BENEFITING FROM THE PROPOSED EPA LANDFILL GAS EMISSION CONTROL REGULATIONS

MELANIE A. HOLTZ LAURILA
Camp Dresser & McKee
Cambridge, Massachusetts

ABSTRACT

The currently proposed Federal regulations entitled "Standards of Performance for New Stationary Sources and Guidelines for Control of Existing Sources: Municipal Solid Waste Landfills", scheduled to be promulgated in Summer 1994, are expected to affect virtually all landfills which have received municipal solid waste since November 8, 1987. In order to conform with these regulations, many of the affected landfills will be required to install active landfill gas collection and treatment systems which will destroy 98% of the nonmethane organic compounds in the gas.

This paper examines the potential economic benefits of recovering and utilizing the landfill gas from four different size landfills subject to these regulations. Combustion of landfill gas in a totally enclosed flare, internal combustion engine, gas turbine, and boiler were examined as the treatment technologies for 10, 25, 50, and 100 acre (4, 10, 20 and 40 hectare) landfills. The gas collection system costs were not examined since the same collection system would be required for any of the treatment technologies. The most cost effective treatment technology determined for each landfill size evaluated is: no treatment for the 10 acre (4 ha) site, flare for the 25 acre (10 ha) site, and internal combustion engine for the 50 and 100 acre (20 and 40 ha) sites.

INTRODUCTION

The proposed Federal New Source Performance Standards (NSPS) regulations entitled "Standards of Performance for New Stationary Sources and Guidelines for Control of Existing Sources: Municipal Solid Waste Landfills" are scheduled to be promulgated in Summer 1994. These regulations are expected to affect virtually all landfills which have received municipal solid waste since November 8, 1987. As a result of these regulations, landfill gas (LFG) collection and treatment processes will prove to be a "hot" area in the upcoming years.

However, these regulations may have potential economic benefits. Instead of landfill owners viewing these regulations as a "burden", they may be able to utilize a valuable resource — landfill gas, to produce energy. This paper examines the economic feasibility of several treatment technologies to destroy 98% of the nonmethane organic compounds (NMOCs) in LFG, as required by the aforementioned proposed regulations. The following four treatment technologies were examined for 10, 25, 50, and 100 acre (4, 10, 20, and 40 ha) landfills: combustion of LFG in a totally enclosed flare, internal combustion (IC) engine, gas turbine, and boiler. Electricity would be generated from both the intern al combustion engine and turbine combustion trains. Electricity, steam, and/or hot water would be generated from the boiler. Since the LFG collection system would be the same for each treatment technology, the costs of this system were not considered in this analysis. The four treatment technologies were compared on an economic basis, as well as on the basis of practicality and reliability basis.

PROPOSED FEDERAL REGULATIONS

The NSPS regulations entitled "Standards of Performance for New Stationary Sources and Guidelines for

Control of Existing Sources: Municipal Solid Waste Landfills (40 CFR Parts 51, 52, and 60) were proposed in May 1991, as a part of the Clean Air Act Amendments (CAAA) to limit emissions from municipal solid waste (MSW) landfills. According to EPA, the intent of the regulations is "to require that certain MSW landfills control emissions to the level achievable by applying the best demonstrated system of continuous emission reduction considering costs, nonair quality health and environmental impacts, and energy requirements" (EPA, 1991c).

For existing landfills which have a design capacity of at least 111,000 tons (100,000 Mg) of MSW, and have received waste since November 8, 1987, the regulations require that the landfill owner or operator determine the quantities of NMOCs emitted from the landfill. If the total quantity of NMOCs, at a particular landfill, exceeds 167 tons/year (150 Megagrams/year), the regulations require that the landfill owner/operator install a LFG collection and treatment system which reduces the emissions of NMOCs in the collected gas by 98 percent by weight. If an active landfill does not exceed the NMOC threshold, the owner/operator must calculate and report the NMOC quantity emitted each year until the landfill is closed. If the NMOC threshold is exceeded any year, the owner/operator must then install an active gas collection and treatment system (EPA, 1991c).

