United States
Environmental Protection
Agency

Hazardous Waste Engineering
Research Laboratory
Cincinnati, OH 45268

Research and Development

EPA/600/S2-86/041 July 1986

EPA

Project Summary

Gas Characterization, Microbiological Analysis, and Disposal of Refuse in GRI Landfill Simulators

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The full report describes the termination of a five-year, pilot scale project that evaluated methane production and gas enhancement techniques in sanitary landfills. Sixteen simulated landfills were constructed in 1980 and operated until January 1985. Data collected during this termination study consisted of characterization of the trace volatile constituents of the gas generated by the experimental landfills and microbiological analysis of the refuse.

The trace volatile organic compounds were found in higher concentrations than previously reported in the literature. Xylenes, ethylbenzene, methylene chloride, toluene, and benzene were found in all of the gas samples analyzed. Xylenes were found in greatest concentrations of the trace compounds analyzed, ranging from 12 mg/m^3 to 500 mg/m^3. The levels and types of trace organics found in the gas indicate that landfill gas could be potentially corrosive and might contain toxic levels of some compounds.

All samples had relatively high aerobic and anaerobic plate counts, *Clostridium perfringens*, and fungi levels. These same samples indicated relatively low levels of total coliforms, fecal coliforms, fecal streptococci, and gram negative rods. Relative numbers and types of microorganisms appeared to reflect the enhancement technique applied to the cell. For example, the highest numbers of microorganisms were found in a cell that had a sewage sludge enhancement.

This Project Summary was developed by EPA's Hazardous Waste Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Methane from sanitary landfills is a potential source of energy that may someday routinely supplement declining natural gas reserves. Currently, gas production from the landfill is often of inconsistent quality and is not produced in sufficient quantities to be a reliable source of gas. The work in the full report represents the termination of a five-year project in which enhancement techniques for optimizing methane production resulting from anaerobic decomposition were investigated. The techniques investigated were moisture addition, elevation of temperature, leachate recycle, sewage sludge addition, buffer addition, and nutrient addition. Several years into the study, the cells were reloaded with different or additional enhancements. Table 1 summarizes the enhancement techniques applied to each of the test cells throughout the project. The project clearly demonstrated that certain enhancements can affect gas production in terms of the quantity of gas produced, the rate at which it is produced, and the amount of methane produced. The original project did not address one significant problem associated with landfill gas utilization; it is that landfill gas may contain trace gases that will not support combustion and may create problems from incomplete combustion

Table 1. *Enhancement Techniques*

Test Cell	Enhancement Technique Feb. '80 - Jan. '82	Enhancement Technique Feb. '83 - Jan. '85
20	Low Infiltration	No Change
21	Low Infiltration	Increase Moisture Content
22	High Infiltration	No Change
23	High Infiltration	No Change
24	High Infiltration, Leachate Recycle	No Change
25	High Infiltration, Leachate Recycle	Sludge Addition
26	High Infiltration, Leachate Recycle, Buffer Addition	No Change
27	High Infiltration, Leachate Recycle, Buffer Addition	Sludge Addition
28	High Infiltration, Leachate Recycle, Nutrient Addition	No Change
29	High Infiltration, Leachate Recycle, Nutrient Addition	Sludge Addition
30	High Infiltration, Leachate Recycle, Buffer Addition, Nutrient Addition	Temperature Increase
31	High Infiltration, Leachate Recycle, Buffer Addition, Nutrient Addition	Temperature Increase
32	High Infiltration, Buffer Addition	No Change
33	High Infiltration, Buffer Addition	Buffer Slurry Addition
34	High Infiltration, Nutrient Addition	No Change
35	High Infiltration, Nutrient Addition	Nutrient Slurry Addition

products. Therefore, one of the objectives of this termination study was to obtain gas samples from five of the higher gas producing cells in order to discern the trace volatile organic compounds present in the simulated landfill gas.

Because methane production is a complex microbial process, it was important to determine which microorganisms were present and were therefore actively stabilizing the waste. Furthermore, the refuse was ground before loading in the cells and since similar microbial investigations of unground refuse were recently reported, the microbiology of these cells was of special interest. The microbiological analyses consisted of routine indicator analyses, examination for fungi, methane-producing bacteria, *Clostridium* and total plate counts distinguishing between aerobic and anaerobic bacteria.

