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Simulating the heat budget for waste as it is placed within a landfill operating in a northern climate

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ABSTRACT

A landfill gas to energy (LFGTE) facility in Ste. Sophie, Quebec was instrumented with sensors which measure temperature, oxygen, moisture content, settlement, total earth pressure, electrical conductivity and mounding of leachate. These parameters were monitored during the operating phase of the landfill in order to better understand the biodegradation and waste stabilization processes occurring within a LFGTE facility. Conceptual and numerical models were created to describe the heat transfer processes which occur within five waste lifts placed over a two-year period. A finite element model was created to simulate the temperatures within the waste and estimate the heat budget over a four and a half year period. The calibrated model was able to simulate the temperatures measured to date within the instrumented waste profile at the site. The model was used to evaluate the overall heat budget for the waste profile. The model simulations and heat budget provide a better understanding of the heat transfer processes occurring within the landfill and the relative impact of the various heat source/sink and storage terms. Aerobic biodegradation appears to play an important role in the overall heat budget at this site generating 36% of the total heat generated within the waste profile during the waste placement stages of landfill operations.

1. Introduction

Landfills still remain a principal method of final disposal around the world. In Canada, 25 million tonnes of waste were sent to a landfill for final disposal in 2010 (Statistics Canada, 2010). Modern landfills are engineered and managed to enhance waste stabilization. Accelerating the biodegradation of waste in a LFGTE facility will enhance settlement and landfill gas generation. Increasing settlement during the filling stage of landfill operations and prior to the final cover will allow more waste to be placed within the approved landfill volume and therefore increase the airspace utilization factor and revenues for the facility. The anaerobic biodegradation process depends on a variety of environmental factors such as moisture content, nutrient content, pH, oxygen concentration, density, and temperature (Pacey et al., 1999).

Instrumentation of landfills is a method of monitoring and potentially controlling some of the parameters that influence the biodegradation of the waste. In northern climates it was observed that temperature plays an important role in the rate of biodegradation of waste. Waste placed frozen was observed to remain frozen for 6 months to 2 years upon placement (Bonany et al., 2013a; Hanson et al., 2006; Zhao et al., 2008). This poses a problem because mesophilic and thermophilic bacteria required during the anaerobic biodegradation of waste function optimally between 30–40 °C and 50–60 °C respectively (Rowe and Islam, 2009). Research groups have measured temperature changes within landfills with time (Lefebvre et al., 2000; Lanini et al., 2001; Yoshida and Rowe, 2003; Hanson et al., 2005; Zhao et al., 2008; Hunte et al., 2011). Spatial and temporal variations of temperature were recorded and in some cases modeled. The two main thermal parameters needed to simulate heat transfer in waste include the thermal conductivity and specific heat capacity. Estimates of these parameters in the literature are summarized in Table 1. Most of the values found in the literature are not directly measured but are estimated from calibrated models.

In a northern climate it was observed that waste placed during the winter months can remain frozen for years. This is important for the anaerobic biodegradation process since temperatures are below the optimal range, limiting waste stabilization and the amount of methane-rich landfill gas produced during this time period. In order to optimize operations at a landfill in a northern climate to enhance waste stabilization, a LFGTE facility in Ste. Sophie Quebec was instrumented with sensors to measure some of the environmental parameters. This site is capable of accepting up to one million tonnes of municipal solid waste per year and is

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Table 1
Thermal parameters for waste.

Reference	Thermal conductivity (W/m K)	Specific heat (J/kg K)
Houi et al. (1997)	0.10	1900–3000
Yoshida et al. (1997)	0.53	3300
Zanetti et al. (1997)	0.0445	2200
Lefebvre et al. (2000)	0.10	1900–3000
Hanson et al. (2006)	0.30	719
Hanson et al. (2008)	0.6–1.5	1200–2200
Rowe et al. (2010)	0.35–0.96	1940–2360
Bonany et al. (2013b)	0.67	1400
Faitli et al. (2014)	0.24–1.15	900–1200

operated anaerobically with no leachate recycle. Landfill gas is collected on site via horizontal and vertical collection wells and is transported to a nearby pulp and paper mill where the landfill gas is used as its primary heat source.

The goal of this paper is to present the temperature data collected during the placement of waste at Ste. Sophie and to simulate the waste temperatures and assess the heat budget to illustrate the impacts of temperatures in a northern climate on the heat budget and heat generation rates associated with aerobic and anaerobic conditions. The model contains the heat transfer that occurs at the base of the landfill and at the waste surface which is exposed to the ambient surroundings. The heat sinks and sources such as the latent heat for phase change, sensible heat and heat generated from aerobic and anaerobic biodegradation, are incorporated in the model. Measured temperature data from the Ste. Sophie LFGTE facility are used to calibrate the model and the model is used to develop a heat budget for the waste column as sequential waste lifts are added. This model is used to better understand the thermal processes which occur in an operating anaerobic landfill located in a northern climate.