The regulations (EPA, 1991c) detail three different methods for the owner/operator to determine the emitted quantities of NMOCs. The first and most conservative method (in terms of NMOC generation) is the utilization of the EPA-approved "Scholl Canyon" LFG generation computer model (EPA computer model) to determine the NMOC concentrations at a particular landfill (EPA, 1991a); the two other methods entail the utilization of field tests detailed in the background document (EPA, 1991b) of the regulations to determine the concentration of NMOCs in the LFG at a particular landfill. The default values for the "Scholl Canyon" model assume that LFG is composed of approximately 50% methane, 50% carbon dioxide, and 8000 parts per million by volume (ppmv) NMOCs (EPA 1991a).

Most landfills with a design capacity greater than 111,000 tons (100,000 Mg) are expected to exceed the NMOC threshold by use of the EPA computer model calculation method. As a result, the landfill owner/operator may install an active LFG collection and treatment system or perform field testing to more accurately calculate the specific landfill's NMOC emissions. This decision is dependent upon a number of site specific factors, and thus has to be determined on a case-by-case basis. However, for this paper, it was assumed that if the NMOC threshold value was exceeded by use of the EPA computer model, an active gas collection and treatment system would be installed at the landfill.

LANDFILL GAS EMISSION RATES

In order to determine the quantity of LFG emitted from each of the selected landfills analyzed in this paper, the EPA computer model was run for each landfill size examined herein. The input to the model requires that the capacity of the landfill and the average waste landfilling rate be entered into the model. In order to calculate the capacity of each landfill, a number of assumptions were made to simplify and standardize the analysis. The landfill acreage was assumed to be the footprint of a landfill with 3 : 1 sideslopes and a minimum top area of 500 feet by 500 feet (152 m by 152 m). Utilizing these assumptions, the volume was calculated for each landfill size. Assuming an average in-place MSW and daily cover combination density of 1000 lb/cy (593 kg/m^3) and 15% daily cover, the quantities of in-place solid waste for each landfill size were estimated. A summary of the results of these calculations are shown in Table 1.

Each of these landfills was assumed to have had a 20-year life—from 1973 to 1993. MSW was assumed to have been landfilled at the same annual rate over the life of the landfill. Utilizing these assumptions, and the quantity of MSW in-place, the EPA computer model was used to calculate the expected NMOC and LFG emission rates for each landfill size examined herein. A summary of the NMOC and LFG emission rates in 1993 is shown in Table 2.

The calculated NMOC quantities exceed the regulatory threshold value of 167 tons/yr (150 Mg/yr) at all landfills, except for the 10 acre (4 ha) site. As a result, according to the proposed regulations, installation of a LFG collection and treatment system would not be required at the 10 acre (4 ha) landfill, however, installation of an active LFG collection system would be required at all other landfills examined herein. As a result, the 10 acre (4 ha) site was no longer considered in the analysis.

In order to determine the size of the treatment technology required to destroy 98% of the NMOCs, it was assumed that 80% of the LFG generated would be recovered by the active gas collection system. Utilizing this recovery rate and converting the LFG recovery rate to a per minute rate, a LFG recovery rate was calculated for each size landfill considered. The calculated recovery rates are shown in Table 3.

In order to size the equipment for each of the treatment technologies, the LFG recovery rates were rounded to 200, 500, and 1500 ft^3/min (6, 14, and 42 m^3/min), for the 25, 50, and 100 acre (10, 20, and 40 ha) sites, respectively. Based on the default LFG composition of 50/50 methane/carbon dioxide utilized in the EPA com-

TABLE 1 LANDFILLS EXAMINED

Landfill Size (acres)	Landfill Size (hectares)	Volume (yd³)	Volume (m³)	MSW In-place (tons)	MSW In-place (Mg)
10	4	364,000	278,000	155,000	139,000
25	10	2,081,000	1,591,000	885,000	795,000
50	20	6,326,000	4,837,000	2,688,000	2,415,000
100	40	18,378,000	14,052,000	7,810,000	7,015,000

