Waste Management 55 (2016) 299–305

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Hotspot detection and spatial distribution of methane emissions from landfills by a surface probe method

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ARTICLE INFO

Article history:
Received 11 October 2015
Revised 24 February 2016
Accepted 2 March 2016
Available online 11 March 2016

Keywords:
Landfills
Methane
Flux mapping
Hotspots
Method

ABSTRACT

A surface probe method previously developed was used to detect hotspots and to determine spatial variation of methane (CH_4) emissions from three landfills located in Mexico, with an intermediate or a final cover, as well as with or without a landfill gas collection system. The method was effective in the three landfills and allowed mapping of CH_4 emissions with a resolution of 24–64 measurements per hectare, as well as the detection and quantification of hotspots, with a moderate experimental effort. In the three selected landfills, CH_4 emissions were quantified to 10, 72, and 575 g m^{-2} d^{-1}. Two straightforward parameters describing the spatial distribution of CH_4 emissions were also developed. The first parameter provides the percentage of area responsible for a given percentage of total emissions, while the second parameter assigns a numerical value to flux homogeneity. Together, the emissions map and the spatial distribution parameters offer an appropriate tool to landfill operators willing to begin recovering CH_4 emissions or to improve the effectiveness of an existing recovery system. This method may therefore help to reduce the greenhouse gas footprint of landfills, which are still the primary option for waste management in developing countries.

1. Introduction

In developing countries, solid wastes are usually disposed in landfills, where methane (CH_4) is produced due to the anaerobic decomposition of organic wastes. The CH_4 produced is the main component of the landfill gas (LFG; 50–70%), which is usually emitted to the atmosphere and also contains carbon dioxide (30–50%), nitrogen, hydrogen sulfide, and non-methane hydrocarbons (Schroth et al., 2012). CH_4 emissions from landfills are highly variable (Abichou et al., 2011), and ranges from 4×10^{-4} to 4×10^{3} g m^{-2} d^{-1} (Bogner et al., 1997; Czepiel et al., 1996). The calculated contribution of landfills to global anthropogenic CH_4 emissions varies from 1.3% (Bogner and Spokas, 2010) to 17% (UNFCCC, 2012), while Fung et al. (1991) estimated an annual CH_4 release from 15 to 40 Teragrams.

Landfills are increasingly being pressured to make sure their LFG collection systems are in compliance with government regulations and to recover energy while reducing odor, health, and safety problems. However, current LFG recovery efficiencies are estimated to be about 50–90% (Capaccioni et al., 2011; Themelis and Ulloa, 2007). Hence, landfills, even with a LFG collection system, are an important source of CH_4 emissions that should be quantified and mitigated. The International Solid Waste Association (ISWA, 2009) has stressed the latter by stating that: "accurate measurements and quantification of greenhouse gas emissions is vital in order to set and monitor realistic reduction targets at all levels."

The characterization of landfill emissions is a complicated task, primarily because emissions are the result of a complex matrix of biological, physical, and engineering factors (i.e. CH_4 generation, oxidation, migration, storage, and recovery) (Spokas et al., 2003). These factors depend on parameters such as organic content, age and distribution of the waste (Georgaki et al., 2008; USEPA, 2005), climate (Chanton et al., 2011), and soil cover properties (e.g. water content, nutrient availability, pH, texture, porosity, fissures, and cracks) (Bogner et al., 2008; Gebert et al., 2011; Giani et al., 2002). Given the number and variability of these factors, CH_4 emissions can vary greatly spatially and temporally.

Several landfill emissions measurement methods have been developed. The ground surface enclosure technique is the most

Abbreviations: IDW, Inverse Distance Weighting; MAE, Mean Absolute Error; MBE, Mean Bias Error; A_i, Subregion of total area; $A_M^{\%}$, Percentage of total area responsible for a given percentage of total emissions; *Cs*, CH_4 Surface Concentration; F_i, Flux class; *H*, Homogeneity factor; M_i, Cumulative normalized emissions; η, Methane recovered per unit area.

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http://dx.doi.org/10.1016/j.wasman.2016.03.004
0956-053X/

Table 1
Main characteristics of the landfills, dates of measurements, and weather conditions.

Landfill	LA	LB	LC
Total area (m^2)	90,000	90,000	13,500
Recovery system	Yes		
Cover	Final	Final	Intermediate
Vegetation	Sparse	Absent	Sparse
Sampling dates	June 11–13, 2012	December 10–12, 2012	June 14, 2012
Weather	Dry/sunny	Dry/sunny	Dry/sunny
Air temperature (°C)	26–31	10–18	20–25
Atmospheric pressure (MPa)	93.2–94.5	77.9–71.0	90.3–90.4
Wind speed ($m\ s^{-1}$)	2.0–4.5	0.2–3.8	1.0–2.1

commonly used method (Bogner et al., 1997; Scheutz et al., 2009). It involves positioning a static chamber (SC) on the surface of the landfill, where the CH_4 concentration buildup allows for flux determination on that specific spot. This method is simple and direct but requires a relatively large number of measurements before being statistically representative of global landfill emissions (Spokas et al., 2003). Another drawback of SCs is that they do not allow for hotspot detection (Borjesson et al., 2000). Despite evident limitations, the use of SCs is still the best method available to date to determine spatial variation of landfill emissions.

