5.77	5.67	5.30	5.29	5.32	5.43	5.45	5.39	5.42	5.38	5.60	--
Alkalinity, mg/L as CaCO ₃	7150	--	--	6700	--	--	--	--	5800	--	--	7500	--	--
Conductivity, μ mhos	11200	--	--	11500	--	--	--	--	12000	--	--	--	--	--
ORP, mV E _c	-81	-74	-107	-101	-73	-93	-86	-93	-76	-71	-63	-66	-51	--

Table B3 (Continued)

Time Since Leachate Production Began, days	28	29	30	32	35	37	44	46	50	51	52	53	55	58
COD, mg/L	37352	--	--	32016	31790	30994	27472	24964	25368	25570	--	--	29824	30565
COD mass, g	--	--	1123	--	--	--	1094	--	--	--	--	--	--	898
BOD ₅ , mg/L	22826	--	--	--	--	19067	17233	--	--	18893	--	--	--	17333
BOD ₅ mass, g	--	--	679	--	--	--	660	--	--	--	--	--	--	609
TOC, mg/L	10400	--	--	--	--	8170	7200	8100	--	9359	--	9240	--	9645
TOC mass, g	--	--	309	--	--	--	283	--	--	--	--	--	--	286
TVA, mg/L	--	16836	--	13840	--	14673	10620	10192	10071	10466	--	10651	12747	11337
TVA mass, g	--	--	500	--	--	--	494	--	--	--	--	--	--	364
Acetic acid, mg/L	--	5664	--	6105	--	5912	5060	4380	4582	4756	--	4780	5748	5072
Acetic acid mass, g	--	--	170	--	--	--	208	--	--	--	--	--	--	165
Propionic acid, mg/L	--	2370	--	2093	--	2098	1554	1584	1497	1570	--	1575	1828	1683
Propionic acid mass, g	--	--	77.5	--	--	--	72.6	--	--	--	--	--	--	54.0
Isobutyric acid, mg/L	--	601	--	662	--	941	927	937	916	948	--	871	1033	876
Isobutyric acid mass, g	--	--	13.9	--	--	--	27.8	--	--	--	--	--	--	31.6
Butyric acid, mg/L	--	10780	--	7592	--	7896	3274	3527	3236	3330	--	3539	4169	3733
Butyric acid mass, g	--	--	342	--	--	--	268	--	--	--	--	--	--	118
Isovaleric acid, mg/L	--	249	--	96	--	137	65	77	73	75	--	86	255	132
Isovaleric acid mass, g	--	--	7.2	--	--	--	4.0	--	--	--	--	--	--	3.5
Valeric acid, mg/L	--	1186	--	606	--	727	605	636	615	640	--	624	853	685
Valeric acid mass, g	--	--	29.8	--	--	--	23.1	--	--	--	--	--	--	22.3
Hexanoic acid, mg/L	--	379	--	0	--	1023	2086	2011	2014	2131	--	2266	2561	2474
Hexanoic acid mass, g	--	--	3.8	--	--	--	17.7	--	--	--	--	--	--	73.4
pH	--	--	--	5.31	--	5.37	5.12	--	--	5.48	--	--	5.35	5.52
Alkalinity, mg/L as CaCO ₃	--	--	--	--	--	6958	6.50	--	--	6231	--	7125	--	--
Conductivity, μ mhos	--	--	--	--	10600	10700	16.00	--	--	--	--	11800	--	10400
ORP, mV E _c	-74	--	--	-40	--	-35	-20	-60	--	-47	--	--	-29	-40

Table B3 (Continued)

Time Since Leachate Production Began, days	62	65	69	70	72	76	77	79	83	84	86	90	93	97	100
COD, mg/L	30121	28408	30656	31162	30702	26472	26918	26329	29174	--	29798	30342	30250	28766	28982
COD mass, g	--	990	--	--	--	--	--	911	--	--	911.8	--	916.6	--	863.7
BOD ₅ , mg/L	--	17000	--	--	20362	--	--	20669	--	--	16832	--	20283	--	21133
BOD ₅ mass, g	--	565	--	--	--	--	--	586	--	--	515.1	--	614.6	--	629.8
TOC, mg/L	--	9720	--	--	8410	--	9270	9063	--	--	8132	--	9450	--	--
TCC mass, g	--	315	--	--	--	--	--	287	--	--	248.8	--	286.3	--	--
TVA, mg/L	10969	12013	10807	--	10172	10182	--	9913	--	--	9949	10453	15100	13167	13397
Acetic acid, mg/L	--	364	--	--	--	--	--	339	--	--	304.4	--	457.5	--	399.2
Acetic acid mass, g	4788	5796	5028	--	4844	4780	--	4484	--	--	4840	4772	5587	7004	6122
Propionic acid, mg/L	--	161	--	--	--	--	--	160	--	--	148.1	--	169.3	--	182.4
Propionic acid mass, g	1697	1716	1685	--	1671	1638	--	1682	--	--	1512	1636	1863	2026	2060
Isobutyric acid, mg/L	--	55.1	--	--	--	--	--	52.6	--	--	46.3	--	56.4	--	61.4
Isobutyric acid mass, g	756	814	767	--	813	730	--	754	--	--	750	860	961	1042	1021
Isobutyric acid mass, g	--	26.4	--	--	--	--	--	24.5	--	--	24.5	--	26.1	--	30.4
Butyric acid, mg/L	3919	3698	3213	--	3027	3140	--	2898	--	--	2984	3318	3846	4430	4290
Butyric acid mass, g	--	125	--	--	--	--	--	103	--	--	91.3	--	115.4	--	127.8
Isovaleric acid, mg/L	273	358	148	--	106	77	--	154	--	--	96	142	148	146	135
Isovaleric acid mass, g	--	6.6	--	--	--	--	--	5.4	--	--	2.9	--	4.5	--	4.0
Valeric acid, mg/L	888	962	754	--	412	621	--	690	--	--	598	686	896	930	862
Valeric acid mass, g	--	25.7	--	--	--	--	--	21.6	--	--	18.3	--	27.1	--	25.7
Hexanoic acid, mg/L	1812	1886	2265	--	2036	1987	--	2090	--	--	1800	1984	2994	3222	2703
Hexanoic acid mass, g	--	69.9	--	--	--	--	--	64.1	--	--	55.1	--	90.7	--	80.7
pH	5.43	5.29	--	5.36	5.25	5.08	--	5.06	--	--	5.15	--	5.17	5.15	5.39
Alkalinity, mg/L as CaCO ₃	6812	--	--	--	--	--	--	6650	--	--	7188	--	7125	7062	7062
Conductivity, umhos	--	10900	--	--	11500	--	--	11200	--	--	--	--	12300	12400	11400
ORP, mV E _c	-13	-186	--	-177	--	--	--	--	--	-103	--	--	-63	-14	-30

Table B3 (Continued)

Time Since Leachate Production Began, days	104	107	111	112	114	119	121	122	123	128	135	142	149	156
COD, mg/L	28900	29282	--	26398	28338	--	30098	29291	--	29826	30305	30186	29967	30433
COD mass, g	--	858.0	--	--	816.1	--	851.8	--	--	832.1	833.4	818.0	758.2	763.9
BOD ₅ , mg/L	--	20947	--	--	22507	--	21280	--	--	23000	23400	19200	18400	17950
BOD ₅ mass, g	--	613.7	--	--	648.2	--	602.2	--	--	641.7	643.5	520.3	465.5	450.5
TOC, mg/L	11126	--	--	--	9986	--	9307	--	--	11165	9455	9060	10532	6504
TOC mass, g	304.9	--	--	--	287.6	--	263.4	--	--	311.5	260.0	245.5	266.5	163.3
TVA, mg/L	13097	12622	--	12022	13763	12865	12349	--	--	12972	14547	14518	12979	12919
TVA mass, g	5231	369.8	--	--	396.4	--	349.5	--	--	361.9	400.0	393.4	328.4	324.3
Acetic acid, mg/L	--	5760	--	5781	6619	6363	6143	--	--	5678	6911	7004	6031	6041
Acetic acid mass, g	--	168.8	--	--	190.6	--	173.8	--	--	158.4	190.1	189.8	152.6	151.6
Propionic acid, mg/L	2859	1840	--	1808	1980	1916	1759	--	--	2143	2087	2115	1942	1951
Propionic acid mass, g	--	53.9	--	--	57.0	--	49.8	--	--	59.8	57.4	57.3	49.1	49.0
Isobutyric acid, mg/L	1008	1031	--	913	1018	958	903	--	--	1076	1078	1103	1079	1071
Isobutyric acid mass, g	--	30.2	--	--	29.3	--	25.6	--	--	30.0	29.6	29.9	27.3	26.9
Isobutyric acid, mg/L	4268	4096	--	3661	4202	3887	3653	--	--	4175	4403	4306	3974	3919
Butyric acid, mg/L	--	120.0	--	--	121.0	--	103.3	--	--	116.5	121.1	116.7	100.5	98.4
Butyric acid mass, g	133	141	--	116	139	49.0	73	--	--	150	164	169	147	137
Isovaleric acid, mg/L	--	4.1	--	--	4.0	--	2.1	--	--	4.2	4.5	4.6	3.7	3.5
Isovaleric acid mass, g	849	814	--	726	859	763	701	--	--	872	920	912	838	828
Valeric acid, mg/L	--	23.9	--	--	24.7	--	19.8	--	--	24.3	25.3	24.7	21.2	20.8
Valeric acid mass, g	2662	2544	--	2250	2713	2341	2258	--	--	2664	3040	2860	2615	2579
Hexanoic acid, mg/L	--	74.5	--	--	78.1	--	63.9	--	--	74.3	83.6	77.5	66.2	64.7
Hexanoic acid mass, g	--	5.20	--	--	5.09	--	5.13	--	--	5.01	4.98	5.09	5.03	5.08
pH	--	7219	--	--	7156	--	7344	--	--	7156	6656	7219	7312	7375
Alkalinity, mg/L as CaCO ₃	--	12400	--	--	12600	--	13000	--	--	10000	9900	11400	10000	9000
Conductivity, μ mhos	--	-110	-67	--	-56	--	--	--	-78	--	-90	-193	-112	-100
ORP, mV _{Ec}	-27	--	--	--	--	--	--	--	--	--	--	--	--	--

Table B3 (Continued)

Time Since Leachate Production Began, days	166	177	184	193	199	220	228	235	244	250	264	274	282
COD, mg/L	29908	29974	30060	30101	30195	28926	30218	30302	30989	30670	30630	30302	30723
COD mass, g	684.9	587.5	649.3	629.1	543.5	552.5	622.5	624.5	743.7	739.1	786.5	760.6	817.2
BOD ₅ , mg/L	17650	16000	16467	16125	16253	15747	15853	15000	17200	16850	15500	14013	15653
BOD ₅ mass, g	404.2	313.6	355.7	337.0	629.6	300.8	326.6	324.0	412.8	406.1	398.4	351.7	416.4
TOC, mg/L	10685	9759	9965	10050	9995	8499	9158	10467	9401	9250	10673	10389	10667
TOC mass, g	244.7	191.3	215.2	210.0	179.9	162.3	188.7	226.1	225.6	222.9	274.3	260.8	283.7
TVA, mg/L	13369	14981	14461	14192	14254	14354	--	14655	16329	16767	15963	14403	16056
TVA mass, g	306.2	293.6	312.4	296.6	256.6	274.2	--	316.5	391.9	404.1	410.2	361.5	427.1
Acetic acid, mg/L	7291	7635	7315	7190	7208	6781	--	6947	8202	8206	7952	6997	7087
Acetic acid mass, g	167.0	149.6	158.0	150.3	129.7	129.5	--	150.1	196.8	197.8	204.4	175.6	188.5
Propionic acid, mg/L	2097	2343	2150	2075	2097	2229	--	2267	2534	2514	2503	2240	2591
Propionic acid mass, g	48.0	45.9	46.4	43.4	37.7	42.5	--	49.0	60.8	60.6	64.3	56.2	68.9
Isobutyric acid, mg/L	1030	1068	1035	995	1015	1163	--	1142	1225	1288	1221	1083	1023
Isobutyric acid mass, g	23.6	20.9	22.4	20.8	18.3	22.2	--	24.7	29.4	31.0	31.4	27.2	27.2
Butyric acid, mg/L	4112	4164	4150	4085	4110	4291	--	4245	4532	4737	4421	4039	4635
Butyric acid mass, g	94.2	81.6	89.6	85.4	74.0	82.0	--	91.7	108.8	114.2	113.6	101.4	123.3
Isovaleric acid, mg/L	155	143	148	148	161	129	--	147	147	150	134	139	177
Isovaleric acid mass, g	3.5	2.8	3.2	3.1	2.9	2.5	--	3.2	3.5	3.6	3.4	3.5	4.7
Valeric acid, mg/L	810	843	821	807	798	952	--	956	993	1083	989	915	1212
Valeric acid mass, g	18.5	16.5	17.7	16.9	14.4	18.2	--	20.6	23.8	26.1	25.4	23.0	32.2
Hexanoic acid, mg/L	2399	2519	2515	2510	2495	2736	--	3001	2863	3275	2858	2863	4248
Hexanoic acid mass, g	54.9	49.4	54.3	52.5	44.9	52.3	--	64.8	68.7	78.9	73.5	71.9	113.0
pH	5.36	5.37	5.52	5.47	5.50	5.43	5.37	5.49	5.48	5.52	5.49	5.27	5.30
Alkalinity, mg/L as CaCO ₃	8000	7875	8188	8100	8250	8663	8605	8745	8718	8690	8910	8278	8250
Conductivity, umhos	6400	7000	7800	8100	9950	8300	7900	8300	9100	7400	10300	9600	9000
ORP, mV E _c	-52	-31	-69	-95	-65	-117	-71	-93	-105	-160	-198	-210	-207

Table B3 (Continued)