TABLE 2 NONMETHANE ORGANIC COMPOUND AND LANDFILL GAS EMISSION RATES

Landfill Size (acres)	Landfill Size (hectares)	NMOC Emission Rate (tons/yr)	NMOC Emission Rate (Mg/yr)	Landfill Gas Emission Rate (tons/yr)	Landfill Gas Emission Rate (Mg/yr)	Landfill Gas Emission Rate (ft³/yr)	Landfill Gas Emission Rate (m³/yr)
10	4	34	31	790	710	3.76E7	1.06E6
25	10	194	174	4,518	4,058	1.07E8	3.04E6
50	20	590	530	13,732	12,334	3.27E8	9.25E6
100	40	1715	1540	39,902	35,840	9.48E8	2.69E7

TABLE 3 LANDFILL GAS RECOVERY RATES

Landfill Size (acres)	Landfill Size (hectares)	Landfill Gas Recovery Rate (ft³/yr)	Landfill Gas Recovery Rate (m³/yr)	Landfill Gas Recovery Rate (ft³/min)	Landfill Gas Recovery Rate (m³/min)
25	10	8.59E7	2.43E6	164	5
50	20	2.61E8	7.40E6	497	14
100	40	7.59E8	2.15E7	1444	41

puter model, the recovered landfill gas would have a heating value of 500 Btu/ft^3 (18.6 MJ/m^3).

TREATMENT TECHNOLOGIES

In order to meet the 98% destruction removal efficiency (DRE) of NMOCs required by the proposed regulations, a totally enclosed flare, IC engine, gas turbine, or boiler may be utilized to combust the LFG (EPA, 1991c). A brief description of each of these treatment technologies follows.

Flares. According to the proposed regulations, either a open or totally enclosed flare can be utilized to combust LFG as long as the flare meets the 98% DRE requirement (EPA, 1991c). Open flares resemble large Bunsen burners with candle-like flames. The flare tip is the same diameter as the stack, and the flame is exposed. Combustion and mixing of air and gas takes place above the flare structure. These types of flares can be either located at ground level or elevated (Barboza, 1992).

Totally enclosed flares are composed of multiple gas burner heads and are staged to operate at a wide range of flowrates. The burners are placed at ground level in an enclosure that is usually refractory lined. The enclosure eliminates luminosity, noise, and heat radiation, associated with open flares (EPA, 1991c). Some enclosed flares are equipped with automatic damper controls that regulate the combustion air depending upon the combustion temperature. The LFG and combustion air are mixed better in enclosed flares due to the high velocity of the fuel gas at the burner nozzles. As a result, totally enclosed flares have better combustion control, and thus better DRE than do open flares.

In general, the temperature of the exhaust gases from flares can range from 1000°F to 2000°F (538°C to 1076°C). These high temperatures result in a relatively high plume rise, and good dispersion of the products of combustion. These, coupled with high combustion efficiency, result in relatively low ground level concentration impacts, depending upon the LFG constituents. Flare combustion efficiency depends on flame temperature, residence time in the combustion zone, turbulence in the combustion zone, and quantities of oxygen available for combustion. Emissions from flares are dependent upon LFG flow rates, heating value and composition of the landfill gas, temperature and residence (retention) time (Barboza, 1992).

Pretreatment Technologies

LFG is saturated with water when it is withdrawn from the landfill. In order to prevent excessive corrosion of the totally enclosed flare, a water knock-out drum or refrigerated air dryer system should be installed in the process line upstream of the flare to reduce the amount of water vapor in the LFG. A filter also should be installed upstream of the flare to remove particulates in the collected gas (McLain, 1993).

Internal Combustion Engines. IC engines can be used to recover energy from the combustion of LFG. They are a proven technology and have been used to combust LFG since the early to mid-1970s. A typical gas engine/generator set used to combust LFG and generate electricity, consists of an IC engine, radiator cooler, electric starter, spark ignition, carburetor and manifolds, directly coupled to an electric generator. These engines are usually a 4-cycle, spark-ignited engine similar in design to a common gasoline engine. IC engines maintain relatively high thermal efficiencies in the range of 30–38 percent. They are relatively easy to install, and can operate over a wide range of speeds and loads (CDM, 1988). IC engines currently are being utilized to combust landfill gas and produce energy at about 40 landfills nationwide (EPA, 1991c). However, varying heating value contents of LFG can cause erratic engine performance, and burning raw LFG decreases the engine's life. In order to increase engine life, the gas quality must be improved by gas pretreatment technologies, resulting in an increased LFG processing cost. Typical scheduled overhauls result in several days of downtime for the entire processing system.

