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Rapid assessment of methanotrophic capacity of compost-based materials considering the effects of air-filled porosity, water content and dissolved organic carbon

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HIGHLIGHTS

- Key bulk parameters: air filled porosity, water content, dissolved organic carbon.
- Parameters are correlated with maximum CH_4 removal rates in compost-based materials.
- A rapid assessment tool for performance estimation of filter media was developed.

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ABSTRACT

Since the global warming potential of CH_4 is 25 times that of CO_2 on a 100-year time horizon, the development of methanotrophic applications for the conversion of CH_4 to CO_2 is emerging as an area of interest for researchers and practicing engineers. Compost exhibits most of the characteristics required for methanotroph growth media and has been used in several projects. This paper presents results from a study that was undertaken to assess the influence of physical and chemical characteristics of compost-based materials on the biological oxidation of CH_4 when used in methane biofilters. The results showed that easily-measurable parameters, such as air filled porosity, water content and dissolved organic carbon, are correlated with maximum CH_4 removal rates. The results obtained were used to develop an empirical relationship that could be regarded as a rapid assessment tool for the estimation of the performance of compost-based materials in engineered methanotrophic applications.

1. Introduction

Engineered applications for the biological removal of methane (CH_4) involve the use of suitable granular materials as growth media for methanotrophic bacteria. The physical and chemical characteristics of granular media are important factors affecting the performance of methanotrophic processes. The presence and availability of intrinsic nutrients, a high specific surface area, high porosity, good moisture retention capacity, structural integrity and biological stability are all desirable characteristics (Delhomenie and Heitz, 2005). Since compost exhibits most of these characteristics, it has been used as the granular growth media in a number of research and pilot studies (Wilshusen et al., 2004a).

The estimation of the methanotrophic capacity of compost-based materials is, however, difficult, due to biological instability and the diversity of feedstock materials that can be used to produce compost. To date, column and batch laboratory experiments have been considered as the most suitable method for predicting methanotrophic capacity, but this process is cumbersome, as it may take about 100 days to obtain reliable results (Wilshusen et al., 2004a).

Recent studies have shed light on the influence of the physical characteristics of compost-based materials on the performance of methanotrophic processes. Humer and Lechner (2001) concluded that filter media with high porosity enhance CH_4 uptake rates. Small particle sizes provide large specific surface areas, but also creates resistance to gas flow; whereas large particle sizes favor gas flow, but reduce the number of potential sites for microbial activity (Delhomenie et al., 2002). According to Bohn and Bohn (1999), Spokas and Bogner (2011), high methanotrophic activity can be associated with high water availability within the filter medium.

Pedersen et al. (2011) characterized seven different compost materials based on the following parameters: water content, loss of ignition, pH, total organic carbon, total nitrogen,

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ammonium-nitrogen, nitrate-nitrogen, carbon/nitrogen (C/N) ratio, total phosphorus, sulfate, and copper. This study concluded that low C/N ratios can be related to high CH_4 oxidation rates and that the C/N ratio could be considered as a reliable indicator of the CH_4 removal capacity of granular media.

Scheutz et al. (2011) evaluated the CH_4 removal capacity and the carbon dioxide (CO_2) production of compost samples obtained from the filter medium of a methanotrophic biowindow at a landfill. They suggested that the biological stability of compost-based materials used as filter media could be associated with their potential to allow the development of methanotrophic processes. Pawlowska et al. (2011) suggested that the physicochemical characteristics of organic granular materials have no significant influence on the performance of engineered methanotrophic processes; however, further research is necessary to explain their interaction effects on the methanotrophic capacity of compost-based filter media.

This paper presents results from a study undertaken to determine the effects of key bulk parameters, namely air filled porosity (φ_g), water content and dissolved organic carbon (DOC), on maximum CH_4 oxidation rates (V_{max}) of compost-based materials. The V_{max} rate constant is determined from Michaelis–Menten kinetics:

$$V = V_{max}\frac{[S]}{K_m + [S]} \quad (1)$$

where V is the rate of reaction, S is the substrate concentration, and K_m is the half velocity constant equal to the substrate concentration at which the reaction rate is one-half of maximum.

