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Estimation of fugitive landfill methane emissions using surface emission monitoring and Genetic Algorithms optimization

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ABSTRACT

As municipal solid waste (MSW) landfills can generate significant amounts of methane, there is considerable interest in quantifying fugitive methane emissions at such facilities. A variety of methods exist for the estimation of methane emissions from landfills. These methods are either based on analytical emission models or on measurements. This paper presents a method to estimate methane emissions using ambient air methane measurements obtained on the surface of a landfill. Genetic Algorithms based optimization combined with the standard Gaussian dispersion model is employed to identify locations as well as emission rates of potential emission sources throughout a municipal solid waste landfill. Four case studies are employed in order to evaluate the performance of the proposed methodology. It is shown that the proposed approach enables estimation of landfill methane emissions and localization of major emission hotspots in the studied landfills. The proposed source-locating-scheme could be seen as a cost effective method assisting landfill operators to reasonably estimate and locate major methane emissions.

1. Introduction

Global Climate Change is expected to put the world on a pathway to experience climate impacts of a dangerous and irreversible magnitude. Several spectacular aspects of these climate impacts are already noticed: global warming, sea level rise, intense rain, as well as more frequent and severe heat waves. Many nations around the world are developing innovative policies and business approaches to build low-carbon economies and adapt to changing climate. In particular, efforts are being made to control greenhouse gas emission from various sources. Therefore a global effort is being made to understand, quantify, and manage greenhouse gas emissions. Major actions aim at making measurable reduction in greenhouse gas emissions contributing thus to stabilize their concentrations in the atmosphere at a level that would prevent the dangerous anthropogenic interference with the climate system.

Methane (CH_4) is the second most important anthropogenic greenhouse gas after carbon dioxide (CO_2). Per mass of the compound, methane global warming potential has been estimated to be more than 28 times of that of carbon dioxide (IPCC, 2013). Globally, over 60% of total methane emissions come from human activities (EPA, 2010; Nisbet et al., 2014). Methane is emitted from industry, agriculture, and waste management activities. Methane emissions from waste management are dominated by the decomposition of organic matter in municipal solid waste and industrial landfills. The associated microbial anaerobic degradation of the organic fraction in waste disposed in landfills generates a mixture of hundreds of different gases. By volume, landfill gas typically contains 45–60% methane and 40–60% carbon dioxide. Waste management is estimated to be the third largest source of methane emissions in the United States (EPA, 2010). In Europe, an estimated 30% of anthropogenic methane emissions are caused by landfills (EEA, 2014). In 2010, global methane emissions from landfills accounted for approximately 11% of total methane emissions (EPA, 2014) and these emissions are projected to grow 13% between 2010 and 2030. In 2030, emissions from landfills are expected to represent 10% of the global total methane from all sources (EPA, 2014).

In the last decade, attention to methane emissions from landfills has grown significantly. The reason is that emission reduction from landfills is amongst the most feasible and cost-effective measures to reduce greenhouse gas emissions (Oonk, 2010). In addition, using landfill gas can provide a continuous source of energy.

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Technologies for converting landfill gas into energy include: electricity generation and production of alternate fuels (EPA, 2014).

Many large landfills are closely monitored and in many countries, authorities have the obligation to quantify landfill methane emissions and subsequently report emissions within international programs aimed at controlling greenhouse gas emissions. In addition, measurements of methane emissions may represent a good way to evaluate the efficiency of landfill gas recovering systems or biocovers (Scheutz et al., 2011). However, quantifying landfill fugitive methane emissions is problematic due to the high temporal variability and spatial heterogeneity of these emissions. Additionally, the relationship between the emission rate and the gas concentration at a given location is dependent on the meteorological conditions and local topography, preventing accurate quantification of the emission rate. Thus, development of reliable and cost-effective methods for measurements of landfill methane emissions is an important task and a challenge to the scientific community.

Several methods exist for the estimation of methane emissions from landfills. Estimation methods are either based on emission models or on measurement methods. In model-based methods, methane emissions can be estimated using existing biogas production mathematical models. These models are aimed at quantitatively describing methane formation from anaerobic waste degradation through simulating the decay of organic material deposed in the landfill. One of the largely used model is the landfill Gas Emissions Model (LandGEM) developed by the U.S Environmental Protection Agency (Alexander et al., 2005). Models also include GasSim (GasSim2.5, 2014) developed by Golder Associates for the Environment Agency of England and Wales. Besides, in the frame of the European Pollutant Emission Register (EPER) various evolving version of the European EPER models are applied in many European countries such as the French EPER model and the German EPER Model (Oonk, 2010; Rajaram et al., 2011). Spokas et al. (2011) have developed an annual inventory model for landfill methane emissions that incorporates both site-specific soil properties and soil microclimate modeling. This new approach has been field-validated at two Californian sites where emission predictions were in the same order of magnitude as field measurements.

