METHANE PRODUCTION, RECOVERY, AND UTILIZATION FROM LANDFILLS

by

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and

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ABSTRACT

Municipal solid waste disposal sites are untapped sources of methane gas. Landfill gas, which is mainly produced during anaerobic decomposition, has a volume composition of 40 to 60 percent methane. Other gases produced are carbon dioxide, nitrogen, and hydrogen sulfide.

The amount of recoverable gas will depend upon two factors: the ultimate gas production (scf/pound of solid waste) and the area-depth relationship. Ultimate gas production values have ranged from .05 to 7.0 scf/pound of solid waste. These estimates include lysimeter studies conducted at optimal conditions and include the addition of sewage sludge to municipal solid waste. It is estimated that 2.53 scf of raw landfill gas per pound of solid waste will be obtained at the Environmental Protection Agency (EPA) gas recovery project at Mountain View, California. Since this raw landfill gas is 44 percent methane, 1.1 scf of methane per pound of solid waste will be obtained.

The other factor concerns the area-depth relationship. Because of the possibility of air infiltration, a deeper landfill is preferred to a shallow landfill, even though volume is constant. If air infiltrates into the landfill, methane production will cease or decline to a level where the methane content of the raw gas is too low for economic recovery.

The heating value of raw landfill gas is approximately 450 BTU/scf. Depending on final use, landfill gas can be compressed, dehydrated, and stripped of carbon dioxide and nitrogen to produce a gas with a heating value range from 650-1,000 BTU/scf.

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Cost estimates for collection, treatment, and yearly expenses indicate that landfill gas, while not presently competitive with natural gas or oil, is competitive with LNG and SNG. Thus landfill gas can be an important supplemental or alternative fuel source.

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INTRODUCTION

The microbiological decomposition process is constantly occurring as leaves, dead animals, sewage sludge, garbage, and other matter decay. This process occurs at solid waste disposal sites, where tons of decomposable organics are placed daily. The decay of these organic materials results in the formation of landfill gas.

LANDFILL GAS PRODUCTION

Decomposition--The Basic Process

The process of landfill gas formation is mainly an anaerobic process, not unlike that of a sewage sludge digester. Aerobic digestion takes place initially because large quantities of air are entrained in the waste during placement. The oxygen is quickly consumed and the process becomes anaerobic shortly after refuse placement.

Anaerobic refuse decomposition is a continuous process that stabilizes the organic wastes and results in the production of methane. The organic material, such as leaves, paper, and food waste, is used as food for the acid-forming bacteria. This organic material is then changed by the bacteria to simple organic material, mainly organic acids. Methane-forming bacteria then use these organic acids as food and produce carbon dioxide and methane gas. This process is shown in figure 1.

When the waste stabilization process proceeds normally, approximately 50 to 60 percent of the gas produced will be methane. The remainder will primarily be carbon dioxide.

Methane formers grow quite slowly compared to the acid formers since they obtain very little energy from their food. This results in the methane formers being very sensitive to slight changes in environmental factors. The acid formers are rapid growers and are not so sensitive to environmental conditions. Thus the production of landfill gas is largely dependent upon maintaining optimum conditions for the methane-forming bacteria.

Environmental Factors Affecting the Decomposition Process

Table 1 summarizes the optimal conditions for anaerobic digestion. Unfortunately, the landfill decomposition process is different from a sewage sludge digestion process because critical environmental factors (temperature, pH, and moisture) cannot be economically controlled.

Temperature control is a key factor for successful anaerobic stabilization of organic matter because sudden temperature changes greater than 2 degrees centigrade will result in losing the buffering capacity and possibly incapacitating the digester. The temperature should also be controlled in the range of 29 to 37 degrees centigrade so that optimum gas production may be achieved. Although the temperature in the landfill cannot be controlled, it has been determined that the internal temperature of many landfills falls within the optimum temperature range for gas production. It has also been observed that the core temperature of deeper landfills is not affected by diurnal temperature fluctuations.

