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Case study on prediction of remaining methane potential of landfilled municipal solid waste by statistical analysis of waste composition data

İlker Sel[a,*], Mehmet Çakmakcı[a], Bestamin Özkaya[a], H. Suphi Altan[b]

[a] Yildiz Technical University Environmental Engineering Department, Davutpasa Campus, 34220 Esenler, İstanbul, Turkey
[b] Ortadogu Enerji A.S. Kaptanpasa M. Piyalepasa Blv. No: 73 Sisli, İstanbul, Turkey

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ABSTRACT

Main objective of this study was to develop a statistical model for easier and faster Biochemical Methane Potential (BMP) prediction of landfilled municipal solid waste by analyzing waste composition of excavated samples from 12 sampling points and three waste depths representing different landfilling ages of closed and active sections of a sanitary landfill site located in İstanbul, Turkey. Results of Principal Component Analysis (PCA) were used as a decision support tool to evaluation and describe the waste composition variables. Four principal component were extracted describing 76% of data set variance. The most effective components were determined as PCB, PO, T, D, W, FM, moisture and BMP for the data set. Multiple Linear Regression (MLR) models were built by original compositional data and transformed data to determine differences. It was observed that even residual plots were better for transformed data the R^2 and Adjusted R^2 values were not improved significantly. The best preliminary BMP prediction models consisted of D, W, T and FM waste fractions for both versions of regressions. Adjusted R^2 values of the raw and transformed models were determined as 0.69 and 0.57, respectively.

1. Introduction

Some candidate landfills for landfill gas to energy (LFGTE) projects are new landfills with fresh solid waste and some are rather old landfills containing materials almost all decomposed. It is well known that fresh waste and landfilled waste do not have same composition after several years under landfill conditions. In that case, it can be difficult and also expensive to evaluate the actual remaining gas potential at a site. Therefore, it can be easily said that the cornerstone of a successful LFGTE project is a reliable estimation of potential LFG generation. LFG generation amount and rates are commonly estimated using mathematical models that are dependent upon features such as amount of disposed waste, waste composition, moisture content, landfill cover material, and LFG collection system efficiency (Amini et al., 2012). Prediction of LFG generation by such models can be misleading if these input variables are not determined precisely. The long-term behavior of landfill gas generation can be divided into six typical phases (Kreith and Tchobanoglous, 2002) which presents a normal or log-normal distribution if decomposition period is extended long enough. Actually, mathematical models are simulating these classical stages of anaerobic biological degradation of organic materials in a landfill site by several methodologies such mass balance, zero-order, first order, second order or a combination of orders (Faour et al., 2007; Kamalan et al., 2011). Among several other estimation models such as GasSim, Afvalzorg, TNO, EPER, Tabasaran-Rettenberger the most commonly used models for simulating decomposition from a batch of waste are IPCC and USEPA LandGEM models using the first-order decay equation for predicting gas generation at landfills (Kim and Townsend, 2012; USEPA, 2012). Both emission model methodologies take into account several factors for prediction of methane emission such as landfill geographical location, waste composition, decay time, methane oxidation in the landfill cover layer, waste amount (IPCC, 2013; USEPA, 2012). One of the most important parameters in USEPA estimation model is the methane generation potential (L_0) which can be determined for any degradable waste by Biochemical Methane Potential (BMP) assay that is a commonly accepted method used for waste characterization and estimation of ultimate methane amount produced under anaerobic conditions (Bilgili et al., 2009; Mou et al., 2014). Despite its reliable results, BMP assay can take 30–100 days to complete (Ward, 2016) since it relies completely on anaerobic degradation capacity of microorganisms. Therefore, it is not practical as a tool for making short term decisions. Additionally, since BMP test procedures are still

* Corresponding author.
E-mail address: ilkersel@gmail.com (İ. Sel).

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not standardized, the analytical methods for BMP tests have several differences in respect to seed addition, sample size and preparation, moisture adjustment and the method of biogas measurement (Wagland et al., 2009). In some estimation models such as the IPCC model, the degradable organic carbon content (DOCC as% or kg C/kg waste, wet weight) is used instead of BMP. Since DOCC value can be directly calculated by waste characterization components such as paper-textile, garden-park waste, food waste and wood-straw (IPCC, 2013), it is assumed that it should be possible to correlate BMP value directly with waste composition categories. Although there are several studies to develop an easier and less time consuming BMP prediction methods which can be classified as studies based on chemical composition analysis such as elemental composition and component composition analyzes (Bayard et al., 2015b; Eleazer et al., 1997; Kelly et al., 2006) and studies based on non-destructive analytical methods (Lesteur et al., 2011; Ward, 2016), according to best of our knowledge, no previous publication has presented BMP prediction models developed by solely using waste composition data such as paper-cardboard, wood, textile etc.