Time Since Leachate Production Began, days	286	291	298	305	311	315	321	329	336	344	352	359	361	362
COD, mg/L	31259	31900	30188	27268	--	27813	27657	25448	24057	21788	20988	21654	--	--
COD mass, g	790.9	787.9	715.5	583.5	--	222.5	619.5	305.4	447.5	348.6	300.1	229.5	--	--
BOD ₅ , mg/L	--	15947	19787	16933	19187	--	17613	20253	17600	15347	14400	8700	--	--
BOD ₅ mass, g	--	398.9	469.0	362.4	153.5	--	394.5	243.0	327.4	245.6	205.9	92.2	--	--
TOC, mg/L	--	10548	7125	6176	4102	--	4241	3707	3815	7069	6491	6675	--	--
TOC mass, g	--	260.5	168.9	132.2	32.8	--	95.0	44.5	71.0	113.1	92.8	70.8	--	--
TVA, mg/L	14460	13923	--	12155	12758	--	12368	12104	11375	10527	11883	8316	--	--
TVA mass, g	365.8	343.9	--	260.1	102.1	--	277.0	145.2	211.6	168.4	169.9	88.1	--	--
Acetic acid, mg/L	7191	6891	--	5587	6070	--	6017	5626	5239	4980	5770	2414	--	--
Acetic acid mass, g	181.9	170.2	--	119.6	48.6	--	134.8	67.5	97.4	79.7	82.5	25.6	--	--
Propionic acid, mg/L	2227	2196	--	1894	2079	--	2279	2581	2951	3484	4475	5260	--	--
Propionic acid mass, g	56.3	54.2	--	40.5	16.6	--	51.0	31.0	54.9	55.7	64.0	55.8	--	--
Isobutyric acid, mg/L	1135	1131	--	1053	950	--	962	910	790	636	592	418	--	--
Isobutyric acid mass, g	28.7	27.9	--	22.5	7.6	--	21.5	10.9	14.5	10.2	8.5	4.4	--	--
Butyric acid, mg/L	3992	3957	--	3509	3124	--	2983	2739	2200	1361	1184	578	--	--
Butyric acid mass, g	101.0	97.7	--	75.1	25.0	--	66.8	32.9	40.9	21.8	16.9	6.1	--	--
Isovaleric acid, mg/L	89	117	--	13	47	--	10	10	10	15	10	158	--	--
Isovaleric acid mass, g	2.3	2.9	--	0.3	0.4	--	0.2	0.1	0.2	0.2	0.1	1.7	--	--
Valeric acid, mg/L	886	878	--	865	846	--	828	848	863	814	906	782	--	--
Valeric acid mass, g	22.4	21.7	--	18.5	6.8	--	18.5	10.2	16.1	13.0	13.0	8.3	--	--
Hexanoic acid, mg/L	2703	2320	--	2724	3292	--	2559	2699	2350	1693	1425	788	--	--
Hexanoic acid mass, g	68.4	57.3	--	58.3	26.3	--	57.3	32.4	43.7	27.1	20.4	8.4	--	--
pH	--	5.29	5.30	5.34	5.58	--	5.74	5.76	5.80	5.76	5.54	5.55	5.45	5.48
Alkalinity, mg/L as CaCO ₃	--	9305	8190	7865	9048	--	8800	8470	7920	7095	6738	5610	--	--
Conductivity, umhos	--	9000	8900	9500	11500	--	9200	10800	10500	10700	10200	10200	--	--
ORP, mv E _c	--	-187	--	--	--	--	--	-219	-228	-231	-221	-235	--	--

Table B3 (Continued)

Time Since Leachate Production Began, days	365	367	371	372	379	383	385	389	398	410	425
COD, mg/L	13686	--	--	8004	5876	--	--	2845	2309	2005	1505
COD mass, g	97.2	--	--	29.6	27.0	--	--	10.5	4.4	1.2	--
BOD ₅ , mg/L	9050	--	--	3830	2540	--	--	1206	650	490	310
BOD ₅ mass, g	64.3	--	--	14.2	11.7	--	--	4.5	1.2	0.3	--
TOC, mg/L	3656	--	--	2551	1470	--	--	580	424	350	175
TOC mass, g	26.0	--	--	9.4	6.8	--	--	2.1	0.8	0.2	--
TVA, mg/L	6274	--	--	3845	2742	--	--	162	162	101	45
TVA mass, g	44.5	--	--	14.2	12.6	--	--	0.6	0.3	0.06	--
Acetic acid, mg/L	2086	--	--	1956	1635	--	--	52	50	49	25
Acetic acid mass, g	14.8	--	--	7.2	7.5	--	--	0.2	0.1	0.03	--
Propionic acid, mg/L	4788	--	--	2197	1276	--	--	113	121	45	15
Propionic acid mass, g	34.0	--	--	8.1	5.9	--	--	0.4	0.2	0.03	--
Isobutyric acid, mg/L	130	--	--	51	41	--	--	6	5	5	5
Isobutyric acid mass, g	0.9	--	--	0.2	0.2	--	--	0.02	0.01	0.003	--
Butyric acid, mg/L	90	--	--	20	6	--	--	5	5	5	2
Butyric acid mass, g	0.6	--	--	0.1	0.03	--	--	0.02	0.01	0.003	--
Isovaleric acid, mg/L	20	--	--	67	56	--	--	10	6	5	2
Isovaleric acid mass, g	0.1	--	--	0.2	0.3	--	--	0.04	0.01	0.003	--
Valeric acid, mg/L	246	--	--	17	5	--	--	5	5	5	2
Valeric acid mass, g	1.7	--	--	0.06	0.02	--	--	0.02	0.01	0.003	--
Hexanoic acid, mg/L	20	--	--	20	10	--	--	5	5	5	5
Hexanoic acid mass, g	0.1	--	--	0.1	0.05	--	--	0.01	0.01	0.003	--
pH	5.56	5.61	6.17	6.37	6.86	6.86	6.89	7.13	7.10	7.13	7.15
Alkalinity, mg/L as CaCO ₃	4345	--	--	3658	3493	--	--	3410	3218	3328	3150
Conductivity, μ mhos	9200	--	--	8400	6400	--	--	5850	5150	5000	4350
ORP, mV E _c	-225	--	--	-243	-243	--	--	-243	-235	-220	-219

* Cell 2

Table R4. Gross Parameter Analyses on Leachate Samples from Control Single Pass Simulated Landfill Cell *

Time Since Leachate Production Began, days	0	1	5	7	8	10	11	12	14	15	17	19	23	26
COD, mg/L	47300	--	--	36130	--	35780	--	--	32798	--	31749	--	31415	--
COD mass, g	189	--	--	406	--	--	--	--	612	--	--	--	801	--
BOD ₅ , mg/L	32333	--	--	26000	--	--	--	--	19067	--	--	--	18000	--
BOD ₅ mass, g	194	--	--	350	--	--	--	--	464	--	--	--	572	--
TOC, mg/L	15700	--	--	9650	--	--	--	--	8800	--	--	--	8220	--
TOC mass, g	94.2	--	--	152	--	--	--	--	205	--	--	--	254	--
TVA, mg/L	5284	--	--	7805	7803	7678	7603	7731	9439	9792	11055	12927	12405	12767
TVA mass, g	31.7	--	--	78.5	--	--	--	--	127	--	--	--	196	--
Acetic acid, mg/L	4817	--	--	2201	2359	2378	2319	2428	3619	3852	4264	5068	5108	5316
Acetic acid mass, g	28.9	--	--	42.1	--	--	--	--	57.8	--	--	--	85.3	--
Propionic acid, mg/L	223	--	--	925	1068	1216	1278	1316	1434	1528	1764	2139	2096	2265
Propionic acid mass, g	1.3	--	--	6.9	--	--	--	--	16.4	--	--	--	27.6	--
Isobutyric acid, mg/L	315	--	--	0	0	0	0	0	117	118	212	273	227	401
Isobutyric acid mass, g	1.9	--	--	1.9	--	--	--	--	2.0	--	--	--	3.3	--
Butyric acid, mg/L	105	--	--	7114	6710	6323	5955	5910	6190	6310	6532	8080	7074	7092
Butyric acid mass, g	0.6	--	--	43.3	--	--	--	--	80.6	--	--	--	122.6	--
Isovaleric acid, mg/L	0	--	--	0	0	0	0	0	0	0	285	101	264	58
Isovaleric acid mass, g	0	--	--	0	--	--	--	--	0	--	--	--	1.0	--
Valeric acid, mg/L	0	--	--	0	0	0	315	246	602	535	683	622	780	794
Valeric acid mass, g	0	--	--	0	--	--	--	--	1.4	--	--	--	5.3	--
Hexanoic acid, mg/L	--	--	--	--	--	--	--	--	--	--	--	0	0	0
Hexanoic acid mass, g	0	--	--	0	--	--	--	--	0	--	--	--	0	--
pH	4.70	4.74	5.92	5.98	5.65	5.56	5.46	5.47	5.44	5.42	5.35	5.40	5.56	--
Alkalinity, mg/L as CaCO ₃	7800	--	--	7250	--	--	--	--	6650	--	--	--	6690	--
Conductivity, μ mhos	11400	--	--	11700	--	--	--	--	10800	--	--	--	--	--
ORP, mV E _c	-82	-82	-132	-120	-97	-113	-92	-89	-68	-57	-63	-57	-58	--

Table B4 (Continued)

Time Since Leachate Production Began, days	28	29	30	32	35	37	44	46	50	51	52	53	55	58
COD, mg/L	31825	--	--	34178	34832	34311	38136	33622	35502	34900	--	--	42734	42888
COD mass, g	--	--	993	--	--	1197	1405	--	--	1620	--	--	--	1852
BOD ₅ , mg/L	19254	--	--	--	--	20333	24509	--	--	28323	--	--	--	24524
BOD ₅ mass, g	--	--	688	--	--	808	930	--	--	1077	--	--	--	1247
TOC, mg/L	9000	--	--	--	--	8660	9225	9600	--	12718	--	11680	--	12632
TOC mass, g	--	--	308	--	--	361	413	--	--	470	--	--	--	543
TVA, mg/L	--	12230	--	14543	--	13379	13079	14132	14762	15783	--	15067	15943	17250
TVA mass, g	--	--	271	--	--	358	439	--	--	523	--	--	--	616
Acetic acid, mg/L	--	5188	--	6374	--	5676	6460	5378	5558	6229	--	6028	6580	7008
Acetic acid mass, g	--	--	117	--	--	155	189	--	--	224	--	--	--	262
Propionic acid, mg/L	--	2201	--	2690	--	2431	2927	2900	2787	3155	--	2624	2746	2721
Propionic acid mass, g	--	--	41	--	--	57.2	71.8	--	--	89.0	--	--	--	106
Isobutyric acid, mg/L	--	475	--	734	--	828	741	820	830	914	--	926	1025	1004
Isobutyric acid mass, g	--	--	5.9	--	--	10.3	15.3	--	--	20.1	--	--	--	25.8
Butyric acid, mg/L	--	6584	--	7577	--	7100	6961	8139	8943	8871	--	8352	8600	9748
Butyric acid mass, g	--	--	164	--	--	209	252	--	--	300	--	--	--	351
Isovaleric acid, mg/L	--	92	--	97	--	145	121	107	119	134	--	144	404	244
Isovaleric acid mass, g	--	--	1.4	--	--	2.0	2.9	--	--	3.6	--	--	--	4.9
Valeric acid, mg/L	--	447	--	453	--	416	381	400	366	424	--	393	636	587
Valeric acid mass, g	--	--	9.0	--	--	11.8	14.3	--	--	16.6	--	--	--	19.5
Hexanoic acid, mg/L	--	253	--	0	--	0	0	0	0	0	--	564	636	427
Hexanoic acid mass, g	--	--	1.3	--	--	1.3	1.3	--	--	1.3	--	--	--	2.7
pH	--	--	--	5.26	--	5.21	5.07	--	--	5.46	--	--	5.31	5.55
Alkalinity, mg/L as CaCO ₃	--	--	--	--	--	7042	7139	--	--	8875	--	9125	--	--
Conductivity, μ mhos	--	--	--	--	10300	10700	12000	--	--	--	14200	14400	--	12300
ORP, mV E _c	-68	--	--	-37	--	-28	-12	-2	--	-12	-2	--	--	-15

Table B4 (Continued)

Time Since Leachate Production Began, days	62	65	69	70	72	76	77	79	83	84	86	90	93	97	100
COD, mg/L	41401	39769	34604	36045	36156	27128	27037	26716	26834	--	26646	2773.3	23264	19613	19424
COD mass, g	--	2096	--	--	--	--	--	2510	2625.9	--	2670.7	--	2814.5	2904.5	2931.9
BOD ₅ , mg/L	--	24689	--	--	24552	--	--	23779	--	--	15248	--	16283	--	15107
BOD ₅ mass, g	--	1394	--	--	1542	--	--	1689	--	--	1781.0	--	1878.7	--	1969.3
TOC, mg/L	--	11850	--	--	10375	--	9980	9218	--	--	7571	--	7364	--	--
TOC mass, g	--	618	--	--	690	--	--	751	--	--	796.0	--	840.2	--	--
TVA, mg/L	15939	14303	13529	--	12555	11882	--	11961	--	--	9542	9341	13154	10174	10633
TVA mass, g	--	716	--	--	801	--	--	874	--	--	931.3	970.8	994.0	1040.8	1055.7
Acetic acid, mg/L	6052	5604	6420	--	5472	5412	--	5396	--	--	4516	4448	4688	5834	5533
Acetic acid mass, g	--	301	--	--	337	--	--	370	--	--	396.6	415.4	423.7	450.4	458.3
Propionic acid, mg/L	2549	2313	2278	--	2254	2107	--	2157	--	--	1838	1813	1931	1794	1926
Propionic acid mass, g	--	122	--	--	136	--	--	149	--	--	159.7	167.4	170.8	179.1	181.1
Isobutyric acid, mg/L	961	872	890	--	897	933	--	956	--	--	893	981	1184	1065	1073
Isobutyric acid mass, g	--	31.7	--	--	37.0	--	--	42.5	--	--	47.9	52.0	54.1	59.0	60.5
Isobutyric acid, mg/L	9168	8232	5872	--	6224	5432	--	5156	--	--	3671	3283	3879	3237	3148
Butyric acid, mg/L	--	401	--	--	452	--	--	486	--	--	507.5	521.4	528.3	543.1	547.6
Butyric acid mass, g	364	440	153	--	80	68	--	151	--	--	62	79	116	100	95
Isovaleric acid, mg/L	--	6.8	--	--	8.5	--	--	9.0	--	--	9.4	9.7	9.9	10.4	10.5
Isovaleric acid mass, g	--	891	459	--	369	348	--	446	--	--	352	398	498	544	528
Valeric acid, mg/L	868	23.8	--	--	27.9	--	--	30.0	--	--	32.1	33.8	34.7	37.2	37.9
Valeric acid mass, g	--	654	570	--	269	349	--	582	--	--	580	578	579	659	574
Hexanoic acid, mg/L	376	5.1	--	--	8.8	--	--	10.6	--	--	14.8	16.5	17.5	20.6	21.4
Hexanoic acid mass, g	--	5.34	--	5.40	5.30	5.13	--	4.93	--	--	5.09	--	5.03	5.00	5.00
pH	5.43	5.34	--	--	--	--	--	7.155	--	--	6500	--	5594	4856	5125
Alkalinity, mg/L as CaCO ₃	--	--	--	--	--	--	--	13600	--	--	--	--	9700	9000	8300
Conductivity, μ mhos	--	13200	--	--	12000	--	--	--	--	--	--	--	--	--	--
ORP, mV E _c	0	-178	--	--	--	--	--	--	--	-143	--	--	-86	-30	-35

Table B4 (Continued)

