Cold Regions Science and Technology 131 (2016) 39–45

Contents lists available at ScienceDirect

Cold Regions Science and Technology

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

Response of compost biocover to freeze-thaw cycles: Column experiments

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ARTICLE INFO

Article history:
Received 22 December 2014
Received in revised form 11 August 2016
Accepted 2 September 2016
Available online 4 September 2016

Keywords:
Biocover
Compost
Climate change
Freeze-thaw
Cold regions
Methane

ABSTRACT

The microbial oxidation of methane in biocover is considered a promising technology for the mitigation of methane emissions from landfills. In the present paper, the behaviour (evolution of methane and oxygen concentration, volumetric water content and temperature) and performance under freeze-thaw cycles (FTCs) conditions are investigated by column experiments. In the utilizing of column experiments, three columns are developed, manufactured, prepared and treated by a period of methane injection (0 FTC), after 1 FTC and 2 FTCs, in three respective stages. One column is instrumented with various sensors to monitor the evolution of temperature, volumetric water content, settlement and gas composition at four different depths for one of the biocover columns. In addition, laboratory testing is carried out on the biocover samples with regards to their organic content and grain size distribution. The results show that two FTCs have effect on the methane removal of compost biocover as well as influence the evolution of the volumetric water content, temperature, settlement, gas composition and organic content of the biocover. However, these effects and influence are more significant in the upper layers (≤15 cm) of the compost biocover column. The results presented in this paper will contribute to a better design of landfill biocovers in cold regions.

1. Introduction

Amongst the greenhouse gases (GHGs), methane (CH_4) has been the subject of exclusive research as the 100-year global warming potential for CH_4 is around 28 times greater than that of CO_2 (IPCC, 2014). One of the major CH_4 production sources is by waste sector landfills (Bogner et al., 2007). Recent studies show that CH_4 gas production from the waste industries are considered as the second highest source of anthropogenic CH_4 emission in Europe (Scheutz et al., 2003, 2009) and the third highest source in the US (EPA, 2014). Landfills produce 21% and 30% of all anthropogenic CH_4 emissions in Canada and Europe, respectively (Perdikea et al., 2008). Moreover, in developing countries that are experiencing economic and population growth, the quantity of CH_4 generated from landfills is increasing (Khoshand and Fall, 2014).

Landfill gas collection systems are mandatory in many countries in order to prevent or decrease the amount of landfill gas (LFG) emissions into the atmosphere (Ait-Benichou et al., 2009). However, these systems are not economically efficient in landfills that are small in size, old in age or located in cold regions (Zeiss, 2006), where the rate of LFG emissions is not sufficient for utilizing burning or energy recovery systems (Huber-Humer et al., 2009). Moreover, as uncontrolled dumps or landfills with (temporary) inactive gas collection systems are also potential sources of LFG (Ait-Benichou et al., 2009), both fugitive and residual emissions may exist during the life time of a landfill (Roncato and Cabral, 2012).

A green and novel solution for preventing or limiting landfill methane escape is the utilization of biocovers. Biocovers are a type of landfill top cover which enhances the environmental circumstances for methanotroph bacteria which consume (i.e. oxidize) CH_4 during its escape from landfills (Huber-Humer et al., 2009). Several studies have demonstrated biocovers to be a promising technology for mitigating CH_4 emission from landfills (e.g. Roncato and Cabral, 2012; Chi et al., 2012; Zeiss, 2006). Moreover, previous investigations (e.g., Humer and Lechner, 1999; Huber-Humer, 2004; Wilshusen et al., 2004) have reported that stabilized compost materials are a suitable biocover medium for CH_4 oxidation.

However, many aspects of the practical application of compost as landfill biocovers in cold regions have not been investigated and/or are not understood. One of these aspects is the response of biocovers to freeze-thaw cycles (FTCs). Cold and freeze-thaw climatic conditions are common in many countries or regions in the world. In such localities, particularly those with long and cold winters, biocovers remain covered under snow or frozen for a long period of time (Rykaart and Hockley, 2009). They will be also subjected to freeze-thaw cycles. FTCs may alter the performance of the biocover. For instance, FTCs may

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http://dx.doi.org/10.1016/j.coldregions.2016.09.005
0165-232X/

lead to the generation of cracks in the biocover system. These cracks may generate preferential pathways for methane to escape into the atmosphere (Khoshand and Fall, 2014).

The concentrations of methane and oxygen, moisture content, and temperature belong to the most important factors influencing the performance of biocovers (e.g., Hettiarachchi et al., 2007; Spokas and Bogner, 2011). Therefore, an understanding of the evolution of these influencing factors or biocover behaviour under freeze-thaw conditions is necessary in order to design cost-effective biocover in cold regions. However, there is no study in the literature that addresses the response of compost biocover to freeze-thaw cycles. Absence of a proper understanding of the behaviour and performance of compost biocovers under freeze-thaw conditions may lead to inaccurate biocover design and consequently, construction of inefficient biocovers in cold regions. Therefore, the aim of the current study is to investigate the evolution of the behaviour and methane removal capacity of compost biocovers, when subjected to FTCs. To achieve the aims of the current study, column experiments have been carried out to assess the evolution of the volumetric water content, gas composition, temperature and methane removal capacity of compost biocovers under freeze-thaw conditions.

