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A decision support tool for landfill methane generation and gas collection

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ABSTRACT

This study presents a decision support tool (DST) to enhance methane generation at individual landfill sites. To date there is no such tool available to provide landfill decision makers with clear and simplified information to evaluate biochemical processes within a landfill site, to assess performance of gas production and to identify potential remedies to any issues. The current lack in understanding stems from the complexity of the landfill waste degradation process. Two scoring sets for landfill gas production performance are calculated with the tool: (1) methane output score which measures the deviation of the actual methane output rate at each site which the prediction generated by the first order decay model LandGEM; and (2) landfill gas indicators' score, which measures the deviation of the landfill gas indicators from their ideal ranges for optimal methane generation conditions. Landfill gas indicators include moisture content, temperature, alkalinity, pH, BOD, COD, BOD/COD ratio, ammonia, chloride, iron and zinc. A total landfill gas indicator score is provided using multi-criteria analysis to calculate the sum of weighted scores for each indicator. The weights for each indicator are calculated using an analytical hierarchical process. The tool is tested against five real scenarios for landfill sites in UK with a range of good, average and poor landfill methane generation over a one year period (2012). An interpretation of the results is given for each scenario and recommendations are highlighted for methane output rate enhancement. Results demonstrate how the tool can help landfill managers and operators to enhance their understanding of methane generation at a site-specific level, track landfill methane generation over time, compare and rank sites, and identify problems areas within a landfill site.

1. Introduction

The improvement of the generation of methane for gas collection and sale from landfills is hampered by a general lack in understanding of landfill processes at the field-scale (Cho et al., 2012). Difficulties in understanding derive from the heterogeneous nature of landfill waste, lack of access to the waste once deposited and the interpretation of a wide variety of landfill parameters. The causes of landfill gas production fluctuations in the field continue to be largely unknown. Therefore, there is a need for decision support tool (DST) that can integrate a wide range of data to understand how well a landfill site is performing in terms of methane output rate and what can be done to improve it.

Landfill operators are concerned with the cost of monitoring sites and the revenues generated from the energy produced from gas collection. Enhancing methane output increases the landfill operator's revenues and offsets the cost of gas extraction system implementation, maintenance and operation. Electricity and heat produced from landfill gas can be sold for revenue in addition to income from government incentives such as the feed in tariff, renewable obligation certificates and the renewable heat incentive. Strickland (2010) argues that a steady profit can be achieved in a relatively short period of time, however costs for all factors involved vary widely among sites and therefore estimates are not quoted here. However, there is a clear business case for improving landfill methane generation at existing sites.

There is currently no DST used specifically for the assessment of landfill methane generation. The majority of tools for landfill sites focus on environmental risk management objectives in accordance with environmental regulations (Laner et al., 2012). Models are also available to predict landfill gas output such as LandGEM and GasSim (Golder Associates, 2013; USEPA, 2005) but these do not provide guidance as to what is problematic in the landfill or what can be done to increase gas production for collection. However, there is a well-established literature base on multi-criteria analysis (MCA) which can be applied to landfill methane generation to assimilate a wide base of landfill gas production knowledge into a decision support tool.

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A DST provides a robust, consistent, transparent and reproducible method for the decision making process (Sorvari and Seppälä, 2010). MCA is essential for the use of a DST in a landfill situation due to the wide range of processes and parameters involved. It is a widely used and tested method in modern policy decision making such as deciding between which waste management technologies to use (Dodgson et al., 2009).

The aim of this research is to develop and present a DST to enhance methane generation within individual landfill sites. The objectives are to: (1) provide landfill decision makers with clear and simplified information on the state of a landfill site in terms of landfill gas production for gas collection with reference to target values; (2) develop a tool that highlights what problems exist within a landfill site; (3) provide recommendations as to what can be done to enhance methane generation; (4) provide supporting information about the tool to the user to understand its limitations and the assumptions made; and (5) provide the framework for a tool which can be improved over time as new data becomes available.

This paper presents a unique DST to assess landfill methane generation on a site-specific basis with two scores. The first score assesses the methane output produced over time compared to predictive model values. The second provides a breakdown of landfill gas indicators to assess the viability of the landfill environment to produce methane. Parameters include pH, ammonia and moisture content. This is achieved by comparing actual values for key indicators to previously recorded data. The user is then able to prioritise areas of management which can enhance landfill methane generation for gas collection. The tool also provides suggestions for possible remedial actions for each indicator where issues have been identified.