Procedures

Of the sixteen original test cells, only ten were dismantled during the course of this project. Six cells remain active as part of a study on gas production prevention by lime injection. Specific cells were selected for gas and microbiological analysis. A summary of the cells selected for each analysis and the final disposition of each cell can be seen in Table 2.

All refuse was removed by hand by a team of two researchers. The ten dismantled cells were evaluated for the overall test cell condition. The refuse was examined to ascertain its condition after five years of disposal and to determine if any recognizable items survived the grinding and disposal.

Five test cells were selected for gas analysis (Table 2). One hundred ml samples were taken directly from the five lysimeters on two different days. These samples were collected on Tenax traps. Selected volatile organic compounds were analyzed by GC/MS using EPA Method 624. The contents of the sample traps were spiked with 5 µl of internal standard. This internal standard was composed of bromochloromethane, 1,4-difluorobenzene, and d5-chlorobenzene. After the traps were spiked with the internal standard, they were thermally desorbed for 10 minutes at 180 °C with organic-free nitrogen bubbled through 5 ml of organic-free water and trapped on an analytical trap. After the ten-minute desorption, the analytical adsorbent trap was rapidly heated to 180 °C with carrier gas flow reversed so that the effluent flow from the analytical trap was directed onto a 6-foot glass column packed with SP-1000 on Carbopack B. The volatile organic compounds were separated by temperature-programmed gas chromatography and detected by low resolution mass spectometry. The mass of the compounds present was calculated using the internal standard technique.

Six of the test cells were selected for microbiological analyses (Table 2). The microbiological samples were collected at two depths from each of the six cells selected for analysis. One sample was collected near the top of the refuse layer (designated sample T) and the other was collected near the bottom of the refuse layer (designated sample B). The samples consisted of five grab samples composited to a total of about 1 kg from each sampling location. Although the refuse was coarsely ground, some large items

Table 2. *Analysis Summary and Final Test Cell Disposition*

Test Cell	Micro	GC/MS	Disposal	Lime Injection Study
20	M		D	
21		G		L
22		G		L
23	M	G	D	
24			D	
25	M		D	
26	M		D	
27				L
28			D	
29				L
30	M		D	
31			D	
32				L
33		G		L
34			D	
35	M	G	D	

escaped the grinding process and were simply balled into fist-sized clumps. These large, inert items were intentionally avoided in the micro sampling. All micro methods were standard methods for water and wastewater with the exception of the methane former analysis. This was essentially a qualitative analysis in which the gas produced by the bacteria was analyzed for methane, indicating the presence or absence of methane-producing bacteria.

Results and Discussion

All of the test cells were in excellent condition. Seals were intact and the cells were gastight. Since the refuse had been ground before placing it in the lysimeters, the cell contents were well mixed. No layering or pockets of materials was noted. Many items survived the grinding process and were able to be identified. The artifacts found documented the resistance of plastic, paper, rubber, dyes, synthetic fabrics, bulk metal, stainless steel, wood, glass, stone and combinations of these materials to biological attack. Other readily biodegradable items such as bread, corn cobs and bits of cheese were protected from biological activity to some extent by plastic and paper that surrounded these items. During the five years that the waste was in the lysimeter, decomposition clearly occurred but was relatively slow. It appeared that most of the refuse placed in the cells was still present.

Gas Analysis

Twenty volatile organic compounds representing a cross section of potential problem-causing compounds were selected for analysis (Table 3). Some of these compounds may cause corrosion of the gas burner and others may produce toxic end products when burned. Some are thought to be carcinogenic or mutagenic and may be a health threat to landfill gas recovery personnel. All have been repeatedly observed in landfill gas and are considered to be characteristic trace components at full-scale landfill sites.

Seven of the original 20 compounds were not found in any of the samples taken. These were 1,1-dichloroethane, chlorobenzene, isooctane, isopropylbenzene, naphthalene, nonane and 1,1,2-trichloroethane. Three additional VOCs—tetrahydrofuran, freon, and carbon disulfide—were found in relatively high levels in many samples and therefore were included in the results. Tables 4 and 5 list the results of the gas sample analyses.

