United States
Environmental Protection
Agency
Research and Development

Air and Energy Engineering
Research Laboratory
Research Triangle Park NC 27711
EPA/600/S2-91/055 Dec. 1991

EPA

# Project Summary

# Analysis of Factors Affecting Methane Gas Recovery from Six Landfills

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**In 1990, EPA's Air and Energy Engineering Research Laboratory (AEERL) began a research program with the goal of improving global landfill methane ($CH_4$) emissions estimates. Part of AEERL's program includes developing a field testing program to gather data to identify key variables that affect $CH_4$ generation and to develop an empirical model of $CH_4$ generation based on those variables. The first step in developing the field testing program was a pilot study of six U.S. landfills that have $CH_4$ gas recovery systems. In order to evaluate the effects of climate on $CH_4$ production and recovery, the sites were chosen to represent a variety of moisture and temperature patterns (i.e., hot and wet, cool and wet, hot and dry). Landfill gas was tested at each of the six landfills in order to evaluate the quality of the gas recovery data available at each site. The testing program included assessing the adequacy of on-site instrumentation and scanning the landfill surfaces for organic vapors that would indicate emissions of $CH_4$. In addition, information on waste composition and landfill characteristics was sought for each landfill. Except for flow measurements, the test procedures selected for this project were well suited to the types of gas recovery installations at the landfills visited. Based on comparisons between EPA Reference Method 3C and instrument analyses of the landfill gas composition, all on-site analysis instruments appeared to be operating with reasonable accuracy. Reviews of calibration procedures and records indicate that long-term instrument accuracy should be comparable to the accuracies noted during on-site testing. A negative correlation between refuse age and $CH_4$ recovery per ton was found; a weak positive correlation was found for normal annual precipitation and $CH_4$ recovery per ton. The results of this pilot study are sufficiently encouraging to warrant further data gathering and analyses.**

***This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, 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

In response to concerns about global warming, the U.S. Environmental Protection Agency's (EPA's) Office of Research and Development (ORD) has initiated a program to characterize the causes and effects of global climate change, and to identify and quantify emission sources of greenhouse gases. To assist in this undertaking, EPA's Air and Energy Engineering Research Laboratory (AEERL) has begun research to improve emissions inventories of greenhouse gases in the U.S. and throughout the world.

One greenhouse gas of particular concern is methane ($CH_4$). Methane's radiative-forcing potential is thought to be much greater than that of carbon dioxide ($CO_2$). In 1990, AEERL began a research program with the goal of improving global landfill $CH_4$ emissions estimates.

To determine the factors that affect $CH_4$ generation in landfills on a global basis, a model is needed that is responsive to a wide range of climates and types of waste. Part of AEERL's program to create a $CH_4$ landfill emissions database, therefore, includes developing a field testing program to gather data to: (I) identify key variables that affect $CH_4$ generation; and (2) develop an empirical model of $CH_4$ generation based on those variables.

Landfills with gas recovery systems were chosen for this study. The landfill gas is being collected and measured by the gas recovery operators; if those data can be verified to be reasonably accurate, and if sufficient data are available on the landfill itself, the landfill gas measurements collected over several years may be used to estimate total $CH_4$ generation.

The first step in developing the field testing program was a pilot study of six U.S. landfills that have landfill gas recovery systems. The objectives of the pilot study were to:

(1) Determine the type and quality of landfill data on landfill gas recovery rates, gas composition, and refuse characteristics available at landfills with gas recovery systems;
(2) Use these data to determine trends in the effects of climate, refuse age, and landfill characteristics on landfill gas recovery; and
(3) Use the results of the emissions testing and data analysis to assess the relationship between gas recovery and gas generation, and the feasibility of expanding the study to include other sites.

To meet these objectives, a pilot study of six sites, chosen to represent a range of climates, was undertaken. The general procedures and methodologies planned were:

(1) Identify potential sites;
(2) Visit the landfills to collect data records from the facility;
(3) Independently measure landfill gas flow;
(4) Assess accuracy and adequacy of the data; and
(5) Develop statistical methods for analysis of the data.

Although the $CH_4$ content of the landfill gas is of most importance at this time, other constituents were also measured (carbon dioxide, oxygen, nitrogen, and nonmethane organic compounds).

## Site Selection and Description

The pilot study included visits to six landfills in the U.S. to gather data on $CH_4$ recovery rates and factors thought to influence these rates. The primary criterion in selecting a landfill for study was that it have a gas recovery system in place. The recovery system needed to be well-controlled (i.e., operating under good engineering practices to minimize leaks and maximize $CH_4$ recovery) so that the $CH_4$ recovery data would be useful in estimating total $CH_4$ production at the site. In addition, well-maintained records on routine monitoring were needed for possible gas migration at the perimeter and surface of the landfill.