2. A DST for landfill methane generation

2.1. Interface

The tool was developed in the Microsoft Excel 2010 to ensure it is accessible to the widest range of audience. The tool includes a series of worksheets in which the user can enter input data, run simulation and see the results and possible actions to landfill gas problems, gain insights into the calculations and underlying data. The user is able, at a basic level, to enter data for a specific site, view results and remedies. At a more advanced level further tabs are available to understand how the scores are calculated and certain model parameters can be altered.

2.2. Method for decision support tool development

2.2.1. Landfill process theory

A general understanding of landfill methane generation processes is necessary to develop a DST. The processes that take place in landfills are widely described in literature through laboratory, field and theoretical experimentation (Mata-Alvarez, 2003; Themelis and Ulloa, 2007; Christensen and Kjeldsen, 1995). It is generally accepted that the organic waste fraction goes through a series of phases of degradation including hydrolysis, acetogenesis, methanogenesis and oxidation (Barlaz et al., 1990). A landfill site is expected to have turned to methanogenic conditions within 2 years and therefore the ideal range of most leachate indicators changes after this time in the DST (World Bank – ESMAP, 2004).

These phases simultaneously produce variations in the environment within the landfill and produce changes in leachate, waste and gas composition. Leachate characteristics, or indicators, include pH, alkalinity, chemical oxygen demand (COD) and biochemical oxygen demand (BOD). These indicators can be used to estimate the expected rate of methane generation within a landfill. Due to the anaerobic nature of landfill sites, parameter values are very similar across a range of landfill sizes in Europe (Kjeldsen et al., 2002) and can therefore be used in a DST to measure landfill methane generation.

2.2.2. Landfill gas models

The move to achieve the complete landfill gas (LFG) recovery for energy production from UK landfill sites has led to some waste management companies using models as a resource and risk assessment tool for landfill gas estimation (Kamalan et al., 2011). The models use various input parameters such as assumed half-life of waste decay and waste composition which determine the amount of carbon in the waste mass that can be transformed into methane and carbon dioxide (Kamalan et al., 2011). Other important factors such as moisture content, climate and temperature influence these parameters and affect the prediction of LFG production. When these factors are poorly defined, the results of the models are significantly uncertain (Amini and Reinhart, 2011; Kamalan et al., 2011).

First-order kinetics are often used in methane production models (GasSim, LandGEM, TNO, Afvalzorg and EPTR) are presented by Kamalan et al. (2011) and Thompson et al. (2009). The three key factors identified for methane generation models for a landfill site are (Thompson et al., 2009):

1. The amount of waste disposed since commissioning.
2. The degradable organic fraction.
3. The decay rate (of each fraction and as a whole).

As many old landfills (pre-2005) do not hold records of waste quality or quantity the composition of the waste is not always known and therefore estimations and extrapolations are necessary in many cases. More recently, the IPCC guidelines (2006) established a method that can be applied to all countries/regions and provides default values (e.g. regional generation rates), estimates and calculation methods to compensate for the lack of historical data (IPCC, 2006). However these estimates introduced higher uncertainty in the final results and sites with poor management data have the highest uncertainties in their calculations. In addition the overall rate of LFG emission can be influenced by operational interventions such as waste compaction, leachate recirculation or aerobic landfilling and theoretically these factors should also be taken into consideration when modelling generation. Thus the main criticism of methane prediction models is their lack of accuracy and validation and therefore simple models are preferred (Bogner and Matthews, 2003; Thompson et al., 2009; Oonk, 2010).

In this study, the LandGEM waste model (USEPA, 2005) was chosen as it requires a small amount of data input but provides an estimation of the evolution of cumulative landfill gas emissions over time. This provides benefits over simpler models such as E-PRTR model (Ademe, 2003) which provides only a total value of gas emissions which cannot be used in a DST to assess methane generation at yearly intervals. The rate of methane output in terms of cubic metres per hour provides the closest current indicator of landfill stability and landfill gas optimisation (Mata-Alvarez, 2003).

Therefore methane generation was selected to estimate rate of emissions from decomposed landfill waste (Eq. (1); Reinhart et al., 2005).

$$Q_{CH_4} = \sum_{i=1}^{n}\sum_{j=0.1}^{1} kL_0\left(\frac{M_i}{10}\right)e^{-k\ t_{ij}} \tag{1}$$

where Q_{CH4} = annual methane generation in the year of the calculation (m^3/year); i = 1 year time increment; n = (year of the