Time Since Leachate Production Began, days	104	107	111	112	114	119	121	122	123	128	135	142	149	156
COD, mg/L	16292	16879	--	14230	14104	--	13346	12677	--	12031	11069	10617	9776	9476
COD mass, g	2997.1	3030.8	--	3088.7	3115.8	--	3195.9	3211.3	--	3268.8	3335.2	3398.9	3457.6	3514.5
BOD ₅ , mg/L	--	13080	--	--	13107	--	11800	--	--	11600	13333	6600	4400	4000
BOD ₅ mass, g	--	2047.8	--	--	2126.7	--	2197.2	--	--	2266.8	2346.8	2386.4	2412.8	2436.8
TOC, mg/L	4644	--	--	--	5390	--	5210	--	--	4612	3520	5060	3152	4059
TOC mass, g	886.7	--	--	--	929.8	--	961.0	--	--	988.7	1009.8	1040.2	1059.1	1083.4
TVA, mg/L	8610	8330	--	7567	9626	6936	6558	--	--	6340	6610	6161	4997	4799
TVA mass, g	1090.2	1106.8	--	1127.0	1159.1	1185.5	1199.9	--	--	1230.2	1269.9	1306.8	1336.8	1365.6
Acetic acid, mg/L	4406	4355	--	4076	4999	3129	3744	--	--	3464	3754	3524	2744	2675
Acetic acid mass, g	475.9	484.6	--	495.5	512.2	526.4	534.6	--	--	555.4	577.9	599.0	615.5	631.5
Propionic acid, mg/L	1651	1560	--	1400	1823	1242	1261	--	--	1349	1296	1196	1012	950
Propionic acid mass, g	188.4	191.5	--	195.2	201.3	206.0	208.8	--	--	216.9	224.7	231.8	237.9	243.6
Isobutyric acid, mg/L	945	924	--	841	1133	808	654	--	--	649	629	587	531	491
Isobutyric acid mass, g	64.3	66.1	--	68.4	72.2	75.2	76.7	--	--	80.6	84.3	87.9	91.0	94.0
Butyric acid, mg/L	2345	2197	--	1754	2311	1497	1297	--	--	1167	1111	982	803	746
Butyric acid mass, g	557.0	561.3	--	566.0	573.7	579.4	582.3	--	--	589.3	595.9	601.8	606.7	611.1
Isovaleric acid, mg/L	100	78	--	71	94	59	18	--	--	40	58	61	46	42
Isovaleric acid mass, g	10.9	11.1	--	11.2	11.6	11.8	11.8	--	--	12.1	12.4	12.8	13.0	13.3
Valeric acid, mg/L	495	460	--	482	660	516	416	--	--	466	500	465	411	387
Valeric acid mass, g	39.9	40.8	--	42.1	44.3	46.3	47.2	--	--	50.0	53.0	55.8	58.2	60.6
Hexanoic acid, mg/L	530	518	--	509	694	565	401	--	--	475	564	560	493	501
Hexanoic acid mass, g	23.5	24.5	--	25.9	28.2	30.4	31.2	--	--	34.1	37.5	40.8	43.8	46.8
pH	--	5.04	--	--	4.87	--	4.91	--	--	4.72	4.90	4.80	4.80	4.83
Alkalinity, mg/L as CaCO ₃	--	4406	--	--	3844	--	350	--	--	3031	2875	2750	2625	2531
Conductivity, μ mhos	--	7900	--	--	7200	--	6900	--	--	5300	4900	5650	4800	4350
ORP, mV E _c	-44	-110	-57	--	-42	--	--	--	-96	--	-87	-144	-109	-96

Table B4 (Continued)

Time Since Leachate Production Began, days	166	177	184	193	199	220	228	235	244	250	264	274	282	286
COD, mg/L	89.4	696.4	479.1	401.5	434.6	425.0	371.4	408.6	429.3	412.0	407.9	537.0	--	567.7
COD mass, g	3583.9	3743.5	3833.5	3877.8	3895.2	3962.9	3983.5	4010.5	4044.9	4066.1	4119.4	4184.8	--	4212.6
BO _D ₅ , mg/L	385.0	340.0	226.7	207.5	216.0	227.3	199.3	258.3	226.7	219.0	210.0	235.3	321.3	337.0
BO _D ₅ mass, g	2466.7	2544.7	2587.2	2610.1	2618.8	2655.0	2666.0	2682.0	2700.2	2711.4	2738.8	2755.7	2775.0	2807.0
TOC, mg/L	302.7	245.7	287.5	240.0	245.0	110.0	108.0	105.0	115.2	109.5	145.2	157.6	182.6	--
TOC mass, g	1107.0	1163.3	1217.2	1243.7	1253.5	1271.1	1277.0	1283.5	1292.8	1298.4	1317.4	1328.7	1339.6	--
TVA, mg/L	51.40	387.9	366.7	370.9	365.3	209.5	--	209.2	219.9	219.6	238.7	279.9	338.6	322.7
TVA mass, g	1405.5	1494.4	1563.3	1604.2	1618.8	1652.2	--	1676.7	1694.3	1705.6	1736.8	1756.9	1777.2	1793.1
Acetic acid, mg/L	308.9	226.8	219.0	220.5	219.2	112.2	--	114.9	125.7	126.5	144.9	146.3	193.0	207.1
Acetic acid mass, g	655.5	707.5	748.6	772.9	781.7	799.6	--	813.1	823.1	829.6	848.6	859.1	870.7	880.8
Propionic acid, mg/L	94.5	72.0	68.9	70.5	69.5	40.0	--	34.9	31.8	29.1	29.8	40.4	54.5	45.8
Propionic acid mass, g	251.0	267.5	280.4	288.2	290.9	297.3	--	301.4	304.0	305.5	309.3	312.3	315.5	317.8
Isobutyric acid, mg/L	41.5	30.7	28.7	29.5	28.5	16.9	--	12.2	13.3	11.6	11.6	17.6	18.8	23.8
Isobutyric acid mass, g	97.2	104.2	109.6	112.9	114.0	116.7	--	118.2	119.2	119.8	121.3	122.6	123.7	124.9
Butyric acid, mg/L	68.1	55.4	49.8	49.9	47.5	36.5	--	38.4	40.2	40.6	42.0	52.1	59.3	54.6
Butyric acid mass, g	616.4	629.1	638.5	644.0	645.9	651.7	--	656.2	659.4	661.5	667.0	670.7	674.3	677.0
Isovaleric acid, mg/L	14.6	32	29	30	27	6.5	--	13.3	18.2	22.6	23.8	29.5	22.8	14.3
Isovaleric acid mass, g	14.4	15.2	15.7	16.0	17.1	18.2	--	19.7	21.2	22.3	25.4	27.6	28.9	29.6
Valeric acid, mg/L	35.4	28.4	22.7	23.2	22.8	16.4	--	16.6	13.8	10.4	9.5	24.6	22.5	13.4
Valeric acid mass, g	63.3	69.8	74.1	76.6	77.5	80.2	--	82.1	83.2	83.7	85.0	86.8	88.1	88.8
Hexanoic acid, mg/L	47.2	49.3	45.6	45.9	44.5	29.0	--	26.9	25.5	28.1	26.2	41.7	41.7	30.1
Hexanoic acid mass, g	50.4	61.7	70.3	75.4	77.1	81.8	--	84.9	87.0	88.4	91.8	94.8	97.3	98.8
pH	5.26	5.08	5.17	5.10	5.42	5.17	5.18	5.29	5.25	5.22	5.38	5.22	5.28	--
Alkalinity, mg/L as CaCO ₃	2563	1906	1375	1105	1313	1155	1155	1155	1238	1210	1320	1403	1650	--
Conductivity, μ mhos	2000	2950	2500	2400	2900	2450	2300	2300	2750	2250	3000	2950	2900	--
ORP, mV E _c	-63	-36	-63	-76	-95	-87	-70	-82	-112	-139	-168	-185	-223	--

Table B4 (Continued)

Time Since Leachate Production Began, days	291	298	305	311	315	321	329	336	344	352	359	365	372	379
COD, mg/L	6242	6528	6498	--	6724	7200	6774	6958	7120	6949	8404	6451	6371	6155
COD mass, g	4241.2	4271.9	4310.9	--	4332.2	4370.6	4413.9	4455.7	4498.6	4540.3	4590.7	4632.3	4670.3	4704.7
BOD ₅ , mg/L	3370	4797	4667	4647	--	5237	5530	5225	5353	5000	3475	4600	3450	2955
BOD ₅ mass, g	2807.0	2829.5	2857.5	2878.3	--	2922.9	2958.3	2989.7	3021.9	3051.9	3072.7	3102.4	3123.0	3139.5
TOC, mg/L	2010	1558	1560	2109	--	2193	1968	1870	1800	1984	1956	1701	1906	1737
TOC mass, g	1358.7	1366.0	1375.4	1384.8	--	1403.5	1416.1	1427.3	1438.1	1450.0	1461.8	1472.7	1484.1	1493.8
TVA, mg/L	3378	--	3743	4074	--	3757	3690	3665	3971	4354	2887	3247	3204	3650
TVA mass, g	1808.5	--	1848.6	1866.8	--	1898.8	1922.4	1944.4	1988.3	1994.4	2011.8	2032.7	2051.8	2072.2
Acetic acid, mg/L	2134	--	2476	2248	--	2167	2159	2155	2352	2444	1464	1602	1584	1871
Acetic acid mass, g	890.6	--	917.1	927.1	--	938.7	952.5	965.4	979.6	994.3	1003.1	1013.4	1022.8	1033.3
Propionic acid, mg/L	502	--	622	599	--	735	786	821	889	1058	887	904	926	1070
Propionic acid mass, g	320.1	--	326.7	329.4	--	325.7	340.7	345.6	351.0	357.3	362.6	368.5	374.0	380.0
Isobutyric acid, mg/L	168	--	145	924	--	184	120	74	90	143	148	119	120	134
Isobutyric acid mass, g	125.7	--	127.2	131.3	--	132.9	133.7	134.1	134.7	135.5	136.4	137.2	137.9	138.9
Butyric acid, mg/L	594	--	583	611	--	681	636	565	588	630	62	470	432	438
Butyric acid mass, g	679.7	--	685.9	688.7	--	694.5	698.5	701.9	705.5	709.2	709.6	712.6	715.2	717.6
Isovaleric acid, mg/L	123	--	10	10	--	15	10	5	10	10	15	15	20	39
Isovaleric acid mass, g	30.2	--	30.3	30.3	--	30.5	30.5	30.6	30.6	30.7	30.8	30.9	40.0	31.2
Valeric acid, mg/L	164	--	150	188	--	279	266	295	312	465	398	363	358	365
Valeric acid mass, g	89.5	--	91.1	92.0	--	94.3	96.0	97.8	99.7	102.5	104.9	107.2	109.3	111.4
Hexanoic acid, mg/L	288	--	335	345	--	448	419	450	478	578	615	559	524	550
Hexanoic acid mass, g	100.1	--	103.7	105.2	--	109.1	111.7	114.4	117.3	120.8	124.5	128.1	131.2	134.2
pH	5.29	5.29	5.30	5.32	--	5.28	5.30	5.34	5.34	5.34	5.39	5.41	5.44	5.62
Alkalinity, mg/L as CaCO ₃	1980	2145	2079	2503	--	2193	2365	2310	2310	2173	2118	2063	2118	2008
Conductivity, μ mhos	3150	3250	3350	3400	--	2850	3200	2700	3100	2800	3000	3000	3100	3000
ORP, mV E _c	-180	--	--	--	--	--	-187	-191	-183	-190	-190	-190	-195	-195

Table B4 (Continued)

Time Since Leachate Production Began, days	389	398	410	425
COD, mg/L	5738	5344	5100	5210
COD mass, g	4759.8	4795.1	4846.4	--
BOD ₅ , mg/L	3100	2970	2800	2910
BOD ₅ mass, g	3169.2	3188.9	3217.0	--
TOC, mg "	1674	1170	1200	1350
TOC mass, g	1509.9	1517.6	1529.7	--
TVA, mg/L	4393	3998	4013	3886
TVA mass, g	2114.4	2140.8	2181.1	--
Acetic acid, mg/L	2136	1639	1705	1650
Acetic acid mass, g	1053.8	1064.6	1081.7	--
Propionic acid, mg/L	1906	1756	1760	1695
Propionic acid mass, g	398.3	409.9	427.6	--
Isobutyric acid, mg/L	166	152	150	145
Isobutyric acid mass, g	140.2	141.2	142.8	--
Butyric acid, mg/L	362	399	380	391
Butyric acid mass, g	721.1	723.7	727.6	--
Isovaleric acid, mg/L	142	103	80	50
Isovaleric acid mass, g	32.6	33.3	34.1	--
Valeric acid, mg/L	366	426	410	390
Valeric acid mass, g	114.9	117.7	121.8	--
Hexanoic acid, mg/L	499	482	450	460
Hexanoic acid mass, g	139.1	143.7	148.2	--
pH	5.53	5.94	5.79	5.85
Alkalinity, mg/L as CaCO ₃	1788	1760	1540	1650
Conductivity, μ mhos	2950	2800	2700	2610
ORP, mV E _c	-195	-187	-180	-185

*Cell 3

Table B5. Gross Parameter Analyses on Leachate Samples from Spiked Single Pass Simulated Landfill Cell*

Time Since Leachate Production Began, days	0	1	5	7	8	10	11	12	14	15	17	19	23	26
COD, mg/L	55800	--	--	37500	--	34190	--	--	32471	--	32138	--	31924	--
COD mass, g	223	--	--	448	--	--	--	--	648	--	--	--	840	--
BOD ₅ , mg/L	39833	--	--	26333	--	--	--	--	18987	--	--	--	18267	--
BOD ₅ mass, g	239	--	--	397	--	--	--	--	511	--	--	--	621	--
TOC, mg/L	19200	--	--	10500	--	--	--	--	8900	--	--	--	8100	--
TOC mass, g	115	--	--	178	--	--	--	--	232	--	--	--	280	--
TVA, mg/	5093	--	--	7664	7112	7333	7016	7266	8030	8280	11758	14826	11907	12660
TVA mass, g	30.6	--	--	76.5	--	--	--	--	121	--	--	--	191	--
Acetic acid, mg/L	4566	--	--	2644	2446	2429	2374	2486	3028	3196	4860	5396	4786	5348
Acetic acid, mass	27.4	--	--	43.3	--	--	--	--	58.6	--	--	--	85.9	--
Propionic acid, mg/L	236	--	--	1072	957	1018	1036	1138	1142	1278	1927	3073	2033	2204
Propionic acid, mass, g	1.4	--	--	7.8	--	--	--	--	14.2	--	--	--	26.7	--
Isobutyric acid, mg/L	183	--	--	0	0	0	0	0	79	30	45	162	178	335
Isobutyric acid, mass, g	1.1	--	--	1.1	--	--	--	--	1.2	--	--	--	1.8	--
Butyric acid, mg/L	309	--	--	5481	5702	5979	5385	5440	5580	5545	7332	9447	1080	7248
Butyric acid, mass, g	1.9	--	--	34.7	--	--	--	--	68.4	--	--	--	112	--
Isovaleric acid, mg/L	0	--	--	0	0	0	0	0	0	0	73	101	286	120
Isovaleric acid, mass, g	0	--	--	0	--	--	--	--	0	--	--	--	0.7	--
Valeric acid, mg/L	0	--	--	699	0	0	217	255	366	414	441	548	598	476
Valeric acid, mass, g	0	--	--	4.2	--	--	--	--	5.2	--	--	--	8.2	--
Hexanoic acid, mg/L	--	--	--	--	--	--	--	--	--	--	0	0	0	0
Hexanoic acid, mass, g	0	--	--	0	--	--	--	--	0	--	--	0	0	--
pH	4.69	4.78	5.89	5.81	5.5	5.52	5.51	5.61	5.55	5.50	5.35	5.35	5.31	--
Alkalinity, mg/L as CaCO ₃	8500	--	--	7650	--	--	--	--	6400	--	--	--	7440	--
Conductivity, μ mhos	12500	--	--	13000	--	--	--	--	12400	--	--	--	--	--
ORP, mV E _c	-94	-51	-136	-111	-96	-101	-78	-68	-58	-51	-66	-63	-68	--

Table B5 (Continued)

