Estimating Methane Generation Rates in Landfills:
Description and Prescription

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Introduction

Methane gas produced by solid waste in disposal sites presents both a problem and an opportunity. The problem is that the gas presents an explosive hazard. To avoid explosions we need to pay to actively remove methane gas and we need to limit the use of land on or near old waste disposal sites. The opportunity of methane gas is the potential to use its energy to heat water or generate electricity. Both the problem and opportunity require good estimates of how much methane gas will be produced and when it will be produced.

Over the past twenty years a number of techniques have been developed to estimate methane generation rates. In an idealised waste disposal site the literature indicates a total production of 150 l methane per kg dry refuse, with about 10 l methane per kg dry refuse per year for 10 years before reaching a point where the methane generation rate begins to decrease towards zero.

This idealised picture disregards a number of subtleties that can lead to very different methane production patterns at any specific waste disposal site. The total methane production has been estimated to vary from 30 to 300 l methane per kg dry refuse. The time that methane production is at its maximum rate has been estimated to be anywhere from 2 to 20 years (Ham and Barlaz, 1989, Willumsen, 1990). After this time, the methane generation rate can fall off rapidly or very slowly. As a result, in some situations engineers believe methane production will be an issue for 10 years, while in other situations it will be an issue for 100 years.

The reasons why there is such a wide range in descriptions of the methane production rate are: 1. variable refuse composition, 2. variable decomposition conditions, and 3. uncertainty in our understanding of the decomposition process. The way forward for estimates of methane production rates is to find estimation techniques that use the latest technical information and mechanistic explanations to reduce factor 3, and to develop techniques that allow us to include variations due to factors 1 and 2.

One might care to group the methods for estimating methane generation into four types: 1. measurements from laboratory bio-degradation studies, 2. interpretation from data at actual landfills, 3. calculations based on as-disposed waste, and 4. calculations based on post-disposal waste.

Redefining Waste Composition

Improvements in any of the four methods will require a redefinition of waste composition-- a change in our view towards waste composition. Instead of classifying

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waste based on consumer use we need to classify waste according to an appropriate waste management function (Centre for Advanced Engineering, 1992). For methane management, it is proper to classify waste materials according to their methane producing ability. Classifying a fraction of the waste as "food" has no firm definition; some might define it in some ways, while others might define it in slightly different ways. In addition, some cities might produce different mixes of food waste leading to very different methane producing ability. The same goes for vague terms such as garden waste or even paper. Bacteria don't make such distinctions when they sit down as a family to eat. They degrade material based on chemical structure: as a group, they love to eat sugar and protein, won't turn down a meal of cellulose, but will not eat lignin. Food waste, garden waste, and paper waste all have varying amounts of these three types of organic material. Table 1 shows a typical composition of waste both in terms of consumer-based descriptions and in terms of bacteria-based descriptions. Table 2 shows the total methane production ability of this hypothetical waste using both descriptions. From the consumer's point of view, most of the methane comes from paper waste, but from the bacteria's point of view almost all of the methane comes from cellulose and hemi-cellulose.

Laboratory Bio-Degradation Studies

Bio-degradation studies accelerate the natural processes in landfills (Halvadakis, 1983; Barlaz et al., 1990). In this way, one can find the total methane production in only a few months instead of in 100 years. The variability between laboratory studies seems to be mainly due to variations in waste composition and if one can find a good way to adjust these data for waste composition, a good estimate of the total methane generation can be made. One cannot readily use the data on methane production rates from bio-degradation studies since the studies modify the landfill conditions to allow for accelerated decomposition. Thus, this method does not help us to analyze the differences in methane generation rates due to variations in decomposition conditions. On the other hand, the total methane generation data from these studies can be very useful.

Interpretation of Data from Actual Landfills

Since the laboratory biodegradation studies give a poor estimate for the rate of methane production because of modifications in landfill conditions, one might assume that measurements of the methane production rate in actual landfills would be a good way to get the rate data. Too bad it's not that simple. One way to estimate the methane generation rate in landfills is to install a well and increase the pumping rate at a well until the gas composition changes. This maximum pumping rate is the rate that gas is produced within the volume of influence of the well. The next step is to estimate the volume of influence of the well. This is generally done by installing pressure monitoring wells at varying distances and depths from the pumping well and identifying which of the monitoring wells respond to pumping at the central well (Moore, 1979; EMCON, 1980; Gardner et al., 1990). Due to a number of vague definitions (when can we say that gas composition has changed? when can we say a well is not affected by pumping?) and practical limitations (what happens when atmospheric pressure changes during a test?

what depths are appropriate for testing?), the uncertainty associated with this method is high. High is also the way to describe the cost of this method.

