ISSUES IN USING MEDIUM TO LARGE SCALE LANDFILL DATA FOR MODELLING, MODEL CALIBRATION AND PREDICTION

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SUMMARY: A better model for full-scale landfills is required based on the more sophisticated component models, with fewer parameters, and able to be used by operators. To work towards developing such a model, an investigation is required examining the issues in using medium to large-scale landfill data for modelling, model calibration and prediction purposes. This investigation used three datasets of varying waste volumes to undertake a parameter sensitivity study for landfill modelling purposes (Lamborn 2010). The first part of this investigation examined the data available from each dataset and undertook an assessment of the issues in using incomplete data for modelling purposes. The data was incomplete as many parameters either had not been measured at larger waste volumes or they were too expensive to measure over long periods of time.

1. INTRODUCTION

Landfill gas is a term used to describe the mixture of gases created by the decomposition of waste within a landfill. A landfill gas generation model is a tool that describes in simple terms the complex changes that occur during decomposition of waste in a landfill. The majority of simple models take into account microbial growth and decay only. The more complex models (known as component models) include not only microbial growth and decay, but also liquid, gas and heat transport through the waste, settlement and the chemical reactions that take place within the landfill. The majority of these models have been verified mostly using laboratory scale data and are highly parameter hungry (White et al. 2004), (McDougall et al. 2001), (Haarstrick et al. 2001). Landfill operators are very unlikely to use such complex models; since the majority of the required parameters are expensive and difficult to obtain at full-scale, or the historical data required to obtain them has never been collected.

A better model for full-scale landfills is required based on the more sophisticated component models, with fewer parameters, and able to be used by operators. To work towards developing such a model, an investigation is required examining the issues in using medium to large scale landfill data for modelling, model calibration and prediction purposes.

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2. LANDFILL MODELLING

Landfill engineering is still a developing technology. Considerable work has been undertaken by others to develop predictive models based on laboratory investigations, which are qualitatively plausible but have to be calibrated 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 complications exists in the interpretation of biochemical and physical effects and the non-uniform nature of the landfill itself (McDougall *et al.* 2001).

The majority of commonly used models make use of simple empirical functions for the rate of methanogenesis. They take into account the microbial growth and decay only; and are normally simple zero and first order kinetic models. These give a prediction of landfill gas generation over time and require significant 'guess' components based on field experience and precedence for the kinetic estimates and model parameters. The US - EPA model LANDGEM is one of the commonly used models of this type (US-EPA 2005). A good comparison of these model types was undertaken by SCS Engineers *et al.* (1995) on behalf of SWANA (Solid Waste Association of North America) and by McBean *et al.* (1995). The advantage of these model types is that they allow a quick estimate of the methane generation to be calculated once the empirical constants have been determined.

The key model results are the ultimate yield of methane (or landfill gas), the generation time and the assumed shape of the output curve. The more 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 allow for an initial time lag due to the time required for waste placement and for the development of methanogenesis to occur. Once waste is placed in a landfill, there is an initial aerobic phase followed by an acidogenesis, acetogenesis and then finally methanogenesis phases. This can mean that there is a considerable time lag between the waste placement and the generation of methane. In the majority of full-scale landfills, waste is placed continuously over many years (and often in varying annual quantities). These actions 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 cases are based on laboratory testing, lysimeter tests, theoretical estimates, pilot scale landfills, gas extraction data, and some on field tests. The rates vary enormously (McBean *et al.* 1995). Real landfills are intuitively expected to have slightly different compositions and operating environments and thus to exhibit different gas generations rates. This is the reason it is necessary to calibrate models for any given landfill site. However, the higher rates tend to be from laboratory studies where the 'norm' is optimised conditions and a high percentage of shredded readily degradable material. The enormous variation, and in particular the tendency for laboratory generated data to be considerably higher than in the field, demonstrate the problems with using empirical constants and models that have been developed using ideal laboratory testing conditions to predict full scale landfill behaviour. The inaccuracies within some of these models and the predictions that come from them need to be viewed with care and an understanding of the underlying assumptions.