Time Since Leachate Production Began, days	28	29	30	32	35	37	44	46	50	51	52	53	55	58
COD, mg/L	32904	--	--	34110	33510	34656	37414	35642	35138	34900	--	--	42982	42858
COD mass, g	--	--	1038	--	--	--	1241	--	--	1665	--	--	--	1899
BOD ₅ , mg/L	20928	--	--	--	--	21000	24636	--	--	29123	--	--	--	25151
BOD ₅ mass, g	--	--	746	--	--	866	992	--	--	1140	--	--	--	1315
TOC, mg/L	8950	--	--	--	--	9165	9200	9538	--	12431	--	12390	--	13134
TOC mass, g	--	--	334	--	--	388	443	--	--	499	--	--	--	574
TVA, mg/L	--	12657	--	12479	--	12993	12486	14550	15443	15669	--	15596	15270	17366
TVA mass, g	--	--	267	--	--	342	420	--	--	504	--	--	--	598
Acetic acid, mg/L	--	5318	--	5598	--	5244	4802	5224	6157	5927	--	5780	5628	6572
Acetic acid mass, g	--	--	118	--	--	152	183	--	--	215	--	--	--	250
Propionic acid, mg/L	--	2299	--	2366	--	2476	2912	2916	2880	2900	--	2722	2974	2875
Propionic acid mass, g	--	--	40.2	--	--	54.4	69.2	--	--	86.6	--	--	--	104
Isobutyric acid, mg/L	--	416	--	524	--	793	748	761	902	868	--	891	943	1013
Isobutyric acid mass, g	--	--	4.1	--	--	7.2	12.0	--	--	16.8	--	--	--	22.2
Butyric acid, mg/L	--	7176	--	6368	--	7220	7085	9034	8803	9536	--	9012	9416	10468
Butyric acid mass, g	--	--	116	--	--	194	237	--	--	--	--	--	--	343
Isovaleric acid, mg/L	--	122	--	97	--	124	115	122	94	122	--	188	159	228
Isovaleric acid mass, g	--	--	1.4	--	--	2.0	2.7	--	--	3.4	--	--	--	4.3
Valeric acid, mg/L	--	391	--	356	--	349	342	366	480	391	--	375	399	539
Valeric acid mass, g	--	--	10.8	--	--	12.9	15.0	--	--	17.4	--	--	--	19.7
Hexanoic acid, mg/L	--	0	--	0	--	0	0	0	0	0	--	395	329	365
Hexanoic acid mass, g	--	--	--	--	--	0	0	--	--	0	--	--	--	1.4
pH	--	--	--	5.35	--	5.30	5.01	--	--	5.41	--	--	5.30	5.50
Alkalinity, mg/L as CaCO ₃	--	--	--	--	--	6917	7144	--	--	7281	--	9281	--	--
Conductivity, μ mhos	--	--	--	10400	--	10700	11500	--	--	--	14000	14000	--	12250
ORP, mV E _c	-74	--	--	-26	--	-34	-10	-12	--	-18	--	--	-6	0

Table B5 (Continued)

Time Since Leachate Production Began, days	62	65	69	70	72	76	77	79	83	84	86	90	93	97	100
COD, mg/L	42516	38727	34309	36328	35914	26399	27336	27229	25607	--	25152	22995	22565	19536	18733
COD mass, g	--	2155	--	--	2374	--	--	2553	2665.3	--	2705.7	2800.3	2842.9	2419.0	2958.4
BOD ₅ , mg/L	--	24852	--	--	23790	--	--	21002	--	--	15548	--	15783	--	13867
BOD ₅ mass, g	--	1460	--	--	1615	--	--	1757	--	--	1850.7	--	1945.4	--	2028.6
TOC, mg/L	--	12100	--	--	10235	--	9233	9083	--	--	7402	--	6940	--	--
TOC mass, g	--	652	--	--	725	--	--	783	--	--	827.8	--	869.5	--	--
TVA, mg/L	15407	14604	13972	--	12790	10868	--	10618	--	--	8309	8747	15296	9609	9524
TVA mass, g	--	696	--	--	782	--	--	853	--	--	902.5	938.4	967.3	1004.7	1024.8
Acetic acid, mg/L	5920	5600	5936	--	5220	5560	--	5016	--	--	3753	3956	4457	5286	4814
Acetic acid mass, g	--	298	--	--	322	--	--	354	--	--	367.9	393.2	401.6	422.2	432.3
Propionic acid, mg/L	2488	2454	2321	--	1759	1898	--	1927	--	--	1501	1611	1891	1672	1737
Propionic acid mass, g	--	120	--	--	134	--	--	145	--	--	154.2	160.8	164.4	170.9	174.6
Isobutyric acid, mg/L	905	884	1028	--	1152	930	--	1062	--	--	970	1172	1291	1364	1276
Isobutyric acid mass, g	--	28.0	--	--	33.7	--	--	39.9	--	--	45.7	50.5	53.0	58.3	61.0
Butyric acid, mg/L	8940	8600	7480	--	5844	4192	--	4180	--	--	3464	3261	3173	3001	2729
Butyric acid mass, g	--	401	--	--	450	--	--	480	--	--	500.5	513.9	519.9	531.5	537.3
Isovaleric acid, mg/L	307	261	119	--	100	71	--	--	--	--	56	54	89	100	91
Isovaleric acid mass, g	--	5.9	--	--	7.1	--	--	7.6	--	--	7.9	8.2	8.3	8.7	8.9
Valeric acid, mg/L	385	335	354	--	500	143	--	317	--	--	273	364	405	527	476
Valeric acid mass, g	--	22.5	--	--	24.6	--	--	26.5	--	--	28.1	29.6	30.4	32.5	33.5
Hexanoic acid, mg/L	385	335	153	--	304	277	--	366	--	--	240	423	431	591	463
Hexanoic acid mass, g	--	3.7	--	--	5.2	--	--	6.9	--	--	8.3	10.1	10.9	13.2	14.2
pH	5.40	5.28	--	5.35	5.30	5.04	--	4.97	--	--	5.06	--	5.04	4.99	4.97
Alkalinity, mg/L as CaCO ₃	9219	--	--	--	--	--	--	7140	--	--	5844	--	5219	4706	4469
Conductivity, μ mhos	--	13600	--	--	11000	--	--	10800	--	--	--	--	9100	8600	8150
ORP, mv E ₃	-17	-182	--	-135	--	--	--	--	--	-100	--	--	--	-20	-40

Table B5 (Continued)

Time Since Leachate Production Began, days	104	107	111	112	114	119	121	122	123	128	135	142	149	156
COD, mg/L	1668	16632	--	14392	14629	--	13346	13071	--	12236	11336	11152	10202	10160
COD mass, g	3025.1	3058.3	--	3098.1	3145.5	--	3225.5	3241.7	--	3300.1	3368.1	3435.0	3496.2	3557.2
BOD ₅ , mg/L	--	12747	--	--	12707	--	11800	--	--	11267	10333	3400	6000	4500
BOD ₅ mass, g	--	2105.1	--	--	2181.3	--	2252.1	--	--	2319.7	2381.7	2402.1	2438.1	2465.1
TOC, mg/L	4467	--	--	--	5564	--	5160	--	--	4500	3662	5126	3257	3686
TOC mass, g	914.1	--	--	--	958.6	--	989.6	--	--	1016.6	1038.6	1069.3	1088.9	1111.0
TVA, mg/L	8734	8451	--	6535	7792	5938	5816	--	--	6265	6488	6490	5217	4877
TVA mass, g	1059.7	1076.6	--	1094.7	1119.9	1141.7	1155.2	--	--	1192.8	1231.7	1270.7	1302.0	1331.2
Acetic acid, mg/L	4563	4572	--	3399	4207	3090	3036	--	--	3435	3699	3898	3004	2738
Acetic acid mass, g	450.6	459.7	--	469.1	482.7	494.1	501.1	--	--	521.7	543.9	567.3	585.4	601.8
Propionic acid, mg/L	1566	1471	--	1170	1354	1069	989	--	--	1248	1152	1133	929	909
Propionic acid mass, g	180.8	183.8	--	187.0	191.4	195.3	197.6	--	--	205.1	212.0	218.8	224.4	229.8
Isobutyric acid, mg/L	1168	1114	--	978	1056	857	858	--	--	768	746	649	603	565
Isobutyric acid mass, g	65.6	67.9	--	70.6	74.0	77.1	79.1	--	--	83.7	88.2	92.1	95.7	99.1
Butyric acid, mg/L	2238	2026	--	1496	1721	1327	1295	--	--	1138	1113	991	838	784
Butyric acid mass, g	546.3	550.3	--	554.5	560.0	564.9	567.9	--	--	574.7	581.4	587.4	592.4	598.3
Isovaleric acid, mg/L	90	72	--	61	64	40	30	--	--	48	63	59	44	38
Isovaleric acid mass, g	9.3	9.4	--	9.6	9.8	9.9	10.0	--	--	10.3	10.7	11.0	11.3	11.5
Valeric acid, mg/L	487	465	--	429	516	440	449	--	--	447	481	450	381	366
Valeric acid mass, g	35.4	36.3	--	37.5	39.2	40.8	41.8	--	--	44.5	47.4	50.1	52.4	54.6
Hexanoic acid, mg/L	468	448	--	413	492	409	445	--	--	443	519	506	442	475
Hexanoic acid mass, g	16.0	16.9	--	18.1	19.7	21.2	22.2	--	--	24.8	28.0	31.0	33.6	36.5
pH	--	5.00	--	--	4.84	--	4.90	--	--	4.72	4.64	4.77	4.93	4.95
Alkalinity, mg/L as CaCO ₃	--	4156	--	--	3225	--	3375	--	--	2938	2844	2750	2625	2625
Conductivity, μ mhos	--	7500	--	--	7000	--	6800	--	--	5300	4950	5300	4900	4400
ORP, mV E _c	-51	-94	-65	--	-48	--	--	--	-110	--	-95	-184	-113	-90

Table B5 (Continued)

Time Since Leachate Production Began, days	166	177	184	193	199	220	228	235	244	250	264	274	282	286
COD, mg/L	9395	7535	5109	4650	4916	5041	4834	4920	5018	4910	5318	5380	6227	6396
COD mass, g	3627.5	3795.6	3889.4	3936.4	3955.6	4035.9	4062.3	4093.0	4133.2	4158.2	4223.6	4261.2	4298.5	4328.9
BOD ₅ , mg/L	4050	3667	3000	2870	2427	2773	2453	2000	3250	3050	2950	2895	3547	--
BOD ₅ mass, g	2495.4	2577.2	2632.3	2661.3	2670.8	2715.0	2728.4	2740.8	2766.9	2782.4	2818.7	2838.9	2860.2	--
TOC, mg/L	3110	2835	2950	2753	2445	1358	1378	1398	1432	1405	1777	1926	2090	--
TOC mass, g	1134.2	1197.5	1251.7	1279.5	1289.0	1310.7	1318.2	1326.9	1338.4	1345.5	1367.4	1380.8	1393.4	--
TVA, mg/L	5225	4355	4042	4121	3953	2724	--	2927	3371	3382	3812	3324	3469	3677
TVA mass, g	1370.3	1467.5	1541.7	1583.4	1598.8	1642.2	--	1676.4	1703.4	1720.6	1767.6	1790.8	1811.6	1829.0
Acetic acid, mg/L	3150	2641	2493	2510	2506	1638	--	1939	2226	2139	2560	2112	2142	2422
Acetic acid mass, g	625.3	684.3	730.1	755.4	765.2	791.3	--	814.0	831.8	842.7	874.2	888.9	901.8	913.3
Propionic acid, mg/L	908	743	679	685	670	489	--	475	509	480	535	504	565	570
Propionic acid mass, g	236.6	253.2	265.7	272.6	275.2	283.0	--	288.6	292.6	295.1	301.7	305.2	308.6	311.3
Isobutyric acid, mg/L	482	382	321	325	290	190	--	138	176	168	174	173	208	173
Isobutyric acid mass, g	102.7	111.3	117.1	120.4	121.6	124.6	--	126.2	127.6	128.5	130.6	131.8	133.1	133.9
Butyric acid, mg/L	763	626	579	620	545	419	--	441	486	513	590	567	626	584
Butyric acid mass, g	615.3	629.3	639.9	646.2	648.3	655.0	--	660.1	664.0	666.6	673.9	677.8	681.6	684.4
Isovaleric acid, mg/L	51	27	25	31	24	10	--	10	20	20	20	25	15	13
Isovaleric acid mass, g	11.9	12.5	13.0	13.3	13.4	13.5	--	13.6	13.8	13.9	14.1	14.3	14.4	14.5
Valeric acid, mg/L	344	265	206	254	210	168	--	126	154	164	179	194	202	181
Valeric acid mass, g	57.2	63.1	66.9	69.4	70.3	72.9	--	74.4	75.6	76.5	78.7	80.0	81.2	82.1
Hexanoic acid, mg/L	500	490	483	472	480	329	--	249	347	367	350	330	335	316
Hexanoic acid mass, g	40.2	51.2	60.0	64.8	66.7	71.9	--	74.8	77.6	79.5	83.8	86.1	88.1	89.6
pH	5.08	5.12	5.12	5.08	5.23	5.09	5.04	5.10	5.04	5.07	5.06	4.95	4.99	--
Alkalinity, mg/L as CaCO ₃	3110	1844	1250	1150	1406	1485	1485	1485	1540	1485	1540	1485	1650	--
Conductivity, umhos	2700	3000	2500	2410	3150	2600	2550	2700	2950	2600	3150	3100	3200	--
ORP, mV E _c	-57	-34	-65	-79	-60	-95	-75	-92	-94	-164	-142	-165	-206	--

Table B5 (Continued)

Time Since Leachate Production Began, days	291	298	305	311	315	321	329	336	344	352	359	365	372	379
COD, mg/L	6890	7161	7343	--	7412	7810	7276	7527	7746	7725	9500	7404	7782	7556
COD mass, g	4359.2	4391.8	4436.2	--	4492.5	4534.0	4580.0	4624.9	4670.9	4717.3	4774.3	4815.8	4861.7	4903.6
BOD ₅ , mg/L	3670	5080	5520	5163	--	5470	5947	5650	5953	5833	4025	5500	4325	3780
BOD ₅ mass, g	2893.8	2916.9	2950.3	2972.6	--	3019.6	3057.1	3090.9	3126.2	3161.2	3185.4	3216.2	3241.7	3262.7
TOC, mg/L	2302	1980	1925	2187	--	2387	2076	2173	1945	2263	2392	1955	2510	2086
TOC mass, g	1414.4	1423.5	1435.1	1444.5	--	1465.1	1478.2	1491.1	1502.7	1516.3	1530.6	1541.6	1556.4	1567.9
TVA, mg/L	4001	--	4068	4252	--	4366	4410	4362	4591	5147	3985	4052	3888	4861
TVA mass, g	1846.6	--	1889.7	1908.1	--	1945.6	1973.5	1999.5	2026.8	2057.7	2081.6	2104.3	2127.2	2154.2
Acetic acid, mg/L	2575	--	2650	2721	--	2586	2699	2583	2741	3078	2078	2116	1911	2812
Acetic acid mass, g	924.6	--	952.7	964.5	--	986.7	1003.7	1019.1	1035.4	1053.9	1066.4	1078.2	1089.5	1105.1
Propionic acid, mg/L	659	--	808	880	--	1027	1093	1064	1040	1150	908	906	882	998
Propionic acid mass, g	314.2	--	322.7	326.5	--	335.4	342.3	348.6	354.8	361.7	367.2	372.2	377.4	383.0
Isobutyric acid, mg/L	190	--	113	146	--	148	102	73	137	156	164	158	180	162
Isobutyric acid mass, g	134.7	--	135.9	136.6	--	137.8	138.5	138.9	139.7	140.7	141.6	142.5	143.6	144.5
Butyric acid, mg/L	671	--	578	573	--	627	568	632	666	762	734	757	754	750
Butyric acid mass, g	687.3	--	693.4	695.9	--	701.3	704.9	708.7	712.6	717.2	721.6	725.8	730.3	734.4
Isovaleric acid, mg/L	15	--	5	5	--	8	10	5	10	10	15	20	20	66
Isovaleric acid mass, g	14.5	--	14.6	14.6	--	14.7	14.7	14.8	14.8	14.9	15.0	15.1	15.2	15.6
Valeric acid, mg/L	223	--	203	260	--	350	345	395	420	465	474	490	515	486
Valeric acid mass, g	83.1	--	85.2	86.4	--	89.4	91.5	93.9	96.4	99.2	102.0	104.8	107.8	110.5
Hexanoic acid, mg/L	320	--	329	332	--	405	309	388	400	448	525	538	602	568
Hexanoic acid mass, g	91.0	--	94.5	95.9	--	99.4	101.4	103.7	106.1	108.7	111.9	114.9	118.5	121.6
pH	4.99	5.01	5.05	5.06	--	5.05	5.06	5.08	5.08	5.08	5.11	5.10	5.07	5.06
Alkalinity, mg/L as CaCO ₃	1953	2145	2503	2475	--	2365	2300	2365	2338	2250	2255	2090	2145	2063
Conductivity, umhos	3350	3350	3550	3850	--	2950	3150	3100	3300	3250	3600	3400	3500	3300
ORP, mV E _c	-208	--	--	--	--	--	-194	-201	-198	-195	-200	-200	-207	-207