At the time of initial loading of the test cells, a spike of benzene, ethylbenzene,

Table 3. *Target Volatile Organic Compounds*

Compound Name	Synonym	Molecular Weight
Pentane		72
Benzene		78
Dichloromethane	Methylene chloride	85
Hexane		86
Toluene	Methylbenzene	92
1,1-Dichloroethylene	Vinylidene chloride	97
1,2-Dichloroethylene		97
1,1-Dichloroethane		99
m,p-Xylene		106
o-Xylene		106
Ethylbenzene		106
Chlorobenzene	Monochlorobenzene	113
Iso-Octane		114
Isopropylbenzene	Cumeme	120
Propylbenzene		120
Naphthalene		128
Nonane		128
Trichloroethylene	TCE	131
1,1,2-Trichloroethane	Vinyl trichloride	133
Tetrachloroethylene	Perchloroethylene	166

Table 4. *Trace VOC Concentrations, mg/m³ at 25°C*

Lysimeter	21*†	21†	22	22	23*
Sample Date	5/22/85	6/20/85	6/20/85	7/01/85	5/22/85
Compound	mg/m³	mg/m³	mg/m³	mg/m³	mg/m³
Pentane	ND	6.42	0.20	1.33	P
Tetrahydrofuran	ND	ND	0.406	ND	ND
Freon	ND	67.7	0.203	13.3	ND
Benzene	12.2	12.1	1.02	1.05	0.40
Dichloromethane	0.05	27.7	0.71	54.1	0.017
Hexane	P	101	1.02	26.4	P
Toluene	11.2	128	20.3	21.1	3.62
1,1-Dichloroethylene	0.04	ND	ND	ND	0.032
1,2-Dichloroethylene	0.99	0.54	1.31	1.85	1.27
1,1-Dichloroethylene	ND	ND	ND	ND	ND
o,m,p-Xylenes	13.3	175	112	118	12.2
Ethylbenzene	8.78	105	24.4	25.1	4.58
Chlorobenzene	ND	ND	ND	ND	ND
Iso-octane	ND	ND	ND	ND	ND
Isopropylbenzene	ND	ND	ND	ND	ND
Propylbenzene	P	33.7	8.11	11.8	ND
Carbon Disulfide	ND	67.7	0.965	128	0.018
Naphthalene	ND	ND	ND	ND	ND
Nonane	ND	ND	ND	ND	ND
Trichloroethylene	0.149	0.506	0.193	0.185	0.389
1,1,2-Trichloroethane	ND	ND	ND	ND	ND
Tetrachloroethylene	0.292	ND	ND	0.146	0.155

* *High sample volume, results tend to be low.*
P *Identified but not quantified.*
ND *Not detected, <5 ng in sample trap.*
† *Waste spiked with benzene, toluene, and ethylbenzene.*

Table 5. *Trace VOC Concentrations, mg/m³ at 25°C*

Lysimeter	33	33	35	35 (duplicate)
Sample Date	6/20/85	7/01/85	6/20/85	6/20/85
Compound	mg/m³	mg/m³	mg/m³	mg/m³
Pentane	ND	ND	2.13	0.90
Tetrahydrofuran	0.653	0.626	0.408	1.08
Freon	1.08	31.3	ND	9.71
Benzene	1.30	0.725	0.821	1.18
Dichloromethane	2.71	115	0.321	38.4
Hexane	1.08	30.5	2.00	10.7
Toluene	33.5	20.8	48.00	65.2
1,1-Dichloroethylene	ND	ND	ND	ND
1,2-Dichloroethylene	ND	0.061	0.651	1.50
1,1-Dichloroethylene	ND	ND	ND	ND
o,m,p-Xylenes	249	9.14	120	513
Ethylbenzene	68.3	25.6	97.1	138
Chlorobenzene	ND	ND	ND	ND
Iso-octane	ND	ND	ND	ND
Isopropylbenzene	ND	ND	ND	ND
Propylbenzene	ND	3.66	3.00	5.34
Carbon Disulfide	8.02	112	10.8	0.142
Naphthalene	ND	ND	ND	ND
Nonane	ND	ND	ND	ND
Trichloroethylene	ND	0.165	0.13	0.171
1,1,2-Trichloroethane	ND	ND	ND	ND
Tetrachloroethylene	ND	0.032	ND	ND

ND Not detected, <5 ng in sample trap.

and toluene was placed in cells 20 and 21. Although this spiking was performed in conjunction with a Ph.D dissertation rather than directly with the five-year gas enhancement project, it provided a basis for comparing the gas data generated. The three spike compounds as well as xylenes and dichloromethane were found in all of the samples analyzed. Xylenes were found in the highest concentrations of any of the VOCs determined.

