A PLURIDISCIPLINARY MODEL TO PREDICT MUNICIPAL LANDFILL LIFE

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ABSTRACT: Most degradation processes that occur within municipal wastes landfills result from different microbial activities interacting all along the landfill lifetime and that are influenced by several non-biological factors. These complex biological and chemical processes require a multidisciplinary pattern in order to assess and control their environmental impact. Thanks to Walloon Region support, we have developed a pattern or model combining the evolution of different key parameters. Such parameters qualify biogas (composition, production rate), leachate (pH, BOD_5, COD, volatile fatty acids, redox potential, nitrogen balance, humic acids...), or solid waste (moisture, settlement, cellulose content...). This paper presents relationships, including our model, between these parameters. Variations of pH, BOD_5/COD ratio, sulfate concentration in leachates, gas composition analysis and settlement measures allow to predict landfill age, on a standard scale, since completion. Evaluation of cellulose and water content in refuse as well as settlement degree are useful to estimate the time required for complete biological degradation. The

mathematical model has been applied to different landfill sites and has already been presented at Sardinia 99 (Steyer et al., 1999).

1. INTRODUCTION

Destined to disappear of high-industrialised countries, according to authority wishes, municipal waste landfills will not yet leave environmental management plans before several decades. New sites show nowadays a few methods designed to reduce or suppress pollution export out of the landfill. However, landfills behave like biological reactors. These reactors are difficult to characterise as regards the degradation rate, and consequently, the time required for complete biological degradation.

In order to develop mathematical models, landfill has to be considered as a biological reactor, described in terms of inflows, outflows and microbial population and responsible for degradation influenced by a few physico-chemical parameters.

The biological evolution model of municipal landfill evolution described in this paper contains several relationships. Each of them translates variations of a parameter that reflects microbial metabolism within the landfill. The model was applied to different landfill sites in Belgium and overseas. Representative parameters were selected according to the opportunity of recording them through current available samples from landfill: biogas, leachate and solid waste samples. This model is useful, first as a management and control tool for modern controlled landfills, but also for old and uncontrolled sites where the main objective is the description of their physiological state and their impact on environment. In both cases, the efficiency of the forecasting model depends directly on the amount and quality of the available data (history of the site, waste composition, management uses, volume, and hydrogeological parameters, etc.).

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2. RESULTS AND DISCUSSIONS

2.1. Influence of water content on biogas production rate

Many authors agree with the fact that methanogenesis is enhanced by a high waste moisture content (Farquhar and Rovers, 1973; Rees, 1980). In the model presented here, moisture content as well as water activity were considered as two major parameters affecting microbial metabolism in landfill ecosystem. A high water content contributes to anaerobic atmosphere development, accelerates settlement and promotes heat transfer and substrate diffusion (Farquhar and Rovers, 1973).

Farquhar and Rovers (1973) report a maximum gas production occurring at water contents from 60 to 80 % wet weights. Rees (1980) and Senior (1990) report several optima of waste moisture for methanogenesis in landfill from 55 to 80 %. We have extended these results and developed the relationship below, between biogas production and waste moisture. Between 20 and 70 % of waste moisture, biogas daily rate can be modelled in function of waste moisture by:

$$\textit{Biogas production} = 0.024 \bullet \exp(0.15 \bullet \%\textit{Moisture}) \qquad \text{(Equation 1)}$$

where the biogas production is expressed in cm^3 produced daily per kg of wet refuses as a function of the water content, expressed as a percentage of wet weight.

Such an exponential and sensitive equation (Equation 1) is represented on figure 1 (Thonart et al., 1997).