The new information provided in this paper may be valuable in the rapid assessment of the suitability of compost-based materials for methanotrophic applications that eliminates the need for time-consuming laboratory methods, such as column and batch experiments.

2. Methods

The materials tested in this study were several mixtures of compost, sand and perlite. First, a series of experiments was conducted using sludge/woodchip compost. The same experiments were then replicated using leaf compost. The sludge/woodchip and leaf composts were provided by the Edmonton Waste Management Centre (EWMC) and by the City of Calgary, respectively. The EWMC uses anaerobically digested sludge from their municipal wastewater treatment facility as the feedstock in an aerated static pile composting operation to produce high quality compost.

As indicated in Table 1, a $2 \times 3 \times 3$ factorial experimental design was formulated to evaluate the influence of the bulking materials used in this experiment (i.e., sand and perlite), the compost/bulking material ratio by volume, and the bulking material moisture content (MC) as a percentage of its water holding capacity (WHC). This experimental design was selected to evaluate the primary and interaction effects of these factors on V_{max}.

Since the concentration of available nitrogen for perlite and sand was low, the compost was considered to be the main attachment growth medium for methanotrophic bacteria. All methanotrophs were Gram-negative bacteria (Anthony, 1982). According to Bohn and Bohn (1999), water availability is a key determinant in CH_4 oxidation rates of Gram-negative bacteria; and, the highest metabolic rates are typically observed in conditions of water availability close to the WHC of the growth support media. Therefore, the MCs of the compost samples were adjusted to values close to WHC.

Table 1
Experimental factors and levels.

	Factor	Level		
		−1	0	1
A	Compost/bulking material volume ratio	30/70	50/50	70/30
B	Bulking material	Sand		Perlite
C	MC as percentage of WHC of the bulking material	0%	50%	80%

2.1. Determination of CH_4 removal rates – batch experiments

Batch incubation experiments were conducted (in duplicate) to determine the maximum V_{max} values for CH_4 oxidation. Samples of screened compost (40 g on a dry basis) were placed in 975-ml glass vials and mixed with perlite and sand according to the previously defined volume and moisture requirements. The vials were incubated for approximately 100 days at room temperature (≈20 °C). The samples were aerated by purging with air initially and then adding air manually using a syringe, and CH_4 (99% purity CH_4) purchased from Praxair was supplied twice a day (once a day on weekends) to maintain a concentration of 5–10% in the air headspace of the vials.

V_{max} was determined periodically during the incubation period. The CH_4 concentration was monitored at regular intervals until it reached minimum detection limits. The percentage of CH_4 removed in the vials was measured using a VARIAN CP 4900 portable micro gas chromatograph (GC). The gas composition was determined using GALAXIE software with the GC. The airspace volume was determined at the end of the incubation process by adding water to fill up the vials and measuring the air displacement. CH_4 removal data were used to determine the V_{max} and K_m of the samples by linearizing the oxidation rates using the Eadie–Hofstee and Lineweaver–Burk methods, as described by Moorthy (2008).

2.2. Determination of DOC

The compost samples were tested for the presence of inorganic carbon (Nelson and Sommers, 1996). The materials were moistened, and 4 M of hydrogen chloride were added drop-wise, allowing sufficient time for inorganic carbon to react. As no effervescence was observed, it was concluded that inorganic carbon was not present in significant quantities. To determine the DOC values of each sample, the extraction method outlined by Chefetz et al. (1998) was used. A 5-ml sample of solution was taken after extraction and immediately analyzed by dichromate oxidation according to the tube digestion procedure described by Nelson and Sommers (1996).

2.3. Determination of air filled porosity (φ_g)

The procedure for the determination of the bulk densities (ρ) of the samples was adapted from Ahn et al. (2008). The particle density (ρ_s) was determined following the volumetric flask method described by Flint and Flint (2002). Considering a unit total volume, total porosity (φ) was calculated as follows (Haug, 1993):

$$\varphi = 1 - \frac{\rho w_s}{\rho_s} \quad (2)$$

where w_s is the solids content on a wet basis (g g^{-1}). Then, the air filled porosity (φ_g) was calculated from:

$$\varphi_g = 1 - \frac{\rho w_s}{\rho_s} - \frac{\rho(1 - w_s)}{\rho_w} \quad (3)$$

where ρ_w is water density in g l^{-1}.