Table B5 (Continued)

Time Since Leachate Production Began, days	389	398	410	425
COD, mg/L	7166	7099	6950	6900
COD mass, g	4972.2	5018.9	5086.1	--
BOD ₅ , mg/L	3950	3850	3690	3750
BOD ₅ mass, g	3300.5	3325.8	3361.5	--
TOC, mg/L	1997	1539	1550	1520
TOC mass, g	1587.1	1597.2	1612.2	--
TVA, mg/L	4757	5342	5308	5389
TVA mass, g	2199.7	2234.9	2286.2	--
Acetic acid, mg/L	2623	2901	2915	2895
Acetic acid mass, g	1130.2	1149.3	1177.5	--
Propionic acid, mg/L	1235	1357	1301	1390
Propionic acid mass, g	394.8	403.7	416.3	--
Isobutyric acid, mg/L	152	182	175	165
Isobutyric acid mass, g	145.9	147.1	148.8	--
Butyric acid, mg/L	648	709	725	695
Butyric acid mass, g	740.7	745.3	752.3	--
Isovaleric acid, mg/L	77	143	150	170
Isovaleric acid mass, g	16.3	17.2	18.7	--
Valeric acid, mg/L	452	565	600	425
Valeric acid mass, g	114.8	118.6	124.4	--
Hexanoic acid, mg/L	535	614	550	595
Hexanoic acid mass, g	126.7	130.8	136.1	--
pH	5.04	5.06	5.06	5.15
Alkalinity, mg/L as CaCO ₃	1870	1815	1623	1740
Conductivity, μ mhos	3550	3450	3300	3000
ORP, mV E _c	-201	-190	-182	-190

* Cell 4

Table B6. Metals, Organic Priority Pollutants, Nutrient and Sulfide Analyses on Leachate Samples
from Control Recycle Simulated Landfill Cell*

Time Since Leachate Production Began, days	0	7	11	14	19	22	35	38	44	46	51	58	59
Cadmium, mg/L	1.30	0.26	--	0.11	--	0.05	--	--	0.10	--	0.07	0.13	--
Calcium, mg/L	3377	2834	--	1416	--	1130	--	--	1311	--	1703	1757	--
Chromium, mg/L	1.58	0.37	--	<0.1	--	<0.1	--	--	<0.1	--	<0.1	<0.1	--
Copper, mg/L	0.69	0.08	--	0.13	--	<0.05	--	--	0.19	--	0.17	<0.05	--
Iron, mg/L	667	378	--	390	--	358	--	--	385	--	535	567	--
Lead, mg/L	38.8	2.50	--	2.00	--	1.60	--	--	1.20	--	1.00	1.80	--
Lithium, mg/L	7.8	--	7.20	--	7.70	--	8.10	--	--	10.0	10.00	9.30	--
Magnesium, mg/L	479	283	--	231	--	186	--	--	219	--	213	247	--
Manganese, mg/L	82	50.8	--	41.1	--	33	--	--	42.1	--	41.1	47.2	--
Nickel, mg/L	3.33	1.46	--	0.93	--	0.76	--	--	1.23	--	0.87	1.09	--
Potassium, mg/L	1176	826	--	599	--	347	--	--	416	--	468	531	--
Sodium, mg/L	1988	1084	--	705	--	615	--	--	751	--	729	783	--
Zinc, mg/L	581	213	--	125	--	103	--	--	116	--	81.0	99.0	--
Di-n-butyl phthalate, µg/L	--	22	--	--	--	--	--	3	--	0	--	--	0
Phenol, µg/L	--	1691	--	--	--	--	--	1816	--	2838	--	--	3039
Ortho-Phosphate, mg/L P	--	--	--	--	16.4	--	--	--	--	--	--	--	--
Ammonia Nitrogen, mg/L N	--	--	--	--	100.5	--	--	--	--	--	--	--	--
Sulfide, mg/L	--	--	--	--	--	--	--	--	0.1	--	--	--	--

Table B6 (Continued)

Time Since Leachate Production Began, days	61	65	67	72	79	86	95	110	114	128	130	139	148
Cadmium, mg/L	--	0.09	--	0.11	0.11	0.12	--	--	--	0.1	--	--	--
Calcium, mg/L	--	1671	--	1937	2078	2175	--	--	--	1491.4	--	--	--
Chromium, mg/L	--	<0.1	--	<0.1	<0.1	<0.1	--	--	--	0.1	--	--	--
Copper, mg/L	--	<0.05	--	<0.05	<0.05	<0.05	--	--	--	0.1	--	--	--
Iron, mg/L	--	485	--	597	640	617	--	--	--	715.5	--	--	--
Lead, mg/L	--	1.50	--	1.36	1.36	1.51	--	--	--	1.6	--	--	--
Lithium, mg/L	--	9.80	--	9.10	9.07	8.99	--	--	--	--	--	--	--
Magnesium, mg/L	--	228	--	218	233	226	--	--	--	184.7	--	--	--
Manganese, mg/L	--	44.7	--	53.7	53.7	54	--	--	--	53.0	--	--	--
Nickel, mg/L	--	0.88	--	1.26	1.27	1.23	--	--	--	2.2	--	--	--
Potassium, mg/L	--	476	--	522	538	541	--	--	--	529.0	--	--	--
Sodium, mg/L	--	763	--	956	1022	859	--	--	--	956.5	--	--	--
Zinc, mg/L	--	105	--	92.0	99.4	94.4	--	--	--	80.4	--	--	--
Di-n-butyl phthalate, ug/L	--	--	5	--	--	--	--	--	--	--	--	--	--
Phenol, ug/L	--	--	346	--	--	--	--	--	--	--	--	--	--
Ortho-Phosphate, mg/L P	14.5	--	--	--	12.0	--	--	--	--	4.65	--	--	--
Ammonia Nitrogen, mg/L N	169.6	--	--	--	--	--	--	--	512.8	--	--	--	--
Sulfide, mg/L	--	--	--	--	--	0.1	0.12	0.19	--	--	0.16	0.15	0.16

Table B6 (Continued)

Time Since Leachate Production Began, days	156	158	175	184	193	195	220	230	244	250	270	274
Cadmium, mg/L	0.13	--	--	0.13	--	--	0.09	--	0.12	--	--	0.09
Calcium, mg/L	1565.5	--	--	1713.5	--	--	1732.0	--	1685.4	--	--	1824.5
Chromium, mg/L	0.1	--	--	0.1	--	--	0.1	--	0.1	--	--	0.1
Copper, mg/L	0.1	--	--	0.1	--	--	0.1	--	0.1	--	--	0.1
Iron, mg/L	774.2	--	--	816.2	--	--	933.6	--	912.5	--	--	984.0
Lead, mg/L	1.4	--	--	1.8	--	--	1.8	--	1.2	--	--	1.3
Lithium, mg/L	--	--	--	--	--	--	--	--	--	--	--	--
Magnesium, mg/L	175.2	--	--	172.5	--	--	177.9	--	175.2	--	--	173.2
Manganese, mg/L	51.9	--	--	52.7	--	--	56.3	--	63.2	--	--	55.8
Nickel, mg/L	2.0	--	--	2.4	--	--	1.8	--	1.1	--	--	1.5
Potassium, mg/L	508.0	--	--	498.0	--	--	508.0	--	531.0	--	--	498.0
Sodium, mg/L	801.3	--	--	786.9	--	--	830.2	--	999.5	--	--	815.8
Zinc, mg/L	89.1	--	--	96.4	--	--	84.7	--	90.5	--	--	67.3
Di-n-butyl phthalate, µg/L	--	--	--	--	--	--	--	--	--	--	--	--
Phenol, µg/L	--	--	--	--	--	--	--	--	--	--	--	--
Ortho-Phosphate, mg/L P	--	1.9	--	1.64	--	--	0.62	--	0.58	--	--	0.45
Ammonia Nitrogen, mg/L N	586.7	--	--	--	576.7	--	573.5	--	627.2	--	--	626.1
Sulfide, mg/L	--	0.17	0.1	--	--	0.15	--	0.31	--	0.28	0.32	--

Table B6 (Continued)

Time Since Leachate Production Began, days	278	290	297	305	313	320	327	335	336	344	346	354
Cadmium, mg/L	--	--	--	0.09	--	--	--	--	0.09	--	--	--
Calcium, mg/L	--	--	--	1602.5	--	--	--	--	1269.4	--	--	--
Chromium, mg/L	--	--	--	0.1	--	--	--	--	0.1	--	--	--
Copper, mg/L	--	--	--	0.1	--	--	--	--	0.1	--	--	--
Iron, mg/L	--	--	--	908.5	--	--	--	--	295.9	--	--	--
Lead, mg/L	--	--	--	0.9	--	--	--	--	0.5	--	--	--
Lithium, mg/L	--	--	--	--	--	--	--	--	--	--	--	--
Magnesium, mg/L	--	--	--	182.2	--	--	--	--	126.5	--	--	--
Manganese, mg/L	--	--	--	50.2	--	--	--	--	14.9	--	--	--
Nickel, mg/L	--	--	--	1.9	--	--	--	--	1.2	--	--	--
Potassium, mg/L	--	--	--	467.0	--	--	--	--	420.0	--	--	--
Sodium, mg/L	--	--	--	945.6	--	--	--	--	1234.2	--	--	--
Zinc, mg/L	--	--	--	65.8	--	--	--	--	46.3	--	--	--
Di-n-butyl phthalate, ug/L	--	--	--	--	--	--	--	--	--	--	--	--
Phenol, ug/L	--	--	--	--	--	--	--	--	--	--	--	--
Ortho-Phosphate, mg/L P	--	--	--	0.1	--	--	--	--	0.1	--	--	--
Ammonia Nitrogen, mg/L N	--	--	--	466.9	--	--	--	--	--	38.6	--	--
Sulfide, mg/L	0.45	0.55	0.65	--	1.31	1.75	1.96	2.46	--	--	3.21	4.21

Table B6 (Continued)

Time Since Leachate Production Began, days	365	377	399	410
Cadmium, mg/L	0.05	--	0.05	--
Calcium, mg/L	399.8	--	148.2	--
Chromium, mg/L	0.1	--	0.1	--
Copper, mg/L	0.1	--	0.1	--
Iron, mg/L	33.3	--	0.95	--
Lead, mg/L	0.5	--	0.3	--
Lithium, mg/L	--	--	--	--
Magnesium, mg/L	77.9	--	21.4	--
Manganese, mg/L	1.1	--	0.1	--
Nickel, mg/L	0.1	--	0.1	--
Potassium, mg/L	352.0	--	282.0	--
Sodium, mg/L	1176.5	--	875.5	--
Zinc, mg/L	40.5	--	1.5	--
Di-n-butyl phthalate, µg/L	--	--	--	--
Phenol, µg/L	--	--	--	--
Ortho-Phosphate, mg/L P	0.1	--	0.1	--
Ammonia Nitrogen, mg/L N	3.0	--	0.85	--
Sulfide, mg/L	3.21	1.86	--	0.32

* Cell 1

Table B7. Metals, Organic Priority Pollutants, Nutrient and Sulfide Analyses on Leachate Samples
from Spiked Recycle Simulated Landfill Cell*

Time Since Leachate Production Began, days	0	7	11	14	19	22	35	38	44	46	51	58	59
Cadmium, mg/L	1.04	0.15	--	0.05	--	0.04	--	--	0.12	--	0.07	0.16	--
Calcium, mg/L	2871	1446	--	1493	--	1354	--	--	1213	--	1693	2188	--
Chromium, mg/L	1.33	0.16	--	<0.1	--	0.36	--	--	<0.1	--	<0.1	<0.1	--
Copper, mg/L	0.13	<0.05	--	<0.05	--	0.05	--	--	<0.05	--	<0.05	<0.05	--
Iron, mg/L	610	389	--	374	--	501	--	--	460	--	513	461	--
Lead, mg/L	32.2	2.00	--	1.50	--	1.20	--	--	1.70	--	1.30	1.70	--
Lithium, mg/L	14.6	8.60	6.60	--	7.40	--	7.40	--	--	9.20	--	9.20	--
Magnesium, mg/L	452	286	--	209	--	239	--	--	200	--	200	218	--
Manganese, mg/L	75.2	51.3	--	40	--	46.5	--	--	39	--	41	42.1	--
Nickel, mg/L	2.80	1.13	--	0.50	--	1.21	--	--	1.60	--	1.80	1.48	--
Potassium, mg/L	1111	713	--	476	--	425	--	--	331	--	407	529	--
Sodium, mg/L	1771	1071	--	634	--	763	--	--	630	--	641	676	--
Zinc, mg/L	373	174	--	121	--	144	--	--	112	--	183	114	--
Di-n-butyl phthalate, µg/L	--	41	--	--	--	--	--	0	--	0	--	--	59
Phenol, µg/L	--	2395	--	--	--	--	--	4012	--	7013	--	--	5450
Ortho-Phosphate, mg/L P	--	--	--	--	18.5	--	--	--	--	--	--	--	--
Ammonia-Nitrogen, mg/L N	--	--	--	--	5.3	--	--	--	--	--	--	--	--
Sulfide, mg/L	--	--	--	--	--	--	--	--	0.1	--	--	--	--

Table 37 (Continued)