Spatial variation of CH_4 emissions from landfills has been previously well described (Abichou et al., 2006; Perera et al., 2004; Sauri-Riancho et al., 2013; Spokas et al., 2003). In these previous works, the spatial variation was addressed successfully by means of geostatistical models, such as the Kriging or Inverse Distance Weighting (IDW) interpolation methods. These works also involved large numbers of SC measurements, from 64 to over 100, thus needing significant experimental effort. Recently, a method using a surface probe instead of a SC was successfully applied by Gonzalez-Valencia et al. (2015) in a landfill with a permanent cover and a LFG collection system. This method is based on the determination of CH_4 concentration at the ground surface which is proportional to CH_4 emissions, and allows determination of CH_4 flux at a large number of locations within a reasonable experimental time. The surface probe method is, therefore, of potential interest to establish the spatial variation of CH_4 emissions in landfills. Additionally, the surface probe method allows hotspot identification that otherwise would be undetected when using SCs.

The main objective of the present work was to describe the spatial variation of CH_4 emissions using the high throughput surface probe method previously developed, in three landfills with contrasting characteristics: (i) one with a final cover and a vacuum LFG collection system coupled to an electric generation system, (ii) one with a final cover and a passive LFG collection flaring system, and (iii) one with an intermediate cover and no LFG collection system.

2. Materials and methods

2.1. Site description and field campaigns

Three landfills were selected for field studies. For confidentiality reasons, the name and exact location of these landfills are not disclosed and will be identified as LA, LB, and LC, hereafter. LA is a municipal solid waste landfill, located in the State of Nuevo Leon (Mexico), with a final clay cover and a vacuum LFG recovery system used to produce electricity. LA is approximately 900 m long and 100 m wide, with a total surface area of approximately 90,000 m^2 of flat terrain, with sparse vegetation. LB is a municipal solid waste landfill, located in the State of Mexico (Mexico), with a final clay cover and a LFG recovery and flaring system. LB is approximately 600 m long and 150 m wide, with a total surface area of approximately 90,000 m^2 of hilly terrain, with no vegetation. LC is a municipal solid waste landfill, located in the State of Nuevo Leon (Mexico), with intermediate uneven clay cover and no LFG recovery system. LC is approximately 150 m long and 90 m wide, with a total surface area of approximately 13,500 m^2 of flat terrain, with sparse vegetation. Field experiments were conducted in June 2012 (LA and LC) and December 2012 (LB), under sunny skies and with wind speeds of less than 5 $m\ s^{-1}$ as recommended by the EPA for the OTM10 method (USEPA, 2006). During the experiments, atmospheric temperature, pressure, and wind

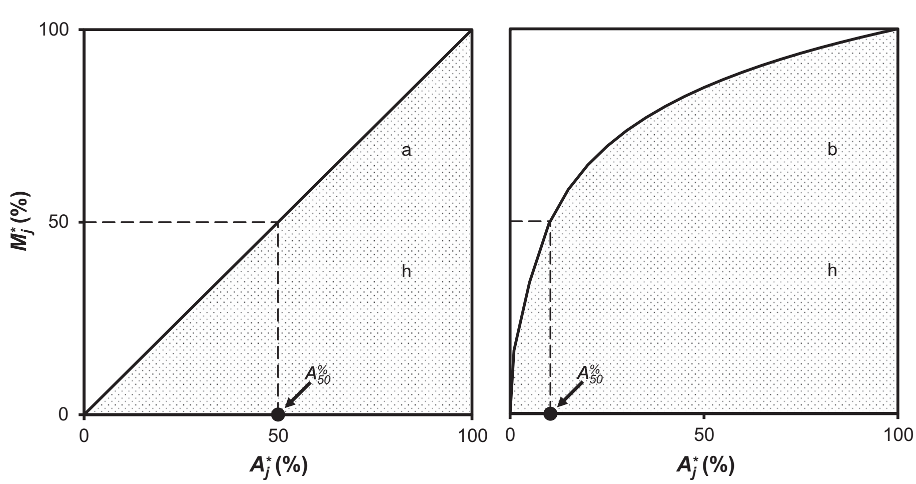

Fig. 1. Theoretical examples of spatial distribution of CH_4 emissions from a landfill by graphing the cumulative normalized emissions (M_j^*) as a function of the cumulative normalized area (A_j^*) in a landfill with homogeneous spatial distribution (a) and in a landfill with a non-homogeneous distribution (b).