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Optimization of a landfill gas collection shutdown based on an adapted first-order decay model

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ABSTRACT

LandGEM's equation was reformulated to include two types of refuse, fast decaying refuse (*FDR*) and slow decaying refuse (*SDR*), whose fractions and key modeling parameters k and L_0 were optimized independently for three periods in the life of the Montreal-CESM landfill. Three scenarios were analyzed and compared to actual biogas collection data: (1) Two-Variable Scenario, where k and L_0 were optimized for a single type of refuse; (2) Six-Variable Scenario, where three sets of k and L_0 were optimized for the three periods and for a single type of refuse; and (3) Seven-Variable Scenario, whereby optimization was performed for two sets of k and L_0, one associated with *FDR* and the second with *SDR*, and for the fraction of *FDR* during each of the three periods. Results showed that the lowest error from the error minimization technique was obtained with the Six-Variable Scenario. However, this scenario's estimation of gas generation was found to be rather unlikely. The Seven-Variable Scenario, which allowed for considerations about changes in landfilling trends, offered a more reliable prediction tool for landfill gas generation and optimal shutdown time of the biogas collection system, when the minimum technological threshold would be attained. The methodology could potentially be applied *mutatis mutandis* to other landfills, by considering their specific waste disposal and gas collection histories.

1. Introduction

When landfill methane (CH_4) generation reaches a critical low value, the system employed to burn biogas must be replaced or, conditions permitting, shut down. The decision-making process is challenging because of the difficulty in predicting relatively accurate future trends sufficiently in advance. This is the type of challenge being faced by the operator of the Montreal CESM landfill. This 72-ha site, which accepted refuse from 1968 to 2008, is located in a former limestone quarry, in a (now) densely populated area of Montreal. The depth of refuse reaches 80 m in certain areas, and it is estimated that some 40 million tons of refuse from various origins were landfilled at the CESM landfill site. Prior to the beginning of the landfill operations, the bottom and side walls of the former quarry were not impermeabilized. As a consequence, most of the waste mass is virtually saturated. The database for this site included 41 years of landfilling data and a compilation of daily entries of 20 years of biogas collection data.

Current methods to predict landfill gas generation include first-order decay U.S. EPA's Landfill Gas Emissions Model (LandGEM) (USEPA, 2005), which considers only one type of municipal solid waste (MSW) for the entire lifetime of a site. The two key parameters in LandGEM are L_0, which represents the methane production potential ($m^3\ Mg^{-1}$ wet waste) and k, which represents the first-order decay rate associated with waste decomposition (yr^{-1}) (USEPA, 2005). Some models, such as the one proposed by the Intergovernmental Panel on Climate Change (IPCC, 2006), allow for a multiphase refuse input, which could potentially lead to more precise predictions. However, a common predicament in landfill management is the lack of information regarding landfilling history and/or lack of specific data about refuse categories and subcategories. This is particularly true for old sites, such as the CESM landfill, which had no guidelines or regulations regarding keeping track of the nature of admitted refuse. This study proposes a methodology of reformulation of a first-order model. It aims at

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improving model predictive performance using available information about the history of the site and gas collection data.

In the past 2 decades, societal changes in landfilling practices have occurred as a result of stricter legislation, improvements in recycling, higher raw material value, etc. One important example of legislation-driven change is the imposed reduction in landfilling of organic matter in the European Union (Directive 1999/31/EC). Quebec's (Canada) recent governmental policy (''Quebec Residual Materials Management Policy'') is now calling for the banishment of organic matter in landfills in this province by the year 2020. Changes in waste characteristics need to be taken into account in biogas generation modeling; for example, by using values of k and L_0 that evolve throughout the site's history. The first important characteristic of the proposed methodology was therefore the subdivision of the lifetime of the CESM landfill into 3 distinct periods – 1968–1989/1990–1999/2000–2008 – that reflect the specific history of refuse admittance, i.e. changes in the characteristics of the wastes. As mentioned previously, while data about quantities landfilled could be found for the entire lifetime of the site, specific data about refuse categories were not available.

It is proposed to distinguish herein two distinct categories of landfill refuse, namely fast decaying refuse (*FDR*) and slow decaying refuse (*SDR*). For instance, as per IPCC-recommended k values, food waste in MSW having a high value of k was segregated as *FDR*, whereas materials whose k values are low, such as wood-straw waste, were assigned to the *SDR* category. The specific segregation of refuse in either *FDR* or *SDR* is presented in Table 1. Based on the k value, once a type of waste was categorized as either *FDR* or *SDR*, its minimum and maximum L_0 values (given as mass of degradable organic carbon; DOC) were assigned following IPCC (2006) recommendations for this type of waste. Given the lack of precise information about the characteristics of the waste, it was decided to limit segregation of the bulk waste to these two main categories.