Standard IC engine/generator sets generally are available in sizes ranging from 125 kW to 800 kW electrical output. Specialized engine/generator sets are available up to 2000 kW, however, the smaller sized engines are utilized more often and are readily available. Gas turbines usually are only available in sizes greater than 1000 kW. This results in an engine being the only electrical generation alternative for smaller landfills (CDM, 1988).

Pretreatment Technologies

Prior to combustion of LFG in an IC engine, several pretreatment technologies are necessary to ensure efficient combustion, low emissions, and to protect the engine from corrosion. As previously mentioned, LFG is saturated with water when it is withdrawn from the landfill. As a result, as with a totally enclosed flare, in order to prevent excessive engine corrosion and to improve engine efficiency, a water knock-out drum or refrigerated air dryer system should be installed in the process line upstream of the engine to reduce the amount of water vapor in the LFG. A filter also should be installed upstream of the engine to remove particulates in the collected gas. Depending upon the gas composition, a gas scrubbing system may be utilized to remove acid and sulfur compounds from the gas prior to combustion in the engine. The scrubbing system helps to minimize engine and generator corrosion due to acid gas and sulfur compounds (Chadwick, 1988).

Gas Turbines. Gas turbines are heat engines which convert energy into work utilizing compressed hot gas as the working medium (EPA, 1991c). A gas turbine consists of an air inlet section, an air compressor, an expansion turbine assembly, a combustor, and an exhaust system. The compressor draws in and compresses ambient air which is then mixed with injected LFG and subsequently combusted. The high-energy hot exhaust gas then passes through the expansion turbine which converts the stream's energy into rotary shaft power. This shaft power drives the inlet compressor and an electrical generator. Gas turbines require large amounts of excess air, about 300–400%. Most of the air is used for combustion of the LFG; however, some of the air is used for cooling the turbine's hot section, and some is mixed with the combustion products to minimize temperature stratification (CDM, 1988). Currently, turbines are being utilized at about 18 landfills nationwide to recover energy from LFG (EPA, 1991c).

Gas turbines have substantially lower day-to-day maintenance requirements than IC engines. They are highly reliable due to the mechanical simplicity of their design. Gas turbines include a dual oil system, eliminating frequent maintenance shutdowns. The turbine is capable of handling LFG heating value fluctuations without disrupting turbine performance, and has lower air pollutant emissions than an IC engine. However, gas turbines have a relatively high minimum compression in the range of 150 to 200 psig (1.03 to 1.38 MPa), of the inlet LFG and air, and a relatively low thermal efficiency of 17–27 percent. In addition, the turbine blades can be damaged by inlet particulates and/or contaminants in the LFG and/or air. As a result, LFG pretreatment is required prior to combustion in a gas turbine. Use of a gas turbine exclusively for peak power generation increases operating and maintenance costs dramatically; therefore a gas turbine should be used only for continuous operation (CDM, 1988).

Pretreatment Technologies

The pretreatment technologies to clean LFG prior to combustion in a turbine are similar to those utilized prior to combustion in a IC engine. Water should be removed from the LFG by a knockout drum or refrigerated air dryer system, installed upstream of the turbine. Particulates should be removed with a filter, and, depending upon the gas composition, acid gas and sulfur compounds may be removed with a scrubbing system.

Boilers. Watertube and firetube boilers also may be used to recover energy from LFG. However, only a few boilers are being utilized nationwide to combust LFG and generate steam and/or electricity. This is probably due to the high capital cost and large quantities of LFG needed to support such a boiler, and the proximity of existing boilers to landfills. In a watertube boiler, hot combustion gases are passed on the outside of heat transfer tubes in which superheated steam is produced. The superheated steam then can be passed through a turbine to produce electricity (EPA, 1991c). Generally, in firetube design, hot combustion gases are passed through heat transfer tubes. Water surrounding the tubes is heated to produce steam. Firetube boilers are generally used to produce saturated steam which is not acceptable for electrical generation. As a result, the saturated steam can be used for process use or passed through a heat exchanger to produce hot water. Thus, LFG can be utilized in an onsite boiler to produce process steam or hot water, or to produce superheated steam which can be fed to a turbine to produce electricity. Alternatively, LFG can be piped and sold as fuel for an offsite boiler (Curro, 1994).