Time Since Leachate Production Began, days	61	65	67	72	79	86	95	110	114	128	130	139	148
Cadmium, mg/L	--	0.25	--	0.31	0.33	0.29	--	--	--	0.31	--	--	--
Calcium, mg/L	--	1953	--	2117	2055	2040	--	--	--	1547.0	--	--	--
Chromium, mg/L	--	<0.1	--	<0.1	<0.1	<0.1	--	--	--	0.1	--	--	--
Copper, mg/L	--	<0.05	--	<0.05	<0.05	<0.05	--	--	--	0.1	--	--	--
Iron, mg/L	--	554	--	655	579	602	--	--	--	698.7	--	--	--
Lead, mg/L	--	2.60	--	3.16	2.77	2.77	--	--	--	2.4	--	--	--
Lithium, mg/L	--	8.90	--	9.10	8.37	8.06	--	--	--	--	--	--	--
Magnesium, mg/L	--	221	--	236	222	208	--	--	--	185.3	--	--	--
Manganese, mg/L	--	47	--	57.3	52	52	--	--	--	53.3	--	--	--
Nickel, mg/L	--	2.15	--	1.66	1.65	1.51	--	--	--	2.6	--	--	--
Potassium, mg/L	--	443	--	539	495	498	--	--	--	508.0	--	--	--
Sodium, mg/L	--	705	--	954	893	913	--	--	--	1032.2	--	--	--
Zinc, mg/L	--	114	--	151	140	137	--	--	--	140.1	--	--	--
Di-n-butyl phthalate, µg/L	--	--	5	--	--	--	--	--	--	--	--	--	--
Phenol, µg/L	--	--	164	--	--	--	--	--	--	--	--	--	--
Ortho-Phosphate, mg/L P	14.0	--	--	--	10.7	--	--	--	--	3.31	--	--	--
Ammonia-Nitrogen, mg/L N	--	--	--	--	170.5	--	--	--	539.0	--	--	--	--
Sulfide, mg/L	--	--	--	--	--	0.1	0.15	0.13	--	--	0.2	0.1	0.19

Table B7 (Continued)

Time Since Leachate Production Began, days	156	158	175	184	193	195	220	230	244	250	270	274
Cadmium, mg/L	0.29	--	--	0.36	--	--	0.33	--	0.36	--	--	0.32
Calcium, mg/L	1676.5	--	--	1880.0	--	--	1787.5	--	1755.2	--	--	1861.5
Chromium, mg/L	0.1	--	--	0.1	--	--	0.1	--	0.1	--	--	0.1
Copper, mg/L	0.1	--	--	0.1	--	--	0.1	--	0.1	--	--	0.1
Iron, mg/L	749.0	--	--	799.4	--	--	908.5	--	912.5	--	--	942.0
Lead, mg/L	1.8	--	--	2.7	--	--	2.6	--	2.2	--	--	2.4
Lithium, mg/L	--	--	--	--	--	--	--	--	--	--	--	--
Magnesium, mg/L	169.8	--	--	177.2	--	--	173.8	--	174.5	--	--	176.5
Manganese, mg/L	55.2	--	--	56.3	--	--	56.3	--	69.9	--	--	55.8
Nickel, mg/L	2.7	--	--	1.8	--	--	2.2	--	1.6	--	--	1.8
Potassium, mg/L	493.0	--	--	498.0	--	--	508.0	--	531.0	--	--	482.0
Sodium, mg/L	801.3	--	--	801.3	--	--	772.5	--	1002.1	--	--	844.6
Zinc, mg/L	150.3	--	--	169.2	--	--	169.2	--	179.8	--	--	151.7
Di-n-butyl phthalate, µg/L	--	--	--	--	--	--	--	--	--	--	--	--
Phenol, µg/L	--	--	--	--	--	--	--	--	--	--	--	--
Ortho-Phosphate, mg/L P	1.13	--	--	0.88	--	--	0.36	--	0.31	--	--	0.25
Ammonia Nitrogen, mg/L N	684.7	--	--	--	554.7	--	603.0	--	656.9	--	--	646.3
Sulfide, mg/L	--	0.15	0.12	--	--	0.09	--	0.26	--	0.39	0.39	--

Table B7 (Continued)

Time Since Leachate Production Began, days	278	290	297	305	313	320	327	335	336	344	346	354
Cadmium, mg/L	--	--	--	0.32	--	--	--	--	0.25	--	--	--
Calcium, mg/L	--	--	--	1732.0	--	--	--	--	1621.0	--	--	--
Chromium, mg/L	--	--	--	0.1	--	--	--	--	0.1	--	--	--
Copper, mg/L	--	--	--	0.1	--	--	--	--	0.1	--	--	--
Iron, mg/L	--	--	--	807.8	--	--	--	--	799.4	--	--	--
Lead, mg/L	--	--	--	2.2	--	--	--	--	0.9	--	--	--
Lithium, mg/L	--	--	--	--	--	--	--	--	--	--	--	--
Magnesium, mg/L	--	--	--	154.9	--	--	--	--	153.6	--	--	--
Manganese, mg/L	--	--	--	55.2	--	--	--	--	36.2	--	--	--
Nickel, mg/L	--	--	--	2.2	--	--	--	--	1.4	--	--	--
Potassium, mg/L	--	--	--	462.0	--	--	--	--	477.0	--	--	--
Sodium, mg/L	--	--	--	987.9	--	--	--	--	1508.4	--	--	--
Zinc, mg/L	--	--	--	140.1	--	--	--	--	129.2	--	--	--
Di-n-butyl phthalate, µg/L	--	--	--	--	--	--	--	--	--	--	--	--
Phenol, µg/L	--	--	--	--	--	--	--	--	--	--	--	--
Ortho-Phosphate, mg/L P	--	--	--	0.15	--	--	--	--	0.1	--	--	--
Ammonia Nitrogen, mg/L N	--	--	--	461.5	--	--	--	--	--	563.3	--	--
Sulfide, mg/L	0.49	0.59	0.61	--	1.29	2.2	2.45	3.62	--	--	4.21	5.59

Table B7 (Continued)

Time Since Leachate Production Began, days	365	377	399	410
Cadmium, mg/L	0.05	--	0.05	--
Calcium, mg/L	991.9	--	485.2	--
Chromium, mg/L	0.1	--	0.1	--
Copper, mg/L	0.1	--	0.1	--
Iron, mg/L	128.1	--	1.5	--
Lead, mg/L	0.5	--	0.3	--
Lithium, mg/L	--	--	--	--
Magnesium, mg/L	100.9	--	29.1	--
Manganese, mg/L	5.4	--	0.1	--
Nickel, mg/L	0.1	--	0.1	--
Potassium, mg/L	352.0	--	250.0	--
Sodium, mg/L	1263.1	--	950.5	--
Zinc, mg/L	110.5	--	2.1	--
Di-n-butyl phthalate, µg/L	--	--	--	--
Phenol, µg/L	--	--	--	--
Ortho-Phosphate, mg/L P	0.1	--	0.1	--
Ammonia Nitrogen, mg/L N	18.1	--	4.2	--
Sulfide, mg/L	4.15	2.86	--	0.29

*Cell 2

Table B8. Metals, Organic Priority Pollutants, Nutrient and Sulfide Analyses on Leachate Samples
from Control Single Pass Simulated Landfill Cell

Time Since Leachate Production Began, days	0	7	11	14	19	22	35	38	44	46	51	58	59
Cadmium, mg/L	0.88	0.14	--	0.08	--	0.11	--	--	0.09	--	0.19	0.20	--
Calcium, mg/L	2770	1763	--	1554	--	1730	--	--	1706	--	1912	1518	--
Chromium, mg/L	0.80	0.16	--	<0.1	--	<0.1	--	--	<0.1	--	<0.1	<0.1	--
Copper, mg/L	0.16	0.09	--	<0.05	--	<0.05	--	--	0.10	--	0.06	<0.05	--
Iron, mg/L	517	359	--	331	--	506	--	--	680	--	603	678	--
Lead, mg/L	35.2	3.00	--	2.00	--	2.60	--	--	3.40	--	6.80	9.50	--
Lithium, mg/L	15.4	--	8.3	--	6.70	--	5.70	--	--	7.90	8.80	8.80	--
Magnesium, mg/L	395	288	--	231	--	228	--	--	263	--	275	290	--
Manganese, mg/L	74.5	56.5	--	42	--	45	--	--	54.9	--	59.4	64	--
Nickel, mg/L	2.20	1.46	--	0.76	--	1.03	--	--	1.83	--	1.46	0.76	--
Potassium, mg/L	861	722	--	534	--	473	--	--	448	--	529	613	--
Sodium, mg/L	1570	1165	--	766	--	738	--	--	708	--	941	964	--
Zinc, mg/L	377	161	--	110	--	127	--	--	166	--	164	154	--
Di-n-butyl phthalate, µg/L	--	42	--	--	--	--	--	11	--	55	--	--	30
Phenol, µg/L	--	2479	--	--	--	--	--	272	--	3056	--	--	3031
Ortho-Phosphate, mg/L P	--	--	--	--	15.7	--	--	--	--	--	--	--	--
Ammonia-Nitrogen, mg/L N	--	--	--	--	69.9	--	--	--	--	--	--	--	--
Sulfide, mg/L	--	--	--	--	--	--	--	--	0.1	--	--	--	--

Table B8 (Continued)

Time Since Leachate Production Began, days	61	65	67	72	79	86	95	110	114	128	130	139	148
Cadmium, mg/L	--	0.17	--	0.21	0.19	0.16	--	--	--	0.07	--	--	--
Calcium, mg/L	--	2308	--	2219	2018	1920	--	--	--	1002.9	--	--	--
Chromium, mg/L	--	<0.1	--	<0.1	<0.1	<0.1	--	--	--	0.1	--	--	--
Copper, mg/L	--	<0.05	--	<0.05	<0.05	<0.05	--	--	--	0.1	--	--	--
Iron, mg/L	--	696	--	673	640	700	--	--	--	824.5	--	--	--
Lead, mg/L	--	9.10	--	11.9	9.61	8.21	--	--	--	1.1	--	--	--
Lithium, mg/L	--	8.60	--	8.20	6.83	6.36	--	--	--	--	--	--	--
Magnesium, mg/L	--	284	--	227	175	125	--	--	--	34.6	--	--	--
Manganese, mg/L	--	66.6	--	67.3	57.1	47.6	--	--	--	21.6	--	--	--
Nickel, mg/L	--	0.93	--	0.98	0.91	0.72	--	--	--	0.8	--	--	--
Potassium, mg/L	--	598	--	562	438	386	--	--	--	79.0	--	--	--
Sodium, mg/L	--	956	--	1040	825	645	--	--	--	84.8	--	--	--
Zinc, mg/L	--	142	--	141	120	106	--	--	--	43.4	--	--	--
Di-n-butyl phtalate, ug/L	--	--	21	--	--	--	--	--	--	--	--	--	--
Phenol, ug/L	--	--	1331	--	--	--	--	--	--	--	--	--	--
Ortho-Phosphate, mg/L P	4.8	--	--	--	1.9	--	--	--	--	1.62	--	--	--
Ammonia-Nitrogen, mg/L N	--	--	--	--	200.8	--	--	--	163.4	--	--	--	--
Sulfide, mg/L	--	--	--	--	--	0.1	0.2	0.19	--	--	0.23	0.15	0.2

Table 88 (Continued)

Time Since Leachate Production Began, days	156	158	175	184	193	195	220	230	244	250	270	274
Cadmium, mg/L	0.08	--	--	0.05	--	--	0.05	--	0.05	--	--	0.05
Calcium, mg/L	752.7	--	--	654.4	--	--	551.1	--	348.5	--	--	257.6
Chromium, mg/L	0.1	--	--	0.1	--	--	0.1	--	0.1	--	--	0.1
Copper, mg/L	0.1	--	--	0.1	--	--	0.1	--	0.1	--	--	0.1
Iron, mg/L	866.5	--	--	514.1	--	--	463.7	--	478.1	--	--	478.1
Lead, mg/L	1.1	--	--	0.5	--	--	0.5	--	0.5	--	--	0.5
Lithium, mg/L	--	--	--	--	--	--	--	--	--	--	--	--
Magnesium, mg/L	18.4	--	--	8.3	--	--	8.0	--	10.6	--	--	9.5
Manganese, mg/L	14.3	--	--	4.8	--	--	3.1	--	4.9	--	--	3.9
Nickel, mg/L	0.6	--	--	0.5	--	--	0.2	--	0.03	--	--	0.03
Potassium, mg/L	33.0	--	--	10.0	--	--	6.0	--	8.0	--	--	5.0
Sodium, mg/L	32.8	--	--	10.4	--	--	6.9	--	13.8	--	--	6.9
Zinc, mg/L	24.7	--	--	18.1	--	--	9.7	--	8.4	--	--	12.5
Di-n-butyl phthalate, µg/L	--	--	--	--	--	--	--	--	--	--	--	--
Phenol, µg/L	--	--	--	--	--	--	--	--	--	--	--	--
Ortho-Phosphate, mg/L P	0.62	--	--	0.15	--	--	0.11	--	0.1	--	--	0.1
Ammonia Nitrogen, mg/L N	108.6	--	--	--	27.0	--	23.5	--	13.0	--	--	24.0
Sulfide, mg/L	--	0.11	0.13	--	--	0.17	--	0.15	--	0.21	0.25	--

Table B8 (Continued)

Time Since Leachate Production Began, days	278	290	297	305	313	320	327	335	336	344	346	354
Cadmium, mg/L	--	--	--	0.05	--	--	--	--	0.05	--	--	--
Calcium, mg/L	--	--	--	171.9	--	--	--	--	141.8	--	--	--
Chromium, mg/L	--	--	--	0.1	--	--	--	--	0.1	--	--	--
Copper, mg/L	--	--	--	0.1	--	--	--	--	0.1	--	--	--
Iron, mg/L	--	--	--	405.6	--	--	--	--	385.1	--	--	--
Lead, mg/L	--	--	--	0.5	--	--	--	--	0.5	--	--	--
Lithium, mg/L	--	--	--	--	--	--	--	--	--	--	--	--
Magnesium, mg/L	--	--	--	11.4	--	--	--	--	9.7	--	--	--
Manganese, mg/L	--	--	--	4.8	--	--	--	--	4.8	--	--	--
Nickel, mg/L	--	--	--	0.03	--	--	--	--	0.03	--	--	--
Potassium, mg/L	--	--	--	4.0	--	--	--	--	4.0	--	--	--
Sodium, mg/L	--	--	--	7.2	--	--	--	--	7.8	--	--	--
Zinc, mg/L	--	--	--	2.6	--	--	--	--	0.2	--	--	--
Di-n-butyl phthalate, µg/L	--	--	--	--	--	--	--	--	--	--	--	--
Phenol, µg/L	--	--	--	--	--	--	--	--	--	--	--	--
Ortho-Phosphate, mg/L P	--	--	--	0.1	--	--	--	--	0.1	--	--	--
Ammonia Nitrogen, mg/L N	--	--	--	49.1	--	--	--	--	--	24.7	--	--
Sulfide, mg/L	0.35	0.75	0.95	--	1.85	1.12	0.79	0.36	--	--	0.19	0.07

Table B8 (Continued)

Time Since Leachate Production Began, days	365	377	399	410
Cadmium, mg/L	0.05	--	0.05	--
Calcium, mg/L	33.4	--	10.4	--
Chromium, mg/L	0.1	--	0.1	--
Copper, mg/L	0.1	--	0.1	--
Iron, mg/L	320.1	--	275.6	--
Lead, mg/L	0.5	--	0.3	--
Lithium, mg/L	0.02	0.02	0.06	0.61
Magnesium, mg/L	9.6	--	5.2	--
Manganese, mg/L	4.5	--	3.9	--
Nickel, mg/L	0.03	--	0.05	--
Potassium, mg/L	4.0	--	1.5	--
Sodium, mg/L	7.1	--	5.2	--
Zinc, mg/L	0.4	--	0.2	--
Di-n-butyl phthalate, ug/L	--	--	--	--
Phenol, ug/L	--	--	--	--
Ortho-Phosphate, mg/L P	0.1	--	0.1	--
Ammonia Nitrogen, mg/L N	6.4	--	2.1	--
Sulfide, mg/L	0.1	0.07	--	0.05

