SUBSURFACE GAS GENERATION AT A LANDFILL IN JOHANNESBURG

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Abstract

Landfill gas (LFG) consisting of 50-60 % v/v CH_4 contributes to global greenhouse gas emissions as well as to local air pollution and nuisance odours; in addition, the uncontrolled subsurface migration of LFG can pose an explosion hazard. LFG is explosive mostly due to its CH_4 content. CH_4 is explosive at concentrations of 5-15 % in air. Venting of the gas to the atmosphere prevents any explosion risk; however, the concern lies with the lateral migration of CH_4 through soil and along cracks and its subsequent accumulation. This highlights the importance of subsurface LFG monitoring. In this study, subsurface LFG generation is measured at a solid waste disposal site situated approximately 20 km west of Johannesburg. The results of three first-order kinetic models (to estimate LFG generation) for the site are compared. The three models are LandGEM, GasSim and the IPCC model contained in the 2006 UNFCCC 2006 National Inventory Guidelines for waste. High LFG concentrations are recorded along the northern boundary of the site (exceeding 60% v/v). Modelled LFG generation simulations are slightly higher from LandGEM whilst the IPCC Waste Model predicts the lowest concentrations.

Keywords: Landfill gas, methane, carbon dioxide, subsurface probes.

1. Introduction

1.1. CH_4 is a radiatively active trace gas (Cicerone and Oremland, 1988; Dlugokencky *et al*., 1998; Shipham *et al*., 1998). The atmospheric concentration of CH_4 during pre-industrial times is estimated at 0.7 ppm, whereas the concentration in 2005 was 1.774 ± 1.8 ppm (IPCC, 2007). There are a number of contributors to the increasing amount of CH_4 in the atmosphere and landfills are among the largest of these sources (Hein *et al*., 1997; Houweling *et al*., 1999).

In South Africa, environmental regulations governing waste disposal are set out in the Minimum Requirements for Waste Disposal, released by Department of Water Affairs and Forestry (DWAF) in 1998 (Morris, 2001). These documents provide a set of standards and criteria for the selection, investigation, design, preparation, operation, closure and monitoring of landfill sites (DWAF, 1998; Morris, 2001). According to the Minimum Requirements waste is classified into two categories namely general (G) and hazardous (H). The eventual size of a landfill is calculated from the maximum rate of deposition expected at the site (from the opening year of the landfill up to and including its year of closure). Once the maximum rate of deposition is calculated, landfills are categorised into four sizes namely communal (C), small (S), medium (M) and large (L) (DWAF, 1998).

The water balance at the landfill is based on the potential for significant leachate generation to occur at the site and is affected by rainfall, evaporation, moisture content of waste and water infiltrating the waste body (DWAF, 1998). If it is positive for less than one year in five, it is assumed that no significant leachate generation will occur at the site and the site is classified as B^- (sporadic leachate generation likely). If B is positive for more than one year, it is assumed that significant leachate generation will occur at the site and the site is classified as B^+ (significant leachate generation likely) (DWAF, 1998; Morris, 2001). There are different requirements for the design and operation of a landfill depending on the classification of the landfill.

According to the Minimum Requirements, gas generation must be monitored at three monthly intervals. At present only a few gas management systems (where LFG is collected and utilised) exist in South Africa. Passive venting to the atmosphere and flaring are the most common practices (Bogner and Lee, 2004). Previous studies on landfills in South Africa have focused on the polluting potential of landfills and seasonal variations in waste composition and its effect on LFG production. There is a need to estimate annual emissions from landfills in South Africa to aid in the assessment of the possibility of gas extraction systems for landfills. This will allow the country to exploit economic resources available under the Kyoto Protocol through the Clean Development Mechanism (CDM) and possibly reduce national CH_4 emissions.