To evaluate the effects of climate on $CH_4$ production and recovery, sites were sought in geographic regions representing a variety of moisture and temperature patterns (i.e., hot and wet, cool and wet, hot and dry). Initial recommendations provided by landfill gas recovery experts in the U.S. were used to identify potential sites. Final site selection was influenced largely by the assurance that long-term gas production and refuse composition data were available at the site, the suitability of the site for sample acquisition, and the landfill operator's willingness to cooperate in the study.

A landfill survey form was sent to the operators of selected sites prior to visiting them so that they could begin gathering the records. Sites were visited between August 6 and 24, 1990.

## Landfill Gas Test Procedures and Results

Landfill gas was tested at each of the six landfills in the pilot study in order to evaluate the quality of the gas recovery data available at each site. The testing program included assessing the adequacy of on-site instrumentation and scanning the landfill surfaces for organic vapors that would indicate emissions of $CH_4$.

The following test procedures were used:

(1) EPA Reference Method (RM) 3C was used to determine $CH_4$, $CO_2$, nitrogen ($N_2$), and oxygen ($O_2$) levels;
(2) EPA RM 25C was used to test for nonmethane organic compounds (NMOC); and
(3) EPA RM 4 was used to test for the volume percentage of moisture.

Initially, the volumetric flow rates of landfill gas were to be tested using EPA RM 2. However, mechanical difficulties were encountered at the landfills, making this test impossible. In lieu of this test, calibration records of on-site flow measurement instruments were obtained for three of the six landfills. Tests for the presence of organic vapors near the landfill surface were conducted using an organic vapor analyzer (OVA).

The on-site gas analyzer measurements were compared to the results of EPA RM 3C testing and found to be reasonably accurate; three of the $CH_4$ analyzers exhibited relative accuracies better than 10%, and five were within 12%. In general, all of the instruments were observed to be operating in a manner consistent with good operating practices.

## Statistical Methods Development and Results

The ultimate objective of this research program is to determine which variables relating to refuse characteristics, landfill characteristics, or climate are significant determinants of gas production. This pilot study addressed a small number of sites, and the results were not intended to be representative of all landfills. Rather, the study was intended to provide the basis for development of statistical methods for use in a larger study, to identify data quality issues, and to look for trends.

The data obtained from each landfill consisted of computer printouts or handwritten data sheets listing total gas flow, percent $CH_4$ composition of the total gas flow, and other information applicable to the individual landfills. The data were usually in the form of daily averages of hourly flow rates, and were reported for each online gas recovery unit.

The descriptive data for each landfill are summarized in Table 1. The average $CH_4$ flow in standard cubic feet per minute (cfm)* was calculated from daily averages supplied by site operators. Although the between-landfill variation is large, ranging from 590 to 3477 cfm (16.71 to 98.47 $m^3$/min), the day-to-day variability is relatively small, as shown by the coefficients of variation, which were generally below 10% except for Landfill 6 (12.4%).

One objective of this study was to determine if sufficient data were available for a time series analysis of $CH_4$ emission rates from individual landfills. Methane recovery is a relatively new process, and none of these landfills had records for $CH_4$ emissions of sufficient length (several years) and completeness for time series analysis. It is highly probable that emissions are autocorrelated so that any attempt to find correlations between $CH_4$ recovery and weather data on a daily or monthly basis is likely to be confounded by autocorrelations in the data. Since the strength of autocorrelation decreases with averaging period, only annual averages were used in the statistical analysis of the relationship between long-term $CH_4$ emissions and weather data between landfills. The annual $CH_4$ averages were correlated to annual averages of temperature and precipitation obtained from 30 years of

* Flow rate at 25°C and 1 atmosphere

**Table 1.** *Summary Statistics for Each Landfill Calculated from Daily $CH_4$ and Weather Data*

| Parameter | Landfill 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| *Analysis period* | 5/89 to 4/90 | 10/89 to 7/90 | 8/89 to 7/90 | 7/89 to 6/90 | 1/90 to 8/90 | 5/89 to 4/90 |
| *Number of wells* | 45 | 65 (44 VA)* | 31 | 111 | 102 | 68 |
| *Average well depth (m)* | 14 | 14 | 23 | 21 | 34 | 10 |
| *Number of hectares* | 35 | 55 | 51 | 57 | 32 | 40 |
| *Refuse mass ($10^6$ Mg)* | 6.3 | 6.1 | 7.3 | 13.8 | 10.9 | 2.6 |
| *Average landfill depth (m)* | 67 | 26 | 66 | 56 | 46 | 10 |
| *1990 average age (years)* | 8 | 10 | 10 | 9.50 | 15 | 7 |
| Total Methane Flow | | | | | | |
| *Number of days* | 194 | 302 | 314 | 85 | 209 | 37 |
| *Mean ($m^3$/min) (cfm)* | 55.36 (1995) | 18.04 (637) | 40.07 (1415) | 98.47 (3477) | 24.86 (878) | 16.71 (590) |
| *Standard deviation* | 2.12 | 1.19 | 2.32 | 1.33 | 1.70 | 2.07 |
| *Coefficient of variation (%)* | 3.80 | 6.60 | 5.80 | 1.40 | 6.80 | 12.40 |
| Temperature | | | | | | |
| *Mean (°C) during analysis period* | 7.34 | 7.67 | 10.51 | 24.96 | 16.12 | 16.57 |
| *30-year normal* | 7.51 | 9.28 | 12.23 | 23.96 | 17.12 | 16.18 |
| Precipitation | | | | | | |
| *Total (in.) (cm) during analysis period* | 31.7 (80.5) | 34.0 (86.4) | 43.9 (111.5) | 40.0 (101.6) | 9.0 (22.9) | 16.6 (42.2) |
| *30-year normal* | 28.8 (73.2) | 35.6 (90.4) | 42.4 (107.7) | 61.4 (156.0) | 17.0 (43.2) | 17.9 (45.5) |