* Cell 3

Table B9. Metals, Organic Priority Pollutants, Nutrient and Sulfide Analyses on Leachate Samples
from Spiked Single Pass Simulated Landfill Cell*

Time Since Leachate Production Began, days	0	7	11	14	19	22	35	38	44	46	51	58	59
Cadmium, mg/L	0.95	0.16	--	0.19	--	0.16	--	--	0.25	--	0.33	0.22	--
Calcium, mg/L	3654	2143	--	1688	--	1557	--	--	1086	--	1876	1776	--
Chromium, mg/L	1.42	0.21	--	<0.1	--	<0.1	--	--	<0.1	--	<0.1	<0.1	--
Copper, mg/L	0.11	0.19	--	0.11	--	0.07	--	--	<0.05	--	<0.05	<0.05	--
Iron, mg/L	742	469	--	318	--	318	--	--	616	--	762	795	--
Lead, mg/L	49.4	6.20	--	2.60	--	2.00	--	--	2.40	--	3.80	4.70	--
Lithium, mg/L	17.0	9.70	7.60	--	6.30	--	5.20	--	--	8.00	8.80	9.00	--
Magnesium, mg/L	478.3	326.9	--	216	--	173	--	--	220.3	--	275.6	292	--
Manganese, mg/L	95.9	72.6	--	48.6	--	40.9	--	--	52.8	--	61.7	60.6	--
Nickel, mg/L	3.71	2.11	--	1.21	--	2.37	--	--	1.69	--	2.04	1.70	--
Potassium, mg/L	1149	715	--	598	--	428	--	--	464	--	492	584	--
Sodium, mg/L	1953	1385	--	802	--	612	--	--	665	--	823	886	--
Zinc, mg/L	431	177	--	93.0	--	72.0	--	--	82.0	--	90.0	90.0	--
Di-n-butyl phthalate, µg/L	--	45	--	--	--	--	--	30	--	47	--	--	--
Phenol, µg/L	--	739	--	--	--	--	--	231	--	3311	--	--	--
Ortho-Phosphate, mg/L P	--	--	--	--	13.0	--	--	--	--	--	--	--	--
Ammonia-Nitrogen, mg/L N	--	--	--	--	64.8	--	--	--	--	--	--	--	--
Sulfide	--	--	--	--	--	0.1	--	--	--	--	--	--	--

Table B9 (Continued)

Time Since Leachate Production Began, days	61	65	67	72	79	86	95	110	114	128	130	139	148
Cadmium, mg/L	--	0.12	--	0.31	0.26	0.28	--	--	--	0.14	--	--	--
Calcium, mg/L	--	1567	--	2123	1928	2399	--	--	--	930.3	--	--	--
Chromium, mg/L	--	<0.1	--	<0.1	<0.1	<0.1	--	--	--	0.1	--	--	--
Copper, mg/L	--	<0.05	--	<0.05	<0.05	<0.05	--	--	--	0.1	--	--	--
Iron, mg/L	--	808	--	675	700	882	--	--	--	824.5	--	--	--
Lead, mg/L	--	5.30	--	4.59	3.04	3.43	--	--	--	1.0	--	--	--
Lithium, mg/L	--	8.70	--	7.90	5.98	5.64	--	--	--	--	--	--	--
Magnesium, mg/L	--	267.5	--	189.2	143	145.4	--	--	--	33.9	--	--	--
Manganese, mg/L	--	68	--	68.3	56.3	65.6	--	--	--	21.6	--	--	--
Nickel, mg/L	--	0.81	--	1.03	1.45	1.06	--	--	--	1.3	--	--	--
Potassium, mg/L	--	556	--	493	404	421	--	--	--	77.0	--	--	--
Sodium, mg/L	--	837	--	878	706	678	--	--	--	64.6	--	--	--
Zinc, mg/L	--	91.0	--	65.4	55.2	64.3	--	--	--	31.0	--	--	--
Di-n-butyl phthalate, µg/L	--	--	0	--	--	--	--	--	--	--	--	--	--
Phenol, µg/L	--	--	603	--	--	--	--	--	--	--	--	--	--
Ortho-Phosphate, mg/L P	8.6	--	--	--	5.8	--	--	--	--	1.64	--	--	--
Ammonia-Nitrogen, mg/L N	--	--	--	--	182.1	--	--	--	171.6	--	--	--	--
Sulfide, mg/L	--	--	--	--	--	0.1	0.15	0.21	--	--	0.14	0.22	0.14

Table B9 (Continued)

Time Since Leachate Production Began, days	156	158	175	184	193	195	220	230	244	250	270	274
Cadmium, mg/L	0.08	--	--	0.05	--	--	0.05	--	0.05	--	--	0.05
Calcium, mg/L	791.9	--	--	664.5	--	--	593.2	--	485.2	--	--	395.2
Chromium, mg/L	0.1	--	--	0.1	--	--	0.1	--	0.1	--	--	0.1
Copper, mg/L	0.1	--	--	0.1	--	--	0.1	--	0.1	--	--	0.1
Iron, mg/L	866.5	--	--	547.6	--	--	530.9	--	584.2	--	--	525.9
Lead, mg/L	0.5	--	--	0.5	--	--	0.5	--	0.5	--	--	0.5
Lithium, mg/L	--	--	--	--	--	--	--	--	--	--	--	--
Magnesium, mg/L	21.7	--	--	10.0	--	--	11.4	--	11.5	--	--	10.2
Manganese, mg/L	14.6	--	--	4.8	--	--	4.0	--	5.6	--	--	3.8
Nickel, mg/L	0.8	--	--	0.5	--	--	0.2	--	0.1	--	--	0.03
Potassium, mg/L	37.0	--	--	9.0	--	--	7.0	--	8.0	--	--	7.0
Sodium, mg/L	24.2	--	--	9.7	--	--	7.9	--	11.3	--	--	7.5
Zinc, mg/L	22.1	--	--	15.0	--	--	9.4	--	9.7	--	--	5.5
Di-n-butyl phthalate, µg/L	--	--	--	--	--	--	--	--	--	--	--	--
Phenol, µg/L	--	--	--	--	--	--	--	--	--	--	--	--
Ortho-Phosphate, mg/L P	0.62	--	--	0.11	--	--	0.1	--	0.1	--	--	0.1
Ammonia Nitrogen, mg/L N	10.8	--	--	--	25.9	--	6.6	--	10.0	--	--	13.0
Sulfide, mg/L	--	0.17	0.10	--	--	0.19	--	0.10	--	0.19	0.25	--

Table B9 (Continued)

Time Since Leachate Production Began, days	278	290	297	305	313	320	327	335	336	344	346	354
Cadmium, mg/L	--	--	--	0.05	--	--	--	--	0.05	--	--	--
Calcium, mg/L	--	--	--	364.5	--	--	--	--	400.6	--	--	--
Chromium, mg/L	--	--	--	0.1	--	--	--	--	0.1	--	--	--
Copper, mg/L	--	--	--	0.1	--	--	--	--	0.1	--	--	--
Iron, mg/L	--	--	--	489.5	--	--	--	--	430.2	--	--	--
Lead, mg/L	--	--	--	0.5	--	--	--	--	0.5	--	--	--
Lithium, mg/L	--	--	--	--	--	--	--	--	--	--	--	--
Magnesium, mg/L	--	--	--	12.6	--	--	--	--	10.6	--	--	--
Manganese, mg/L	--	--	--	5.0	--	--	--	--	5.1	--	--	--
Nickel, mg/L	--	--	--	0.03	--	--	--	--	0.03	--	--	--
Potassium, mg/L	--	--	--	6.0	--	--	--	--	4.0	--	--	--
Sodium, mg/L	--	--	--	8.5	--	--	--	--	7.5	--	--	--
Zinc, mg/L	--	--	--	3.6	--	--	--	--	0.2	--	--	--
Di-n-butyl phthalate, µg/L	--	--	--	--	--	--	--	--	--	--	--	--
Phenol, µg/L	--	--	--	--	--	--	--	--	--	--	--	--
Ortho-Phosphate, mg/L P	--	--	--	0.1	--	--	--	--	0.1	--	--	--
Ammonia Nitrogen, mg/L N	--	--	--	35.5	--	--	--	--	--	12.8	--	--
Sulfide, mg/L	0.32	0.90	0.92	--	2.56	1.21	0.85	0.51	--	--	0.21	0.09

Table B9 (Continued)

Time Since Leachate Production Began, days	365	377	399	410
Cadmium, mg/L	0.05	--	0.05	--
Calcium, mg/L	147.8	--	15.6	--
Chromium, mg/L	0.1	--	0.1	--
Copper, mg/L	0.1	--	0.1	--
Iron, mg/L	401.1	--	320.6	--
Lead, mg/L	0.5	--	0.3	--
Lithium, mg/L	0.02	0.01	0.06	0.56
Magnesium, mg/L	11.0	--	6.6	--
Manganese, mg/L	4.8	--	4.0	--
Nickel, mg/L	0.03	--	0.03	--
Potassium, mg/L	5.0	--	1.75	--
Sodium, mg/L	7.0	--	6.1	--
Zinc, mg/L	0.5	--	0.3	--
Di-n-butyl phthalate, µg/L	--	--	--	--
Phenol, µg/L	--	--	--	--
Ortho-Phosphate, mg/L P	0.1	--	0.1	--
Ammonia Nitrogen, mg/L N	3.3	--	1.0	--
Sulfide, mg/L	0.1	0.09	--	0.08

*Cell 4

Table B10. Gas Production and Composition for the Recycle Simulated Landfill Cells

Time Since Leachate Production Began, days	Cell 1							Cell 2						
	Cumulative Gas Prod., L/wk	Weekly Gas Prod., L	N ₂	CO ₂	O ₂	H ₂	CH ₄	Cumulative Gas Prod., L/wk	Weekly Gas Prod., L	N ₂	CO ₂	O ₂	H ₂	CH ₄
227	--	--	39.7	23.8	3.0	0.5	1.8	--	--	43.7	16.2	3.5	0.5	ND
233	--	--	37.5	26.2	2.5	0.5	2.3	--	--	38.8	20.1	2.2	0.5	ND
236	--	--	61.6	22.2	1.5	0.5	ND	--	--	66.9	15.1	2.0	0.5	ND
237	0.6	0.6	--	--	--	--	--	2.4	2.4	--	--	--	--	--
239	--	--	63.2	22.4	3.2	0.5	2.4	--	--	70.5	14.5	2.4	0.5	ND
243	--	--	63.2	18.5	3.6	0.6	3.4	--	--	70.8	14.2	2.9	0.4	ND
244	0.8	0.2	--	--	--	--	--	2.5	0.1	--	--	--	--	--
245	--	--	43.0	16.0	8.1	0.4	2.8	--	--	47.5	14.5	7.5	0.4	ND
251	1.1	0.3	--	--	--	--	--	3.1	0.6	--	--	--	--	--
252	--	--	54.8	22.5	2.7	0.4	8.3	--	--	63.4	17.2	3.6	0.4	3.6
254	--	--	53.3	21.0	1.8	0.6	11.5	--	--	61.8	14.5	2.7	0.6	2.3
258	4.0	2.9	47.2	23.9	1.7	0.6	12.6	8.8	5.7	65.1	16.7	3.4	0.6	3.4
262	--	--	48.6	20.0	4.8	0.8	13.9	--	--	60.8	18.0	4.0	0.5	6.4
265	8.0	4.0	--	--	--	--	--	15.0	6.2	--	--	--	--	--
268	--	--	43.2	31.6	1.8	ND	17.8	--	--	53.9	26.3	1.8	ND	10.1
272	11.6	3.6	41.2	33.1	1.7	0.4	20.3	21.4	6.4	54.0	27.0	2.5	0.4	10.1
276	--	--	41.4	23.1	3.0	0.6	20.7	--	--	50.2	22.4	3.0	0.6	13.4
279	20.9	9.3	--	--	--	--	--	31.3	9.9	--	--	--	--	--
281	--	--	46.5	31.8	4.4	ND	28.5	--	--	54.7	26.0	3.7	ND	19.6
285	--	--	39.2	30.9	3.6	ND	28.7	--	--	46.7	28.8	3.6	ND	21.7
286	37.8	16.9	--	--	--	--	--	46.5	15.2	--	--	--	--	--
290	--	--	26.6	36.8	1.5	ND	40.4	--	--	45.1	28.7	2.0	ND	25.7
293	67.7	29.9	--	--	--	--	--	65.9	19.4	--	--	--	--	--
294	--	--	19.6	36.8	1.6	ND	46.4	--	--	32.5	29.5	2.8	ND	34.6
297	--	--	16.8	36.2	1.3	--	49.6	--	--	29.9	31.5	2.3	--	35.3
299	125.0	57.3	--	--	--	--	--	98.6	32.7	--	--	--	--	--

Table B10(Continued)

Time Since Leachate Production Began, days	Cell 1							Cell 2						
	Cumulative Gas Prod., L/wk	Weekly Gas Prod., L	N ₂	CO ₂	O ₂	H ₂	CH ₄	Cumulative Gas Prod., L/wk	Weekly Gas Prod., L	N ₂	CO ₂	O ₂	H ₂	CH ₄
301	--	--	13.1	47.0	ND	--	59.4	--	--	34.3	44.4	2.4	--	47.4
306	263.0	138.0	--	--	--	--	--	176.4	77.8	--	--	--	--	--
307	--	--	8.5	41.1	1.2	--	52.4	--	--	19.7	38.1	1.7	--	43.2
310	--	--	14.6	31.4	1.7	--	44.2	--	--	28.8	26.7	4.5	--	40.6
314	461.3	198.3	11.3	39.1	2.8	--	53.3	251.1	74.7	19.4	33.5	3.0	--	41.7
319	--	--	6.1	46.2	3.3	--	64.7	--	--	8.6	41.2	2.1	--	55.5
321	679.4	218.1	--	--	--	--	--	331.1	80.0	--	--	--	--	--
326	--	--	4.8	37.2	ND	--	54.0	--	--	4.0	36.5	ND	--	51.9
328	997.5	318.1	--	--	--	--	--	439.5	108.4	--	--	--	--	--
330	--	--	3.1	33.9	ND	--	66.9	--	--	4.2	34.6	ND	--	6.9
335	1425.5	428.0	9.2	48.6	2.9	--	63.4	663.6	224.1	11.9	49.1	1.7	--	62.2
339	--	--	4.5	46.6	1.1	--	51.6	--	--	6.1	38.6	1.9	--	54.7
342	1922.7	497.2	--	--	--	--	--	1004.8	341.2	--	--	--	--	--
343	--	--	4.4	38.3	1.3	--	56.6	--	--	7.7	37.1	1.3	--	50.9
345	--	--	--	--	--	0.01	--	--	--	--	--	--	0.01	--
349	2577.5	654.8	6.2	30.1	1.6	--	47.1	1571.4	566.6	7.0	44.4	1.9	--	49.7
355	--	--	17.5	29.5	6.2	--	56.9	--	--	16.6	33.1	6.2	--	56.2
356	3359.3	781.8	--	--	--	--	--	2325.0	753.6	--	--	--	--	--
361	--	--	8.7	31.2	2.0	--	60.2	--	--	8.7	31.8	2.2	--	61.1
363	4138.3	779.0	--	--	--	--	--	3255.4	930.4	--	--	--	--	--
364	--	--	7.6	31.0	2.2	--	57.8	--	--	7.6	32.9	2.2	--	58.8
367	--	--	5.3	30.6	1.5	--	54.4	--	--	8.7	31.7	2.2	--	57.3
370	4850.3	712.0	--	--	--	--	--	4175.4	920.0	--	--	--	--	--
373	--	--	8.0	33.1	2.2	--	57.3	--	--	8.6	31.9	3.2	--	59.1
377	5409.3	559.0	7.5	36.5	2.1	--	58.8	4837.4	662.0	9.9	32.5	2.4	--	56.7
382	--	--	8.8	34.6	2.3	--	53.8	--	--	6.9	35.1	1.7	--	59.7
384	5976.3	567.0	--	--	--	--	--	5523.4	686.0	--	--	--	--	--
397	--	--	8.6	32.2	2.6	--	49.6	--	--	11.4	29.2	2.2	--	48.1

