Journal of Rock Mechanics and Geotechnical Engineering 8 (2016) 596–604

Contents lists available at ScienceDirect

Journal of Rock Mechanics and Geotechnical Engineering

journal homepage: www.rockgeotech.org

Full length article

Geotechnical characterization of peat-based landfill cover materials

Afshin Khoshand [a], Mamadou Fall [b,*]

[a] Faculty of Engineering, K.N. Toosi University of Technology, Tehran, Iran
[b] Department of Civil Engineering, University of Ottawa, Ottawa K1N 6N5, Canada

ARTICLE INFO

Article history:
Received 3 March 2016
Received in revised form
5 May 2016
Accepted 17 May 2016
Available online 4 August 2016

Keywords:
Landfill
Geotechnical engineering
Landfill cover
Peat
Compaction
Compressibility
Hydraulic and thermal conductivity

ABSTRACT

Natural methane (CH_4) oxidation that is carried out through the use of landfill covers (biocovers) is a promising method for reducing CH_4 emissions from landfills. Previous studies on peat-based landfill covers have mainly focused on their biochemical properties (e.g. CH_4 oxidation capacity). However, the utilization of peat as a cover material also requires a solid understanding of its geotechnical properties (thermal, hydraulic, and mechanical), which are critical to the performance of any biocover. Therefore, the objective of this context is to investigate and assess the geotechnical properties of peat-based cover materials (peat, peat–sand mixture), including compaction, consolidation, and hydraulic and thermal conductivities. The studied materials show high compressibility to the increase of vertical stress, with compression index (C_c) values ranging from 0.16 to 0.358. The compressibility is a function of sand content such that the peat–sand mixture (1:3) has the lowest C_c value. Both the thermal and hydraulic conductivities are functions of moisture content, dry density, and sand content. The hydraulic conductivity varies from 1.74×10^{-9} m/s to 7.35×10^{-9} m/s, and increases with the increase in sand content. The thermal conductivity of the studied samples varies between 0.54 W/(m K) and 1.41 W/(m K) and it increases with the increases in moisture and sand contents. Increases in sand content generally increase the mechanical behavior of peat-based covers; however, they also cause relatively high hydraulic and thermal conductivities which are not favored properties for biocovers.

1. Introduction

Greenhouse gases (GHGs) reabsorb infrared radiation which is reflected from the Earth and retain heat in the lower level of the atmosphere. GHGs have both natural and anthropogenic sources, but human induced GHG emissions have increased, more than emissions from most natural sinks, particularly after the Industrial Revolution (Albanna et al., 2011). The continuous increase in concentration of GHGs has caused an increase of over 0.5 °C in the global surface temperature in the last 150 years (Wuebbles and Hayhoe, 2002), a phenomenon known as global warming. Global warming is one of the greatest environmental challenges in the 21st century, which has caused global and regional climate changes (Peixoto and Oort, 1992; Albanna et al., 2010).

Methane (CH_4) is a potent GHG with a global warming potential that is 25 times that of carbon dioxide (CO_2) (IPCC, 2007). The anaerobic biodegradation of municipal solid waste (MSW) in landfills is one of significant global sources of anthropogenic CH_4 emissions. The total global CH_4 emissions from landfills almost doubled during the period from 1970 to 2010. It has also been estimated that 627.34 tonnes CO_{2-e} (CO_{2-e} or equivalent CO_2 is the concentration of CO_2 that causes the same level of radiative forcing as a given type and concentration of GHG) per year is generated in landfills worldwide, of which more than 85% is emitted into the atmosphere (IPCC, 2014). Therefore, mitigation actions are urgently required in light of the significant levels of CH_4 found in the atmosphere (Stern and Kaufmann, 1996).

The extraction and utilization of landfill gas (LFG) are commonly used to control CH_4 emissions from landfills. However, there is evidence that a large amount of CH_4 escapes from sites despite the use of extraction and utilization systems (Börjesson et al., 2007).

Therefore, one of the most promising methods that would actually reduce CH_4 emissions from landfills is the natural processing of microbial CH_4 oxidation through active biological soil covers or biocovers (Scheutz et al., 2009a, 2011). This oxidation process principally relies on the activity of a group of bacteria known as methanotrophs, which are able to use molecular oxygen

* Corresponding author. Fax: +1 613 562 5173.
E-mail address: mfall@uottawa.ca (M. Fall).
Peer review under responsibility of Institute of Rock and Soil Mechanics, Chinese Academy of Sciences.

http://dx.doi.org/10.1016/j.jrmge.2016.05.007
1674-7755

(O_2) to oxidize CH_4 into CO_2. Biocovers are an alternative effective option for the mitigation of CH_4 emissions where the implementation of LFG extraction and utilization systems is not technically or economically feasible (Scheutz et al., 2011).