All of the samples contained chlorinated compounds. Dichloromethane, freon, 1,2-dichloroethylene, trichloroethylene and tetrachloroethylene were found in many of the samples. The chlorinated compounds are of special interest, since incomplete combustion of the compounds can produce toxic end products.

Carbon disulfide was found in varying concentrations for all test cells, although not in every sample analyzed. Because carbon disulfide contains sulfur, its presence in the gas generated is also of concern. Both sulfur dioxide, SO_2, and sulfuric acid, H_2SO_4 are potential decomposition products and both are very corrosive.

Of those compounds found, concentrations were generally higher than has been reported in the literature, primarily because of the controlled setting in the lysimeter. Most literature data comes from sites where the gas releases cannot be controlled, such as at large landfills or hazardous waste sites. The landfill is constantly exposed to atmospheric changes, and ambient air moves to and from the landfill as pressure increases or decreases, thus causing the gas to dilute and disperse within the landfill. The lysimeter gas, however, was taken directly from the test cell piping. Therefore, there was no dilution of the sample by ambient air.

Microbiology

Before the microbiological results are reviewed, two factors should be pointed out relating to the original gas enhancement study that undoubtedly influenced the microbiology of the test cells. The grinding process used to shred the refuse involves extremely high temperatures that can and probably did destroy some of the microbial population. Since no microbiology was performed on the original bulk refuse or on the original shredded refuse, the actual impact of the grinding process could not be quantified. Second, the experimental landfills were loaded without a clay liner on top of the refuse, as would be found in a full-scale landfill and as is commonly done in experimental landfill design. This was purposefully omitted in order to concentrate on the effects of the enhancement technique applied; however, the result to these lysimeters was that no source of microorganisms was available to reseed the refuse. Since some of the microorganisms were undoubtedly destroyed in the grinding process, this lack of a source of microorganisms probably slowed the decomposition process and perhaps limited the levels of organisms found in the refuse during this study.

Microbiological analyses appeared to fall into three distict groups. Group 1 consisted of the organisms found in relatively high numbers in all samples. The Group 1 organisms were the fungi, *Clostridium perfringens*, and both the aeraobic and anaerobic standard plate counts. Group 2 consisted of the organisms generally found in lower numbers and often not found at all in the lowest dilutions analyzed. This group consisted of the gram negative rods, total and fecal coliforms, fecal streptococci, and the clostridia, as determined by tryptone sulfite cycloserine agar plate counts. The last group consisted solely of the methane bacteria.

The Group 1 organisms are shown in Figure 1. The numbers and types of organisms present in the refuse appeared to reflect the type of enhancement applied to the cell. This was most clearly demonstrated in cell 25, which showed the most dramatic change in organism levels from the top sample to the bottom sample. The aerobic standard plate count from the top sample in cell 25 was the highest count recorded in any of the samples. The anaerobic plate count and *Clostridium perfringens* counts were also higher than in most other samples, due to the addition of anaerobically digested sludge at the time of cell reloading. This would not only introduce large numbers of organisms but also provide excellent conditions for organism growth and survival.

