DEVELOPING A LANDFILL GAS MODEL

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SUMMARY: A landfill gas generation model is a tool that provides an estimation of generated methane or total landfill gas volume over time from a particular volume of waste. The purpose of a model is to describe in simple terms the complex changes during decomposition of waste in a landfill. For a model to accurately reflect the processes within a landfill, it must take into account the complex nature of the microbiological decomposition of waste within a landfill, the nature of the landfill itself and the ability of gases and liquids to move through the landfill. It should describe the condition of a landfill over time and space in respect of all significant parameters, components and climatic measures. A model needs to replicate generation and movement of gases over time and space. Therefore a component model is required to adequately predict the landfill processes. These models also need to be validated with sufficient full-scale data to give confidence in their application.

1. INTRODUCTION

Methane and other gases are produced as a result of the natural processes of decay that waste materials undergo within a landfill. The degradation of the organic component of waste in landfills is a process carried out by a succession of microbial populations. The process is a dynamic system that relies on the success of each previous stage to create the correct microbiological environment for change to occur. Landfills gradually become anaerobic as oxygen is depleted. Methane is then produced. The interaction of different factors is complex and the processes are not completely understood or able to be measured.

Landfill engineering is still a developing technology. Considerable works have been undertaken by others to develop predictive models based on laboratory investigations and are qualitatively plausible but have yet to be verified against sufficient data from actual large-scale landfill sites. However, accurate non-site specific models are not readily available. The degradation processes at full landfill scale are not well understood. Smaller scale testing gives useful information about the fundamental processes but at field scale complication exists in the interpretation of biochemical and physical effects and the non-uniform nature of the landfill itself (McDougall and Philip 2001).

2. EXISTING SIMPLE MODELS

The majority of commonly used models are based on simple empirical functions for the rate of methanogenesis. They are simple zero and first order kinetic models that only take into account
the microbial growth and decay. These give a prediction of landfill gas generation over time and require significant ‘guess’ components, field experience and precedence for the kinetic estimates and model parameters. The US - EPA model is probably the most commonly used model of this type. A good comparison of these model types was undertaken by SWANNA (SCS Engineers and Augenstein 1998) and by McBean (McBean; Rovers, and Farquhar 1995). The advantage of these model types is that it allows a quick and simple estimate of the methane generation to be calculated once the empirical constants have been determined. The essential model elements are: the ultimate yield of methane (or landfill gas), the generation time and the assumed shape of the output curve. The most accurate of the commonly used models take into account the different waste fractions but most assume that the waste is placed instantaneously and is homogeneous. Some do take an initial time lag due to the time for waste placement and the development of methanogenesis into account. These assumptions though can have a significant impact on the overall gas predictions.

A large number of landfill gas generation rates have been cited in the literature. Most of these results are based on laboratory testing, lysimeter tests, theoretical estimates, pilot scale landfills, gas recovery data, and some on field tests. The rates vary enormously from 0.073 – 3.2 m³/dry kg/yr (McBean and others 1995). The higher rates tend to be from laboratory studies under optimised conditions with a high percentage of readily degradable material. The enormous variation in these landfill gas generation rates demonstrate the issues with empirical constants and models that have been developed using ideal laboratory testing conditions rather than full scale landfill data. The inaccuracies within some of these models and the predictions that come from them need to be viewed with carefully with an understanding of the underlying assumptions.

Another issue with most of these models is that they treat methane generation as equivalent to methane recovery. The actual methane recovery efficiency is not a model parameter. The recovery efficiency can vary significantly from site to site and accurate data is not readily available.

3. MODEL COMPONENTS

For a model to accurately reflect the processes within a landfill, it must take into account the complex nature of the microbiological decomposition of waste within a landfill, the nature of the landfill itself, the chemical reactions and the ability of gases and liquids to move through the landfill. It should describe the condition of a landfill over time and space in respect of all significant parameters, components and climatic measures.