However, since boilers have high capital costs, compared with the other LFG destruction alternatives, they only will be economical on very large landfills. In addition, piping LFG to an offsite boiler or piping steam and/or hot water (generated by an onsite boiler) to an offsite user, are site specific cases and only can be economical if an offsite boiler or offsite user is in close proximity to the landfill site. As a result, neither of these alternatives were considered any further in the economic analysis.

ANALYSIS OF OPTIONS

Cost estimates were prepared for combustion of LFG in flares, IC engines, and gas turbines for each of the proposed landfill sizes which would require that an active gas collection and treatment system be installed. Combustion of LFG in boilers was not considered in this analysis due to the few LFG-fired boiler installations in existence, relatively high capital cost, and the range of site specific cost considerations.

The cost estimates were prepared based on vendor quotes, information contained in the literature, and CDM cost estimates. The cost estimates do not include costs for the: LFG collection system, blower, engineering and contingencies, contractor's fees, freight, taxes, and Public Utility Regulatory Policies Act of 1978 (PURPA) tax incentives. As previously stated, the type of gas collection system which is installed at a landfill is not dependent upon the treatment technology employed, and since this paper is comparing costs of treatment systems only, collection system costs, including blower costs, were not considered.

For each of the cost estimates, it was assumed that the major equipment utilized would have a 20-year life. As a result, major equipment replacement costs are not included in either the estimated capital or the operation and maintenance (O&M) costs.

In addition, for the basis of calculating energy revenues for the I.C. engine and turbine options, it was assumed that there would be no change in electrical generating revenue due to decreased LFG quantities or quality.

The estimated installed 1994 capital and O&M costs and estimated gross energy production for each of the treatment technologies are shown in Tables 4 through 6. The capital costs for the flare include the costs for an installed totally enclosed flare system, instrumentation and controls, foundation and concrete pad. The costs for the IC engine/generator and gas turbine/generator include installed pretreatment and equipment system costs, instrumentation and controls, foundation and concrete pad, building, utility interconnection fee, and a totally enclosed flare. Since the destruction of NMOCs is regulatory driven, if and when the IC engine and/or gas turbine are down for repairs, a totally enclosed flare will be utilized as a backup system to combust the LFG and destroy the NMOCs. As a result, the costs of the backup totally enclosed flare are included in the IC engine and gas turbine capital costs. The O&M costs for each of the options were estimated as 6% of the capital costs.

The costs for each of the three size treatment technologies considered were compared on a 20-year annualized basis, from 1994 to 2013. The capital costs were annualized at a bond interest rate of 6.5% over the 20 years. The 1994 O&M costs were increased each year at a 3% inflation rate. The total gross annual cost for each system represents the sum of the annualized capital and O&M costs for each year of the 20-year period. The net revenues generated from the sale of electrical power to the local utility were subtracted from the gross annual cost each year to obtain the net annual cost for each treatment technology.

In order to compare each alternative on the same basis, and evaluate the most economical alternative for each of the landfill sizes and associated LFG flow rates, each of the total gross annual costs was converted into present costs, utilizing a 6% discount rate. The discounted present costs for each year were summed to represent the net present cost for each of the alternatives. The results of these analyses are summarized in Table 7.