The moisture content required for optimum anaerobic decomposition has been reported to be greater than 60 percent. This, again, often occurs in the landfill situation, although many landfills with far lower percentages of moisture have been found to produce large quantities of gas. Moisture addition at landfills has been proposed to enhance gas production; however, potential leachate problems (ground and surface-water contamination) have precluded this approach on a large scale.

The optimal operating range for pH is from 6.8 to 7.2. Many landfills report lower pH levels but still produce significant quantities of gas. It is believed that the pH within a landfill does not fall below 6.2 when methane is produced.

The factor which is probably most critical to the landfill stabilization process, particularly when methane gas recovery is anticipated, is air infiltration. Whenever methane gas is removed from a landfill, there is a tendency for air infiltration due to leakage through the recovery wells and landfill surface. Air is toxic to the methane-forming bacteria and thus will stop the production of methane gas. Here the physical configuration (depth) of the landfill becomes an important factor because the oxygen in the infiltrating air is consumed in the upper portion of the landfill and does not hinder the anaerobic process at the bottom of the landfill. Depths greater than 100 feet are ideal for landfill gas recovery. Depths as low as 30 to 40 feet are suitable for gas recovery, but more control over minimizing air infiltration is needed.

LANDFILL GAS RECOVERY

In the last 10 years, landfill operators, owners, and engineers have become increasingly aware of the potential hazard caused by the methane component of landfill gas. Methane migrating through soils adjacent to the landfill has on occasion collected in nearby structures and ignited, resulting in structural damage, injuries, and even deaths.

Control and Recovery Methods

Actual recovery of landfill gas for methane resulted from efforts to stop the migration of gas to adjacent properties. The first control methods used to prevent landfill gas migration were peripheral trenches filled with porous media or peripheral vent pipes which allowed gas to vent to the atmosphere. These control methods were found to be generally ineffective.

Recently, the technology has advanced to the point that most new control systems are power exhaust vent systems composed of wells and a header connected to an exhaust blower. This advance in the technology coupled with the impending natural gas shortage was the catalyst necessary to launch the Los Angeles Sanitation District's Palos Verdes Gas Recovery Project. The project is cosponsored by Reserve Synthetic Fuels (formerly NRG Nu Fuel). Reserve Synthetic Fuels has constructed a molecular sieve treatment facility which takes raw, saturated landfill gas with a heating value of approximately 500 BTU/scf and sweetens it to 1,000 BTU/scf. The upgraded gas is then injected into a nearby Southern California Gas Company main.

At the Palos Verdes landfill, the gas is recovered from 6 to 8 wells to meet a specific demand. The withdrawal rate is up to 300 scfm per well, and each well is over 100 feet deep. Very little trouble with air infiltration occurred due to the depth of the recovery well. However, severe corrosion in the regeneration heat exchanger system occurred because of the presence of chlorinated hydrocarbons in the raw landfill gas. The use of a corrosion-resistant nickel alloy in the heat exchanger coupled with changes in the absorbent material in the pretreating towers has eliminated the corrosion problem

Factors Affecting Recovery

The amount of gas recoverable at a site is dependent upon the specifics of site construction and the operational aspects of a gas recovery system. Site geology is important because it can permit containment of the landfill gas. A landfill located in a clay formation or lined with a clay or synthetic material will inhibit the movement of landfill gas from the site and thus increase the potential for gas recovery.

The depth of the landfill is important because of air infiltration. A minimum depth of 30 to 40 feet is required for satisfactory recovery. This depth limitation is both an economic and an engineering consideration. At a depth less than 30 feet, the withdrawal rate must be kept low so that air infiltration will not stop methane production. This hurts the economics of gas recovery since the quantity of recoverable gas is limited.