In this study, LFG generation and emission rates from landfills in South Africa have been evaluated by analysing subsurface LFG data and estimating emissions using theoretical models namely the USEPA's LandGEM, the UK developed GasSim and the IPCC Waste Model 2006. LFG generation was estimated at a landfill in Johannesburg, denoted Landfill B.

2. Materials and methods

2.1. Site description

The site is located approximately 20 km to the west of Johannesburg and services the western part of the Greater Johannesburg Metro and the northern parts of Soweto. The landfill covers 44 hectares and surrounding land is mainly used for industrial and mining purposes. The landfill accepts approximately 30 000 tonnes of waste a month and is divided into two cells. Cell 1 is closed and currently not operational. The site is generally in a good condition and well managed. The cell does not have a final cap although most of the surface is covered with a temporary thin layer of soil (mostly builders rubble).

A number of subsurface probes were placed on the boundary of the landfill site. A survey conducted in September 2008 highlighted the need for the design of the probes to be changed as most probes at the sites were blocked or damaged. The probes are perforated allowing for gas movement and range in depth from 1-3m along the perimeter of the site (Figure 1).

Figure 1. Location of subsurface gas probes at Landfill A. There are 25 probes located along the landfill boundary.

Direct readings of gas concentrations (CH_4, CO_2, O_2, H_2S and CO) are taken using the GA2000 hand-held infrared gas analyser. Sampling was conducted in September 2009.

The spatial distributions of the LFG from the landfills are presented in contour plots. It is important to recognize that the gas concentrations are only correct at the probe. Other areas are interpolated values calculated using a gridding function feature on the program, Surfer, a grid-based contour program.

2.2. Landfill gas estimation models used

The amount of CH_4 emitted from the surface of the landfill requires an estimate of the CH_4 potential of the waste (Peer *et al.*, 1993). The development of LFG models started in the 1970's. These models require knowledge on mechanisms controlling LFG production and describe these factors with simplified mathematical equations (Cossu *et al.*, 1996). A model chosen for LFG analysis should be based on the availability of data and the output required. The majority of LFG estimation models follow first order kinetics (Cossu *et al.*, 1996) where the amount of product is always proportional to the amount of reactive material (IPCC, 2006). In a multi-phase first order model, waste fractions are divided into slow (wood and wood products), moderate (paper and textiles) or fast (food and garden) decomposing materials (EMCON, 1980; Cossu *et al.*, 1996; IPCC, 2006).

Due to variations in waste types, disposal rates, climate and operational conditions, the rate of LFG generation varies from landfill to landfill. Most LFG estimation models can account for this variability (Pitchel, 2005). Site management and local or regional climate conditions also affect the rate of LFG production (Coops *et al*, 1995). It is important that data is available on all these factors before an attempt is made to model LFG generation. LFG estimation models LandGEM, GasSim and the IPCC Waste Model 2006 are applied to estimate gas generation from the landfill site in this study.

The Landfill Gas Estimation Model (LandGEM) was developed by the Clean Air Technology Centre (CTC) of the United States Environmental Protection Agency (USEPA) (Pelt *et al.*, 1998). The model is classified as a simplified deterministic model according to Cossu *et al.* (1996) as it uses a simplified mathematical equation to describe the decay of waste. It is based on a first order decomposition rate reaction. Model defaults are based on empirical data from US landfills (Alexander *et al.*, 2005). Inventory default values are based on emission factors in the USEPA's Compilation of Air Pollutant Factors (AP-42). LandGEM determines the mass of CH_4 generated using the CH_4 generation capacity and the mass of annual waste deposited at the landfill since its opening.