If your pump test happens to be in a section of the landfill that is particularly moist and rich in garden waste, your high estimate of methane generation might be misleadingly applied over the whole landfill. In addition, if your interest is in the future methane production potential, it might be misleading to examine the methane produced by wastes that were disposed of many years ago under different consumer patterns or government regulations.

Calculations Based on As-Disposed Waste Composition

The third method calculates a methane generation rate based on waste composition data and the methane production ability of each waste constituent. Instead of measuring changes in waste composition to infer generation rates, generation rates are assumed based on literature values (EMCON, 1980). We have good estimates of the methane production ability of different chemical feedstocks and so we can get good estimates of the total methane production ability of refuse if we measure the amount of cellulose, sugar, protein and lignin in solid waste. This method allows a simpler way to account for waste variations than a method based on laboratory bio-degradability.

This method still suffers from the problem of a need for generation rates. Although we know the factors that affect methane generation rates (Barlaz et al., 1990; Stegmann and Spandlin, 1989), we don't have tested quantitative equations that relate landfill properties to the methane generation rates for each substrate type. In addition, we are not able to evaluate whether a mixed-waste landfill behaves like a linear sum of individual waste types. Perhaps significant non-linear interactions would prevent this type of analysis from proving useful.

Calculations Based on Post-Disposal Waste Composition

Since much of the uncertainty in the previous method is due to uncertain values for decomposition rates, there is an opportunity for a method that uses the composition of partially-decomposed refuse to infer the methane production rate. Since most of the methane is produced by the bio-degradation of cellulose (Barlaz et al., 1989), the change in the cellulose content can give an indication of the rate of methane production. Lignin is inert in landfills (Young and Frazer, 1987), common in landfills, and of low variability in mixed waste, and so it makes an excellent marker to be used to assess the degradation state of a landfill. Because of the landfill behaviour of cellulose and lignin, the ratio of the two is a good indicator of the methane production ability of a waste (Bookter and Ham, 1982). Figure 1 shows the ratio of cellulose to lignin in solid waste as a function of age for a number of sites (adapted from Bookter and Ham, 1982). One can use one value of the cellulose/lignin ratio plus Figure 1, or two values in time for the ratio to estimate the methane production rate.

The problem with this method is that to be able to distinguish relatively small changes in refuse composition one would need to take a large number of solid samples for analysis. Again, this is because of the variability in refuse composition. It might be impractical to take 1 kg samples of decomposing refuse from many (say 100) different bore holes and analyze a composite sample. But if you could take many samples at two different times, then you should get a good estimate of the methane that was produced between the two different times.

Prescriptions

Engineers can make good estimates for the total methane production potential from solid waste. The most appropriate methods are laboratory lysimeters and calculations based on substrate content. Methods should be developed to combine the information from these two approaches to give a flexible tool that can be used over a wide range of solid waste composition.

Improvements in techniques for estimating gas generation rates are desperately needed. The pump tests commonly in use have high uncertainties and give no guidance to design engineers before waste is in place. It doesn't seem that improvements in pump test techniques are likely.

Ideally, one should be able to develop mechanistic, quantitative equations to relate gas production rates to landfill conditions. There are prospects for progress on this front. We know the factors that influence the rate of biodegradation of chemical feedstocks by bacteria. The factors are moisture, temperature, segregation of waste types, the mixing processes in a disposal site, nutrients, and toxins. It should be possible to parameterise the problem and develop a function that could estimate the methane generation rate in a micro-environment as a function of a limited number of variables. To estimate the methane generation rate for a large disposal site, one would need to divide refuse into discrete time segments-- years, months, or maybe even days-- and then for each time segment use the waste composition and landfill decomposition parameters to estimate a methane generation function for the waste disposed within a given time segment. The total methane generation would then be the sum of the time-lagged methane production rates for the waste disposed in each time segment.

The development of this method would require the use of laboratory lysimeters to examine particular relationships between the process variables. The laboratory work will be more useful when it used to confirm or refute mechanistic hypotheses. The laboratory work will be less useful as a large data base with methane generation varying with waste composition and system parameters. The latter method leads to empirical techniques that will not prove valuable for the wide range of waste composition and disposal settings an engineer is likely to encounter in practice.

A final issue needs investigation. There is currently a poor understanding of the dynamics of souring in solid waste landfills. The cessation of methane production due to souring can create enormous environmental hazards. We know enough to realise that high moisture, highly degradable substrate, or high toxin concentrations can cause souring, but we are not able to disentangle the effects of landfill system variables from the effects of waste composition. An understanding of when methane is not produced is as important as how much methane is produced and the rate of production.

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