Climate Change Research: Evaluation and Policy Implications
S. Zwerver, R.S.A.R. van Rompaey, M.T.J. Kok and M.M. Berk, (Eds.)

Validation of landfill gas formation models

Hans Oonk, Tonnie Boom

TNO Institute of Environmental and Energy Technology, P.O. Box 342, Apeldoorn, The Netherlands

Abstract

Three models for landfill gas formation were validated and the model parameters were estimated for Dutch landfills. Landfill gas formation could be well described, using a first-order and a multi-phase model. The half time of biodegradation was estimated to be about 7 years; ultimately 60% of the organic carbon is estimated to be converted into landfill gas.

1. INTRODUCTION

When solid waste is deposited, its organic content is converted into landfill gas: a mixture of about 40-50 vol% carbon dioxide and 50-60 vol% methane. Landfills are considered to be one of the main methane sources in The Netherlands, contributing significantly to the total emissions of about 1200 ktonnes [1].

Emissions of methane from landfills may be quantified, starting from the methane material balance. Assuming no accumulation this material balance goes:

Emission = Formation - Oxidation - Recovery

In order to enable a quantification, landfill gas formation has to be described as a function of the amounts of waste, waste age and composition. For this purpose, existing models for landfill gas formation were validated and the values of the model parameters were estimated.

In this paper it is described how landfill gas formation is determined for several landfill sites. This is done in two ways: by performing emission measurements, and by interpretation of the results of landfill gas formation projects. The observed landfill gas formation is subsequently correlated to the characteristics of the waste in place.

2. LANDFILL GAS FORMATION MODELS

Several models for landfill gas formation are described in literature [2]. Three models are listed in table 1, along with the values of the model parameters, as determined in this study. The zero-order model (1) and the first-order model (2) are the most well-known, and are frequently used in national emission estimates [e.g., 1,3]. The multi-phase model (3) is often used in the design of Dutch landfill gas recovery projects [4].

Table 1
Landfill gas formation models

- Zero order model	$\alpha_t = \zeta 1.87 \times k_0 A$	$\zeta\, k_0 = 2.4$ kg tonne^{-1} y^{-1}
- First order model	$\alpha_t = \zeta 1,87 A C_0 k_1 \times e^{-k_1 t}$	$\zeta = 0.58$ $k_1 = 0.094$ y^{-1}
- Multi-phase model	$\alpha_t = \zeta \sum_{j=1}^{3} 1.87 A C_{0,i} k_{1,i} \times e^{-k_{1,i} t}$	$\zeta = 0.58$ $k_{1,1} = 0.185$ y^{-1}; $k_{1,2} = 0.100$ y^{-1} $k_{1,3} = 0.003$ y^{-1}

In this table α_t is the landfill gas formation in m^3 per year, ζ is the generation factor. This generation factor expresses the part of the organic carbon that is ultimately converted into landfill gas. Excavations show that not all of the organic material is converted into landfill gas, so this generation factor is less than one. The factors k_n are the model parameters, A is the amount of waste in place in tonne; C_0 and $C_{0,i}$ are the amount of organic carbon in the waste and the amount of organic carbon of a specific fraction in kg per tonne, respectively; t is the time in years, elapsed since the depositing of the waste; the factor 1.87 has the dimension m^3 per kg.

Of the models in table 1, the zero-order model is the most simple one, assuming landfill gas formation to be equivalent to the amounts of waste in place. The first-order model reckons also with waste age and carbon content. This results in a better estimate of formation, provided that the amounts of waste, waste age and the origin of the waste are sufficiently well known. In the multi-phase model, a fast, a moderate and a slow degradable fraction are distinguished in the waste, each decaying in a first-order way, but with different rate-constants of biodegradation.

The amounts of carbon in the waste and the degradability of the carbon (slow, moderate or fast) can be calculated, using the mean composition of landfilled waste, as it has been determined in The Netherlands. This composition is given in table 2.