Another issue with most of the laboratory tested models is that they treat methane generation as equivalent to methane extraction. It is therefore assumed that all the methane generated by the landfill, is captured by the gas collection system. However, normally the gas collection system is installed some time after the waste was first placed in the landfill and consequently the methane generated during this period is never captured. Also no gas collection system is 100% efficient in capturing gas, no matter how well its been designed and operated. The actual methane extraction efficiency is not generally used as a model parameter in landfill models. The extraction efficiency can vary significantly from site to site and accurate data is not readily available (Bogner *et al.* 1993), (Spokas *et al.* 2006). However, field tests undertaken in France enabled the calculation of default extraction values for different situations:

- 35% for an operating cell with an active landfill gas recovery system,
- 65% for a temporary covered cell with an active recovery system,
- 85% for a cell with clay final cover and active recovery, and
- 90% for a cell with a geomembrane final cover and active recovery. (Spokas et al. 2006)

Differences between simple model predictions and measurements from full-scale landfills occur due to the following reasons:

- Models do not accurately reflect real landfill behaviour
- Site processes do not fit the idealised model assumptions as landfills are not well-mixed anaerobic digesters
- Waste is assumed to be placed instantaneously
- The generation of methane is assumed to start as soon as waste is placed
- The waste body is assumed to be homogeneous with uniform particle size and waste composition
- Site input data are poorly known
- Recoverable gas depends on how much of the waste can have gas wells installed as the landfill is being constructed
- All generated landfill gas is assumed to be collected

While many of these differences will create radical errors in predictive models, some will not, and some will only create significant errors under specific conditions. One of the purposes of the more complex modelling is to determine under which conditions the simpler models are useful and when their results should be treated with caution. The more complicated component models may prove impractical to be used in full-scale landfill sites (too many parameters requiring too much effort and cost to measure). One of the purposes of their development is to verify and validate the simpler models. Ironically, then, more complex modelling may be required, not necessarily to generate a better picture and predictive ability of models, but to provide boundaries around the use of simpler, but more pragmatic models.

3. LABORATORY SCALE DATA: HPM2 MODELLING CHALLENGE

The first modeller's challenge in 2007 involved two consolidating anaerobic reactors (CARS) with each containing 27 kg dry weight of MSW. The operational and waste composition information was provided to the modellers (Ivanova et al. 2007), (Beaven et al. 2008). In order to promote rapid waste degradation a synthetic leachate mixed with 10 % (v/v) anaerobic sewage sludge was added to each CAR. This was to ensure the presence of viable methanogenic bacteria. The anaerobically digested sludge was derived from an anaerobic digester at Millbrook Sewage Works (Southern Water, UK (Beaven *et al.* 2008). These CARS were then run for 919 days under different applied loads of 150 kPa for CAR1 and 50 kPa for CAR2.

Detailed waste composition information and particle size distribution of the waste was provided. The HPM2 challenge provided the full analyses on the generated leachate chemistry for the first 77 days of the experiment.

Following the modelling challenge, the gas composition, gas flowrate and settlement was made available. There was a short period at the start of the test before gas generation started, which shows that under the ideal laboratory conditions, methanogenesis commences very quickly after waste placement.

4. FIELD TEST CELL LANDFILL DATA: BROGBOROUGH TEST CELLS

The construction of the Brogborough test cells commenced in 1986 and filling occurred from 1987 – 1988 with capping completed in 1989 (Knox et al. 1999), (Croft et al. 2001) (Knox et al. 2005). There were six cells constructed, each 25 m wide by 40 m long. Originally it was planned for a depth of 10 m, however that was extended to 20 m (Caine et al. 1999). Each test cell contained approximately 20,000 tonnes of waste. These test cells were used to investigate a range of techniques to examine the enhancement of waste degradation rates.

One major negative regarding this data set was the lack of detailed waste composition data. Zacharof *et al.* (2001) in their modelling work estimated the waste composition data using the disposal history at the landfill and the origin of the waste, including the addition of the sewage sludge and non-hazardous and commercial waste added to cells 5 and 6 (Zacharof *et al.* 2001).

For these field-test cells, the gas generation occurs much more slowly than for the laboratory scale test. In addition, there is a distinct time lag before gas is generated. In the field, waste takes time to place in the cells (i.e. 2 years), the waste is not shredded or homogenous; and the cell is not operated under constant temperature and moisture conditions, as it usually is in a laboratory. This lag time and slower cumulative gas generation are normal for field-test cell and full-scale sites when compared with laboratory tests.