Even largely used, the landfill generation models are generally considered insufficiently accurate and not mutually comparable (Di Bella et al., 2011). Jacobs and Scharff (2005) compared several methane emission models with methane emission measurements. They showed that emission models give different results, even when the same data are entered. Jacobs and Scharff (2005) also stated that further development of methane emission measurement techniques may provide a more reliable tool in the near future than modeling.

As an alternative to model-based methods, measurement techniques are having an increasing interest for landfill methane emission estimation. Closed chamber measurement is frequently employed both for monitoring methane emissions from small parts of a landfill as well as estimating overall emissions from an entire landfill (Abichou et al., 2011; Scheutz et al., 2009). Also micrometeorological measurements are used for methane emission quantification (Lohila et al., 2007). Recently, several methodologies have been proposed in order to estimate methane emissions from landfills while delivering cost- and labor-effective results (Cambaliza et al., 2015; Foster-Wittig et al., 2015). These methods include: static and mobile plume measurement methods using tracer gas (Mønster et al., 2015, 2014; Scheutz et al., 2011), radial plume mapping (RPM) using optical remote sensing by means of laser infrared radiation emissions (Goldsmith et al., 2011; Thoma et al., 2010), differential absorption light detection and ranging (LiDAR) (Babilotte et al., 2010) and inverse plume modeling (Mackie and Cooper, 2009; Oonk, 2010).

In inverse plume modeling technique, methane concentrations above the landfill surface are mapped. A field survey can be done by walking a predefined grid with a portable Flame Ionization Detector or another field gas analyzer. Surface concentrations are relatively inexpensive and much easier to obtain compared to alternative experimental techniques. Mapping of methane concentration could be exploited to identify point sources of relatively high concentrations (emission hotspots) such as cracks in the landfill cover (Figueroa et al., 2009). Methane concentration data are already frequently sampled in many municipal solid waste landfills. Furthermore, employing such approaches allows for reduced costs and uncertainties associated with other experimental and model-based estimations of emissions. In this context arises the need for efficient approaches to correlate surface concentrations to emissions allowing thus for better estimation of the tendencies of methane oxidation and emission rates at landfills. Mackie and Cooper (2009) proposed an emissions prediction approach exploiting ambient air volatile organic compound measurements. They used Voronoi diagrams to predict the locations of maximum likelihood of the point sources, and emission rates are then calculated using linear regression aiming at identifying statistical best fit for solving multi-source problems.

This study presents an alternative methane emission estimation method exploiting ambient air methane concentration measurements on landfill surface. The proposed approach aims at establishing an estimation of methane emissions from a given landfill, and also to identify positions of leakage sources and to quantify the gas emission rate. An optimization-based approach using Genetic Algorithms is employed to solve the inverse problem that consists on identifying source data (locations of hot-spots and corresponding emission rates) having receptor locations and surface measurements along with meteorological conditions as input data. Stochastic search methods such as Genetic Algorithms are particularly useful in hard optimization tasks. Hard optimization problems include practical optimization tasks that are difficult (if not impossible) to solve exactly in a reasonable time (Dréo, 2006). Stochastic methods are able to efficiently explore complex and large solution space using special strategies. Although there is no guarantee of reaching a global optimum, near optimal solutions are usually obtained. Single and also multi-objective optimization schemes through Genetic Algorithms are tested in this study based on measurement data available. The optimization methodology uses atmospheric dispersion calculations to predict major methane emissions sources in a landfill. Four case-studies are presented to show effectiveness of the proposed methodology.

2. Optimization-based methane emission estimation

2.1. Description of the proposed approach

The proposed methane emission estimation technique exploits ambient air methane concentration measurements that are already frequently obtained and monitored in many municipal solid waste landfills. Single and also multi-objective optimization schemes through Genetic Algorithms are tested in this study based on surface emission monitoring data. In the optimization-based solution of the identification task (Fig. 1), the proposed methodology uses atmospheric dispersion calculations to evaluate emission source configurations on a landfill. Detailed description of the major steps of the proposed approach is presented in subsequent sections.

2.2. Generation and evaluation of candidate models

Assuming that a field survey has resulted in a vector of methane concentration measurements denoted $C_{measured}$ performed at m

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