Table 2
Carbon contents of Dutch municipal waste [4]

Fraction	$C_{0,1}$	$C_{0,2}$	$C_{0,3}$	$C_{0,tot}$
Degradability	fast	moderate	slow	
		(in kg tonne^{-1})		
household waste	51	66	66	66
industrial waste	9	51	51	111
demolition waste			11	11
agricultural waste	61	61	13	135
mean				112

3. ESTIMATING FORMATION FROM EMISSIONS

As stated in the introduction, formation models are validated by correlating the waste characteristics with the observed landfill gas formation. One way for determining landfill gas formation is by measuring landfill gas emissions. Landfill gas emissions are *not* affected by oxidation, since the total amount of methane and carbon dioxide emitted remains constant. Assuming no accumulation, landfill gas formation can be estimated as the sum of the amounts emitted and recovered.

Several methods for measuring emissions are described in literature [5]. Two of these methods were tested: the closed chamber method and the micrometeorological method [6]. In the closed chamber method, the small area (10 m^2) is sampled and emissions are directly obtained. In a micrometeorological method, methane concentrations are measured along with wind-velocities at various heights. From these wind-velocity and concentration profiles, vertical fluxes from a large area (> 2000 m^2) can be calculated [7].

Landfill gas emissions proved to occur in a very inhomogeneous way: using the closed chamber method, emissions varied over a factor of 1000 at different spots on a single landfill. Besides that landfill gas emissions also varied widely on a time-scale. As a result of this, a large number of measurements on different spots, pertained for longer times is required in order to get a reliable impression of emissions. Doing this, using the closed-chamber method results in a very time-consuming and labour-intensive procedure, because of the large number of transpositions required.

The micrometeorological method does not have this disadvantage. Using this method - equipped with automated sampling, analysing and data-acquisition - it proved to be possible to measure emissions from a large part of a landfill, within about two weeks. In this way emission estimates were obtained, which were fairly well in line with expected emissions.

This micrometeorological method is subsequently used in a measurement campaign, measuring emissions from about 15 to 20 landfills in The Netherlands [8].

4. ESTIMATING FORMATION FROM RESULTS OF RECOVERY PROJECTS

At about 22 landfill sites in The Netherlands landfill gas is recovered and utilised. For recovery of the gas, a well-system is installed which the gas is collected with. The amounts of gas recovered may be used to estimate landfill gas formation, provided the recovery efficiency is known.

Amounts of gas recovered, and specific information about the landfill site, and its well-system was obtained from nine Dutch landfills [9]. The recovery efficiencies were estimated by Grontmij, a consultant with over 10 years of experience with landfill gas. These estimates were based on landfill geometry, composition top liner system and lay-out of the recovery system. In several landfills the waste is completely wrapped in gas-tight liner systems and the efficiency was assumed to be 100%.

From the amounts of landfill gas recovered and this estimated recovery efficiency, the landfill gas formation was estimated: the formation is the ratio of the recovery and the recovery efficiency.

5. VALIDATION

Both the emission measurements and the results of the landfill gas projects provide information about landfill gas formation on the individual landfills. On the other hand, landfill gas formation may be calculated, starting from the waste characteristics, using the formation models in table 1.

Comparison of the results of the models with the observed landfill gas formation for all the landfills, provides information about the accuracy of the model. Since the calculated formation is a function of the model parameters, the model accuracy is also a function of the accuracy of these parameters.

This provides a tool for estimating the values of the model parameters. Assuming a type of model (e.g. a first-order model), the best-estimate for the model-parameters yields a maximum accuracy of the calculated and the observed landfill gas formation.

In this study, this maximum accuracy was obtained numerically using SAS (software for statistical analysis). The resulting best-estimates of the values of the model parameters are given in table 1. The result of the first-order model is illustrated in figure 1.

The mean relative difference between observed and calculated formation was 44% for the zero-order model; 22% for the first order model and 18% for the multi-phase model.