5. FULL-SCALE LANDFILL DATA: NARRE WARREN LANDFILL

The Narre Warren North Regional Landfill is managed by the City of Casey (an outer council of Melbourne) on behalf of six adjoining councils. Gas collected from a well field on the site is fed into a power station producing 4.5 MW, which is supplied into the Victorian electricity grid (Lamborn 1999). The Narre Warren landfill commenced use in 1982. The landfill was closed in June 1996 and a final clay sealing cover was then applied. The average depth is 30 m and the deepest part of the landfill is 45 m below the final surface. The landfill covers 45 hectares with a filled volume of 3.5 million cubic metres.

Council records showed the landfill contains 60 % municipal solid waste (MSW), 20 % commercial waste, 10 % low-level hydrocarbon contaminated soil and 10 % miscellaneous waste. The Narre Warren site was well drained with no leachate collection or recirculation system. The density measured by the Council during waste placement showed values to be approximately 1.3 tonne/m^3.

EDL had collected a large amount of gas extraction data since 1992, when the landfill gas power station commenced operation. This was the first landfill gas project that EDL had undertaken (and the first in Australia), and data were collected for a variety of reasons, both by EDL, the author and by the local Council. The data had been collected usually on a weekly basis from individual wells and sections; and at least on a daily basis at the power station, (some readings had been taken three hourly).

The entire well field was re-drilled in 1996 following the final capping of the landfill. This was undertaken because of the physical failure of a number of wells. These physical failures were partially due to the damage done by waste trucks whilst unloading the waste on the landfill. Other problems with the original wells occurred due to cracking of the well pipes from differential settlement and lack of sufficient UV protection in the plastic pipes. This meant that the well layout and well depths prior to 1996 and after 1996 were different.

The cumulative gas generation data commenced being collected in 1992 when the landfill gas power station was installed. The landfill commenced filling in 1982. There is no data available to quantify the amount of gas that was generated during that 10-year period. This is a problem with all full-scale landfills, where it is normal practise to install the power station after waste filling has commenced and then usually in stages as waste placement proceeds across the landfill. This means that complete gas generation data for full-scale landfills is normally not possible to obtain. Estimates have to be made regarding the amount of gas generated in this intervening period in order to compare measured gas generation with any model predictions.

The other parameters that have not been measured at this site that are needed for modelling purposes were the change in volume as the waste degrades (landfill settlement) and the capture efficiency of the gas extraction system. To undertake predictive modelling using this site, assumptions would be required on these issues to allow the selection of appropriate input parameters.

6. DISCUSSION AND CONCLUSIONS

With the laboratory scale data set (HPM2 challenge data), detailed information was collected and has been made available for researchers. For the field-test cell (Brogborough) and full-scale landfill (Narre Warren) issues arise because not all data that is necessary for model validation and calibration has been collected. Assumptions must be made regarding the missing data to enable the date to be used for modelling, model calibration or predictive purposes. However, in the two later cases considerably more data exists than is normally available from field-test cell sites and, in particular, from full-scale landfills.

Arguably, however, the inability of models to cope with missing or inadequate input parameters is an inherent weakness with many models, particularly the more complex, parameter hungry models. At full-scale, landfill operators will never have all the data that would be useful for modelling purposes. The issue therefore, is what data is critical for modelling purposes and which landfill sites have that data available and accessible.

For the field-test cell data, the missing information is the waste composition data and the efficiency of the gas collection system. For the full-scale data, the missing information was the change in landfill volume over time, the capture efficiency of the gas extraction system, the volume of gas generated before the installation of the gas collection system.

In both the field-test cells and full-scale landfill, the capture efficiency is assumed to be the gas generation rate. Future work is needed in this area. Many models treat landfill gas generated as equivalent to landfill gas captured. Actual landfill gas generation is not a model parameter in the majority of predictive models.

The conversion of waste composition to model input parameters is an area that also requires further investigation. The variation in calculated results from the different methods, highlight the need to be cautious with predictions based on one conversion method alone. It is important to look at the sensitivity of the predictions by varying the waste composition parameters.

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