Mountain View, California

In June 1975, the U.S. Environmental Protection Agency's Office of Solid Waste partially funded a project to demonstrate the feasibility of recovering methane gas from a landfill of "normal" depth. The landfill at Mountain View, California, was chosen for its 40-foot depth. Additional participation came from the Pacific Gas and Electric Company. The primary objectives of this project were:

1. to determine the optimum withdrawal rate for a shallow landfill;

2. to determine the gas quality at the chosen rate;

3. to determine the optimum well spacing;

4. to determine the effect of additional moisture on gas production; and

5. to evaluate the applicability of various modes of gas utilization.

In order to accomplish the above objectives, the demonstration phase was conducted. Two test pumping wells were constructed with perforations at two depths (middle and bottom of the landfill). A monitoring system was also installed to determine the pressure gradient under both static and pumping situations. The ensuing testing program revealed a great deal of information, especially concerning air infiltration. It was found that air moved freely in and out of the surface of the landfill as barometric pressure rose and fell. This was unexpected, as it was thought that 2 feet of compacted clay cover would severely reduce air infiltration. Consequently, when the pumping rate of 200 scfm at these 40-foot wells commenced, the methane content of the gas went from 52 percent by volume to 32 percent in 20 days. Nitrogen, during the same period, rose from 12 percent to 39 percent. After several more months of testing it was found that at a pumping rate of 50 scfm, gas containing 44 percent methane, 34 percent carbon dioxide, 21 percent nitrogen, and 1 percent oxygen could be consistently withdrawn. Gas composition for this period is provided in Table 2. This composition was then used to evaluate the various upgrading and utilization options available.

LANDFILL GAS UTILIZATION

By far, the most inexpensive utilization option is direct usage eith onsite or offsite by a nearby industrial user. Direct utilization at Mountain View was not feasible since there was no nearby user.

The decision was made by Pacific Gas and Electric Company to inject the gas into a transmission line that ran across the landfill site. Since the raw gas was deficient in several respects (low heating value, saturated, and presence of carbon dioxide, nitrogen, and oxygen), upgrading by removal of contaminants was needed. Two conditions were required for injection into the utility pipeline. First, the value of the mixed gases had to remain about 975 BTU/scf in the service area. Second, the average heating value solid to a customer had to be within ± 2 BTU/scf of that shown on the customer's utility bill.

Gas Upgrading

Various upgrading schemes from simply dehydration to dehydration, carbon dioxide, and nitrogen removal are available. The more contaminants removed, the greater the heating value, but the cost to produce the treated gas would also increase.

The raw gas at Mountain View has a heating value of 450 BTU/scf as compared to 1,000 BTU/sf for natural gas. Because the volume of natural gas in the pipeline was much greater than the volume of upgraded landfill gas to be added, it was decided to upgrade the raw gas to approximately 700 BTU/scf. This upgrading would be economically feasible and would meet the two aforementioned criteria. To reach this quality, dehydration and carbon dioxide removal by the molecular sieve process was required. Figure 2 shows the basic flow diagram for this process.

Gas Recovery Economics

Table 3 shows the cost estimate for landfill gas recovery at Mountain View. This estimate is based on a landfill gas flow of 1 million cubic feet per day. If the pilot-scale project is successful, a production rate of 5 million cubic feet per day is anticipated. This increased gas production rate should allow for a 20 percent decrease in energy costs. Thus the cost per million BTU should be reduced to around $2.00. The data for Table 3 was based on an overall efficiency of 70 percent, a 12 percent cost of capital, a 10-year life, and a salvage value of 30 percent.

While landfill gas economics indicate that energy costs will be more than the current price of natural gas and oil, this technology holds promise because the economics are competitive with SNG or LNG. Thus, landfill gas can be an important supplemental or alternative fuel source.

BIBLIOGRAPHY

Blanchet, M.J. Recovery of methane due from north California landfill. The Oil and Gas Journal, 74(46): 82-85, Nov. 15, 1976.

Blanchet, M.J. [Pacific Gas and Electric Company, San Francisco]. Treatment and utilization of landfill gas; Mountain view project feasibility study. Environmental Protection Publication SW-583. [Washington], U.S. Environmental Protection Agency, 1977. 115p.