The ultimate aim of this study was to determine an easier and faster equation for BMP prediction which may represent a more actual value to be used in landfill gas models by using values of easily obtainable main waste composition parameters by simple sorting of waste samples. Reducing the time required to obtain BMP results would help the operator and engineers for a better operation of the landfill and precise estimation of methane potential for LFGTE projects. Since the whole study will be based on the quality of waste sorting results, it is obvious that a precise sorting effort of excavated samples must be performed. Multivariate analysis was carried out using the principal component analysis (PCA) to identify and gather more understanding on the inter-relationships of the waste composition dataset. As a final step, a preliminary prediction models to estimate the BMP values of landfilled MSW samples was built by applying the Multiple Linear Regression (MLR) Analysis to the entire data set of most significant variables.

2. Materials and methods

2.1. Study area

This study was performed in a sanitary landfill located at the Asian side of Istanbul, Turkey. The Komurcuoda landfill is about 20 years old and represents an example of modern, well-operated site, in which domestic solid wastes and industrial wastes are accepted into separate cells. The closed section of the landfill (cLF) is about 45 ha with >20 million tons of municipal solid waste landfilled between the years 1995–2011. The maximum waste depth at cLF and aLF is approximately 60 m and 40 m, respectively. All surface at both landfills is covered with good quality clay layer (1–3 m) to prevent additional water infiltration and oxygen intrusion to maximize landfill gas collection efficiency. The whole cLF is subjected to active landfill gas extraction. On the other hand, 10 ha is available for gas extraction at the active landfill section (aLF) in which landfilling is still ongoing. Extracted landfill gas from both sections is used for electricity production by reciprocating engines in a plant having an installed capacity of almost 20 MW_e according to data from the year 2015. Waste is currently being deposited at an annual rate of 2 million tons. It is estimated that around 8 million tons solid waste is already landfilled between the years 2012–2015. Fresh waste is being separated in a sorting and recycling facility having a capacity of around 2000 t/d. Several materials such as plastic, paper and metals are recycled at this plant operated by a Turkish-Italian private company.

2.2. Waste characterization and analyzes

In this study, samples from different waste depths were collected during new vertical gas well constructions as replacements of deformed wells due to landfill settlement or pipe clogging. The wells were bored with a drilling rig operated in auger mode with a borehole diameter of 800 mm and height of 1500 mm. Hence, the maximum drilling depth was decided as 35 m in order to obtain samples from three waste depths (10, 20 and 30 m) for a representative waste characterization study. For each waste depth in every sampling point only one sample could be taken in order to comply with study budget constraints. Samples were collected from 12 locations representing the landfill as much as possible with respect to waste age and landfill sections. The aim was to divide the samples roughly into older (cLF) and fresher (aLF) samples representing different landfilling periods of the entire landfill. Since more problematic LFG generations occur in cLF section according to information given by operator, it was decided to take more samples from this section. 27 samples from 9 sampling points at cLF and 9 samples from 3 sampling points at aLF were planned for this study. All planned samples were successfully taken except the sample EN7-30. The volume of each sample was ensured by using a metal box having a 500 L volume. The average weight of taken samples was measured between 250 and 380 kg, hence, the average waste density was around 0.50–0.76 t/m^3. Waste characterization studies of landfilled wastes are mainly applied by screening the waste into different particle sizes and manually sorting the remaining larger size materials into several categories. Samples brought directly to sorting area after drilling, then spread on a 3×3 m plastic layer and randomly mixed until all materials were distributed as equal as possible. From each 500 L sample, 6 L composite samples were taken to the laboratory for BMP and moisture analyzes. The rest of sample was used for classification and manual sorting. Sorting was based on visual inspection and sieving with a 20 mm sieve as practiced in former similar research studies (Kurian et al., 2003). Large materials were removed manually and sorted. The rest was sieved and sorted manually into 10 waste categories (Table 1), namely paper and cardboards (PCB), plastic bags (PB), other plastics (PO), diapers (D), wood (W), metal (M), textiles (T), glass (G), soil-stones (S) and fine materials (FM). All kinds of plastic bags were included to PB and all other plastic materials were included into group PO.

The analysis of moisture content of samples was also included to laboratory analyzes. The moisture content is commonly expressed as the percentage of wet weight of the material and is suggested to be the most critical factor that affects solid waste stabilization (Reinhart and Townsend, 1998). The raw samples were dried at 105 °C in an oven until a stable weight and cooled in a desiccator. The moisture content was measured by weight loss from the raw waste sample and expressed as percent dry weight (ASTM, 1998).

In order to evaluate the anaerobic biodegradability of MSW samples, the BMP test was conducted using a modified method of ASTM E1196-92 (ASTM, 1992). Raw samples were dried at 105 °C in oven, then all parts, including hard materials, were crushed and blended to a size of 3–5 mm with a special blender. Then, in order to convert the samples into a powder-like consistency it was grinded with a laboratory mill (Kelly et al., 2006). For each BMP test, 5 g of finely crushed and grinded powder-like sample (Sormunen et al., 2013) was placed in a nitrogen gas flushed 100 mL bottle together with 45 mL of granulated anaerobic media (10% solids). Bottles were agitated for at least 5 min before incubated at 35 °C which is the optimum temperature for mesophilic methanogenic bacteria (Yu et al., 2014) by using Gallenkamp Incubators for a period of 52–103 days. The accumulated volume of gas in the bottles was measured and collected periodically (at least