**VA = very active; other wells were primarily for odor control.*

data, as well as to other landfill parameters.

Table 2 shows the Pearson correlation coefficients between annual $CH_4$ flow rates and $CH_4$ flow rates per unit mass with the annual and long-term (normal) weather data and other landfill parameters for the six landfills. Only two correlations with $CH_4$ flow rate were found to be significant at the 95% confidence level, and no correlation coefficients were significant with the $CH_4$ flow rate per unit mass. The low number of significant correlations can be attributed, at least in part, to the low number of observations. The normal annual precipitation correlated fairly well with the 1-year annual mean $CH_4$ flow rate and, even though it was not significant for the $CH_4$ flow rate per unit mass, it had the largest positive correlation coefficient. The correlation coefficient for refuse mass with $CH_4$ flow rate was just under the cutoff point for significance at the 95% confidence level, but its value of 0.71 suggests that perhaps with more data it would be significant.

**Table 2.** *Correlation Coefficients of $CH_4$ Recovery Variables with Landfill Parameters and Summarized Weather Data (n=6)*

| | Dependent Variables: Annual Methane Recovery Rate | Annual Methane Recovery Rate per Unit Mass |
|---|---|---|
| Independent Variables | | |
| *Annual temperature (1989-1990)* | 0.56 | 0.12 |
| *Normal annual temperature* | 0.51 | 0.01 |
| *Annual precipitation (1989-1990)* | 0.55 | 0.33 |
| *Normal annual precipitation* | 0.81* | 0.25 |
| *1990 mean age of landfill* | -0.15 | -0.80** |
| *Number of wells* | 0.37 | -0.15 |
| *Tons of refuse* | 0.71 | -0.18 |
| *Mean depth of landfill* | 0.62 | 0.26 |
| *Area of landfill* | 0.37 | -0.04 |
| *Volume of landfill* | 0.74* | 0.24 |
| *Mean well depth* | 0.10 | -0.58 |

* *Correlation coefficient significant at 95% confidence level.*
** *Correlation coefficient significant at 90% confidence level.*

## Conclusions

Except for flow measurements, the test procedures selected for this project were well suited to the types of gas recovery installations encountered at the landfills visited. Alternative flow measurement methods that are more appropriate to the site conditions must be identified if flow measurements are desired in the future. Since all sites record flow data, however, a quality assurance program could be used to determine the acceptability of the on-site data.

Based on comparisons between the RM 3C and instrument analyses of the landfill gas composition, all on-site analysis instruments appeared to be operating within reasonable accuracy ranges. Reviews of calibration procedures and records indicate that long-term instrument accuracy should be comparable to the accuracies noted during on-site testing.



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Although the results of this pilot study are sufficiently encouraging to warrant further data gathering and analyses, some limitations need to be recognized. The main problem was that the collection efficiencies of the $CH_4$ recovery systems were not known. Where emission control was one (or the only) reason for the collection system's existence, efficiency appeared to be high. However, this is a qualitative assessment based on visual inspection of the landfills and an assessment of operating practices at the landfills.

One key piece of information is missing from most landfills: the average composition of the refuse. Waste composition undoubtedly contributes to data variability but, unfortunately, it is not possible to get composition information for most landfills in the U.S. Also, it is impossible to fully account for differences in the structure and operating characteristics of landfills. All of these unknowns contribute to the variability of the $CH_4$ flow rate data. Although it should be possible to explain some of the variability, a certain amount will always remain.

It is likely that the functional relationship between $CH_4$ per ton of refuse and age and climate are nonlinear, or that interactions between these variables produce nonlinearities. With a larger sample, it may be possible to identify these nonlinearities, and fit the data to the appropriate model.

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*The complete report, entitled "Analysis of Factors Affecting Methane Gas Recovery from Six Landfills," (Order No. PB92-101351/AS; Cost: $35.00, subject to change) will be available only from:*
*National Technical Information Service*
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