2. Experimental programs and procedure

2.1. Materials

2.1.1. Compost

The compost material was collected from the composting facilities of the Moose Creek landfill located in Moose Creek (near the Cities of Cornwall and Ottawa), Ontario (Canada) and operated by Lafleche Environmental Inc. Several laboratory tests were conducted to determine the basic properties of the sampled compost materials. The organic matter content (measured according to ASTM D 2974) of the compost material was found to be equal to 26%. Its thermal conductivity was determined (by using KD2) to be equal to ~0.5 W/(m. K). Fig. 1 illustrates the grain size distribution of the compost. The chemical composition of the compost material is presented in Table 1. In addition, the pH of the original compost was determined to be equal to 6.8. The compost was mature and stable according to the Canadian Council of Ministers of the Environment (2005). The O_2 consumption rate of the compost was 0.9 μmol O_2/h.$g_{dry\ wt}$, whereas the CO_2 evolution rates 0.7 μmol CO_2/h.$g_{dry\ wt}$. These respiration and CO_2 evolution rates are within the acceptable limits for mature and stable compost specified by the Canadian Council of Ministers of the Environment (2005).

2.1.2. Methane gas

CH_4 gas with a purity of 99%, grade IV, from Linde Ltd., was used. A bottle of CH_4 (Fig. 2) was connected to each of the columns and injected at a rate of 250 g m^{-2} day^{-1}.

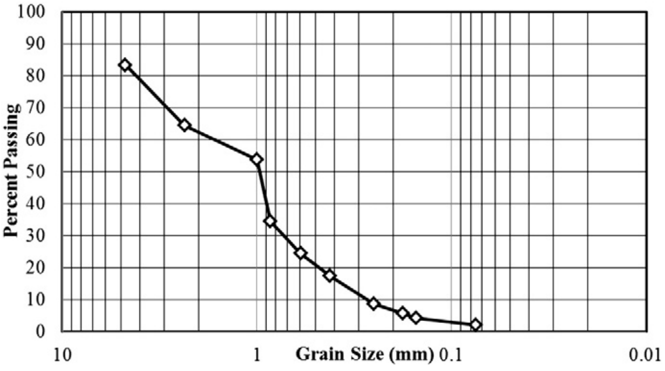

Fig. 1. Grain size distribution of the compost material.

2.2. Compost sample preparation

To prepare the samples for the column experiments, mature compost was mixed well with distilled water. A gravimetric water content of 30% was selected based on the recommendation in several studies (e.g., Huber-Humer, 2004; Huber-Humer et al., 2009).

2.3. Developed column experimental set up

In order to investigate the response of compost biocovers to FTCs, three columns were developed and then manufactured (one instrumented column for monitoring; two columns not instrumented to take samples for testing). The schematic of the experimental set-up of the columns is presented in Fig. 2. Plexiglass tubes with internal and external diameters of 25.4 and 26 cm respectively were utilized to build the columns. The height of each column from the base upwards was 60 cm. Each plexiglass column was inserted into a cardboard tube with an internal diameter of 30.4 cm. The gap between the plexiglass and the cardboard tube was filled with expansive insulation foam with a thermal resistance (k-factor thermal resistance) of 0.033 W/m C (Abdul-Hussain, 2011). This provides the opportunity to simulate one-dimensional freezing-thawing by preventing heat transfer from the bottom and the surrounding around the column set-up (Eigenbrod, 1996). An aluminum brace was placed at the bottom of the columns. A perforated stainless steel plate was also placed at the top of the aluminum brace. The diameter of the plate is roughly equal to the internal diameter of the column. The space below the stainless steel plate provides sufficient volume for any water accumulation at the base of the column, if necessary. A drainage layer which consisted of gravel that ranged from 20 to 30 mm in size was installed at the top of the plate. A gas inlet was installed on the bottom of the columns. The gas pipe that passed throughout the drainage layer was in the shape of a circle. For homogenous gas distribution, the circular part of the gas pipe was perforated. Then, the columns were filled with a well-mixed compost to a height of 40 cm. The columns were equipped with various sensors and gas probes at depths of −5, −15, −25 and −35 cm of the biocover profile. The methane escaping from top of the columns were not measured during the experiment. Water tapes and O rings were utilized to avoid any leakage; however, all of the ports were checked for leakage prior to the column experiments. CH_4 gas (with a purity of 99%, grade IV from Linde Ltd. and rate of 250 g m^{-2} day^{-1}) was fed to each of the columns by an injector pipe. Commonly found CH_4 concentrations that are usually injected into landfills were determined based on the data from Bogner et al. (1997). To apply a similar gas flux found in landfills into the columns, the recommended rate of injection is 200 to 300 g CH_4 m^{-2} day^{-1} (Bogner et al., 1997). These values represent the mid to high range of CH_4 fluxes, respectively. This value is calculated based on the assumption that a landfill filled with 20 m of waste would generate this average value for the first 10–15 years after waste is buried into the landfill (Willumsen and Bach, 1991). Also, Scheutz et al. (2009) concluded after reviewing numerous studies that 100 to 150 g CH_4 m^{-2} day^{-1} and 200 to 250 g CH_4 m^{-2} day^{-1} could be the average and maximum rates of CH_4 oxidation, respectively. Hence, by choosing this value for the CH_4 injection rate, a conservative approach has been used in the current study. Besides that, the rate of CH_4 injection was controlled by using a flow stream controller (D5111) (M + W Instruments GmbH, Leonhardsbuch, Germany), for steady and uniform gas injection over time.

2.4. Column instrumentation, monitoring and experimental procedures

2.4.1. Procedure

The experimental columns offer the opportunity to compare the behaviour (evolution of the gas composition, volumetric water content, gas retention time and temperature) and performance of compost