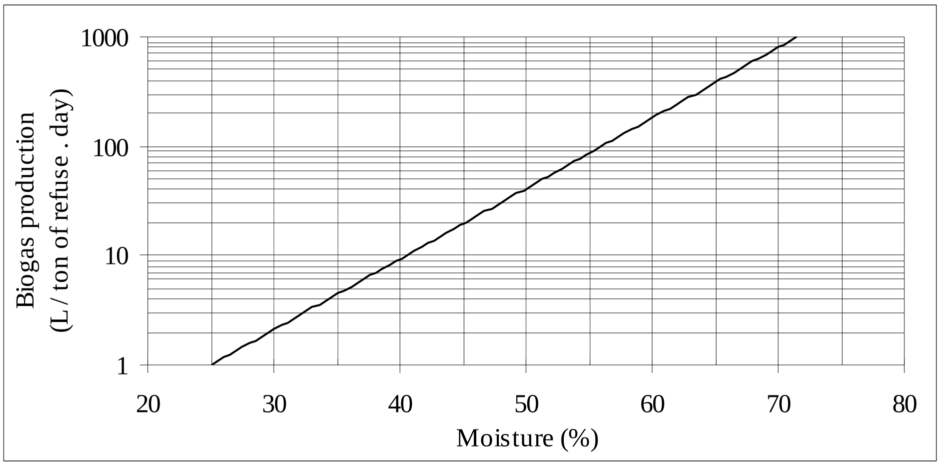

Figure 1. Effect of waste moisture on biogas production rate adapted from Rees (1980), Farquhar and Rovers (1973) and Senior (1990)

A total biogas yield between 96 and 135 m^3 biogas per ton of humid waste was reported by several authors as a good average for municipal waste landfills (Barlaz et al., 1989; Pacey, 1990; Gendebien et al., 1992).

2.2. Modelling landfill lifetime by settlement

Settlement is a parameter widely used, and often imposed by authorities, to control landfill evolution. More than a direct index of degradation rate, total settlement is also a necessary condition for the site rehabilitation. Assessments of the total settlement of sanitary landfill range from 25 % to 50 % of the initial thickness (Wall and Zeiss, 1995). Under optimum methanogenesis conditions, a theoretical 40 % settlement of initial thickness (after initial compression) could occur (Emberton and Parker, 1987). Practically, settlements of 35 % are recorded.

Global settlement includes three major components :

• initial compression, directly observed and depending on the compaction treatment type applied to wastes. Emberton and Barker (1987) compared settlements recorded with compacted waste (density 1.0 ton/m^3) and non-compacted wastes (density 0.6 ton/m^3). In the first case, no physical settlement was observed and in the second case, a 35 % physical settlement was recorded;

• primary compression, quickly occurring after completion of the landfill, within the first 30 days and due to the dissipation of pore water and gas from empty space;

• secondary compression due to biological degradation and resulting in a settlement of about 18 to 24 % of the initial thickness.

According to Swiss investigations led by the CSD Society and adapted by Thonart et al. (1993), the last two compression components follow the pattern presented on figure 2 and modelled as

$$Settlement = (-0.21 + 0.06 \cdot log(t)) \cdot (250 + log(t^{110}) / log(0.0275 \cdot t) \qquad \text{(Equation 2)}$$

where the settlement is expressed in percentage of the landfill thickness after completion as a function of time (t), in years, since completion.

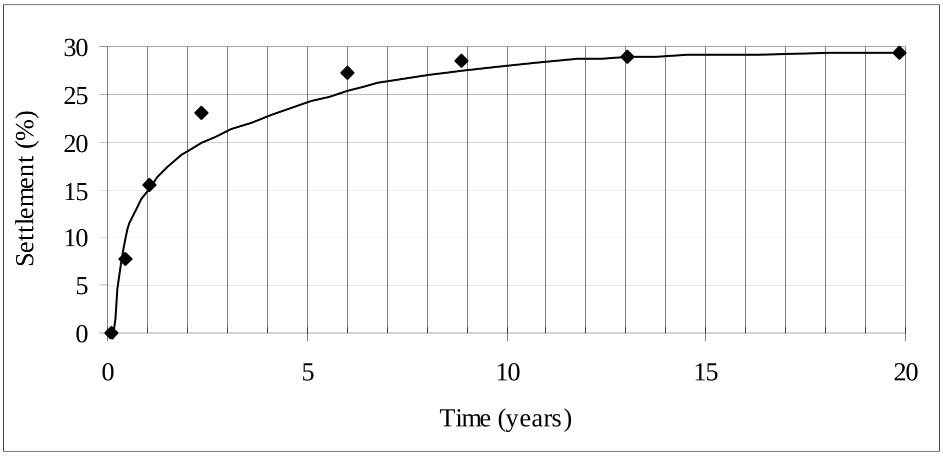

Figure 2. Settlement evolution versus time in landfills adapted from Thonart et al. (1993) and Dumont et al. (1993)