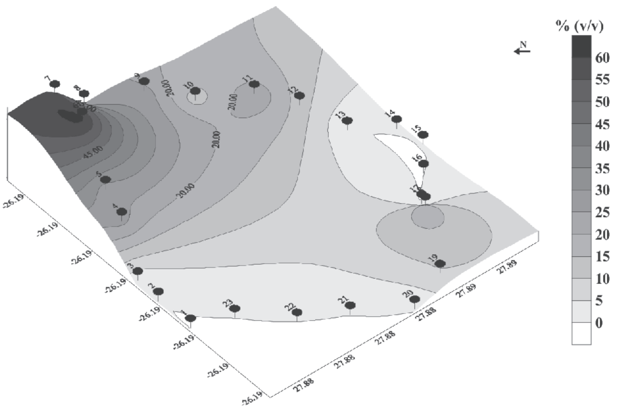
GasSim has been developed for the UK Environmental Agency. It is a conceptual model that considers the landfill as individual cells each with their own engineering and waste composition. GasSim uses both a multi-phase model (described by van Zanten and Scheepers (1994)) and another approach based on the LandGEM model to calculate an estimate of CH_4 emissions (Gregory *et al.*, 2003). The multi-phase model utilises waste input in various categories and fractions and the detailed decomposition of the waste during the particular year of disposal.

The IPCC Waste Model 2006 is a first order multi-phase model based on waste composition data. The amounts of degradable waste material (food, garden and park waste, paper and cardboard, wood, textiles) contained in the waste are entered separately. It uses a number of equations that allow total LFG to be estimated. These require accurate country specific variables (Bogner and Matthews, 2003).

3. Results and discussion

3.1. Monitored subsurface LFG

Subsurface LFG monitored at the site in September 2009 (using a hand held gas analyser GA2000 infrared gas analyser) was analysed and CH_4 and CO_2 fractions in LFG identified. The CH_4 and CO_2 generation from Landfill A is given in Figure 2.



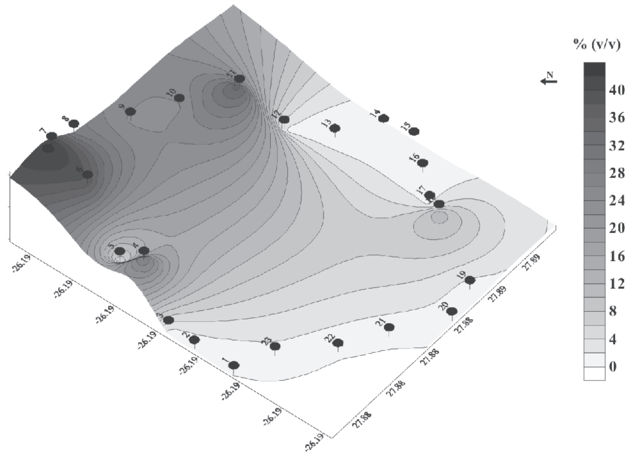


Figure 2. CH_4 (top) and CO_2 (bottom) generation at Landfill A. Concentrations of CH_4 exceed 60% v/v.

CH_4 generated from the landfill is fairly high with probes 6 and 7 recording concentrations exceeding 60% v/v. CO_2 concentrations follow a similar trend to CH_4 concentrations but concentrations are lower. Highest LFG concentrations are along the northern boundary of the site. The landfill is in the methanogenic stage (demonstrated by the high concentration of CH_4 and lower concentrations of CO_2).

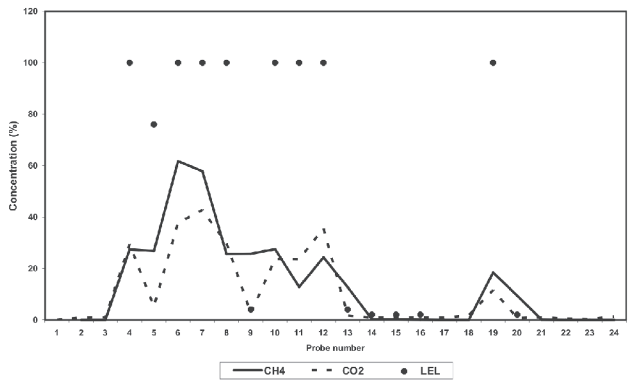


Figure 3. CH_4 and CO_2 concentrations at the site. Lower explosive limits (LEL %) at some locations are above 100%.