Previous studies have demonstrated that various organic soils (e.g. compost, peat, loam soil) can support the growth and activity of methanotrophic bacteria (Watson et al., 1997; Humer and Lechner, 1999; Stein and Hettiaratchi, 2001; Wilshusen et al., 2004; Einola, 2010; Gupta, 2011; He et al., 2012; Abushammala et al., 2014; Zainal and Buyong, 2015), and are suitable for practical applications in mitigating CH_4 emissions. Peat is one of the more promising biocover materials. Indeed, peat is able to provide environmental conditions suitable for the proliferation and activity of methanotrophic bacteria (Stein and Hettiaratchi, 2001; Streese and Stegmann, 2003; Einola, 2010; Lu et al., 2011; Zainal and Buyong, 2015). Furthermore, many researchers (e.g. Stein and Hettiaratchi, 2001; Einola et al., 2009) have experimentally demonstrated that peat materials show a high CH_4 oxidation rate (up to 90%) as illustrated in Table 1, which provides a summary of the CH_4 oxidation rates of various biocover materials. It can be observed that the CH_4 oxidation rate of peat (up to 90%) is close to that of compost (up to 100%) and much higher than that observed in other types of biocover materials (loam soil, topsoil, agricultural soil, and sand). However, for the peat biocover material to be of interest, aside from a high CH_4 oxidation rate (Table 1), the material should demonstrate its geotechnical properties that are comparable to or better than those of existing biocover materials (particularly compost) used in construction practices.

The geotechnical properties (mechanical, hydraulic, and thermal) of biocover materials are of prime importance for design, construction and maintenance of any biocover as will be discussed later. Absence of a proper understanding of the geotechnical properties of cover materials may lead to inaccurate biocover design and consequently, construction of inefficient biocovers. However, to date, the geotechnical characteristics of peat-based biocover material are not well understood. Therefore, the goal of this paper is to provide insight into the geotechnical properties of peat-based biocover materials and assess their suitability for use as biocover media from a geotechnical point of view.

2. Materials and methods

2.1. Material selection and characterization

Mixing potential biocover materials with sand minimizes the settlement and compaction of biocovers (Powelson et al., 2006; Philopoulos et al., 2009; Scheutz et al., 2009a; Khoshand and Fall, 2014). Compaction is especially important when consideration is given to any field installations, as there will be some traffic on the surface of the medium (e.g. maintenance) (Philopoulos et al., 2009). Therefore, laboratory investigations have been conducted in this study on peat and peat–sand mixture samples with ratios of 1:3, 1:1 and 3:1 (w/w). The aforementioned ratios are recommended in Pokhrel et al. (2011), a study on the CH_4 oxidation capacity of different mixtures of potential biocover materials.

Ottawa sand, obtained from Unimin Canada Ltd. is used in this study. The sand was oven-dried prior to use in the experiments in order to eliminate any methanotrophic bacteria that may be present in the sand. Also, the sand was free of organic content based on the results of laboratory tests performed in accordance with ASTM D2974-14 (2014). The peat soil samples were collected from the Moose Creek Bog in Moose Creek, Canada, which is owned and operated by Lafleche Environmental Inc. The peat samples were transported to a laboratory and stored at a temperature of 3 °C before further characterization.

The mineralogical compositions of the peat material and peat–sand mixtures were determined by X-ray diffraction analyses and the results are presented in Table 2. The selected geotechnical properties of all the samples were determined in accordance with the procedures described by ASTM standards. A grain size analysis was performed in accordance with ASTM D422-63(1998) (1998). It can be seen in Fig. 1 that all of the samples have a grain size that ranges from 0.07 mm to 5 mm and the grain size distribution becomes coarser as the sand ratio is increased.

The grain size distribution of the peat samples indicates that the percentage of grains that pass through the sieves Nos. 10, 40 and 100 is 79%, 22% and 7%, respectively. The pure peat sample in this study is classified as organic SW (well graded sand) and the rest of samples are organic SP (poorly graded sand) based on the Unified Soil Classification System (USCS). However, this classification system is not suited for organic soils because samples are only considered as peat when the organic content is more than 75%. Therefore, a classification system proposed by Wüst et al. (2003), based on the ash and organic contents of peats, is also used in this study. Based on this classification, peat and peat–sand mixture with a mix ratio of 3:1 are considered as peat, while peat–sand mixtures with mix ratios of 1:1 and 1:3 are considered as muck. A summary of the properties and pH value of the samples are shown in Table 3. The pH value of the peat sample is 6.72, which falls within the range quoted by Cola and Cortellazzo (2005).

Table 1
Summary of CH_4 oxidation rates of different organic soils.

Biocover material	CH_4 oxidation rate (%)	Reference
Loam soil	50	Stein and Hettiaratchi (2001)
	65	Scheutz et al. (2003)
	65	De Visscher et al. (1999)
Topsoil	40	Kightley et al. (1995)
	37	Humer and Lechner (1999)
Sand	41	Kightley et al. (1995)
	63	Powelson et al. (2006)
Peat	85	Stein and Hettiaratchi (2001)
	90	Einola et al. (2009)
Agricultural soil	32	Stein and Hettiaratchi (2001)
	45	De Visscher et al. (1999)
Compost	53	Humer and Lechner (2001)
	96	Haubrichs and Widmann (2006)
	100	Philopoulos et al. (2009)

2.2. Methods

2.2.1. Compaction test

In order to experimentally determine the values of the optimum moisture content and corresponding maximum dry density of the studied materials, standard Proctor compaction tests were performed in accordance with ASTM D698-12 (2012).

2.2.2. Consolidation test

Conventional consolidation tests were performed on the samples at the dry side of the optimum moisture content and the optimum moisture content in accordance with ASTM D2435/D2435M-11 (2011) to determine the consolidation characteristics of the peat and its mixture samples. The dried samples were moistened and compacted to reach the desired densities for specific moisture contents that correspond to standard Proctor compaction test results. Each test consisted of five increments of loading (5 kPa, 10 kPa, 20 kPa, 40 kPa and 80 kPa) and the duration of each loading was 24 h to ensure that the long-term compressibility of the samples was properly simulated (Moo-Young and Zimmie, 1996). Each test was repeated twice.