The Group 2 organisms can be seen in Figure 2. None of the samples had counts for all of these organisms. In fact, cell 26 did not show the presence of any of these organisms at the lowest dilutions used. The traditional indicator organisms were present only in numbers high enough to quantify in three of the twelve samples. The grinding process would have destroyed or removed many of the original microbes, and the environment found in the lysimeter would have been so different from the natural environment of the in-

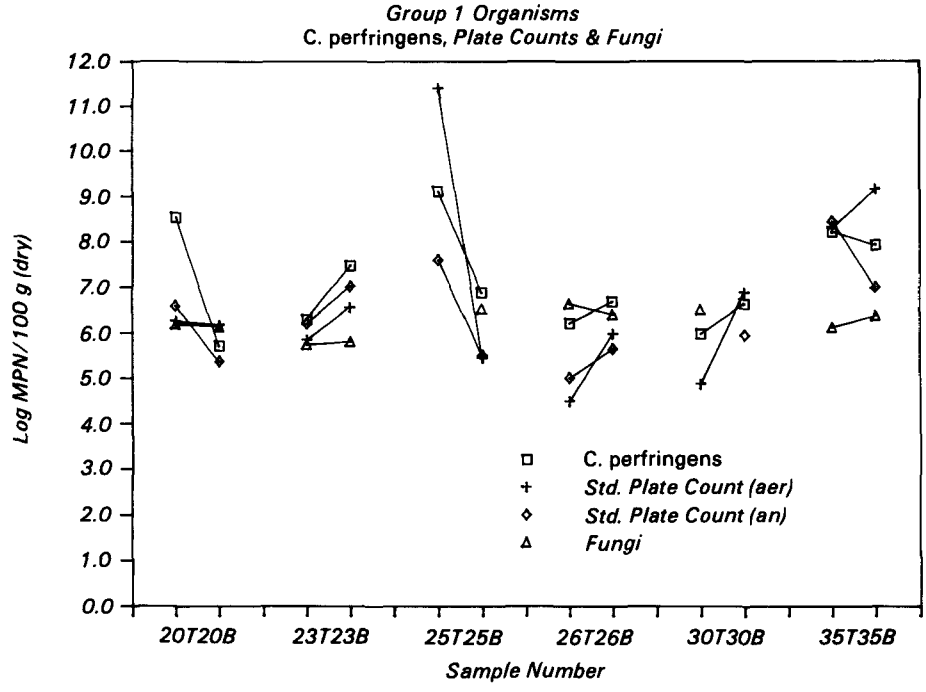

Figure 1. *Fungi and* Clostridium perfringens *total plate count (aerobic and anaerobic).*

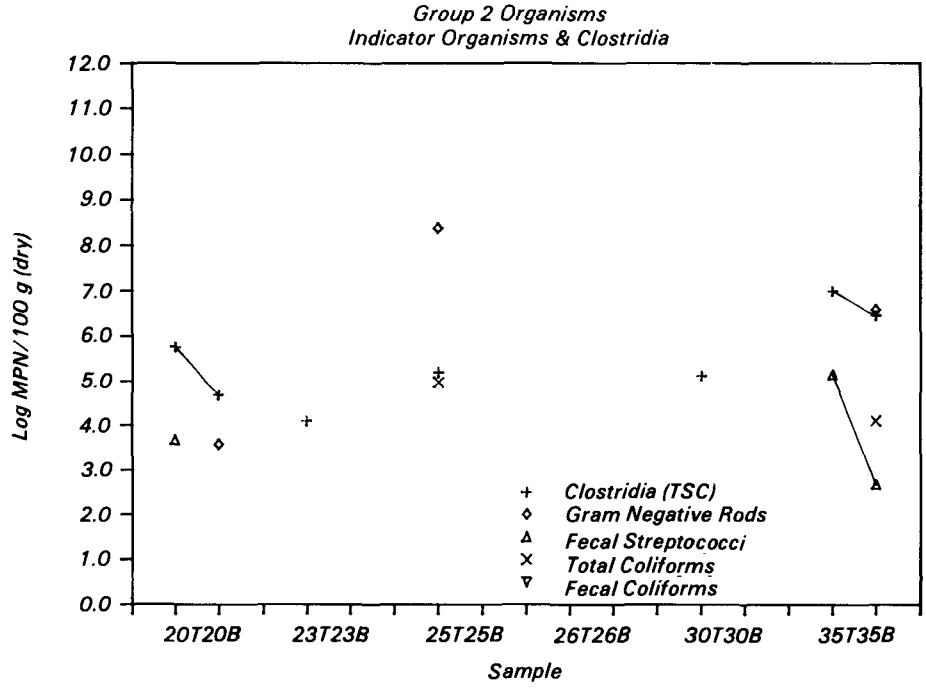

Figure 2. *Fecal streptococci, Clostridia, and gram negative rods.*

dicator organisms that conditions would not have been amenable to survival or growth of these populations.