CH_4 is explosive at concentrations of 5-15 % in air. The lower explosive limit (LEL) at the site in some areas (probes 4,6,7,8, 10, 11, 12 and 19) exceed 100% (Figure 3). This highlights the importance of subsurface LFG monitoring at the site.

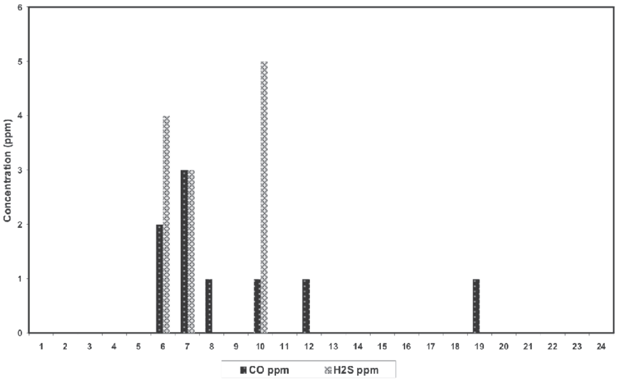


Figure 4. H_2S and CO concentrations at the site. H_2S peaks at 5 ppm. Concentrations in probes with no readings are below detectable limits of the instruments.

H_2S and CO concentrations at probes 6, 7 and 10 are high, peaking at 5 ppm at probe 10 (Figure 4). H_2S is a highly toxic gas that has serious implications for odours at the site as well as health implications (Kim, 2006).

3.2. Modelled LFG generation

LFG generation was modelled using monitored gas data collected between 2003 and 2006 at the site (using a hand held gas analyser GA94 infrared gas analyser). The subsurface probes were located at different points than the current probes. CH_4 concentrations ranged between 5 and 50 % v/v whilst CO_2 concentrations ranged from 2 – 30 % v/v.

LandGEM LFG generation simulations are slightly higher (due to the models inability to allow waste fractions to be used as input) whilst the IPCC Waste Model predicts the lowest concentrations (Figures 5).

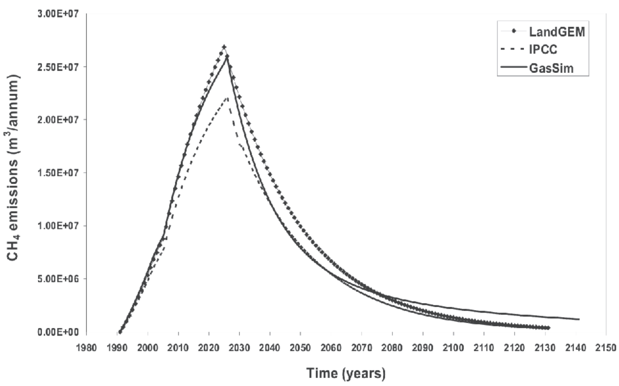


Figure 5. CH_4 generation simulations by LandGEM, IPCC Waste Model and GasSim at Landfill A.

The total percentage of inert waste was subtracted from the total waste and entered into LandGEM. Hence, 70% of waste was considered to be degradable waste. All the models show an increase in LFG emissions with increasing waste deposition over time. Emissions at the site increase with time and peak in 2025/2026. LandGEM simulates peak LFG emissions during closure year (2025) of the landfill whilst GasSim and IPCC Waste Model simulate peak emissions during the year after closure. Since the modelling is based on CH_4 and CO_2 concentrations much lower then more recent measurements at the site it is possible that simulations (based on current fractions) will be higher.

In conclusion, the concentrations of LFG observed highlight the need for continuous monitoring of subsurface gas generation, with particular attention to the north and north-eastern sections at the site. These measurements are indicative that lateral migration of LFG could be occurring in these areas. High H_2S and CO concentrations recorded in these areas are of concern.

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