According to IPCC-recommended L_0 and k values (IPCC, 2006), *FDR* can be characterized by low values of L_0 and fast kinetics (high values of k), while *SDR* is characterized by high methane generation potentials (high values of L_0) and slow kinetics (low values of k). These considerations about k and L_0 values are generalizations of the observed tendencies in IPCC-recommended k and L_0 values and are representative of the bulk behaviour of the waste mass and not that of specific components. This approximation results in the overlapping of *FDR* and *SDR* L_0 values, as discussed when presenting the data in Table 2. It is considered herein that a decrease in the quantity of landfilled *FDR* results in a decrease of the bulk mass' k value and an increase in L_0. An important caveat is given by Wang et al. (2011) (Wang et al., 2011), who have shown that component-specific low decay rates among species of wood do not necessarily correlate with high methane yields. In this study, the magnitude of the variation in L_0 is a resultant of the optimization technique, which sets L_0 within IPCC-recommended ranges.

Table 2
k and L_0 optimization ranges for the Two-, Six- and Seven-Variable Scenarios (Based on IPCC (2006) values).

		Optimization range for k (yr^{-1})	Optimization range for L_0 (m^3 CH_4 Mg^{-1})
Two-Variable Scenario		[0.030–0.700]	[21–241]
Six-Variable Scenario		[0.030–0.700]	[21–241]
Seven-Variable Scenario	*FDR*	[0.100–0.700]	[21–115]
	SDR	[0.030–0.085]	[105–241]

These adaptations of the biogas generation modeling process were considered in order to develop a more reliable management tool to predict landfill gas generation. So far, LandGEM has been used at the CESM landfill.

By attributing independent values of k and L_0 and different fractions between *FDR* and *SDR* that best reflected the changing proportions of admitted refuse during the 3 periods mentioned previously, the same first-order model equation used in LandGEM was adapted to generate production curves. Minimization of error between modeled generation and generated gas helped to find the best fitting curve, i.e. the optimized values of k, L_0, and fraction of *FDR* for each period. In an intermediate step, collection data were transformed into generation data by adopting a fixed recovery efficiency rate.

The objective is to use the optimized generation curves to predict the optimal moment to shut down the biogas collection system, when the minimum technological threshold (MTT) would be attained. The optimized values of the independent variables were tested against the known history of refuse admittance. In principle, the methodology adopted could be replicated to other landfills, by considering the specific evolution of the *FDR* fraction in the landfilled waste and the available gas collection database.

2. Methods

2.1. Landfill gas collection and landfilled mass data

Landfill gas (LFG) collection data were obtained between 1994 and 2013. For this period, yearly compilations were performed using daily biogas collection data. A global relative error of 2.9% was calculated for the flowmeter and chromatograph used to measure collected CH_4 at the CESM landfill (Lagos, 2014). The total landfilled mass was determined on a yearly basis starting in the opening year, in 1968, until its closure, in 2008. The types of refuse admitted were mainly household, commercial, institutional and industrial waste, as well as construction and demolition debris. The latter included negligible amounts of inert (non LFG-generating) matter such as, asphalt, concrete and bricks.

Table 1
Segregation of *FDR* and *SDR* and corresponding k values as per IPCC recommended ranges. Adapted from IPCC (2006).

	Type of Waste		Climate Zone*								
			Boreal and Temperate (MAT ≤ 20°C)				Tropical[1] (MAT > 20°C)				
			Dry (MAP/PET < 1)		Wet (MAP/PET > 1)		Dry (MAP < 1000 mm)		Moist and Wet (MAP ≥ 1000 mm)		
			Default	Range[2]	Default	Range[2]	Default	Range[2]	Default	Range[2]	
SDR	Slowly degrading waste	Paper/textiles waste	0.04	0.03[3,5] – 0.05[3,4]	0.06	0.05 – 0.07[3,5]	0.045	0.04 – 0.06	0.07	0.06 – 0.085	***Max = 0.085*** ***Min = 0.03***
		Wood/ straw waste	0.02	0.01[3,4] – 0.03[6,7]	0.03	0.02 – 0.04	0.025	0.02 – 0.04	0.035	0.03 – 0.05	
FDR	Moderately degrading waste	Other (non – food) organic putrescible/ Garden and park waste	0.05	0.04 – 0.06	0.1	0.06 – 0.1[8]	0.065	0.05 – 0.08	0.17	0.15 – 0.2	***Max = 0.7*** ***Min = 0.15***
	Rapidly degrading waste	Food waste/Sewage sludge	0.06	0.05 – 0.08	0.185[4]	0.1[3,4] – 0.2[9]	0.085	0.07 – 0.1	0.4	0.17 – 0.7[10]	

N.B.: References to specific values are found in the original IPCC document.

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