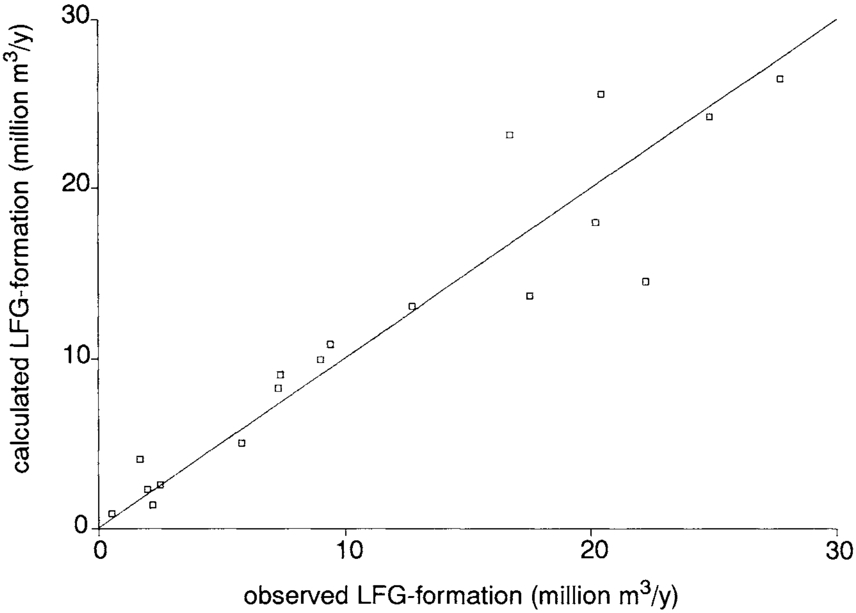

Figure 1. Observed versus calculated formation (using the first-order model)

6. DISCUSSION AND CONCLUSIONS

The resulting values of the rate-constants of biodegradation correspond with a half-time of landfill gas formation of about seven years. The calculated generation factor indicates, that ultimately about 60% of the organic carbon is converted into landfill gas.

Landfill gas formation, both on a single landfill as on a national scale may be calculated, using the models in table 1. Use of the zero-order model results in less reliable estimate than use of the first-order or multi-phase model. The accuracy of a national formation estimate depends upon the accuracy of the amounts of waste and the waste composition. In The Netherlands, these amounts are known within an accuracy of about 10-15%. Using the first order model, as described above, will result in a formation estimate with a relative error of about 25%.

It has to be stressed, that landfill gas formation is affected by waste composition, landfill-site management and climatological conditions. For this reason, the results obtained in The Netherlands can not be used for estimating landfill gas formation in other countries, without any proviso.

7. ACKNOWLEDGEMENTS

This work is funded by NOP-MLK (Dutch National Research Programme Global Air Pollution and Climate Change) and NOVEM (Netherlands Agency for Energy and the Environment).

8. REFERENCES

1. Amstel A. v., Swart R.J., Krol M.S., Beck J.P., Bouwman A.F., Hoek K.W. v.d.: 1993, *Methane, the other greenhouse gas*, RIVM-Report no. 481507001, RIVM, Bilthoven, The Netherlands;
2. Augenstein, D., Pacey J.: 1991, Modelling landfill gas generation, *Sardinia 91, 3rd International Landfill Gas Symposium,* 14-18 october 1991, Sardinia, Italy.
3. US-EPA: 1993, *Anthropogenic methane emissions in the Unites States: estimates for 1990,* Report to Congress EPA-430-R-93-003;
4. Bogner J. and Spokas P.: 1994, *Landfill CH_4 emissions, guidance for field measurements,* Argonne National Laboratory, USA.
5. Scheepers M.J.J., Zanten B. van: 1994, *Handleiding stortgaswinning,* Adviescentrum Stortgas, Utrecht. (Manual landfill gas recovery, in Dutch)
6. Verschut C., Oonk J., Mulder W.: 1993, *Broeikasgassen uit vuilstorts in Nederland,* TNO-report 91-444, TNO-ME, Apeldoorn, The Netherlands (Greenhouse gases from landfills in The Netherlands, in Dutch).
7. Fowler D., Duyzer J.H.: 1989, Micrometeorological techniques for the measurement of trace gas exchange, in *Exchange of trace gases between terrestrial ecosystems and the atmosphere,* Andreae M.O, Schimmel D.S., eds., John Wiley & Sons, pp. 189-207.
8. Oonk J., Boom A.: 1995, *Landfill gas formation, emission and recovery in The Netherlands, a measurement study,* TNO-report, to be published early 1995.
9. Oonk J., Weenk A., Coops O., Luning L.: 1994, *Validation of landfill gas formation models,* TNO-report no 94-315, TNO-Apeldoorn, The Netherlands.