2.3. Modelling landfill lifetime and biogas production by cellulose content

Cellulose is the major biopolymer found in municipal waste landfills. During methanogenesis, the cellulose will progressively become the last carbon source available for microorganisms.

Indeed, a first order kinetic is reported (Gendebien et al., 1992) to model organic matter degradation (equation 3).

$$C_t = C_0 \cdot exp(-k \cdot t) \qquad \text{(Equation 3)}$$

where C_0 represents the initial organic content; C_t, the organic content at time t and k, a first order constant (t^{-1}) called the inverse of the half-life constant.

Since heterogeneity is characteristic of waste composition, the biodegradable content needs to be divided into three different fractions characterised by their half-life constant: 1 year for fraction containing sugars, lipids and proteins, 5 years for garden waste and 15 years for the fraction containing cellulose and lignin.

However, a complete cellulose degradation would not be achieved; 71 to 77 % of the initial cellulose content would be degraded at the end of the landfill life and would contribute to 90 % of the total methane produced (Gendebien et al., 1992).

2.4. Evolution of leachate characteristics

Leachate is an important data source to describe microbial activity that takes place in a landfill. Evolution indicators are numerous. They vary on short periods but, thanks to leaching processes, they give a relatively homogeneous image of the 'waste bed'.

The application of such models, based on leachate evolution, is primarily useful during the first ten years after landfill covering. Indeed, this period is characterised by an intense degradation and dissolution of organic matter. After this period, organic matter is mainly constituted of high molecular weight polymers called fulvic and humic acids. It should be mentioned that quantitative separation and analysis of these acids is still complex nowadays (Thonart et al., 1995).

Three global parameters adapted from the literature allowed to describe the mathematical models seen in table 1. in function of time (t).

Table 1 - Evolution of leachate parameters versus time

Leachate parameter	Relation in function of time (t) since completion [years]	Remark
pH	$pH = 0.71 \bullet t + 4.5$ (Equation 4)	Only between 2 and 6 years after landfill completion; adapted from Rees (1980)
BOD_5/COD ratio	$BOD_5/COD = 1.0024 - 0.1015 \bullet t$ (Equation 5)	Adapted from Ehrig (1983)
Sulfate content (mg/l)	$[SO_4^{--}] = 2553.3 - 454.7 \bullet t$ (Equation 6)	Adapted from Gendebien et al., (1992)

3. CONCLUSIONS

Contrasting to the well-known heterogeneity of municipal landfills, it is now possible to describe the microbial activity that takes place in landfills. The model reported in this paper contains different equations based on parameters such as settlement, wastewater content and waste cellulose content.

Equations using leachate parameters are interesting in most cases during the first six to eight years of biological evolution. Biogas quality also varies during the first four years before a stabilisation at a CH_4/CO_2 ratio of 60/40. The equations involving settlement and waste composition are more useful to predict future landfill life and environmental impact.

This model has been experimented on different landfill sites in Belgium and overseas confirming the mentioned evolution patterns. Furthermore, experimental data presented in other papers also confirm the patterns (De Poli et al. 1999, Hilde and Leonard, 1999, Urbini et al, 1999).

Being conscious of the real difficulty to collect all of the useful data at the approach of an unknown site, a particular attention was paid to present a relatively simple and pluridisciplinary model able to predict biological landfill age and future biological activity. This model emphasizes the better biological parameters to record or control in a municipal landfill.

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