Table B10(Continued)

Time Since Leachate Production Began, days	Cell 1					Cell 2								
	Cumulative Gas Prod., L/wk	Weekly Gas Prod., L	N ₂	%CO ₂	%O ₂	%H ₂	%CH ₄	Cumulative Gas Prod., L/wk	Weekly Gas Prod., L	N ₂	%CO ₂	%O ₂	%H ₂	%CH ₄
391	6432.3	456.0	8.9	31.6	2.2	--	65.6	6074.4	551.0	10.4	29.7	2.5	--	62.1
395	--	--	8.8	33.7	2.2	--	60.9	--	--	9.7	32.1	2.8	--	60.9
398	6629.6	197.3	--	--	--	--	--	6378.4	304.0	--	--	--	--	--
399	--	--	8.4	32.7	2.2	--	64.4	--	--	9.8	38.9	2.8	--	66.9
405	6725.7	96.1	--	--	--	--	--	6482.7	104.3	--	--	--	--	--
409	--	--	11.1	35.8	2.7	--	56.8	--	--	5.4	33.1	1.2	--	58.3
412	6799.5	73.8	--	--	--	--	--	6546.6	63.9	--	--	--	--	--
413	--	--	10.5	31.9	2.2	--	58.8	--	--	9.6	34.6	1.5	--	64.5
419	6881.8	82.3	9.2	30.1	1.6	--	53.8	6606.2	59.6	8.5	27.8	1.6	--	54.6
426	6965.6	83.8	9.0	31.5	1.5	--	52.5	6664.9	58.7	8.9	29.5	1.6	--	53.2
433	7032.0	66.4	9.2	29.5	1.2	--	50.5	6715.9	51.0	9.2	31.2	1.4	--	51.9
440	7067.9	35.9	8.5	32.5	1.1	--	48.7	6753.4	37.5	9.5	29.7	1.4	--	54.5
447	7108.5	40.6	9.0	30.1	1.5	--	51.0	6798.1	44.7	8.5	32.5	0.9	--	52.5

ND = Not detected

Cell 1 = Control Recycle Cell

Cell 2 = Spiked Recycle Cell

Table B11. Gas Production and Composition for the Single Pass Simulated Landfill Cells

Time Since Leachate Production Began, days	Cell 3						Cell 4					
	Cumulative			Weekly			Cumulative			Weekly		
	Gas Prod., L/wk	%N ₂	%CO ₂	%O ₂	%H ₂	%CH ₄	Gas Prod., L/wk	%N ₂	%CO ₂	%O ₂	%H ₂	%CH ₄
227	--	34.7	31.4	ND	1.0	2.4	--	39.4	25.2	1.7	1.2	ND
233	--	29.1	36.6	2.0	1.0	4.5	--	37.1	27.9	1.5	1.1	2.3
236	--	52.4	27.8	1.5	1.0	4.5	--	59.6	22.7	1.8	1.1	3.4
237	2.6	--	--	--	--	--	4.4	--	--	--	--	--
239	--	50.3	30.3	2.4	1.0	7.2	--	59.2	23.7	1.6	1.3	3.6
243	--	49.0	29.6	0.8	0.4	6.9	--	60.4	23.2	2.4	0.8	5.7
244	4.7	--	--	--	--	--	6.9	--	--	--	--	--
245	--	33.9	33.3	4.7	0.6	11.4	--	35.6	24.6	1.9	1.0	5.7
251	7.8	--	--	--	--	--	10.4	--	--	--	--	--
252	--	45.4	29.0	3.6	0.4	11.9	--	54.8	17.8	3.6	0.7	8.3
254	--	42.9	26.0	2.7	0.2	11.5	--	49.8	21.0	1.8	0.5	9.2
258	12.6	41.1	29.7	2.5	0.2	11.5	26.0	46.2	23.0	3.4	0.3	10.3
262	--	35.7	35.6	1.6	0.1	13.9	--	46.2	29.9	3.2	0.5	12.8
265	24.8	--	--	--	--	--	43.9	--	--	--	--	--
268	--	30.5	44.2	0.9	ND	19.0	--	39.5	36.8	1.8	ND	15.2
272	38.2	33.0	41.4	2.5	ND	20.3	59.3	40.3	36.8	3.3	0.8	15.2
276	--	21.1	35.9	2.3	ND	20.7	--	38.8	37.1	3.0	ND	18.3
277	59.4	--	--	--	--	--	84.1	--	--	--	--	--
281	--	41.4	45.0	2.7	ND	28.5	--	41.3	38.5	3.7	ND	21.6
282	--	31.0	42.1	3.6	ND	26.1	--	35.4	41.4	2.9	ND	23.5
283	17.5	--	--	--	--	--	112.8	--	--	--	--	--
284	--	18.1	--	--	--	--	28.7	--	--	--	--	--
285	--	--	43.5	1.4	ND	32.3	--	30.1	42.0	1.5	ND	29.0
286	14.3	--	--	--	--	--	143.9	--	--	--	--	--
287	--	22.0	43.1	2.0	ND	35.2	--	26.1	41.2	2.8	ND	32.0
288	--	21.8	39.2	1.9	--	35.8	--	21.8	38.2	1.9	--	30.9
289	14.3	--	--	--	--	--	176.9	--	--	--	--	--

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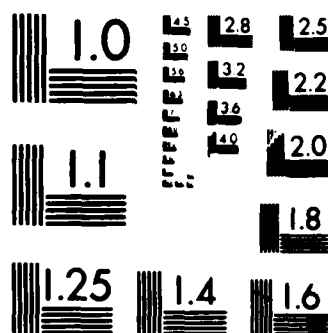
THE FATE OF SELECTED ORGANIC POLLUTANTS DURING LANDFILL
DISPOSAL OPERATIO. (U) GEORGIA INST OF TECH ATLANTA
SCHOOL OF CIVIL ENGINEERING F G POHLAND ET AL. MAR 87
UNCLASSIFIED SCEGIT-86-108 DAND17-85-C-5024

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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

Table B11 (Continued)

Time Since Leachate Production Began, days	Cell 3						Cell 4					
	Cumulative Gas Prod., L/wk	Weekly Gas Prod., L	\$N ₂	\$CO ₂	\$O ₂	\$H ₂	Cumulative Gas Prod., L/wk	Weekly Gas Prod., L	\$N ₂	\$CO ₂	\$O ₂	\$H ₂
301	--	--	25.5	51.6	2.4	--	--	--	28.8	51.6	2.4	--
306	127.0	20.0	--	--	--	--	214.4	37.5	--	--	--	39.4
307	--	--	21.6	41.1	3.3	--	--	--	26.3	38.4	4.1	--
310	--	--	21.0	36.6	3.8	--	--	--	24.3	37.9	6.2	30.8
314	150.3	23.3	14.4	37.5	2.9	--	262.5	48.1	19.2	34.3	3.8	34.2
319	--	--	17.1	48.0	2.1	--	--	--	17.9	50.1	2.5	27.0
321	168.7	18.4	--	--	--	--	298.7	36.2	--	--	--	39.9
326	--	--	18.1	37.2	2.2	--	--	--	16.1	38.3	1.1	--
328	189.4	20.7	--	--	--	--	340.6	41.9	--	--	--	38.8
330	--	--	11.8	39.0	1.7	--	--	--	15.6	36.8	1.7	--
335	219.1	29.7	20.2	48.1	2.5	--	392.4	51.8	16.1	49.1	1.7	41.9
339	--	--	11.2	37.0	1.1	--	--	--	11.4	34.9	1.6	47.9
342	235.3	16.2	--	--	--	--	431.8	39.4	--	--	--	37.9
343	--	--	13.2	34.7	0.9	--	--	--	14.3	32.7	1.8	--
345	--	--	--	--	--	0.01	--	--	--	--	--	37.0
349	265.1	29.8	11.7	33.3	1.3	--	492.6	60.8	10.9	30.1	1.3	--
355	--	--	12.7	31.3	3.1	--	--	--	17.1	39.6	3.9	41.1
356	282.8	17.7	--	--	--	--	541.4	48.8	--	--	--	43.7
361	--	--	14.8	40.2	2.3	--	--	--	13.5	41.2	3.0	--
363	299.7	16.9	--	--	--	--	600.8	59.4	--	--	--	40.6
364	--	--	12.2	37.0	2.2	--	--	--	14.1	35.1	2.7	--
367	--	--	15.2	36.8	2.2	--	661.2	60.4	16.0	36.8	2.2	42.3
370	322.9	23.2	--	--	--	--	--	--	--	--	--	43.9
373	--	--	17.2	36.3	5.3	--	--	--	19.6	34.4	2.9	--
377	336.8	13.9	23.6	32.0	2.5	--	718.7	57.5	19.6	36.0	2.5	43.2
382	--	--	16.5	36.0	2.4	--	--	--	17.0	36.5	2.5	39.2
384	357.6	20.8	--	--	--	--	791.8	73.1	--	--	--	42.5
387	--	--	14.9	33.1	2.8	--	--	--	13.3	33.4	2.9	--
												40.2

Table B11(Continued)

Time Since Leachate Production Began, days	Cell 1							Cell 2						
	Cumulative Gas Prod., L/wk	Weekly Gas Prod., L	N ₂	%CO ₂	%O ₂	%H ₂	%CH ₄	Cumulative Gas Prod., L/wk	Weekly Gas Prod., L	N ₂	%CO ₂	%O ₂	%H ₂	%CH ₄
391	376.8	19.2	10.4	34.2	2.7	--	57.6	850.3	58.5	11.5	35.1	1.9	--	54.1
395	--	--	18.5	36.4	3.3	--	51.4	--	--	14.9	36.4	2.2	--	50.4
398	387.9	11.1	--	--	--	--	--	892.8	42.5	--	--	--	--	--
399	--	--	12.6	37.8	2.8	--	56.8	--	--	13.5	35.1	2.8	--	51.7
405	396.0	8.1	--	--	--	--	--	923.7	30.9	--	--	--	--	--
409	--	--	14.2	31.0	2.5	--	42.0	--	--	14.7	34.2	2.4	--	41.1
412	404.5	8.5	--	--	--	--	--	961.6	37.9	--	--	--	--	--
413	--	--	13.3	37.8	2.5	--	54.0	--	--	14.1	34.8	2.2	--	47.6
419	414.4	9.9	10.5	29.7	1.6	--	45.0	1002.2	40.6	15.7	33.9	2.4	--	43.8
426	429.2	14.8	11.2	32.8	2.0	--	43.5	1048.2	46.0	14.5	33.5	2.2	--	46.5
433	443.3	14.1	10.5	35.4	2.1	--	45.6	1097.5	49.3	13.8	31.8	1.9	--	47.8
440	453.1	9.8	12.2	31.4	2.0	--	45.8	1139.7	42.2	13.9	34.5	2.1	--	46.4
447	467.4	14.3	10.7	33.5	1.5	--	43.9	1195.0	55.3	12.5	31.5	0.9	--	45.5

ND - Not detected

Cell 3 - Control Single Pass Cell

Cell 4 - Spiked Single Pass Cell

Table B12. Lithium Concentration in Leachate from the Single Pass Cells During the Second Tracer Study

Time Since Leachate Production Began, days	Concentration, mg/L Li	
	Cell 3	Cell 4
365	0.02	0.02
375	0.01	0.01
377	0.02	0.01
379	0.02	0.01
381	0.01	0.01
383	0.01	0.01
385	0.02	0.01
387	0.01	0.01
389	0.01	0.01
391	0.02	0.03
393	0.04	0.04
395	0.02	0.02
397	0.03	0.06
399	0.06	0.06
401	0.11	0.08
402	0.13	0.08
404	0.22	0.26
406	0.21	0.31
408	0.24	0.33
410	0.61	0.56
412	0.58	0.70
414	0.52	0.65
416	0.67	0.64
418	0.93	1.10
420	0.98	1.20
422	1.00	1.20
424	1.54	1.69
426	1.54	1.89
428	1.63	2.01
430	1.67	1.99
432	2.04	2.50
434	2.33	2.75
436	2.41	2.73
438	2.52	2.98
440	2.56	3.07
442	2.60	3.09

Cell 3 = Control Single Pass Cell
Cell 4 = Spiked Single Pass Cell

Table B13. Initial Gas Production and Composition for Recycle Simulated Landfill Cells

Time Since Leachate Production Began, days	Cell 1						Cell 2					
	L/d	%N ₂	%CO ₂	%O ₂	%H ₂	%CH ₄	L/d	%N ₂	%CO ₂	%O ₂	%H ₂	%CH ₄
0	36	20.7	52.4	4	22.7	0	50	6.4	62.7	0.5	30.6	0
1	69	--	--	--	--	--	52	--	--	--	--	--
2	34.5	--	--	--	--	--	--	--	--	--	--	--
4	--	26.9	55.2	1.5	16.5	0	--	5.5	71.3	0	23.2	0
5	23	--	--	--	--	--	19	--	--	--	--	--
6	6.2	--	--	--	--	--	7.9	--	--	--	--	--
7	--	14.7	67.9	0.2	17	0	--	5.9	77.8	0	16.3	0
8	0	10.9	74.2	0.2	14.7	0	0	4.3	81.1	0	14.5	0

Cell 1 - Control Recycle Cell; Cell 2 - Spiked Recycle Cell

Table B14. Initial Gas Production and Composition for Single Pass Simulated Landfill Cells

Time Since Leachate Production Began, days	Cell 3						Cell 4					
	L/d	%N ₂	%CO ₂	%O ₂	%H ₂	%CH ₄	L/d	%N ₂	%CO ₂	%O ₂	%H ₂	%CH ₄
0	43	5.5	69.5	0	25.1	0	37.5	6.7	64.3	1.2	27.9	0
1	49	--	--	--	--	--	49	--	--	--	--	--
2	30	--	--	--	--	--	32	--	--	--	--	--
4	--	7.9	72.5	0.2	19.4	0	--	10.7	67.7	0.9	20.5	0
5	17	--	--	--	--	--	20	--	--	--	--	--
6	7.5	--	--	--	--	--	8.6	--	--	--	--	--
7	--	5	78.9	0	17.4	0	--	6.9	74.5	0	18.4	0
8	3.8	8.5	75.8	0	15.7	0	3.1	7.7	73.8	0	18.5	0

Cell 3 - Control Single Pass Cell; Cell 4 - Spiked Single Pass Cell

APPENDIX C

Example Computation of Mass from Concentration

Single Pass Cell:

6 liters of leachate collected during the week
COD concentration = 15,000 mg/L
15,000 mg/L
x 6 L/wk

90,000 mg/wk - to be added to previous weeks subtotal
to maintain cumulative total (mg).

Recycle Cell:

20 liters of leachate collected in reservoir during the week
COD concentration = 15,000 mg/L
15,000 mg/L
x 20 L

300,000 mg - current mass of COD in leachate (total equal to
current mass plus mass removed for sampling).

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