A more accurate model needs to take into account:

- Biological/Microbial processes
- Biochemical processes
- Transport of liquid, gases and heat

The biological component describes the dynamics of the landfill ecosystem in terms of organic carbon sources, pathways and sinks. This component is normally based on Monod Kinetics, which requires the definition of limiting substrates and microbial populations, and the selection of values for the biokinetic constants (Haarstrick and Hempel 2001). A multistage microbial model would give the best approach.

The biochemical component consists of two parts. These are the hydrolysis of cellulose material, which is likely to be rate-limiting step for methane production and the prediction of the pH and its effect on the methanogens. This section assumes that anaerobic conditions have been
established and that the gas-liquid system is at equilibrium (El-Fadel; Findikakis, and Leckie 1996a).

And finally the transport of liquid, gases and heat component consists of the gas and liquid flow through a porous media and the heat generation and transport in a porous media. The basis of the transport component of this section is on groundwater (hydrogeologic) principles. The differences are that the underlying principles relate to the flow of groundwater and assume laminar flow through a two-dimensional layered homogenous material. In the past this component has often been done using a water balance approach (Zacharof and Butler 2004).

The nature of landfills with their random nature, differences in compaction, waste types and composition make them a highly heterogeneous body. Consequently, many of the properties required for calculation of the gas-liquid transport such as porosity, moisture content and hydraulic conductivity vary markedly throughout the landfill causing problems in trying to apply a simple model over the entire landfill as a single body (Zacharof and Butler 2004).

The gas transport within a landfill remains a major area of uncertainty. Gas generation implies that there could be major changes in volume and pressure. Currently it is assumed that any gas with a pressure greater than the surrounding pore pressure is vented immediately and consequently the transport is modelled as a liquid-gas mixture with both components having the same pore pressure (White; Robinson, and Ren 2004).

The heat generation and transport through the landfill can be considered by a heat or energy balance approach. The heat gain from the degradation reactions and the heat loss to the environment needs to be taken into account (El-Fadel and others 1996a). The temperature conditions within the landfill influence the type of microbes that are predominant and consequently the level of gas generation.

4. EXISTING COMPONENT MODELS

A number of more complex models have been proposed: (Young and Davies 1992), (El-Fadel and others 1996a), (El-Fadel; Findikakis, and Leckie 1996b), (El-Fadel; Findikakis, and Leckie 1997), (McDougall and Philip 2001), (Swarbrick and Lethlean 2001), (White and others 2001), (White; Robinson, and Ren 2004), (Zacharof and Butler 2001) and (Zacharof and Butler 2004).

The model proposed by Young and Davies was a component finite element model. Their work recommended further field testing but this has not been reported in the literature and consequently there is not much evidence that this model represents actual landfill behaviour. However, their work set out the equations and processes required for a component model and is commonly quoted as a reference in subsequent component models (Young and Davies 1992), (Young 1989).

The work by El-Fadel (El-Fadel and others 1996a) and Swarbrick (Swarbrick and Lethlean 2001) have become the basis of majority of component models. El-Fadel et al used four years of data from the Mountain View Controlled Landfill Project in California USA. The test site involved six landfill test cells using MSW from San Francisco. In their paper on the model application they stated that their model simulated the gas generation and temperature data, and that it could be used to predict design gas recovery and emission control systems.

However, they noted that the functional relationships, which describe the inherent complexities of a landfill ecosystem and the inter-relations between many variables, were not present. They went on to state that these relationships may be necessary for making reliable predictions and for successfully using the model (El-Fadel and others 1996b).

Swarbrick’s model used a laboratory bioreactor for validation purposes. This bioreactor used normal MSW and was monitored over an 18-month period with some addition of leachate and
water during the monitoring period. Some results from the model and bioreactor correlated well together such as observed and modelled gas concentrations in the early carbon dioxide peak. However the observed concentrations of Volatile Fatty Acids (VFAs) was far lower than predicted and possible errors in the model, the analysis of VFAs, or concentrations of VFAs were acknowledged as possible error sources (Swarbrick and Lethlean 2001).