1.1. Ste. Sophie LFGTE Instrumentation

The Ste. Sophie LFGTE facility is located approximately 50 km northwest of Montreal, Quebec, Canada (N45.78° W73.90°). The average high and low daily temperatures for January are −5 °C and −15 °C and the corresponding values for July are 27 °C and 15 °C. The average annual precipitation is 950 mm. The site accepts municipal solid waste as well as institutional, commercial and industrial (ICI) wastes and is permitted to accept up to one million tonnes of waste annually. To study waste stabilization within the waste, twelve instrument bundles were installed within two vertical waste profiles as the waste was placed within the landfill. Fig. 1 provides an aerial view of Zone 4 at the site and the approximate locations of the two vertical profiles of instrument bundles and the instrument shed. Also included in Fig. 1 is a drawing that indicates the top surface of the landfill with 30% side slopes and a 2% slope on the top of the landfill. Each instrument bundle includes a: total earth pressure cell, oxygen sensor, moisture and electrical conductivity sensor, vibrating wire piezometer to record any leachate mounding, and a liquid settlement system (Fig. 2). Data are recorded every half hour using a data acquisition system. This paper focusses on the temperatures and the heat budget for the five waste lifts as they were placed within the landfill; as a result only the temperature data are presented here along with the oxygen data to support the argument of aerobic activity near top of a waste lift.

The temperature was measured by several sensors included on each instrument bundle; these include the moisture, settlement, oxygen, and total earth pressure sensors. The temperature measured by the oxygen sensor was, on average, approximately 0.5 degrees higher than the other sensors as the oxygen sensor has a small heater to prevent water condensation on the sensor device. The maximum difference between the lowest and highest temperature readings, excluding the oxygen sensor, never exceeded 0.5 °C at any time during the course of the study; reinforcing the reliability of the temperature data. The average measured temperatures are presented and the average included the measured temperatures of at least two sensors as during the course of the study, some sensors failed. The oxygen was measured using an oxygen sensor designed by Apogee Instruments. The sensor was placed vertically in a layer of sand directly above the instrument bundles.

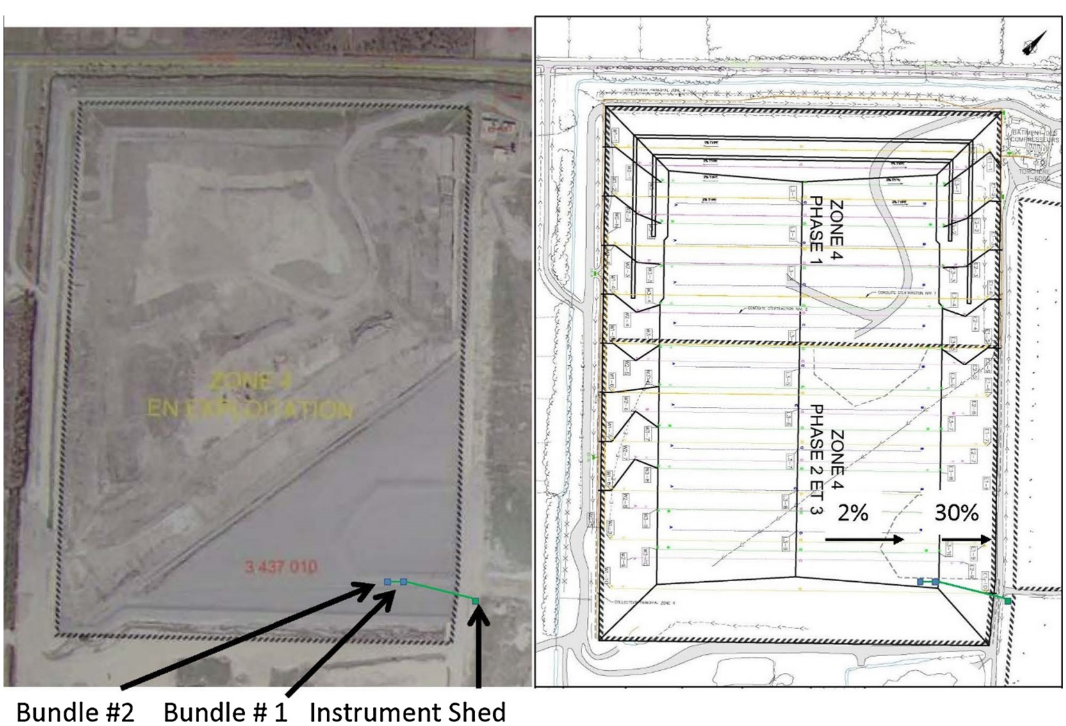

Fig. 1. Aerial view of zone 4 with approximate locations of vertical profiles of instrument bundles and shed.