An electrical purchasing rate of $0.035 per kilowatt-hour (kwh), (New England Power, 1993), was assumed, based on a conversation with a major local utility in the Boston area. According to the utility, this cost represents the utility's cost of producing electricity, and this is the lowest rate which would be offered to an alternative energy source electrical power supplier. Sometimes utilities offer special rate programs for purchase of electricity from electrical generating facilities utilizing alternative power sources. This rate may be on the order of $0.04 to $0.055/kWh. However, these rates are area and utility spe-

TABLE 4 CAPITAL AND OPERATION & MAINTENANCE COSTS—25 acre (10 ha) SITE

Estimated Landfill Gas Flow Rate: 200 ft³/min (5.7 m³/min)
Proposed Landfill Size: 25 acres (10 hectares)

Treatment Technology	Gross Energy Production (kW)	Capital Costs (1994 $)	Annual O&M Costs (1994 $)
Enclosed Flare	None	$90,000	$5,000
I.C. Engine/Generator	500	$1,073,000	$64,000
Gas Turbine	N.A.*	N.A.*	N.A.*

NOTE: * - There are no gas turbines available in this size

TABLE 5 CAPITAL AND OPERATION & MAINTENANCE COSTS—50 acre (20 ha) SITE

Estimated Landfill Gas Flow Rate: 500 ft³/min (14.2 m³/min)
Proposed Landfill Size: 50 acres (20 hectares)

Treatment Technology	Gross Energy Production (kW)	Capital Costs (1994 $)	Annual O&M Costs (1994 $)
Enclosed Flare	None	$116,000	$7,000
I.C. Engine/Generator	1300	$2,347,000	$141,000
Gas Turbine	1100	$2,879,000	$173,000

TABLE 6 CAPITAL AND OPERATION & MAINTENANCE COSTS—100 acre (40 ha) SITE

Estimated Landfill Gas Flow Rate: 1500 ft³/min (42.5 m³/min)
Proposed Landfill Size: 100 acres (40 hectares)

Treatment Technology	Gross Energy Production (kW)	Capital Costs (1994 $)	Annual O&M Costs (1994 $)
Enclosed Flare	None	$154,000	$9,000
I.C. Engine/Generator	4000	$6,591,000	$395,000
Gas Turbine	3300	$7,065,000	$424,000

TABLE 7 NET PRESENT COST FOR EACH LANDFILL SIZE

	Net Present Cost (1994 $)		
Site Size:	25 acre(10 hectare)	50 acre(20 hectare)	100 acre(40 hectare)
Cont/LFG Flow	200 cfm(5.7 m^3/min)	500 cfm(14.2 m^3/min)	1500 cfm(42.5 m^3/min)
Enclosed Flare	$173,000	$223,000	$296,000
I.C. Engine	$349,000	$56,000	($1,039,000)
Gas Turbine	N.A.	$1,765,000	$2,273,000

cific. As a result, a conservative $0.035/kWh was used in the revenue analysis. This conservative rate was inflated by 3% each year, starting in 1995. However, in the actual financing process for LFG collection and treatment systems, the developer or landfill owner/operator can adjust the financing accordingly to obtain more revenue earlier in the project, and pay off the capital costs in a 10-year or less period. Since, the technology alternatives considered in this paper were evaluated on a net present cost basis, the revenue allocation was not as crucial. For simplicity's sake, the revenues were inflated yearly.

In addition, the gross energy production from the IC engines and gas turbines was decreased by 10% to account for parasitic loads. These loads are electricity consumed to run the treatment process itself.

There is not a breakeven point for the utilization of a totally enclosed flare on any sized landfill, since no revenues are generated as a result of combustion of the LFG. This technology is purely used to destroy the NMOCs in the LFG by 98% by weight. If an IC engine is utilized to combust LFG for the 25 acre (10 ha) site, producing 200 ft^3/min (5.7 m^3/min), even though there are revenues generated from the sale of electricity, this alternative never breaks even over the 20-year period. However, for the 50 acre (20 ha) site producing 500 ft^3/min (14.2 m^3/min), a net profit is generated in 2003 through 2013. Similarly, for the 100 acre (40 ha) site producing 1500 ft^3/min (42.5 m^3/min), a net profit is generated in 1998 through 2013. However, the utilization of a gas turbine for the 50 and 100 acre (20 and 40 ha, respectively) generating 500 and 1500 ft^3/min, respectively (14.2 m^3/min and 42.5 m^3/min, respectively), never generates a net profit, despite electrical revenues over the 20-year life of the project. The gas turbine may be more economical for a larger landfill site.