The conclusion from their paper stated that future work needed to concentrate on improving the knowledge of heat capacity and generation, to compare the model to field scale bioreactors and improve the physical modelling of gas, fluid and heat movement (Swarbrick and Lethlean 2001).

The model by White (White and others 2004) has built on the work by El-Fadel and Swarbrick and brought together a four component model including degrading waste, solids, biomass, leachate and gas. This model has been designed to have a wider role as a container or framework for other models of component landfill processes. This would allow other models to be imbedded into this model and linked together to provide a useful basis for degradation modelling. The paper concluded that a theoretical framework had been created for constructing a numerical model of landfill processes, however, it was not clear what calibration and validation work had been undertaken on this model except for a mention of comparison of the calculation of pH inhibition factors against the laboratory results from Bogner (Bogner and Spokas 1995). The comment was that this comparison was only carried out on the one set of data and further comparisons with other data sets was needed before confidence in this method could be confirmed. Even without this confirmation, the model calculation can show the sensitivity of the initial biomass growth rate to the acid substrate concentration (White and others 2004).

Work into the development of more accurate models has highlighted that the previous work carried out in this area has been very instructive however two main drawbacks have been identified. These are the lack of a multiphase approach and the significant contrast between overly simplistic approaches and procedures so highly complex that they cannot be easily followed (Zacharof and Butler 2004). Zacharof also pointed out that the majority of work in the literature has been done in examining the liquid phase, in other words the leachate quantity and quality and that the work on gas modelling, the gas phase, was usually always considered separately. Little work has been done to combine the two phases together. The development of a more comprehensive model would therefore be much more representative of a real landfill environment.

Zacharof et al examined the degree of uncertainty in the quality of the data being used for the model parameters and performance assessment. This is due to landfill operations being highly irregular and often either not recorded or sections of data not being available. Consequently a model needs to take into account this data ‘noise’ by looking taking uncertainty into account. All models are a trade off between accuracy and ease of use or the complexity of the model and the associate identification of the required parameters to solve the model. The paper concluded that this area of uncertainty needs to be examined in more detail and in a quantifiable manner (Zacharof and Butler 2004).

5. IMPROVEMENTS TO COMPONENT MODELS

A model needs to replicate generation and movement of gases over time and space. The important descriptors are waste composition, temperature, moisture, microbial condition, porosity, density, time and location of waste placement. The issue is that a number of these descriptors are very hard if not impossible to collect for an existing full-scale landfill and laboratory tests often do not replicate full-scale landfill conditions and often over-estimate gas
predictions. The models discussed above all refer to the issues with either a lack of validation with sufficient real landfill data or requiring an approach taking into account the data uncertainty inherent with landfill parameters.

These component models have started by using theoretical component formula and then found a mathematical modelling approach to put these components together. Some have undertaken some degree of validation on the model but often in a limited extent. No component models reported in the literature have started from the other approach and used data sets from full-scale landfills and then tried to fit theoretical process models to it. This is mostly due to the lack of suitable full-scale landfill data sets.

In most operating landfills the necessary data such as accurate waste composition and waste placement history were never recorded. Also the various parameters required for modelling work are not recorded at normal operating landfills and require significant effort and expense to measure. Often landfill operators are reluctant to allow researchers unhindered access to full-scale landfills as it interrupts their operation and can cause issues with methane energy recovery programs. Several good full-scale data sets do exist but they are rare and well spread across the world. The best easily available data is the Brogborough test cells. Zacharof used the Brogborough test cell results and concluded that the model performed well against the site data and was capable of predicting correct responses to changes in operation however, there was still considerable variability in the data and parameters had to be estimated (often roughly) from field observations (Zacharof and Butler 2001).

6. CONCLUSIONS

The way to improve the current models is to combine the best component models with the best available full-scale data sets or large scale test-cells results. With more data being used to validate the models, the outcome should be models, which are more accurate and applicable to sites other than the validation site. The goal is to develop a more accurate landfill gas model with universal application.

REFERENCES


SCS Engineers and Augenstein, D. Comparison of models for predicting landfill methane recovery. SWANNA; 1998; GR-LG 0075.