The Group 3 organisms, the methane bacteria, can be seen in Figure 3. This was essentially a qualitative test. If methane bacteria are present, then the gas produced in each test vial will contain measurable quantities of methane. Figure 3 confirms the presence of methane bacteria in each of the cells analyzed.

Summary and Conclusions

Refuse and gas were sampled and analyzed from test lysimeters being dismantled upon termination of a five-year gas enhancement study. Gas analysis for 20 selected volatile compounds indicated the presence of many potentially harmful compounds in relatively high concentrations in some of the lysimeters. The trace volatile organic compounds were generally found in higher concentrations than previously reported in the literature. Xylenes were present in the highest concentrations, ranging from 12 mg/m^3 to 500 mg/m^3 in the samples analyzed. Chlorinated and sulfur containing compounds were found in every test cell. The potential for problems arising from incomplete combustion of these compounds complicates landfill gas utilization. Microbial populations reflected the enhancement technique applied to the cell. Enhancements that provided a suitable source or medium for supporting microbial growth (for instance, sludge addition) showed higher numbers of microorganisms. Cells with enhancements that created less favorable conditions for microbial survival—leachate recycle, for example—showed fewer organisms.

The full report was submitted in fulfillment of Contract 68-03-3210, Task 12, by the University of Cincinnati under the sponsorship of the U.S. Environmental Protection Agency.

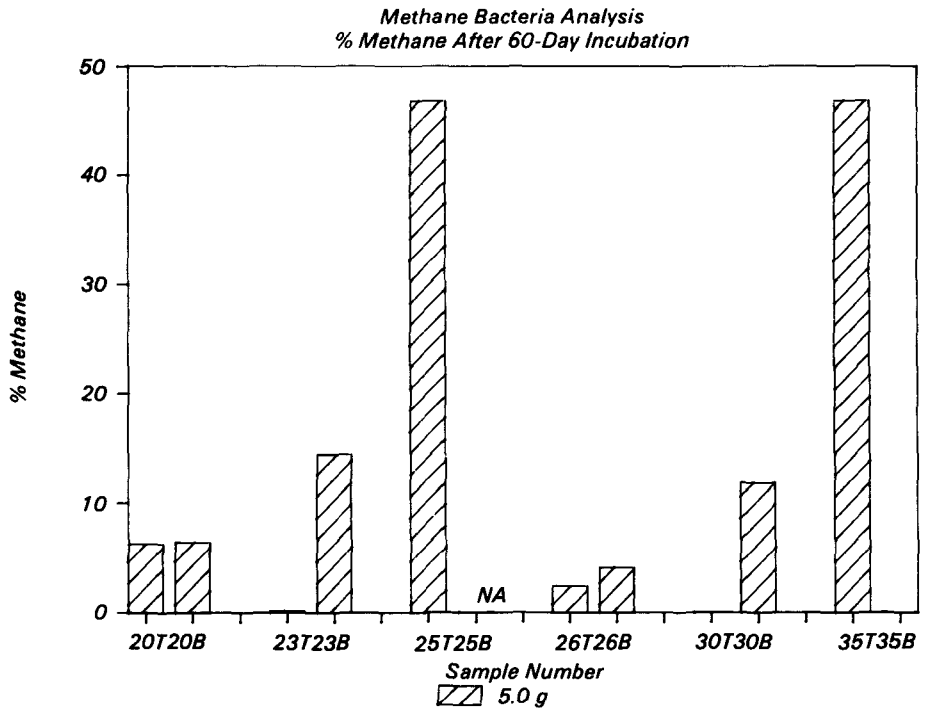

Figure 3. *Methane bacteria after 60-day incubation.*

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Joseph K. Burkart *is the EPA Project Officer (see below).*

The complete report, entitled "Gas Characterization, Microbiological Analysis and Disposal of Refuse in GRI Landfill Simulators," (Order No. PB 86-179 504/AS; Cost: $11.95, subject to change) will be available only from:

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