This analysis indicates that utilization of a flare is the most economical option for the 25 acre (10 ha) site projected to produce 200 ft^3/min (5.7 m^3/min) of LFG. The IC engine is the most economical option for the 50 acre (20 ha) and 100 acre (40 ha) sites, projected to produce 500 ft^3/min (14.2 m^3/min) and 1500 ft^3/min (42.5 m^3/min), respectively. In fact, the use of an IC engine would generate a net revenue for the owner/operator of the 100 acre (40 ha) landfill. The gas turbine is not economical for any of the options. However, the gas turbine probably would be economical for a larger sized landfill.

CONCLUSIONS

This paper compared the costs for utilization of a flare, I.C. engine, and gas turbine for treatment of LFG to destroy the NMOCs by 98% by weight on a number of different sized landfills. This requirement is driven by the proposed federal LFG NSPS regulations which are expected to be promulgated in Summer 1994.

The analysis concluded that, using the assumptions described herein, the 10 acre (4 ha) landfill site will not require the installation of an active LFG collection and treatment system since, according to the EPA computer model, the landfill will not emit more than the regulatory threshold amount of NMOCs triggering installation of such a system. However, according to the EPA computer model, the 25, 50, and 100 acre (10, 20, and 40 ha) landfill sites will exceed the NMOC threshold, and thus, the landfill owner/operator will have to install an active LFG collection and treatment system on these landfills. According to the 20-year economic analysis included in this paper, the most economical treatment technology for the 25 acre (10 ha) site would be utilization of a totally enclosed flare for combustion of the NMOCs; and the most economical treatment technology for the 50 and 100 acre (20 and 40 ha, respectively) sites would be the utilization of an I.C. engine to destroy 98% by weight of the NMOCs.

REFERENCES

Air and Energy Research Laboratory, 1992, "Landfill Gas Energy Utilization: Technology Options and Case Studies." pp. 14–19, 49–56.

Barboza M. & Air and Waste Management Association, 1992, *Air Pollution Control Engineering Manual,* pp. 867–871.

Camp Dresser & McKee, Inc., 1991, "Kimpo Sanitary Landfill, South Korea, Use of Landfill Gas for Power Generation."

Camp Dresser & McKee, Inc., 1988, "Phase I, Feasibility Analysis for Methane Recovery System at the Chicopee and Granby Landfills."

Camp Dresser & McKee, Inc., 1989, "Partyka Energy Recovery Interim Systems Report."

Camp Dresser & McKee, Inc., 1988 "Preliminary Design for Methane Recovery Systems at the Chicopee and Granby Landfills."

Chadwick, C., 1989, "Application of Caterpillar Spark-Ignited Engines for Landfill Gas," Proceedings GRCDA, 12th International Landfill Gas Symposium. pp. 187–195.

Curro, J., Camp Dresser & McKee Inc., 1994, Personal Communication.

Eppich, J, et al., 1990, "Puente Hills Energy Recovery from Gas (PERG) Facility," presented at, The First United States Conference on Municipal Solid Waste Solutions for the 90's, Washington D.C.

Holtz M., 1989, "Separation of Landfill Gas by Pressure Swing Adsorption," Masters Thesis, Tufts University, Medford, MA.

McLain, D., John Zink Co., 1993, Personal Communication.

McNamee R., Solar Turbines, Inc., 1993, Personal Communication.

New England Power, 1993, Personal Communication.

Simpson, P., Southworth Machinery, 1989, Correspondence.

Smith, S., 1988, "Landfill Flares," Proceedings, GRCDA 11th International Landfill Gas Symposium. pp. 130–136.

Swanson J., Caterpillar Capital Co, Inc., 1993, Personal Communication.

United States Environmental Protection Agency, 1991a, "Landfill Air Estimation Model, Version 1.1."

United States Environmental Protection Agency, 1991b, "Air Emissions from Municipal Solid Waste Landfills. Background Information for Proposed Standards and Guidelines."

United States Environmental Protection Agency, 1991c, "Standards of Performance for New Stationary Sources and Guidelines for Control of Existing Sources: Municipal Solid Waste Landfills (40 CFR Parts 51, 52, and 60), Federal Register, Vol. 56, No. 104, Thursday, May 30, 1991, Proposed Rules.