Bowerman, F.R., N.K. Rohatigi, K.Y. Chen, and R.A. Lockwood. A case study of the Los Angeles County Palos Verdes landfill gas development project. Environmental Protection Publication EPA/600/3-77/047. Cincinnati, U.S. Environmental Protection Agency, 1977. 114p. (Distributed by National Technical Information Service, Springfield, Va. as PB-272 241).

Carlson, J.A. [City of Mountain View, Calif.]. Recovery of landfill gas at Mountain View; engineering site study. Environmental Protection Publication SW-587d. [Washington], U.S. Environmental Protection Agency, 1977. 63p. (Distributed by National Technical Information Service, Springfield, Va., as PB-267.373.)

Dair, F.R. Methane gas generation from landfills. APWA Reporter, 44(3): 20-23, Mar. 1977.

Eberhart, R.C., ed. Proceedings; a symposium on the utilization of methane generated in landfills, Laurel, Md., March 9-10, 1978. Sponsored by U.S. Department of Energy. The Johns Hopkins University. Applied Physics Laboratory.

FIGURE 1.

DIAGRAM OF WASTE STABILIZATION

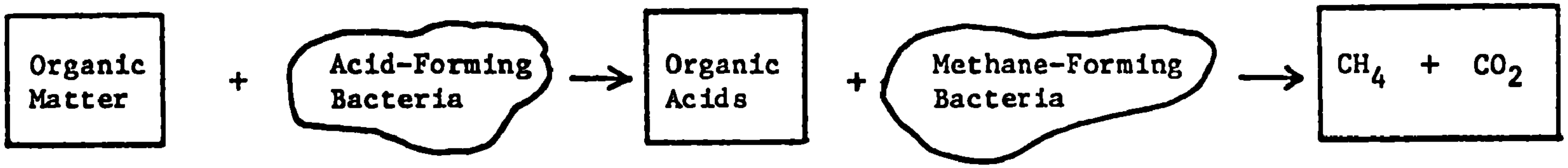

FIGURE 2.

RAW LANDFILL GAS UPGRADING PROCESS AT MOUNTAIN VIEW, CALIFORNIA

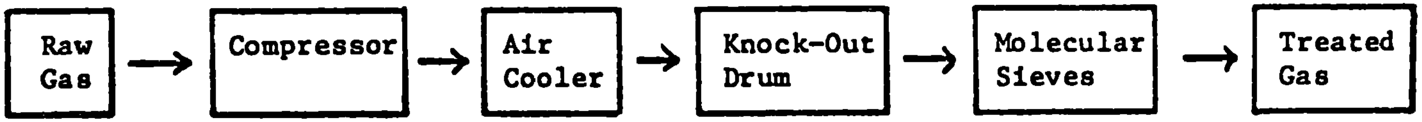

TABLE 1.

OPTIMAL CONDITIONS FOR ANAEROBIC DECOMPOSITION

Anaerobic Conditions	No Oxygen (Air)
Temperature	85 - 100° F (29 - 37° C)
pH	6.8 - 7.2
Moisture Content	Greater Than 40 Percent
Toxic Materials	None

TABLE 2.

MEASURED GAS COMPOSITION AT MOUNTAIN VIEW

	Average	High	Low
Methane	44.03	46.49	41.38
Carbon Dioxide	34.20	36.80	30.73
Nitrogen	20.81	23.51	19.98
Oxygen and Argon	0.96	1.69	0.48

TABLE 3

COST ESTIMATE FOR LANDFILL GAS RECOVERY AT MOUNTAIN VIEW, CALIFORNIA

	Equipment Cost	Installed Cost
Molecular Sieves	$245,000	$368,000
Compression	200,000	350,000
Wells and Gathering System	— — — —	70,000
Total Installed Cost		$788,000

Yearly Costs	$/Year
Maintenance	25,000
Manpower	30,000
Fixed Charges	195,000
Feedstock Costs	22,320
Total	272,320
Energy Output, MMBTU/yr	97,650
Energy Costs, $/MMBTU	$2.79

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